Appeal No. 2014-1732

United States Court of Appeals

for the

Federal Circuit

CONVOLVE, INC.,

Plaintiff-Appellant,

THE MASSACHUSETTS INSTITUTE OF TECHNOLOGY,

Plaintiff,

– v. –

COMPAQ COMPUTER CORP., SEAGATE TECHNOLOGY, INC., SEAGATE TECHNOLOGY, LLC,

Defendants-Appellees.

ON APPEAL FROM THE UNITED STATES DISTRICT COURT FOR THE SOUTHERN DISTRICT OF NEW YORK, IN CASE NO. 1:00-CV-05141-GBD-JCF, HONORABLE GEORGE B. DANIELS

BRIEF FOR PLAINTIFF-APPELLANT

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Form 9

FORM 9. Certificate of Interest

UNITED STATES COURT OF APPEALS FOR THE FEDERAL CIRCUIT

Convolve, Inc. v. Compaq Computer Corp.

No. 2014-1732

CERTIFICATE OF INTEREST

Counsel for the (petitioner) (appellant) (respondent) (appellee) (amicus) (name of party) Convolve, Inc. certifies the following (use "None" if applicable; use extra sheets if necessary):

1. The full name of every party or amicus represented by me is:

Convolve, Inc.

2. The name of the real party in interest (if the party named in the caption is not the real party in interest) represented by me is:

None

3. All parent corporations and any publicly held companies that own 10 percent or more of the stock of the party or amicus curiae represented by me are:

None

4. ☑ The names of all law firms and the partners or associates that appeared for the party or amicus now represented by me in the trial court or agency or are expected to appear in this court are:

See Schedule A attached hereto.

9/5/2014
Date

Signature of counsel

Gregory A. Markel
Printed name of counsel

Please Note: All questions must be answered
cc: counsel of record in U.S.D.C. proceedings

SCHEDULE A TO CERTIFICATE OF INTEREST

The names of all law firms and the partners or associates that appeared for the party now represented by me in the trial court or are expected to appear in this Court are:

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STATEMENT OF RELATED CASES

This matter has been before this Court on three previous occasions:

- A petition for a writ of mandamus was before this Court *en banc*, captioned as *In re Seagate Tech., LLC*, 497 F.3d 1360 (Fed. Cir. 2007) (*en banc*).
- The district court's prior entry of summary judgment was before this Court captioned as *Convolve v. Compaq Computer*, No. 2012-1074. It was reported as *Convolve, Inc. v. Compaq Computer Corp.*, 527 F. App'x 910 (Fed. Cir. 2013) (Unpublished) ("*Convolve I*"), *cert. denied*, 134 S. Ct. 801 (2013). A1993-2033.
- The district court's order denying American International Underwriters Insurance Company and National Union Fire Insurance Company of Pittsburgh, PA leave to intervene and to modify the district court's "Stipulation and Protective Order" was before this Court, captioned as *Convolve, Inc. v. Compaq Computer Corp.*, No. 14-1049. On June 30, 2014, the Court granted movant-appellants' unopposed, pre-briefing motion to voluntarily dismiss their appeal pursuant to Fed. R. App. P. 42(b).

The patent-in-suit, U.S. Patent No. 6,314,473 (the "'473 patent"), was successfully asserted by plaintiff-appellant Convolve, Inc. in a separate action against Dell, Inc.; Western Digital Corporation; and Hitachi Global Storage Technologies, Inc. and Hitachi Ltd. (collectively, "Hitachi"), captioned as: *Convolve, Inc. v. Dell, Inc.*, No. 2:08-CV-244-CE (E.D. Tex.). In July 2011, the jury in that action found that the '473 patent was not invalid and was willfully infringed by all defendants. A2868-73. The defendants in that action filed motions for JMOL, some of which remain pending as of the filing date of this brief. In 2014, the defendants in that action filed several motions seeking to overturn the jury's infringement verdict based on the district court's summary

judgment order at issue in this appeal. A3857-58 (Dkt. Entry Nos. 664-73). Those motions, too, remain unresolved. *Id.*

JURISDICTIONAL STATEMENT

The district court had jurisdiction pursuant to 28 U.S.C. §§ 1331, 1332(a), 1338(a). Final judgment was entered on July 14, 2014. Appellant's Notice of Appeal was timely filed on August 13, 2014. 28 U.S.C. § 2107(a); Fed. R. App. P. 4(a)(1)(A). This Court has appellate jurisdiction under 28 U.S.C. § 1295(a)(1).

STATEMENT OF ISSUES

1. Did the district court err in granting summary judgment of non-infringement on the '473 patent's "user interface" element, by misapplying its own claim construction to the facts, and in contravention of this Court's *Convolve I* mandate?

2. Did the district court err in granting summary judgment of non-infringement on the '473 patent's "commands" element, despite evidence that Seagate drives in Compaq computers output shaped "commands," and despite the 2005 *Markman* Order's holding that the shaped "commands" may originate from within the disk drive?

3. Did the district court err in awarding appellees intervening rights, by imposing a *per se* rule in violation of controlling precedent, and applying the wrong standard to reach the conclusion that the reexamination amendment substantively changed the scope of the originally-granted claims, despite: (a) the

'473 patent's intrinsic record evidence establishing that the original claims and amended claims are legally identical, (b) admissions from appellees and their experts that the asserted claims would be understood to be originally drawn to seek noise, (c) the USPTO's characterization of Convolve's reexamination amendment as "clarifying," and (d) another federal district court's adjudication of the same intervening rights defense in Convolve's favor?

STATEMENT OF THE CASE

This case has a long history dating back nearly fifteen years. A174. Notably, this case has yet to go to trial. By contrast, Convolve's Eastern District of Texas (EDTX) case asserting the same patent against appellees' industry allies went from filing to willful infringement verdict in just three years.

Convolve's latest roadblock to a long-requested trial in the Southern District of New York (SDNY) is the district court's summary judgment dismissing—*for the second time*—Convolve's claim against Seagate Technology, LLC and Seagate Technology, Inc. (collectively, "Seagate") and Compaq Computer Corp. (now owned by Hewlett-Packard) ("Compaq") for infringement of U.S. Patent No. 6,314,473. The '473 patent improves hard drive design by reducing "seek acoustics"—noise generated by movement of the drive's read/write head—by minimizing vibrations of the head as it moves over the rotating hard disk. A1998.

Convolve asserts that certain Seagate drives, and Compaq computers containing them, infringe the '473 patent. A2008. In August 2011—eleven years after filing—the district court granted summary judgment, holding that no accused products met the patent's "selected unwanted frequencies" limitation. *Id*.

In 2013, this Court reversed the district court's 2011 summary judgment, finding that genuine fact issues precluded summary judgment of no direct or induced infringement. A2021-27 (*Convolve I*). This Court credited the detailed declaration of Convolve's expert (Dr. Joshua Phinney) regarding infringement of the '473 patent by all accused instrumentalities. A2022-23 (ATA-IV), A2024 (SCSI drives), A2025 (ATA3, U5 drives), A2027 (Compaq computers). This Court also held that Convolve provided sufficient evidence that customers used the accused "user interface" on Seagate's ATA/SCSI drives in an infringing manner. A2026-27.

On remand, appellees again moved for summary judgment on eleven separate grounds, asserting that:

- The accused products do not meet the "inverse relation" limitation;
- Seagate's drives lack the claimed "user interface";
- Compaq's computers do not meet the "commands" limitation;
- Convolve cannot show induced infringement;
- The Ray Thesis anticipates all asserted claims;
- Seagate's "Hawk 2" drive anticipates all asserted claims;

- The "Koizumi" patent, combined with Ray, renders obvious all asserted claims;
- Koizumi, combined with Hawk 2, renders obvious all asserted claims;
- Convolve cannot show willful infringement;
- Defendants are entitled to intervening rights; and
- Compaq has no liability for products with non-Seagate drives.

A2191-43. These arguments were recycled from appellees' 2009 summary judgment motions—*i.e.*, next-best arguments the district court declined to adjudicate in its 2011, now-vacated, summary judgment order. A2344-46.

On July 11, 2014, the district court entered summary judgment, holding:

- Seagate's drives do not infringe, because their ATA/SCSI interfaces are not "user interfaces";
- Compaq's products do not infringe, because the commands issued by Compaq's F10 BIOS do not satisfy the "commands" element; and
- Appellees are entitled to intervening rights based on Convolve's amendment of some asserted claims in reexamination.

A24-25.

The district court deemed these holdings "dispositive of the issue of direct infringement," thus mooting induced and willful infringement. A24 (n.3). The district court "[did] not rely on any other grounds for summary judgment asserted by Defendants" (*id.*)—presumably leaving those damages, invalidity, and non-infringement defenses ripe for yet-additional rounds of summary judgment on any remand from this Court, ***a decade and a half*** after the '473 patent was first asserted against appellees. Convolve has thus spent nearly the entire lifespan of

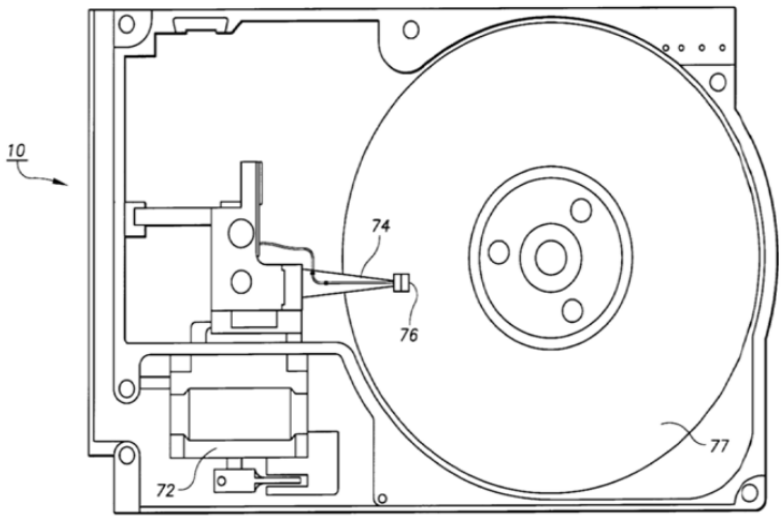
the ’473 patent simply trying to get to trial in the SDNY while successfully fending off Seagate’s numerous reexamination attacks at the USPTO. And the district court’s summary judgment is now being used to collaterally attack the willful infringement jury verdict Convolve won three years ago before a Texas jury. *Supra*, pp. x-xi. Convolve timely filed a Notice of Appeal. A268.

STATEMENT OF FACTS

A. This Case—Filed In 2000—Is About *Seeks*

As this Court stated: “The technology at issue relates to improving ‘seeks’ in computer hard drives. The figure below depicts a generic hard drive.”

FIG. 10A



A1996-97.

Hard drives store data in magnetized spots on a magnetic coating on the surface of platters (77) inside the drive. Data is arranged in “tracks” on each

platter. Data can be stored randomly on the platter surface, such that a single file may be stored in non-contiguous blocks. To retrieve data, the drive uses an inductor to detect each bit's magnetic polarization. To store data, electromagnets change a bit's polarization. The inductor and electromagnet are located on a "head" (76) that is located on an "arm" (74). A1997.

The voice coil motor (72) (VCM) moves the arm across the spinning platters. The VCM is controlled by a microcontroller or processor using feedback from the arm's position. When the microcontroller receives instructions, it directs the VCM to move the head toward the target track. The process of moving track-to-track is called "seeking," and the time required for the head to arrive at the correct track is called "seek time." A component of seek time is "settle time," the time it takes for the arm to settle from residual vibrations caused by the arm's movement. Quickly stopping the arm will cause it to vibrate; those vibrations must stop before read/write operations. A1998.

At the time of the '473 patent invention, fast seeks were "noisy." Quickly moving and stopping the head caused vibrations that created "seek acoustics," a distinct, irritable clicking noise. Convolve's technology—including the '473 patent—minimizes seek acoustic noise resulting from fast seeks. A1998. The '473 patent does not address, in any way, the acoustics generated by any drive component other than the seek arm.

B. The 2005 *Markman* Order

The parties briefed claim construction from late 2002 to early 2003. The district court held a *Markman* hearing on March 30-31, 2004 and issued its claim construction Order in August 2005. A63-91 (2005 *Markman* Order). No party challenged that claim construction Order in the appeal from the 2011 summary judgment Order (A2022), and that 2005 *Markman* Order remained the law of the case on remand.

"User Interface"

The 2005 *Markman* Order, as amended in January 2006, construed "user interface" to mean:

> software, hardware, firmware, or a combination thereof that allows a person, directly or indirectly, to alter parameters.

A96. The July 2014 summary judgment Order, on appeal here, did not change that construction. A31-38, A26 (n.4).

The district court's straight-forward construction is based squarely on the intrinsic record. For example, the '473 patent's "Summary of the Invention" describes the "user interface" invention in broad terms. A128-29 (2:13-4:19). The specification does not require a specific type of user interface or specify where that user interface must be located in a device vis-à-vis the user. *Id.* As the 2005 *Markman* Order noted, the specification cites a variety of user interfaces to indicate

the simple-to-complex expansive breadth of the user interface invention. A80-81, A132 (9:32-44). According to the '473 patent specification, all the invention requires is "a simple way to control operation of the disk drive, which permits the user to select operational parameters, such as seek time and acoustic levels." A129 (4:2-5). Thus, a "user interface" simply "enables the user to customize operation of a disk drive relatively easily without requiring significant hardware and/or software modifications." A129 (4:11-13).

The 2005 *Markman* Order's construction also comports with the file history. As originally filed, the claims were drawn to a "graphical user interface," but Convolve amended those claims during prosecution to more broadly claim a "user interface." A1930-42. This amendment sought "broader coverage specifically in an effort to make sure" the claims covered "the Seagate disk drive now accused of infringing." A1096 (¶ 96). At the *Markman* hearing, Convolve argued that this file history amendment meant that, *inter alia*, "the interface on a disk drive" fell within the scope of "user interface." A1137 (Tr. at 116). The district court agreed, because the examples cited were "examples of an immediate, timely command given by a human being." A1137-38 (Tr. at 116-17). Appellees' repeated insistence that a "user interface" can never be a "machine to machine interface" was flatly rejected by the 2005 *Markman* Order and the subsequent orders denying reconsideration. *Compare* A1195, *with* A92-94, *and* A95.

"Outputting Commands to the Data Storage Device"

During claim construction, appellees sought restrictive constructions of both the phrase "outputting commands to the data storage device" and its constituent term "data storage device." A85, A84. Specifically, appellees' proposed constructions sought "to exclude from the scope of the claims situations where electronics located within the disk drive itself perform a shaping method on commands sent to the data storage device." A85, A84. The 2005 *Markman* Order twice rejected this argument, because the specification clearly discloses an embodiment in which "'a separate controller dedicated to the disk drive … receives commands' from the main processor of the computer." A85 (citing A132 (10:6-8)), A84 (also citing A132 (10:6-8)).

> The specification discloses in the preferred embodiment a software application, the disk drive engine, which "generates and outputs commands to the disk drive." ('473 patent, Col. 6 lines 43-45). This application is executed either on the main processor of the computer of which the disk drive is a component, ***or "a separate controller dedicated to the disk drive which receives commands" from the main processor of the computer.*** ('473 patent, Col. 10 lines 6-8).

A85 (emphasis added). "Such a configuration" was expressly deemed "within the scope of the claim[s]." A85. The district court thus construed "outputting commands" to mean:

> sending a command to a device, ***which may originate from within the device***.

A86 (emphasis added). The district court construed "data storage device" to mean:

> a computer disk drive … ***which receives shaped commands from a processor which may be integrated into the drive***.

A85 (emphasis added).

Neither the claims, nor the 2005 *Markman* Order, require the claimed user interface to output shaped commands. A86, A149-50. The 2014 summary judgment Order, on appeal here, did not change the 2005 *Markman* Order's construction of: (1) "outputting commands," which still permits the claimed output commands to "originate from within the device"; or (2) "data storage device," which still may "receive[] shaped commands from a processor which may be integrated into the drive." *Compare* A38-43, *with* A85-86.

"Acoustic Noise"

The 2005 *Markman* Order did not construe the claim term "acoustic noise" because there was no need.

Prior to the 2004 *Markman* hearing, the district court directed the parties to identify terms for which "real substantive difference" existed between the parties. A954 (Tr. at 3), A959-60 (Tr. at 23-24). Convolve provided a list by letter two weeks before the *Markman* hearing; noticeably absent was "acoustic noise," because there was no "substantive difference" between the parties' constructions. A969. Convolve did not dispute defendants' proposed construction to exclude

"electrical noise or audible noise emanating from the spindle motor" from the scope of "acoustic noise." A656. This is because the claimed inverse relation and "in accordance with" language of the asserted claims ties the "alter[ed] seek trajectory shape … to reduce selected unwanted frequencies" to the altered "acoustic noise" settings in the user interface, *e.g.*:

> 10. Method of controlling operation of a data storage device, comprising:
>
> providing a user interface for controlling one of a seek time of the data storage device and an ***acoustic noise level*** of the data storage device;
>
> operating the user interface so as to alter settings of one of the seek time and the acoustic noise level of the data storage device ***in inverse relation***; and
>
> outputting commands to the data storage device causing the data storage device to ***alter seek trajectory shape*** by shaping input signals to the data storage device ***to reduce selected unwanted frequencies*** from a plurality of frequencies ***in accordance with the altered settings.***

A149 (claim 10) (emphasis added).

Convolve's expert opined, concurrent with that letter, that "the control between 'seek time' (quicker) and 'acoustic noise level' (quieter) addresses the acoustic noise created by seeking, and ***not other noises of the disk drive***." A1021 (¶ 159) (emphasis added). Appellees' expert agreed, testifying in 2008 that he did not "believe that there was a dispute" during claim construction that acoustic noise

"does not include … audible noise emanating from the spindle motor." A2803 (Tr. at 194-95).

C. The Accused Seagate Drives Have A "User Interface"

Seagate's accused drives were designed to allow a user to alter the settings of the drive between quiet and performance modes. On this point, everyone agrees. *E.g.*, A2219-20. Specifically, Convolve's expert opined that the ATA/SCSI code within the accused drives' firmware are user interfaces that allows the user to control the drive's seek time or acoustic noise level. A2441-44 (¶¶ 178-90). As he explained, the ATA/SCSI interfaces accept user commands, such as SET FEATURES command (ATA drives) and MODE SELECT (SCSI drives), that allow the drive's user to alter settings in the user interface. A2442-43 (¶¶ 182-83, 186). In other words, when a user of an accused drive changes the settings from a quiet to a performance mode, or vice versa, the drive's operation is correspondingly altered in response to the user's input. *Id.*

Convolve cited detailed evidence showing how users can switch between quiet and performance modes on the accused drives. A2621-28 (¶¶ 461-89). Specifically, Convolve cited the relevant ATA/ATAPI-6 technical standards in which appellees and their industry allies standardized the commands issued through the ATA interface to permit users to select performance-mode or quiet-mode in "AAM-compliant" drives. A2621-25 (¶¶ 463-77). Convolve referred to

Seagate product manuals instructing users how to select quiet or performance modes in ATA interface and SCSI interface accused drives. A2621-22, A2625 (¶¶ 463-64, 467, 478-89). Convolve also cited specific source code files and relevant Fed. R. Civ. P. 30(b)(6) testimony showing how the accused drives respond to quiet mode or performance mode commands issued by users through the drives' ATA or SCSI interfaces. A2625, A2627 (¶¶ 477, 487), A2623-28 (¶¶ 469, 471-72, 478-79, 481, 493-85, 487-89).

This evidence shows how the ATA/SCSI interfaces—in the words of the '473 patent itself—"enable[ ] the user to customize operation of a disk drive relatively easily without requiring significant hardware and/or software modifications." A129 (4:11-13).

This Court Credited Evidence of a "User Interface" in the Accused Drives

The evidence Convolve cited to establish the accused drive's direct infringement of the user interface limitation should sound familiar to this Court; Convolve cited that very same evidence in its successful appeal on indirect infringement in *Convolve I*. A2026-27.

In reviewing the district court's first bite of the "user interface" apple, *Convolve I* addressed the district court's dismissal of Convolve's induced infringement claim, because Convolve purportedly "failed to present evidence of a

user who actually altered drive parameters, *i.e.*, who used the user interface in an infringing way." A2026. This Court reversed, because Convolve provided:

> evidence from Seagate and Compaq including: press releases, ***end-user instructions***, and distributed tools that allowed and even encouraged computer users to select between different performance levels of the disk drives, *i.e.*, quiet and slower versus noisy and faster.

A2026-27 (emphasis added).

The "end-user instructions" allowing "users to select between different performance levels of the disk drives" (*id.*)—cited to and credited by this Court in *Convolve I*—are the same product manuals Convolve cited on remand as evidence that Seagate's ATA/SCSI drives have a "user interface." *Compare* A3498 (citing former A3834 ("Barracuda ATA IV Family Product Manual, Rev. B," providing users ATA interface performance/quiet mode commands for ATA4 drive) and former A4057 ("SCSI Interface Product Manual, Rev. B," providing "JIT bit" "reduce[d] acoustics" commands for SCSI drives)), *with* A2621-28 (¶¶ 461-89) (citing those same Seagate product manuals).

In other words, this Court determined that Convolve's evidence showed use by Seagate customers of the accused "user interface" on Seagate's drives. A2026-27. The district court nevertheless ignored this Court's mandate and took a second bite of the "user interface" apple, holding that "[t]he ATA and SCSI interfaces, and

therefore the [Seagate] disk drives by themselves, cannot support a finding that the accused products infringe the 'user interface' element." A38.[1]

The EDTX Jury Found That the ATA Interface is a '473 Patent "User Interface"

In Convolve's EDTX action, the court twice rejected summary judgment that the industry-standard ATA interface is not a claimed "user interface." A2577-79 (¶¶ 277-80), A2121-22, A2124-25. The EDTX jury later rejected that defense by returning a verdict that ATA interface drives *willfully* infringe the '473 patent. *Compare* A2967, *with* A2581-82 (¶¶ 290-93). Appellees conceded that, for the purpose of this case, the SCSI interface on Seagate's accused Cheetah drives "serves the same purpose and function as the ATA interface" at issue in the EDTX case. A2211. Not surprisingly, Convolve's summary judgment opposition in the SDNY pointed to the EDTX willful infringement verdict as evidence that raises genuine fact issues precluding summary judgment that the ATA/SCSI interfaces on

[1] In a footnote, the district court precluded evidence of Seagate's SeaTools and seaaam.exe from Convolve's *direct* infringement case. A39 (n.21). Convolve does not read that footnote as contradicting this Court's 2013 opinion finding that SeaTools and seaaam—*i.e.*, the "distributed tools that allowed and even encouraged computer users to select between different performance levels of the disk drives" (A2027)—were relevant, admissible evidence precluding summary judgment on Convolve's "separate allegation" of *indirect* infringement (A39 (n.21)). Convolve was not required to identify *indirect* infringement evidence in its infringement contentions. A2357 (n.4), A3393.

accused Seagate drives are not claimed "user interfaces." A2353, A2577-79 (¶¶ 277-80), A2581-82 (¶¶ 290-91).

In response, the district court summarily refused to "consider the determinations made by the [EDTX] judge or jury … applicable, persuasive, or compelling." A44 (n.24). The district court reasoned that the "Texas magistrate judge adopted a different claim construction for 'user interface' than that adopted by this Court." *Id.* Notably, the district court did not even recite the EDTX construction, much less explain *how* the constructions were different in relevant manner. *Id.* Indeed, the two constructions are virtually indistinguishable. The following chart shows those purportedly "different" constructions side-by-side:

SDNY	**EDTX**
"software, hardware, firmware, or a combination thereof that allows a person, directly or indirectly, to alter parameters." A96.	"control (e.g. software, hardware, firmware, or a combination thereof) accessible to the end user that allows a person to alter operational parameters." A3160.

The two constructions are almost verbatim and virtually identical in scope. Importantly, the EDTX construction of "user interface" is slightly narrower than, and encompassed within the *broader* SDNY construction.

D. The Accused Compaq Products "Output Commands"

Accused Compaq computers, having the F10 BIOS in combination with Seagate drives, are accused of infringing the '473 patent. A25. The BIOS of the accused Compaq computers issues generic commands to the drives, which

themselves generate and output the claimed shaped commands, as contemplated by both the specification and the 2005 *Markman* Order. *Compare* A2354-56, A2455-56 (¶¶ 222-25), *and* A2613-16 (¶¶ 430-41), *with* A84-A86 (twice citing A132 (10:6-8)). Seagate implicitly admitted as much when it expressly declined to join Compaq's 2009 summary judgment argument that the accused products do not meet the "outputting commands" limitation. A2611 (¶¶ 414-15).

The district court entered summary judgment in Compaq's favor on this limitation, because the F10 BIOS utility does not itself output commands. A38-43. But Convolve did not, as the district court stated, argue that the generic BIOS commands to the drive satisfied the "outputting commands" element. A41-42, A2355. *To be clear: Convolve accuses Compaq* ***computers*** *of infringement, not just Compaq's F10 BIOS utility.* A2008, A2334.5-34.6, A2355, A2614 (¶ 434), A2658 (¶ 613). On summary judgment, Convolve provided evidence that—expressly consistent with the 2005 *Markman* Order—the claimed output commands "originate from within" the Seagate drives installed within Compaq computers that Compaq sold. *Compare* A86, *with* A2354-56, A2455-56 (¶¶ 222-25), A2613-16 (¶¶ 430-41).

Specifically, Dr. Phinney explained how his expert reports had shown how the disk drive engine of each accused drive "outputs commands to the HDA in the form of seek current," which are the "shaped commands from a processor [the

servo microprocessor] which may be integrated into the drive." A2455-56 (¶ 224); *see also* A2452-55 (¶¶ 212-21) (Dr. Phinney's opinion that his prior expert reports also identified the seek current input signal for each accused product). Convolve's opposition also cited Compaq's 2009 summary judgment brief, which: (a) did not dispute that Convolve identified the claimed "output commands to the data storage device" for each of the accused devices, but merely contended that Convolve had not done so for every asserted claim; and (b) admitted that Convolve had identified, for all accused drives, the "seek current" or "seek current samples" as the "input signal," which the 2005 *Markman* Order recognized can be construed to be synonymous with the output commands. A2354-56, A2613-14 (¶¶ 430-36). As Convolve argued, Compaq's 2009 concessions were "fatal to defendants' new argument, which is predicated on the same 'command' element present in all asserted claims—*i.e.*, an accused product that meets the 'command' element for one claim meets it for all claims." A2354-55.

In their reply, appellees did not dispute that the drives within accused Compaq computers generate/output the claimed shaped commands and thus themselves satisfy the "commands" element. A3226-27. At oral argument, Compaq's counsel appeared to concede that "the command designations from the claim language are found in the underlying disc drives." A3349 (Tr. at 109).

Convolve also cited evidence showing that appellees' non-infringement arguments on the "commands" limitation conflicted with their invalidity arguments, which cited the commands output by the firmware of prior art drives for the "commands" limitation. A2356, A2611-13 (¶¶ 416-29). The summary judgment Order, on appeal here, did not address this contradiction. A38-43.

In entering summary judgment of non-infringement on the "outputting commands" limitation, the district court never recited or discussed its complete prior constructions of "outputting commands" or "data storage device." In particular, despite several cites to the 2005 *Markman* Order, the district court never mentioned that it had previously *rejected* appellees' bid to exclude from the scope of those terms disk drives that receive shaped commands from a processor internal to the drive, nor even hinted at the portions of its construction expressly permitting shaped commands to "originate from within the device." A86. Instead, in the final paragraph of its "commands" analysis, the district court appears to have conflated appellees' "user interface" and "commands" arguments:

> As there is no other user interface that has been properly identified and accused by Plaintiff, this finding of non-infringement with respect to the F10 BIOS leaves Plaintiffs allegations devoid of a basis upon which to allege direct infringement of the "user interface" claim element, which is required by each asserted claim.

A43. However, neither the claims nor the 2005 *Markman* Order require that a "user interface" output shaped commands. A86, A149-50. On summary

judgment, the district court never substantively addressed Convolve's argument that the Seagate drives that *Compaq* had installed in *Compaq* computers that *Compaq* sold meet the "commands" limitation (A40) despite its own 2005 *Markman* Order's express holding that "[s]uch a configuration is within the scope of the claim" (A85, A86).

E. Convolve's "Clarifying" Amendment In Reexamination Did Not Substantively Change The Scope Of The Claims

Over the course of five years, the '473 patent survived multiple validity attacks by Seagate in USPTO reexamination proceedings. Seagate filed the first of three serial requests for USPTO reexamination of the '473 patent starting in 2006. A26. The first two reexaminations ended with Reexamination Certificates confirming all asserted claims. A152-54, A2091-93. The USPTO declined to initiate a third reexamination in 2011; Seagate's petition failed to raise even a substantial new question of patentability. A2097-16.

During the first reexamination, the USPTO convened an interview with Convolve to discuss the Koizumi patent under the Examiners' broadest reasonable interpretation of the asserted claims. A2701-07. The '473 patent originally issued over Koizumi's '570 patent (A99), which was discussed extensively during initial prosecution. A1839, A1852, A1894-97, A1908-13. Convolve argued in the reexamination proceeding that the '473 patent was patentable over Koizumi, because "in Koizumi spindle noise was reduced as opposed to the noise resulting

from seek operations." A2704. The examiners used the term "clarifying" to describe proposed claim amendments that would make more clear "that seek noise is reduced by the input shaped signals … in distinguishing the '473 claims over Koizumi." *Id.*

On July 31, 2008, Convolve amended claims 1, 3-4, 7-10, and 14-15 to clarify that the original language "acoustic noise" relates specifically to seek noise. A2716-21. Convolve argued that amendment was unnecessary, because construing "acoustic noise" to cover spindle noise would render "the inverse relationship [between seek time and acoustics] defined by the claims … nonsensical." A2724. Convolve nevertheless "added the clarifying term 'seek' before acoustic noise" in all independent claims (except claim 11) to "expedite the examination and potential appeal process." A2725. Convolve expressly stated that the amendment was "only a clarifying amendment, because it makes explicit what a PHOSITA [person having ordinary skill in the art] would have understood the original claims to mean." A2727.

The USPTO thereafter issued a Notice of Intent to Issue Reexamination Certificate. A2708-15. The USPTO agreed that all asserted claims were patentable over Koizumi:

> Prior art Koizumi discloses that noise attributed to the spindle is reduced by selecting a quiet mode, but does nothing to modify the actual seeks, thereby reducing the

> ***seek*** noise for selected frequencies as now clearly required by independent claims 1, 7-11, 14, and 15.

A2712. A Reexamination Certificate issued in December 2008. A152-54.

The Original Issued Claims Referred to Seek Noise, Not Spindle Noise

The modifier "acoustic" for the term "noise" was added to the pending claims during the original prosecution that led to the '473 patent, in an Amendment dated April 2, 2001. A1906-13. The Amendment was made to "state explicitly that the noise to be controlled is acoustic noise as opposed to electric noise" (A1908-09) and to distinguish Koizumi, the same reference that was at issue when the Reexamination Amendment was made. The Examiner during the original prosecution characterized Koizumi as reducing "the spindle speed to achieve the quiet mode." A1896. Referring to this characterization of the Koizumi reference, the Applicant argued that "there would be no motivation to combine Koizumi with a reference that modifies the seek operation as opposed to spindle speed to reduce noise." A1912. In addition to distinguishing the spindle control of Koizumi, the April 2, 2001 Amendment also contains several passages explicitly linking *seek* operations to the resulting acoustic noise reduction:

- The invention provides "seeks substantially as fast as current high performance seeks without *the attendant* high acoustic noise levels." A1909 (emphasis added).
- "As recited in the claims, the acoustically quiet mode is achieved by changing seek trajectory shape." A1909.

- "[I]t is the acoustic noise level of the data storage device that is controlled by changing seek trajectory shape … by shaping input signals to the data storage device." A1910.
- Convolve distinguished other prior art whose "acoustic noise reduction technique … involves control only of the spindle motor to reduce acoustic noise." A1911, A1912.

In addition, the March 15, 2001 Supplemental Preliminary Amendment previously distinguished the prior art of record—including Koizumi—that "did not teach or suggest allowing selection of a quick or *quiet mode by changing seek trajectory shape* …." A1852 (emphasis added). The pending claims were not rejected again with respect to Koizumi during initial prosecution and ultimately were allowed in a Notice of Allowance, dated May 11, 2001. A1946-48.

Each original independent claim defines an inverse relationship between a seek time and an acoustic noise level of a data storage device. A149-50. "If the acoustical noise level being controlled was generated by a source other than the actuator implementing the seek, then the inverse relationship defined by the claims would be nonsensical" (A2724), particularly because the spindle and arm are controlled by separate motors utilizing different technology. A2727, A1998, A1377-78 (¶¶ 13-14), A2867.25 (Tr. at 378-79).

Each original independent claim also uses the term "in accordance with" to define a causal relationship between "acoustic noise" settings in the user interface and the subsequently-output commands to alter seek trajectory shape, *e.g.*:

> A method of controlling operation of a data storage device, comprising:
>
> [1] generating a user interface, the user interface controlling one of a seek time of the data storage device and an acoustic noise level of the data storage device;
>
> [2] altering settings in the user interface for one of the seek time and the ***acoustic noise level*** of the data storage device in inverse relation; and
>
> [3] ***outputting commands to the data storage device to alter seek trajectory shape by shaping input signals to the data storage device*** to reduce selected unwanted frequencies from a plurality of frequencies ***in accordance with the altered settings in the user interface.***

A149 (Claim 7) (emphasis added), A151. The district court's interpretation of "acoustic noise" to cover spindle motor noise did not consider the cause-and-effect relationship defined by the "in accordance with" claim language. A149-50.

The Specification Is Limited to Seek Noise

As disclosed in the specification, the '473 patent concerns *seek-induced* vibro-acoustics. A128 (1:28-36). The "Background of the Invention" states that acoustic noise is caused by "[v]ibrations … result[ing] from th[e] movement" of the actuator arm reading/writing data to the drive's magnetic platters—*i.e.*, the patent concerns *seek* acoustic noise:

> A computer disk drive includes an actuator arm having a head mounted at a distal end of the arm for reading from, and writing to, tracks on a magnetic disk. ***This head is moved by the arm from track-to-track on the disk. Vibrations in the system result from this movement.*** That is, the head and actuator arm vibrate after reaching a nominal final position. Reading and writing cannot take

> place by the disk drive until these vibrations go below a certain level; otherwise read/write errors occur. ***These vibrations may also cause noise.***

A128 (1:28-36) (emphasis added). The "Field of the Invention" describes the patent as "altering inputs" to reduce vibrations that cause "read/write errors or excessive noise." A128 (1:15-20). The specification contains many other passages discussing the "acoustic noise excited by the move," or linking the "acoustic noise" controlled by the invention to vibrations caused by the seeking arm. A137 (19:6-32), A128 (2:5-10, 2:13-16), A130-31 (6:65-7:5), A131 (7:31-35), A132 (9:55-67, 10:22-28, 10:58-62), A137 (20:24-29), A141 (27:59-62), A148 (42:4-9).

The '473 patent contains 46 columns of detailed written description, which *never once* mention the spindle motor or spindle motor noise. A128-50. "The spindle is controlled by a completely independent motor and the skills necessary to design spindles are distinct from the skills necessary to design seeks." A2727; *see also* A1377-78 (¶¶ 13-14) (Seagate's expert declaring that "seeking" and "spindle" are separate technologies), A2867.25 (Tr. at 378-79) (Compaq's expert admitting that the '473 patent "only discusses seek technology" and does not disclose "any technology for quieting the spindle"), A1998 (this Court's recognition that the spindle and seek arm are controlled by two separate motors). Engineers cannot "alter[] inputs to, and generat[e] feedforward signals for," spindle motors, which spin at a fixed speed. *Compare* A128 (1:15-16), *with* A1377 (¶ 12). Figure 10A in

the patent, moreover, does not depict the spindle motor or number it for description in the "Detailed Description of the Preferred Embodiments." A109, A1997.

FIG. 10A

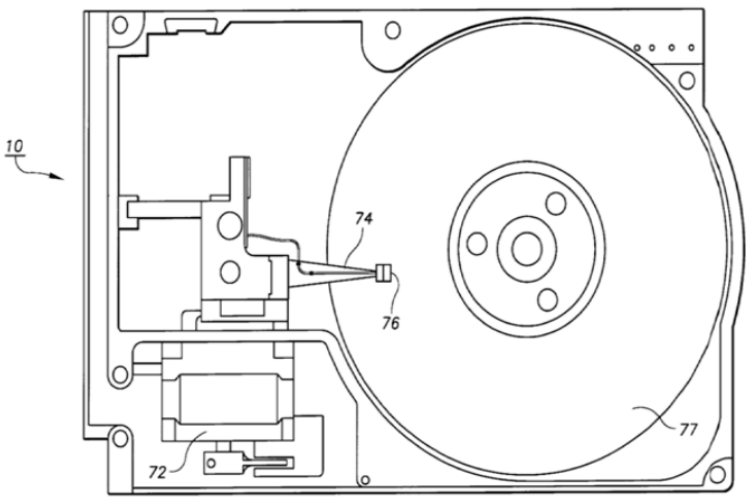


Figure 10A does, however, number the parts that the patent identifies as generating the "vibrations [that] may also cause noise"—*i.e.*, "voice coil motor 72" driving "actuator arm 74" holding "head 76." A128 (1:28-36), A132 (10:1-21).

The specification's teachings concerning seek acoustics are fully consistent with this Court's finding that the asserted claims "disclose generating a user interface that gives a user the ability to choose between ***seeks*** that are 'slower' but quieter, or 'faster' but louder." A2026 (emphasis added).

Appellees and Their Experts Admitted That
the Claims Do Not Cover Spindle Motor Noise

Appellees and their experts themselves recognized that, in fact, "the 'seek' limitation [was] implicit in the original claims." A57.

Specifically, appellees took the position during claim construction that the term "acoustic noise" in the original '473 patent claims "does not include electrical noise or audible noise emanating from the spindle motor of the 'data storage device.'" A656. The parties did not dispute this construction at the 2004 *Markman* hearing (A1021 (¶159), A2803 (Tr. at 194-95)); thus, the 2005 *Markman* Order did not construe "acoustic noise." To support their proposed claim construction, appellees argued:

> All of the control methods disclosed in the '473 patent involve a trade-off between speed and noise: more speed, less quiet, less speed, more quiet. (10:58-62).

A3075. That passage (10:58-62) discusses vibration (*e.g.*, acoustic) reduction via "shapers"—*e.g.*, "shap[ed] input signals" that "alter seek trajectory shape." A132 (10:58-62), A149 (Claim 10). That passage does *not* mention spindle motors.

Appellees' experts concurred that the '473 patent claims—as originally granted—concerned *only* seek acoustics. Their expert's *Markman* declaration, for example, stated that the '473 patent addresses shaping inputs "to reduce … seek acoustic noise." A3126 (¶ 131). That same expert later declared, under penalty of perjury:

> The technology in this case relates to software for controlling the actuator more ***specifically software to control seeks***. See arrow above.

A1378 (¶ 14) (emphasis added). That "arrow above" points to "Seeking"—and

excludes "Spindle"—on a list of hard disk drive technologies. A1377 (¶ 13).

During expert discovery, which proceeded during the first '473 patent reexamination, Convolve's lawyers asked appellees' experts under oath whether the '473 patent in any way targets spindle motor noise. Seagate's expert reaffirmed his 2002 opinion that the original "acoustic noise" claim language "does not include … audible noise emanating from the spindle motor." A2803 (Tr. at 194-95). He added, without prompting, that he did not believe this was even disputed during the *Markman* proceedings years prior. *Id.* Compaq's expert testified that: (a) the '473 patent "seek technology can only achieve acoustic noise level reduction in the seek"; (b) the patent "only discusses seek technology"; and (c) the patent does not "discuss any technology for quieting the spindle." A2867.25 (Tr. at 378-379).

The EDTX Court Rejected Intervening Rights

The EDTX court rejected the *same* intervening rights defense asserted by appellees—that the amendments in the December 2008 Reexamination Certificate "change[d] the scope of the claims." A2595 (¶ 341); *infra*, pp. 29-30. Convolve urged that "[t]he result should be no different here." A2376, A2594-95 (¶¶ 340-42). The district court, however, summarily refused to consider the EDTX court's adjudication of intervening rights in Convolve's favor:

> Despite Plaintiff's contentions that the "same" arguments were made in the Texas case as in this case …, ***it is highly***

> ***unlikely—and this Court finds no basis for presuming***—that those arguments were made in exactly the same way, nor could they have been based on the same facts, circumstances, accused products, and alleged infringing conduct.

A44 (n.24) (emphasis added).

F. Convolve's EDTX Case: 3 Years From Filing To Verdict

In June 2008, Convolve sued other drive manufacturers (Western Digital, Hitachi) and a computer maker (Dell) in the Eastern District of Texas (EDTX). A2577 (¶ 276). Similar to the SDNY action, Convolve accused disk drives utilizing the industry-standard ATA interface, and Dell computers containing those drives, of infringing the '473 patent. A2941-42 (Tr. at 68-69). Seagate's accused U5, ATA3, and ATA4 drives use the same industry-standard ATA interface as the EDTX accused drives. A2441-44 (¶¶ 178-90), A2621-25 (¶¶ 461-77). Seagate, moreover, is no stranger to the EDTX litigation; its witnesses collaborated with the EDTX defendants on a failed invalidity defense that had hoped to get the EDTX defendants and Seagate all "off the hook for infringement." A3211.42-3211.43 (Tr. at 42-43).

Like appellees here, the EDTX defendants requested intervening rights based on Convolve's amendment during reexamination. A2594 (¶ 340). They "argue[d] that inserting 'seek' in front of 'acoustic noise,'" as reflected in the December 2008 Reexamination Certificate, "change[d] the scope of the claims." A2595 (¶ 341). The EDTX court rejected this defense, holding that the "claims

were not narrowed by the amendment," and that "the 'acoustic noise' of the original claims was that generated by and associated with seek operations." A3186.

Like Seagate, Western Digital and Hitachi both moved for summary judgment that the industry-standard ATA interface is not a claimed "user interface." A2577-79 (¶¶ 277-80), A2121-22, A2124-25. The court denied both motions, finding that genuine fact issues precluded summary judgment. *Id*. That same argument was pressed to the jury, which nevertheless returned a *willful* infringement verdict in July 2011 as to those ATA-interface drives. A2967, A2581-82 (¶¶ 290-93).

The EDTX defendants filed JMOL motions, some of which remain pending as of the filing date of this brief. In 2014, those defendants filed motions seeking to overturn the jury's infringement verdict based on the summary judgment order at issue on this appeal. A3857-58 (Dkt. Entry Nos. 664-73). Those motions, too, remain unresolved. *Id.*

SUMMARY OF ARGUMENT

The district court erred in granting summary judgment on the "user interface" limitation in the face of genuine issues of material fact. Convolve raised questions of fact as to whether or not this limitation was met under the district court's claim construction Order. Moreover, this Court's holding in *Convolve I*—

that Convolve introduced sufficient evidence to establish *indirect* infringement of the "user interface"—alone demonstrates that genuine issues of material fact exist on *direct* infringement. A jury's verdict of willful infringement in another federal court further demonstrates the existence of genuine issues of material fact. It is undisputed that the accused drives were designed to be interfaced with by a user. To conclude that no genuine issues of material fact exist, in view of this Court's holding in *Convolve I*, Convolve's expert opinions, and a jury's verdict is erroneous.

The district court's grant of summary judgment in Compaq's favor on the "commands" limitation should be vacated. The district court erroneously focused on whether Compaq's F10 BIOS feature itself issues shaped commands and ignored its own claim construction that twice held that the claimed "commands" can come from the drive itself. It is Compaq computers, and not just the F10 BIOS feature, that are accused of infringement. Convolve provided fact and expert evidence that the Seagate drives within accused Compaq computers themselves output shaped commands. This undisputed evidence creates genuine fact issues that preclude summary judgment.

The district court's grant of summary judgment of intervening rights—based on an improper *per se* rule that violates binding Federal Circuit precedent, and a misapplication of the standards for claim interpretation to be applied by the PTO

during a reexamination and the district court when performing an intervening rights analysis—should be vacated. It was error to conclude that the reexamination amendment substantively changed the scope of the amended claims, in view of the intrinsic record evidence that the original and amended claims were legally identical, admissions from the appellees and their experts that the patent and its original claims concern only seek acoustics, the USPTO's characterization of the amendment as "clarifying," and the EDTX adjudication of the *same* intervening rights defense in Convolve's favor.

ARGUMENT

The district court's entry of summary judgment in appellees' favor, which denied Convolve a trial in New York and is now being used to collaterally attack the willful infringement jury verdict Convolve won three years ago in Texas, should be vacated.

STANDARD OF REVIEW

This Court reviews summary judgment "under the law of the regional circuit." *Convolve I*, 527 F. App'x at 921 (citations omitted). The Second Circuit reviews summary judgment *de novo*, "and will affirm 'only where, construing all the evidence in the light most favorable to the non-movant and drawing all reasonable inferences in that party's favor, there is no genuine [dispute] as to any

material fact and the movant is entitled to judgment as a matter of law.'" *Id.* (citations omitted). The non-moving party should "have all reasonable inferences drawn in its favor." *Id.* at 927. On summary judgment, the evidence of the non-moving party "'is to be believed' and the court 'must disregard all evidence favorable to the moving party that the jury is not required to believe.'" *Redd v. N.Y. St. Div. of Parole*, 678 F.3d 166, 174 (2d Cir. 2012) (citations omitted). "'"Credibility determinations, the weighing of the evidence, and the drawing of legitimate inferences from the facts are jury functions, not those of a judge"'" ruling on a summary judgment motion. *Id.* (citations omitted).

A literal patent infringement analysis involves two steps: "the court must first construe the disputed claims and then compare the claims to the allegedly infringing devices." *Convolve I*, 527 F. App'x at 926. The first step—claim construction—"is a question of law and is reviewed *de novo*." *Optical Disc Corp. v. Del Mar Avionics*, 208 F.3d 1324, 1333 (Fed. Cir. 2000). The second step—whether the district court "properly applied its own claim construction" to the accused products in granting summary judgment—is a question of fact, subject to *de novo* review on summary judgment. *Xerox Corp. v. 3Com Corp.*, 267 F.3d 1361, 1369 (Fed. Cir. 2001); *Convolve I*, 527 F. App'x at 921. Intervening rights is a claim construction issue and is reviewed without deference. *Laitram Corp. v. NEC Corp.*, 163 F.3d 1342, 1346-47 (Fed. Cir. 1998) ("*Laitram III*").

POINT I

THE DISTRICT COURT ERRED IN GRANTING SUMMARY JUDGMENT ON THE "USER INTERFACE" LIMITATION

The district court properly construed the "user interface" limitation in its *Markman* Order but improperly granted summary judgment by misapplying its own claim construction. Had the district court properly applied its own correct construction, summary judgment should have been denied. Moreover, in granting summary judgment, the district court violated the mandate rule and the spirit of this Court's *Convolve I* holding on indirect infringement. The district court's grant of summary judgment on the "user interface" limitation should be vacated.

A. The 2005 *Markman* Order Properly Construed "User Interface"

This Court reviews district court claim constructions *de novo*. *Optical Disc*, 208 F.3d at 1333. The "user interface" limitation was construed as:

> software, hardware, firmware, or a combination thereof that allows a person, directly or indirectly, to alter parameters.

A96. Rightly so; the district court relied heavily on the intrinsic record in arriving at its construction. A93. More specifically, the district court relied heavily on the '473 patent specification in construing "user interface." *Supra*, pp. 7-8.

Appellees were not satisfied with the broad construction of "user interface" and moved for reconsideration. A92-94. In denying those motions, the district court defended its construction as grounded in the intrinsic record: "[I]n

construing each term or phrase at issue, this Court first focused on intrinsic evidence in reaching each of its conclusions." A93.

The district court expressly rejected appellees' attempt to limit the claimed "user interface" to one where a user only "directly interacts … with a machine." A31 (n.11), A81. The district court, instead, construed user interface "specifically to include circumstances where a person has, ***at some point***, dictated what the parameters should be." A81 (emphasis added). The inclusion of "indirectly" in the construction of "user interface" specifically contemplated "an intermediate device" being placed between the user and the user interface; a feature would nevertheless remain a "user interface" if "a person has, at some point, dictated what the parameters should be." *Id.* To argue otherwise would be—in the district court's own words—"pedantic." *Id.*

The district court also rejected appellees' attempt to limit the breadth of "user interface" to either "a GUI [graphical user interface] or electromechanical switches" but not "the spectrum of user interfaces in between." A80-81. The district court, instead, found that the specification "demonstrates the range of user interfaces encompassed by the invention." *Id.* The 2005 *Markman* Order thus construed "user interface" to encompass a broad "spectrum" of "means by which [a user] can interact with a device" or "enables the alteration of parameters on the system." A81, A83.

The summary judgment Order, on appeal here, did not alter the district court's well-reasoned, prior construction of "user interface," which remains:

> software, hardware, firmware, or a combination thereof that allows a person, directly or indirectly, to alter parameters.

A96, A31-38.

1. The Accused Drives Meet the "User Interface" Limitation

On summary judgment, once the claim term has been construed, it is then compared to the infringing devices to determine if genuine issues of material fact exist. *Xerox*, 267 F.3d at 1369; *Convolve I*, 527 F. App'x at 921. On this point, Convolve's summary judgment evidence overwhelmingly demonstrates that the accused drives infringe the "user interface" limitation; at the very least, this evidence raises genuine fact issues that a jury must decide.

Dr. Phinney opined that the Seagate drives' ATA/SCSI interfaces are "user interfaces" that allow the user to control the drives' seek time/seek acoustic noise levels. A2441-44 (¶¶ 178-90). He explained that the ATA/SCSI interfaces accept user commands that allow the user to alter settings in the user interface. *Id.* This Court previously credited Dr. Phinney's detailed declaration in vacating summary judgment of non-infringement on all accused products. A2022-23 (ATA-IV), A2024 (SCSI drives), A2025 (ATA3, U5 drives), A2027 (Compaq computers). For the same reasons as in *Convolve I*, his expert declaration should have

precluded summary judgment on remand. *Metro. Life Ins. Co. v. Bancorp Servs., LLC*, 527 F.3d 1330, 1338-1339 (Fed. Cir. 2008) (expert testimony created genuine fact disputes that precluded summary judgment).

Convolve's summary judgment opposition also cited industry standards, Seagate product manuals, and appellees' corporate testimony evidencing how users could use the ATA/SCSI interfaces to switch acoustic and performance seek modes on accused Seagate drives. A2621-28 (¶¶ 461-89). This evidence at least raises genuine fact issues concerning whether the ATA/SCSI interfaces are "user interfaces" under the 2005 *Markman* Order—*i.e.*, "software, hardware, firmware, or a combination thereof that allows a person, directly or indirectly, to alter parameters." A96; Fed. R. Civ. P 56(a).

2. The EDTX Court Arrived At a Similar Construction and the Jury Found Willful Infringement

As discussed above, the EDTX "user interface" construction is virtually identical to the district court's construction in this case. *Compare* A96, *with* A3160. As such, the district court erred in completely ignoring the EDTX verdict that the industry-standard ATA interface, also utilized on accused Seagate drives, is a "user interface." *Compare* A44 (n.24), *with* A2581-82 (¶¶ 290-93). "Convolve was entitled to have all reasonable inferences drawn in its favor," *Convolve I*, 527 F. App'x at 927, but the district court "improperly declined" to do so, *Raytheon Co. v. Indigo Sys. Corp.*, 688 F.3d 1311, 1317 (Fed. Cir. 2012)

(vacating summary judgment that "drew impermissible factual inferences *against the non-moving party*").

The district court improperly substituted its own supposition that the cases had different claim constructions and different "alleged infringing conduct." A44 (n.24). While the two district court cases involved different disk drives, they shared the same accused "user interface"—the industry-standard ATA interface. *Compare* A2941-42 (Tr. at 68-69), *with* A2441-44 (¶¶ 178-90), *and* A2621-25 (¶¶ 461-77). (Appellees conceded that, for the purpose of this case, the SCSI interface on Seagate's accused Cheetah drives "serves the same purpose and function as the ATA interface" at issue in the EDTX case. A2211). Where, as here, two products share a standardized feature, "a finding of infringement against one will create a persuasive case against the other." *Fujitsu Ltd. v. Netgear Inc.*, 620 F.3d 1321, 1327 (Fed. Cir. 2010). The district court erred in failing to reasonably infer that the EDTX jury verdict against ATA interface drives evidences that Seagate's accused ATA interface drives also have a '473 patent "user interface." *See id.*

Indeed, the EDTX "user interface" construction was encompassed within the broader SDNY construction, essentially replacing "directly or indirectly" (SDNY) with "accessible to the end user" (EDTX). *Compare* A96, *with* A3160. If a reasonable juror could have found literal infringement under the narrower EDTX construction, "then the same reasonable juror *could not have avoided* finding literal

infringement under [a] broader construction." *Teleflex, Inc. v. Ficosa N. Am. Corp.*, 299 F.3d 1313, 1329 (Fed. Cir. 2002) (emphasis added). The EDTX willful infringement verdict against ATA interface drives, at the very least, raises genuine fact issues precluding summary judgment on the "user interface" limitation.

B. The District Court Misapplied Its Claim Construction

The district court's application of its claim construction to the accused products is a question of fact reviewed *de novo* on summary judgment. *Xerox*, 267 F.3d at 1369; *Convolve I*, 527 F. App'x at 921. In this case, the district court failed to properly apply its "user interface" construction, thereby necessitating vacatur of summary judgment.

The 2005 *Markman* Order was correct in broadly construing "user interface" consistent with the specification, and without regard to the parties' infringement and non-infringement positions. *Supra*, pp. 7-8, 34-35; *see SRI Int'l v. Matsushita Elec. Corp. of Am.*, 775 F.2d 1107, 1118 (Fed. Cir. 1985) (holding that claims are "construed in the light of the claim language, the other claims, the prior art, the prosecution history, and the specification, *not* in light of the accused device").

By contrast, the district court on summary judgment erred by restricting the claimed "user interface" to only those on the host PC, because of the particular language of claim 1. A35 (n.15). The fact that claim 1 is drawn to a user interface "operatively working' with a host processor is why Convolve asserted it only

against *Compaq*—a computer maker—and not against *Seagate*—a disk drive manufacturer. A2334.5-34.6. This language does not appear in claims 7-15 that were actually asserted against Seagate. *Compare* A2334.6, *with* A149-50. The "single use" of the phrase *operatively working with a processor* in claim 1 "does not, however, import [that] limitation into all other claims." *Wilson Sporting Goods Co. v. Hillerich & Bradsby Co.*, 442 F.3d 1322, 1329 (Fed. Cir. 2006). Rather, it implies that "user interface," "when used elsewhere in the patent does not inherently carry a … limitation" requiring the user interface to be located in or near the host processor. *Id.* (*citing Phillips v. AWH Corp.*, 415 F.3d 1303, 1314 (Fed. Cir. 2005)). In other words, the particular language of Claim 1 does not *limit* "user interface" to user interfaces on the host computer, but rather *expands* that term beyond the host PC to embrace user interfaces on the drives themselves.

The summary judgment Order's newly-imposed limitations on what constitutes a "user interface" also conflicts with the '473 patent prosecution history. Convolve broadened the claims before allowance specifically to bring Seagate's drives *themselves* within the scope of the claims. A1930-42; A1096 (¶ 96). This file history was highly relevant "evidence of how … the inventor understood the patent." *Phillips*, 415 F.3d. at 1317.

The original, straight-forward construction of user interface "stays true to the claim language and most naturally aligns with the patent's description of the

invention," *Phillips*, 415 F.3d. at 1316—*i.e.*, "a simple way to control operation of the disk drive, which permits the user to select operational parameters, such as seek time and acoustic levels," A129 (4:2-5). This, "in the end, [was] the correct construction." *Phillips*, 415 F.3d. at 1316. The district court's failure to adhere to the proper construction should be reversed. *Cf. Globetrotter Software, Inc. v. Elan Computer Grp.*, 362 F.3d 1367, 1379-81 (Fed. Cir. 2004) (vacating summary judgment that "altered [correct] construction when applying it").

C. This Court's *Convolve I* Opinion Precludes Summary Judgment

The district court should not be permitted to revisit old arguments; no more judicial resources should be wasted needlessly analyzing what this Court effectively decided. Specifically, the district court violated *Convolve I*'s mandate in entering summary judgment in Seagate's favor on the "user interface" limitation.

Convolve's argument and evidence that the ATA/SCSI interfaces are claimed "user interfaces" is fully consistent with this Court's *Convolve I* opinion vacating summary judgment on induced infringement. A2026-27. This Court credited Convolve's evidence that Seagate customers "used the user interface in an infringing way," because they were instructed by Seagate on how to issue quiet/performance seek mode commands to the drives via the ATA/SCSI

interfaces. *Id.* The district court's holding to the contrary—that those *same* interfaces are not claimed "user interfaces"—cannot stand. A38.

The mandate rule forecloses re-litigation of issues expressly or impliedly decided by the appellate court, such that "the district court's actions on remand should not be inconsistent with either the letter or the spirit of the mandate." *Laitram Corp. v. NEC Corp.*, 115 F.3d 947, 951 (Fed. Cir. 1997) ("*Laitram II*"). The *same* product manuals this Court deemed sufficient evidence that Seagate's customers used the accused drives' "user interface in an infringing manner" should have been sufficient on remand to preclude summary judgment that the drives themselves lacked that same "user interface." *Supra*, pp. 13-14. Summary judgment on the "user interface" limitation should be vacated on this ground alone. *Id.*

POINT II

THE DISTRICT COURT ERRED IN GRANTING SUMMARY JUDGMENT ON THE "COMMANDS" LIMITATION

The district court's decision to grant summary judgment to Compaq on the "commands" limitation should be vacated.

Compaq computers are accused of infringement, not just the F10 BIOS feature. A2008, A2334.5-34.6, A2614 (¶ 434), A2658 (¶ 613). The district court erred by narrowly focusing on whether the F10 BIOS itself issues the "shaped"

commands. A38-43. Neither the claims, nor the 2005 *Markman* Order, require that the claimed "user interface" itself issue shaped commands. A86, A149-50.

The 2005 *Markman* Order soundly rejected appellees' attempts to exclude shaped commands generated within the disk drive itself from the scope of the claims; on summary judgment, the district court did not once mention its constructions expressly permitting the claimed "output commands" to "originate from within the device" itself. A86, A85. The district court ignored Dr. Phinney's expert opinion and Compaq's concessions that the Seagate drives installed in accused Compaq computers *themselves* generate/output the claimed shaped commands, as expressly contemplated by the 2005 *Markman* Order. *Compare* A2452-56 (¶¶ 212-25), *and* A2354-56, *and* A2613-14 (¶¶ 430-36), *with* A85-86. Seagate expressly declined to join Compaq's "commands" argument in the 2009 summary judgment briefing; that refusal alone spoke volumes concerning the merits of Compaq's 2009 argument and appellees' rehashed summary judgment argument in 2014. A2611 (¶¶ 414-15).

The district court also erred by failing to consider appellees' own contentions that the internal commands outputted by ***prior art drives*** met the "commands" limitation. *Compare* A38-42, *with* A2356, *and* A2611-13 (¶¶ 416-29). Appellees cannot treat the outputting commands limitation "like a 'nose of wax' … twisted one way" to invalidate the asserted claims, and twisted another

way for non-infringement. *Cf. Amazon.com v. Barnesandnoble.com*, 239 F.3d 1343, 1351 (Fed. Cir. 2001). Appellees' invalidity contentions on the "commands" limitation at least raise genuine fact issues precluding summary judgment of non-infringement.

Convolve's evidence would support a jury verdict that Compaq infringed by making, offering to sell, and selling computers practicing or embodying the "outputting commands" claim element. 35 U.S.C. § 271(a). Compaq cannot escape infringement liability by pointing an accusatory finger at disk drives that *Compaq* had installed in *Compaq* computers that *Compaq* sold. *Id.* Summary judgment in Compaq's favor on the "commands" element should be vacated. *Metro. Life*, 527 F.3d at 1338-39.

POINT III

THE DISTRICT COURT ERRED IN GRANTING SUMMARY JUDGMENT OF INTERVENING RIGHTS

The district court's summary judgment of intervening rights, based on a *per se* rule that is in direct violation of controlling precedent—and on reading of the original claim language no person of ordinary skill in the art would make—should be vacated.

A. The District Court Imposed An Invalid *Per Se* Rule

This court has made clear that "a claim amendment made during reexamination following a prior art rejection is not *per se* a substantive change." *Laitram III*, 163 F.3d at 1347 (citing *Laitram Corp. v. NEC Corp.*, 952 F.2d 1357, 1362 (Fed. Cir. 1991) ("*Laitram I*")). In order to "'determine whether a claim change is substantive, it is necessary to analyze the claims of the original and the reexamined patents in light of the particular facts, including the prior art, the prosecution history, other claims, and any other pertinent information.'" *Id.* In this case, the district court failed to properly analyze the scope of the claims, as required, and instead imposed an improper *per se* rule.

The district court acknowledged that the case raised by plaintiff's counsel during oral argument, *Kaufman Co. v. Lantech, Inc.*, 807 F.2d 970 (Fed. Cir. 1986), involved a patent claim that was amended "without substantive change." However, because the case purportedly did not involve amendment following rejection over prior art, the district court erroneously considered it to be consistent with the proposition of a *per se* rule that "where—as here—a patent's claims, having previously been rejected as unpatentable over prior art, only become allowable once amended, those amendments are properly deemed to be 'substantive' and not 'clarifying.'" A50, A44. This inference was squarely rejected by this Court in *Laitram I*, which refused the invitation to allow a *per se*

rule for amendments following a prior art rejection by limiting cases like *Kaufman* and *Tennant Co. v. Hako Minuteman, Inc.*, 878 F.2d 1413 (Fed. Cir. 1989) to 35 U.S.C. § 112:

> When claims are amended during reexamination following a rejection based on prior art, the claims are not deemed substantively changed as a matter of law. There is no per se rule.

Laitram I, 952 F.2d at 1362. The *dicta* in later panel decisions cited by the district court (A50) cannot supersede *Laitram I*'s controlling precedent. *Tex. Am. Oil Corp. v. U.S. Dep't of Energy*, 44 F.3d 1557, 1561 (Fed. Cir. 1995) (*en banc*). Nor obviously can a district court. Yet that is precisely what the district court did—rewording *dicta* from a later *Laitram* panel as a pretense for rejecting compelling evidence that the original claims were not substantively changed. A51.

Other courts, applying *Laitram I*'s binding precedent, disagree with such a *per se* conclusion. In *Engineered Data Prods. Inc. v. GBS Corp.*, language was added to the last clause of the independent claims that resulted in their allowance after rejection over prior art in a reexamination proceeding. 506 F. Supp. 2d 461, 472 (D. Colo. 2007). The court acknowledged the same dicta from *Laitram IV* but found no intervening rights based on "the plain language, specification and prosecution history" of the original claims and on "the examiner's Statement of Reasons for Patentability and/or Confirmation." *Id.; see also Henrob Ltd. v. Böllhoff Systemtechnick GmbH & Co.*, No. 05-CV-73214-DT, 2009 WL 3188572,

*13-14 n.6 (E.D. Mich. Sept. 29, 2009) (amendments following prior art rejection deemed "clarifying" in light of "language and scope of the original patent"). A3740-57.

The initial taint of an improper *per se* rule infected the entirety of the district court's analysis, leading it to serially reject all of Convolve's evidence pointing to the correct interpretation of "acoustic noise" as excluding spindle motor noise. Accordingly, the district court's summary judgment should be vacated.

B. The District Court Misapplied The Proper Standards In Doing Its Identity Analysis

It is well-settled that "[d]istrict courts and the PTO employ different evidentiary standards and rules for claim construction." *Am. Calcar, Inc. v. Am. Honda Motor Co.*, 768 F.3d 1185, 1189 (Fed. Cir. 2014). The USPTO's "broadest reasonable interpretation" rule of claim construction "is inapplicable" in litigation, *Atl. Thermoplastics Co. v. Faytex Corp.*, 970 F.2d 834, 846 (Fed. Cir. 1992), and it was error for the district court to apply this type of standard in its intervening rights analysis and reject any evidence that seemingly deviated from the language of the original claim.

Rather, a proper intervening rights analysis required the district court to "analyze the claims of the original and the reexamined patents in light of the particular facts, including the prior art, the prosecution history, other claims, and any other pertinent information." *Laitram I*, 952 F.2d at 1362-63. A proper

analysis under *Laitram I*—and the *Phillips* claim construction methodology applicable in litigation—compels reversal of both the district court's interpretation of "acoustic noise" in the original issued claims to encompass spindle motor noise and the grant of summary judgment that appellees are entitled to intervening rights. By failing to perform the more fulsome construction analysis on both the original and amended claims, the district court misinterpreted much of the evidence demonstrating that the scope of the claims are "legally identical." *Tennant*, 878 F.2d at 1417.

The flawed analysis of the district court was guided by an overly narrow principle that "claim language itself is the most significant interpretative guide for the courts, and the terms of the original '473 claims are unambiguous." A51. When allegedly comparing the scope of the original and amended claims, the district court's analysis was completely focused on its own reading of the claim language and an oversimplified analysis of the impact of the addition of the modifier "seek."

Even under a "broadest reasonable interpretation" analysis, the district court should have considered the '473 patent specification, which repeatedly ties seek operations to the acoustic noise generated by seeks. *Supra*, pp. 24-25. Indeed, dead center in the middle of Column 1, the specification defines acoustic "noise" as caused by seek operations. A128 (1:28-36). The '473 patent's lengthy written

description does not *once* mention the spindle motor, let alone any noise that might be generated by the spindle motor or whether such noise would even be so problematic as to be "unwanted." A128-50.

The district judge found that his interpretation of the plain language of the original claims—which instead should be interpreted from the prospective of the person of ordinary skill in the art—would include "seek," "spindle" and other acoustic noise. A58. The district court's resort to its own reading of the plain language of the claims, without regard to how a POSITA would interpret that claim language, was fundamental, reversible error. *Nazomi Commc'ns, Inc. v. Arm Holdings, PLC*, 403 F.3d 1364, 1370-71 (Fed. Cir. 2005) (reversing where "district court provided no analysis of the level of ordinary skill in th[e] art nor the likely understanding" of the term to a POSITA).

The district court erred by ignoring the "substantial guidance as to the meaning of ['acoustic noise']" provided by "the claims themselves." *Phillips*, 415 F.3d at 1314. Interpreting "acoustic noise" on it face to cover reduced spindle motor noise and even other, unspecified noise (A58) ignores the "inverse relation" between seek time and acoustic noise recited in the claims. A149-50. Speeding up or slowing down seeks has ***zero effect*** on spindle noise, because the seek arm and spindle are controlled by separate motors involving different technologies. A2727; A1998, A1377-78 (¶¶ 13-14), A2867.25 (Tr. at 378-79). The district court's

interpretation of acoustic noise thus renders illogical to a person of ordinary skill in the art the inverse relation recited in all asserted claims and should be rejected. A2724. *Tennant*, 878 F.2d at 1417 (reversing grant of intervening rights based on claim construction that defied "common sense dictates" of claim language); *Interactive Gift Exp., Inc. v. Compuserve Inc.*, 256 F.3d 1323, 1336 (Fed. Cir. 2001) (rejecting an "illogical" claim construction that "does not accord with the plain import of the claim language").

The district court's interpretation of "acoustic noise" also reads out of the claims the cause-and-effect relationship—between the "altered settings in the user interface" and the subsequently-output "commands … to alter seek trajectory shape"—that is explicitly defined by the "in accordance with" language in all independent claims. A149-50; *see Am. Calcar, Inc. v. Am. Honda Motor Co.*, 651 F.3d 1318, 1340 (Fed. Cir. 2011) (construing analogous term "in response to" to require cause-and-effect relation). The district court's interpretation of purported "plain language" of the claim thus "improperly read out of the claim[s]" not one, ***but two*** limitations, and should be rejected. *Dayco Prods., Inc. v. Total Containment, Inc.*, 329 F.3d 1358, 1370 (Fed. Cir. 2003).

The inaccuracy of the district court's proposed scope of the original claims is evident from consideration of the prosecution history and prior art. During the April 2, 2001 Amendment, the claims were amended to include the modifier

"acoustic," without the further modifier "seek," to distinguish the claims from the prior art reference Koizumi, which both the examiner and the applicant agreed dealt with reducing "the spindle speed to achieve the quiet mode." A1912, A1896. The claims were subsequently allowed with this understanding that they were directed at seek noise reduction and were distinguished from spindle noise reduction.

The district court summarily rejected this analysis, concluding that the 2001 Amendment "cannot establish that the term 'seek' was thereafter implicitly incorporated into the original claim language," because allegedly this history was considered during the reexamination and it was "*nevertheless* determined that the reexamined claim language must be rejected, on the grounds that it was insufficiently specific to disclose all of the invention's allegedly required elements, or to distinguish it from Koizumi." A56 (emphasis original). This inference is wrong and once again misinterprets the distinction between the standard of review applied by the PTO during a reexamination and that which a district court must follow in doing an intervening rights analysis. "Although claims of issued patents are interpreted in light of the specification, prosecution history, prior art and other claims, this is not the mode of claim interpretation to be applied during examination." M.P.E.P. § 2111.01 (8th ed. rev. 6 Sept. 2007). The examiners apply the "broadest reasonable interpretation" rule of claim construction, which

applies only in USPTO examinations and reexaminations, not in district court proceedings. A3287 (Tr. at 47); A3416. During the reexamination proceeding, the PTO must give the claims their broadest reasonable interpretation in light of the specification. *In re Am. Acad. of Sci. Tech. Ctr.*, 367 F.3d 1359, 1369 (Fed. Cir. 2004). Therefore, the examiners do not consider or limit the interpretation of the claims using the prosecution history or the prior art. *See* M.P.E.P. § 2111.01.

C. The Admissions Of Appellees And Their Experts Are Strong Extrinsic Evidence That The '473 Patent Does Not Cover Spindle Motor Noise

The district court erred in rejecting appellees' and their experts' admissions that a POSITA would understand that the '473 patent is not directed to spindle motor noise. A53-54, A57. Such extrinsic evidence was highly relevant to "help the court determine what a person of ordinary skill in the art would understand claim terms to mean." *Phillips*, 415 F.3d at 1319.

Specifically, appellees admitted during claim construction that a POSITA would understand that "acoustic noise" in all original asserted claims *excluded* spindle motor noise. A656. Convolve and its expert agreed (A969, A1021 (¶159)), and this non-controversial claim construction was not even contested at the 2004 *Markman* hearing. The parties' harmony on this particular issue—in a fiercely-contested, 14-year old litigation in which Convolve and

appellees agreed on little—was highly relevant to "reflect the understanding of a skilled artisan in the field of the patent." *Phillips*, 415 F.3d at 1318.

Both experts proffered by appellees testified unambiguously that the '473 patent and its original claims have nothing *whatsoever* to do with spindle motor noise. A2803 (Tr. at 194-95), A2867.25 (Tr. at 378-379). This expert testimony was "subject to cross-examination" and, thus, was relevant to ensuring that the district court's "understanding of the technical aspects of the ['473 patent was] consistent with that of a person of skill in the art." *Phillips*, 415 F.3d at 1318. Indeed, this Court may look no further than the expert declaration supporting appellees' 2009 intervening rights summary judgment motion; that declaration unambiguously stated that this case is about ***seek technology and not about spindle motors***. A1377-78 (¶¶ 13-14).

Appellees and their experts effectively conceded that intervening rights was a defense grounded in a reading of the original claim language that no POSITA would make. Thus, summary judgment of intervening rights should have been denied on these admissions alone.

D. The USPTO Itself Called Convolve's Amendment "Clarifying"

The district court erred in rejecting, as a mere aside, strong contemporaneous evidence that the original and reexamined claims were substantially identical in

claim scope: the USPTO's own use of the term-of-art "clarifying" to describe Convolve's amendment. A57-58.

The examiners who reexamined the '473 patent are not simply, as appellees conceded, the USPTO's "most senior and experienced patent examiners." A3197 (n.5). They are "quasi-judicial officials trained in the law," *Markman v. Westview Instruments, Inc.*, 52 F.3d 967, 986 (Fed. Cir. 1995) (*en banc*), which would include this Court's precedents on intervening rights triggered by claim amendments in reexamination. Dismissing, as a mere "isolated incident," the USPTO's own characterization of Convolve' amendment as "clarifying" disregards "the expertise of patent examiners and the presumption that they have done their jobs properly." *Norian Corp. v. Stryker Corp.*, 363 F.3d 1321, 1329 (Fed. Cir. 2004). Simply put, it was not the district court's job to decide "whether the examiner 'really did understand what he was ruling.'" *Id.* Indeed, the district court simply accepted virtually all of the Examiners' analysis without question, except for their statement regarding the proposed "clarifying" amendment—*i.e.*, critical evidence defeating intervening rights. But "at the summary judgment stage the judge's function is not himself to weigh the evidence." *Anderson v. Liberty Lobby, Inc.*, 477 U.S. 242, 249 (1986).

This file history evidence, showing that the original and reexamined claims were considered substantially identical, precludes summary judgment of

intervening rights. *See Engineered Data Prods.*, 506 F. Supp. 2d at 472 (citing examiner's use of "highlight" and "emphasizing" in rejecting intervening rights).

E. The EDTX Court Rejected The Very Same Intervening Rights Defense Alleged Against The Very Same Patent

The district court erred in summarily rejecting Convolve's evidence that the EDTX defendants made the *same* intervening rights argument based on the *same* amendment in reexamination. A44 (n.24). "Convolve was entitled to have all reasonable inferences drawn in its favor" about the similarity of the intervening rights defenses asserted in the two cases. *Convolve I*, 527 F. App'x at 927. But the district court erred by "drawing impermissible factual inferences *against* [Convolve] *the non-moving party*." *Raytheon*, 688 F.3d at 1317; *see* A44 (n.24). The EDTX rejection of the very same intervening rights defense is strong extrinsic evidence bolstering what the intrinsic record makes abundantly clear—that "acoustic noise" in the original claims was directed to seek acoustic noise and did *not* cover spindle motor noise.

* * *

The cumulative weight of this evidence demonstrates that Convolve's amendment in reexamination was precisely what the USPTO dubbed it: a "clarifying" amendment to make explicit what was always implicit in the original claim language. Amendments that merely clarify claim text "to make specific

what was always implicit or inherent," or "makes it more definite without affecting its scope" are not substantive changes and do not trigger intervening rights. *Laitram I*, 952 F.2d at 1361; *Bloom Eng'g Co. v. N. Am. Mfg. Co.*, 129 F.3d 1247, 1250 (Fed. Cir. 1997); *Kaufman*, 807 F.2d at 977 (no intervening rights where amendments did not "alter the meaning or scope of the [original] claims"). The district court's faulty reading of "acoustic noise" should be reversed, and summary judgment of intervening rights should be vacated.

CONCLUSION

For these reasons, the district court's summary judgment of non-infringement and intervening rights should be vacated, and the case remanded for a prompt jury trial.

Dated: December 10, 2014 Respectfully submitted,

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ADDENDUM

USDC SDNY
DOCUMENT
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UNITED STATES DISTRICT COURT
SOUTHERN DISTRICT OF NEW YORK

CONVOLVE, INC.,

Plaintiff,

-against-

COMPAQ COMPUTER CORP. and SEAGATE TECHNOLOGY LLC,

Defendants.

MEMORANDUM DECISION AND ORDER

00 Civ. 5141 (GBD) (JCF)

GEORGE B. DANIELS, United States District Judge:

Defendants Compaq Computer Corp. and Seagate Technology LLC bring this motion for summary judgment pursuant to Federal Rule of Civil Procedure 56, seeking dismissal of Plaintiff Convolve, Inc.'s Tenth – and only remaining – Claim for Relief. (Mot. for Summ. J. ("MSJ"), ECF No. 1029.) Plaintiff's Tenth Claim for Relief seeks damages and injunctive relief for Defendants' alleged infringement of United States Patent No. 6,314,473 ("the '473 patent"), which discloses a particular method for controlling computer disk drive speed and acoustics by means of input shaping and user interface technologies.[1] (Am. Compl. ¶¶ 63-66, 115-120, ECF No. 50.) Specifically, Plaintiff alleges that Defendants infringed the '473 patent by selling Compaq computers containing Seagate disk drives that, alone or in combination with Compaq's F10 BIOS interface, wrongfully incorporated Plaintiff's claimed technology. (*See, e.g.*, Am. Compl. ¶¶ 1-2, 4-13, 38-44, 54-62, ECF No. 50.)

Defendants move for summary judgment on the grounds that: (1) the accused drives do not

[1] The '473 patent is entitled: "System for removing selected unwanted frequencies in accordance with altered settings in a user interface of a data storage device." (Pl.'s Ex. 1.)

Plaintiff's exhibits were submitted with the May 2, 2014 Affidavit of Kevin J. McNamee Opposing Defendants' Motion for Summary Judgment. (ECF No. 1035.) Defendants' exhibits are annexed to the April 2, 2014 and May 16, 2014 Declarations of Eric W. Hagen in Support of Defendants' MSJ papers. (ECF Nos. 1033, 1039.)

infringe the '473 patent because they do not satisfy the "inverse relation," "user interface," or "commands" elements of the asserted claims under this Court's construction of those terms; (2) there is no evidence that Defendants specifically intended to induce infringement with respect to the accused drives;[2] (3) the asserted claims are invalid under the doctrines of anticipation and obviousness; (4) the doctrine of intervening rights precludes a finding of infringement liability for conduct that pre-dates a December 2, 2008 substantive amendment of certain asserted claims; (5) Plaintiff cannot establish that Defendants' alleged conduct satisfies the legal standard for willful infringement; and (6) Plaintiff cannot establish Defendants' damages liability with respect to non-Seagate disk drives. (Mem. in Support of MSJ, ECF No. 1031 ("MSJ Mem."); Reply Mem. in Support of MSJ, ECF No. 1038 ("Reply Mem.").) Plaintiff opposes the motion for summary judgment on all grounds. (Mem. in Opp'n to MSJ, ECF No. 1035 ("Opp'n Mem.").)

The evidence presented by the parties raises no genuine issue of material fact as to the lack of Defendants' infringement liability based on the following three independent grounds: (i) the ATA and SCSI interfaces in Seagate's accused disk drives do not satisfy the patent's required "user interface" element, as construed by this Court; (ii) the commands issued by Compaq's F10 BIOS utility do not satisfy the patent's required "commands" element, as construed by this Court; and (iii) Defendants are entitled to intervening rights arising from the substantive December 2, 2008 amendment of certain asserted claims.[3] Defendants' motion for summary judgment is

[2] On June 19, 2014, Defendants filed a Motion for Leave to File Supplemental Memorandum of Law Regarding New Controlling Authority on Induced Infringement in light of the Supreme Court's recent decision in *Limelight Networks, Inc v. Akamai Techs., Inc.*, 134 S. Ct. 2111 (June 2, 2014). That motion was denied. This Court has, however, reviewed the *Limelight* opinion.

[3] This Court finds determination of the intervening rights, user interface, and commands issues to be dispositive of the issue of direct infringement liability, and of this action. In light of this ruling, Plaintiff's claims of inducement and willful infringement, which depend on a finding of direct infringement, fail as a matter of law. *Limelight*, 134 S. Ct. at 2117 (internal quotation marks and citation omitted) ("[O]ur case law leaves no doubt that inducement liability may arise if, but only if, there is direct infringement."); *Cook Biotech Inc. v. Acell, Inc.*, 460 F.3d 1365, 1379-1380 (Fed. Cir. 2006) ("[B]ecause we have concluded that there was no direct act of infringement . . . [Plaintiff's willful infringement case is] rendered moot."). This Court does not rely on any other grounds for summary judgment asserted by Defendants.

therefore GRANTED. Plaintiff's Tenth, and only remaining, Claim for Relief is DISMISSED.

I. Factual Background [4]

Convolve, Inc. accuses Defendants Compaq Computer Corp., a manufacturer of computing systems, and Seagate Technology LLC, a manufacturer of disk drives, of selling disk drives and computer systems that infringe Convolve's '473 patent. (Am. Compl. ¶¶ 115-120.) The '473 patent teaches a method of customizing disk drive speed and acoustics that allows computer users "to control the trade-off between speed and acoustics." (Am. Compl. ¶ 1.) Specifically, Convolve alleges that Defendants directly and indirectly infringed claims 1, 3, 4, and 7-15 of the '473 patent through sales of the following products: Seagate's Barracuda ATA-III, Barracuda ATA-IV, and U Series 5 drives (collectively, the "ATA drives"); Seagate's Cheetah 73LP, Cheetah X15 18LP, and Cheetah X15 36LP drives (collectively, the "SCSI" or "JIT" drives, *see* PFII ¶ 478), and Compaq computers containing Compaq's F10 BIOS utility in combination with Seagate's ATA drives. (Oct. 30, 2007 Initial Expert Report, Pl.'s Ex. 3 at 3, Table 1; Pl.'s Resp. to Defs.' Local Rule 56.1 Statement of Undisputed Facts ("PFI") ¶ 7; Pl.'s Local Rule 56.1 Counter-Statement of Undisputed Facts ("PFII") ¶¶ 634, 636.) [5]

On July 13, 2000, original plaintiffs and patent holders Convolve and the Massachusetts Institute of Technology ("MIT") filed a Complaint against Defendants alleging, among other claims, misappropriation of trade secrets and infringement of U.S. Patent Nos. 4,916,635 and 5,638,267. (Compl., ECF No. 1.) On November 6, 2001, the Patent & Trademark Office ("PTO") granted Convolve's application for the '473 patent. (Am. Compl. ¶ 6; PFI ¶ 2.) On January 25,

[4] Unless otherwise noted, the facts herein are undisputed.

[5] Plaintiff's Statement of Undisputed Facts is one document comprised of two distinct parts: Part I is a response to Defendants' Local Rule 56.1 Statement of Undisputed Facts; Part II is Plaintiff's Local Rule 56.1 Counter-Statement of Undisputed Facts. The numbered paragraphs in Plaintiff's Counter-Statement begin anew at 1; so as to avoid confusion, citations to Plaintiff's responsive 56.1 filing are denoted by "PFI," and references to Plaintiff's Counter-Statement are cited as "PFII."

2002, Convolve and MIT filed an Amended Complaint asserting the additional claim that Defendants sold products infringing the '473 patent after the patent was issued.[6] (Am. Compl. ¶ 6; PFII ¶ 663.) Beginning March 30, 2004, this Court held a two-day *Markman* hearing to address the construction of the '473 patent claims, and issued a *Markman* Order on August 9, 2005. (Mar. 30-31, 2004 *Markman* Hr'g Trs., ECF Nos. 265-266; *Markman* Order, ECF No. 397.) An Amended *Markman* Order was issued on January 13, 2006, modifying only this Court's construction of the "user interface" claim element.[7] (Am. *Markman* Order, ECF No. 442.)

During the 2006-2011 time period, Defendant Seagate filed three separate *ex parte* requests with the PTO for reexamination of the '473 patent, seeking to invalidate the asserted claims. (Pl.'s Ex. 6: Dec. 1, 2006 Seagate Reexam. Request; Pl.'s Ex. 14: Aug. 22, 2008 Seagate Reexam. Request; Pl.'s Ex. 85: PTO Denial of Seagate's Feb. 23, 2011 Reexam. Request.) The PTO granted Defendant Seagate's December 2006 Reexamination Request and, on November 27, 2007, rejected claims 1, 3, 4, and 7-15 as anticipated by prior art (i.e., Koizumi, U.S. Patent No. 5,982,570). (Pl.'s Ex. 7: Jan. 26, 2007 PTO Office Action; Defs.' Ex. 38: Nov. 27, 2007 PTO Office Action.) Plaintiff Convolve submitted a Request for Reconsideration of the PTO's decision, explaining why it believed Koizumi did not anticipate the rejected claims. (Defs.' Ex. 46: Jan. 28, 2008 Request for Reconsideration of Nov. 27, 2007 Office Action.) On June 16, 2008, the PTO issued a Final Office Action, responding to Convolve's reconsideration arguments and maintaining its rejection of claims 1, 3, 4, and 7-15 as anticipated by Koizumi. (Defs.' Ex. 47: June 16, 2008 PTO Final Office Action.) In response, Plaintiff Convolve amended patent claims 1, 3, 4, 7-10,

[6] The Amended Complaint also asserted claims for breach of contract, tortious interference with contract, fraud, violation of California Business and Professions Code § 17200, et seq., breach of confidence, and breach of good faith and fair dealing, which have since been dismissed. (Am. Compl. ¶¶ 67-95, 121-138.)

[7] At Plaintiffs' request, to which Defendants did not object, the word "software" was added to this Court's construction of the "user interface" limitation, so that the final, amended claim construction reads: "software, hardware, firmware, or a combination thereof that allows a person, directly or indirectly, to alter parameters." (Am. *Markman* Order at 1.)

14 and 15, modifying all instances of the term "acoustic noise" to read "seek acoustic noise," and again requested that the PTO reconsider reissuing the '473 patent. (Pl.'s Ex. 11 at 1-10: July 31, 2008 Amendment After Final and Interview Summary.) On December 2, 2008, the PTO issued a Reexamination Certificate determining the rejected claims patentable as amended and allowing claims 11-13 as originally issued. (Pl.'s Ex. 1 at 58: '473 C1, Dec. 2, 2008 Reexam. Certificate ("First Reexamination Certificate").)

The PTO also granted Defendant Seagate's August 2008 Reexamination Request and, in an Office Action dated June 8, 2009, rejected claims 1, 3, 4, and 7-15 as obvious in light of prior art (i.e., the combination of the Ray Thesis and the Koizumi patent). (Pl.'s Ex. 13: Nov. 20, 2008 PTO Office Action; Defs.' Ex. 41: June 8, 2009 PTO Office Action.) In a Final Office Action dated January 4, 2010, the PTO allowed as patentable claims 11-13 and claims 1, 3, 4, 7-9, and 14, as amended on December 2, 2008. The PTO maintained its June 8, 2009 rejection of claims 10 and 15 as obvious in light of the Ray Thesis and the Koizumi patent. (Defs.' Ex. 42: Jan. 4, 2010 PTO Final Office Action.) Following Plaintiff Convolve's response to the rejection of claims 10 and 15, the PTO ultimately certified the patentability of all reexamined claims, including claims 10 and 15, without further amendment. (Pl.'s Ex. 15: July 20, 2010 Reexam. Certificate ("Second Reexamination Certificate").) Defendant Seagate's third and final Reexamination Request was denied by the PTO on April 1, 2011. (Pl.'s Ex. 85.)

On August 16, 2011, this Court granted Defendants' motion for summary judgment, dismissing the last remaining trade secret and patent infringement claims in this action,[8] and denied Plaintiffs Convolve and MIT's motion for summary judgment. (Aug. 16, 2011 Mem. Decision and Order, ECF No. 994.) Plaintiffs filed a timely Notice of Appeal on November 3, 2011. (ECF

[8] These claims pertained to the '473 and '635 patents only. In March 2010, this Court dismissed the '267 patent from the case. (*See* Order, ECF No. 982.)

No. 1005.) On July 1, 2013, the Federal Circuit affirmed summary judgment on the trade secret and '635 patent claims, but vacated this Court's judgment of non-infringement of the '473 patent for failure to meet the "selected unwanted frequencies" limitation, and remanded for further proceedings.[9] (Fed. Cir. Opinion, ECF No. 1013; Mandate, ECF No. 1014.) On remand, Defendants renew their motion, on the grounds not previously addressed by this Court, for summary judgment dismissal of Plaintiff Convolve's '473 infringement claims.[10]

II. Summary Judgment Standard

Summary judgment is appropriate when the evidence presented demonstrates that "there is no genuine dispute as to any material fact and the movant is entitled to judgment as a matter of law." Fed. R. Civ. P. 56(a). The moving party bears the initial burden of establishing the absence of any material factual dispute. *See Celotex Corp. v. Catrett*, 477 U.S. 317, 323 (1986). To defeat a motion for summary judgment, the nonmoving party must raise a genuine issue of material fact by citing to admissible evidence that supports each claim on which summary judgment is sought. *Matsushita Elec. Indus. Co. v. Zenith Radio Corp.*, 475 U.S. 574, 585-86 (1986); Fed. R. Civ. P. 56(a), (c).

In determining whether there exists a genuine issue as to a material fact, this Court is required to "resolve all ambiguities and draw all inferences in favor of the party against whom summary judgment is sought." *Stern v. Trustees of Columbia Univ.*, 131 F.3d 305, 312 (2d Cir. 1997). However, a nonmoving party cannot avoid summary judgment simply by relying on

[9] This Court previously granted summary judgment on the grounds that "only one frequency was targeted in the ATA IV drive," the "low-pass filters" employed by the SCSI drives did not "identify and then target specific unwanted frequencies," and the "Convolve method" was "too generic to refer to the identification, targeting and reduction of specific frequencies," as required by the patent. (Aug. 16, 2011 Mem. Decision and Order at 49, 50, 52.) The Federal Circuit reversed the dismissal on these grounds, holding that, with all reasonable inferences drawn in Convolve's favor, Convolve's expert's testimony and certain documentary evidence created a genuine issue of material fact remained on each of these issues. (Fed. Cir. Opinion at 31-33.)

[10] Because MIT brought claims only with respect to the '635 patent, the dismissal of which was affirmed by the Federal Circuit, it is no longer a party to this case.

"conclusory allegations or unsubstantiated speculation." *Fujitsu Ltd. v. Fed. Express Corp.*, 247 F.3d 423, 428 (2d Cir. 2002) (citation omitted). Nor is the "mere existence of a scintilla of evidence" sufficient for this purpose. *Anderson v. Liberty Lobby*, 477 U.S. 242, 252 (1986); *see also Niagara Mohawk Power Corp. v. Jones Chem., Inc.*, 315 F.3d 171, 175 (2d Cir. 2003). Instead, a nonmoving party must show that there is a genuine dispute as to a material fact by pointing to the presence of evidence in the record "such that a reasonable jury could return a verdict for the nonmoving party." *Anderson*, 477 U.S. at 248.

"Summary judgment is as appropriate in a patent case as it is in any other case." *C.R. Bard, Inc. v. Advanced Cardiovascular Sys., Inc.*, 911 F.2d 670, 672 (Fed. Cir. 1990); *see also Desper Prods., Inc. v. QSound Labs, Inc.*, 157 F.3d 1325, 1332 (Fed. Cir. 1998). A patent infringement analysis involves two steps. First, the court determines the scope and meaning of the patent claims asserted. *See Markman v. Westview Instruments, Inc.*, 52 F.3d 967, 970-71 (Fed. Cir. 1995) (en banc), *aff'd*, 517 U.S. 370 (1996) ("[T]he interpretation and construction of patent claims, which define the scope of the patentee's rights under the patent, is a matter of law, exclusively for the court."). Second, the accused product, method, or process is compared to the asserted claims, properly construed. *See Cybor Corp. v. FAS Techs., Inc.*, 138 F.3d 1448, 1454 (Fed. Cir. 1998). The plaintiff bears the burden of showing that each and every claimed element of the patent, or its equivalent, is present in the accused device. *Uniloc USA, Inc. v. Microsoft Corp.*, 632 F.3d 1292, 1301 (Fed. Cir. 2011) (quoting *Lemelson v. United States*, 752 F.2d 1538, 1551 (Fed. Cir. 1985)).

III. There Is No Genuine Factual Dispute As To Whether The Accused Products Meet All Required Claim Limitations

The parties disagree on the meaning – and thus the correct application – of this Court's construction of the "commands" and "user interface" elements of the asserted claims. Defendants submit that infringement of these claim elements is ripe for summary judgment because the only

remaining dispute concerns the meaning of this Court's construction of these terms. (Tr. 12:8-20; MSJ Mem. at 18-20; Reply Mem. at 9-10.) Plaintiff contends that summary judgment is inappropriate because Defendants' interpretation of the claim limitations contradicts the *Markman* Order and, pursuant to Plaintiff's understanding, the undisputed facts satisfy the claims as construed by this Court. (Opp'n Mem. at 11-13; Tr. 63:14-64:8.) Plaintiff urges this Court to reject the "new claim construction argument[s]" made by Defendants with respect to these elements. (*See, e.g.*, Tr. 64:11-17.) Plaintiff misconstrues and misapplies the "user interface" and "commands" claim limitations as construed by this Court. Because the parties do not dispute any material facts with respect to the "user interface" or "commands" limitations, summary judgment is warranted.

A. Claim Construction

It is well-established that "the construction of a patent, including terms of art within its claim, is exclusively within the province of the court." *Markman v. Westview Instruments, Inc.*, 517 U.S. 370, 372 (1996); *Cheese Sys., Inc. v. Tetra Pak Cheese & Powder Sys., Inc.*, 725 F.3d 1341, 1347 (Fed. Cir. 2013) (citation omitted) ("Claim construction presents only legal questions."). Moreover, "[w]hen the parties present a fundamental dispute regarding the scope of a claim term, it is the court's duty to resolve it," lest the parties submit an incompletely constructed claim to the jury. *O2 Micro Int'l Ltd. v. Beyond Innovation Tech. Co.*, 521 F.3d 1351, 1362 (Fed. Cir. 2008); *see also Every Penny Counts, Inc. v. Am. Ex. Co.*, 563 F.3d 1378, 1383 (Fed. Cir. 2009) ("[T]he court's obligation is to ensure that questions of the scope of the patent claims are not left to the jury. In order to fulfill this obligation, the court must see to it that disputes concerning the scope of the patent claims are fully resolved.").

A district court may deem it necessary to modify its claim construction due to new information gleaned from an evolving record. *Pfizer, Inc. v. Teva Pharm., USA, Inc.*, 429 F.3d 1364, 1377 (Fed. Cir. 2005) ("[A] conclusion of law such as claim construction is subject to change upon the development of the record."). Or, a dispute between the parties may prompt clarification of the court's own claim interpretation. *O2 Micro*, 521 F.3d at 1360 ("When the parties raise an actual dispute regarding the proper scope of these claims, the court, not the jury, must resolve that dispute."); *Pressure Prods. Med. Supplies, Inc. v. Greatbatch Ltd.*, 599 F.3d 1308, 1316 (Fed. Cir. 2010) (holding that district court properly undertook to clarify claim term during trial, since failure to do so would "invite[] the jury to define th[e] term on its own in a manner [the Federal Circuit] has questioned in [previous decisions]").

B. The "User Interface" Limitation

The "user interface" element of the asserted claims has been construed as follows: "software, hardware, firmware, or a combination thereof that allows a person, directly or indirectly, to alter parameters." (Am. *Markman* Order at 1.)[11] The parties do not dispute that, in the accused products, "the commands from a person . . . must travel through intermediate devices or software" before the drive parameters are changed pursuant to the user's mode selection. (Opp'n Mem. at 8-9; MSJ Mem. at 14.) In its contention that the ATA and SCSI interfaces on the disk drives are "user interfaces" in the context of this case, Plaintiff relies on an interpretation of

[11] In construing the "user interface" claim term, this Court considered Plaintiffs Convolve and MIT's proposed construction ("Any software, hardware, firmware, or combination thereof which can be used to alter operational parameters of a data storage device. A user interface does not require direct access by a person but may be accessed via other software or hardware, e.g., as a jumper, protocol, software program, keyboard or mouse.") and Defendants' proposed constructions ("an electrical device, a mechanical device, or a software method with which a [human end-]user directly interacts to communicate with a machine"; "a graphical user interface [GUI] or electro-mechanical switches, either of which must be controllable by the computer's end-user"; and "a way for an *end-user* to select settings and enter them into the computer, either through a GUI or using mechanical switches"). (Pl.'s '473 Claim Constructions at 1, Ex. A to Joint Claim Construction and Prehearing Statement, ECF No. 79 (Nov. 12, 2002); Defs.' '473 Claim Constructions at 1-2, Ex. B to Joint Claim Construction and Prehearing Statement, ECF No. 79 (Nov. 12, 2002); Jan. 15, 2003 Defs.' Resp. Claim Construction Brief at 20; *see also Markman* Hr'g Tr. 210:4-15.)

the "user interface" limitation that effectively reads the term "user" out of the claim language. Applying the proper construction to the undisputed facts establishes that the ATA and SCSI disk drives, by themselves, do not meet the "user interface" claim limitation and therefore cannot support a finding of infringement of this element.

Defendants move for summary judgment on Plaintiff's allegation that an accused ATA or SCSI disk drive, regardless of the presence of an F10 BIOS interface in the computer, may by itself constitute a "user interface" sufficient to meet the claim limitation as constructed by this Court. (*See* MSJ Mem. at 12-18; Reply Mem. at 6-8; Opp'n Mem. at 7-10.) Plaintiff asserts that there is a genuine issue of material fact as to whether an ATA or SCSI interface – a "device-to-device" connector located in or on the disk drive that enables the disk drive and host processor to communicate "in the same language" (MSJ Mem. at 13) – is a "user interface" under this Court's construction of that term. (Opp'n Mem. at 7-8; PFII ¶¶ 448-460.) Plaintiff bases this argument not on this Court's adoption of its proposed construction, but on this Court's inclusion of the words "directly" and "indirectly" in the "user interface" construction. (Am. *Markman* Order at 1.) Plaintiff contends that, by including the word "indirectly" in its "user interface" claim construction, this Court intended to allow for broad constructions of the term "user interface" in which the interface is several degrees removed from the user, and the user "indirectly" uses the interface, such as the construction advocated by Plaintiff. (Opp'n Mem. at 7; PFII ¶¶ 457-460.) Defendants argue that, in the context of the construed claim, Plaintiff's interpretation of "indirectly" is incorrect. (MSJ Mem. at 16-17.) It is Defendants' position that an accused disk drive, on its own, does not constitute or contain a user interface, and thus Plaintiff fails to demonstrate that the

accused products satisfy this required element of the asserted claims.[12] (MSJ Mem. at 12-18; Reply Mem. at 6-8.)

The parties' dispute over the "user interface" limitation turns on the proper scope and application of this Court's claim construction – specifically, on whether Plaintiff's contention that the ATA and SCSI interfaces located in the disk drive qualify as "indirect" user interfaces within this Court's construction of that term; thus, resolution of this issue is appropriate for summary judgment. *See Gen. Mills, Inc. v. Hunt–Wesson, Inc.*, 103 F.3d 978, 983 (Fed. Cir. 1997) ("Where the parties do not dispute any relevant facts regarding the accused product, . . . but disagree over possible claim interpretations, the question of literal infringement collapses into [one of] claim construction and is amenable to summary judgment."); *accord Mantech Envtl. Corp. v. Hudson Envtl. Servs., Inc.*, 152 F.3d 1368, 1371 (Fed. Cir. 1998) ("Where the determination of infringement turns solely on the legal question of the proper construction of the claims, summary judgment is appropriate.").

Plaintiff's application of the "user interface" construction is inconsistent with that ordered by this Court, and advances a position that cannot be accepted under principles of proper claim interpretation. In Plaintiff's construction of the term, an ATA or SCSI interface would be deemed to be a "user interface," despite being a part of "multiple layers" that are remotely situated from the site of contact at which a user selects a preferred mode of computer operation.[13] (Opp'n Mem.

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[12] Specifically, Defendants argue that Plaintiff erroneously "reads the [user interface] construction in such a way that allows it to claim that device-to-device connection interfaces are 'user interfaces,'" and that Plaintiff's interpretation of the "user interface" element demonstrates that Plaintiff "has ignored the Court's express requirement that the user interface requires interaction by a 'person,' not a device." (MSJ Mem. at 12-13.) Defendants conclude that "a disk drive merely having the ability to accept commands from the actual user interface on the host computer does not make the ATA / SCSI interface part of the 'user interface.'" (MSJ Mem. at 17.)

[13] In contrast, Plaintiff distinguishes software programs like Compaq's F10 BIOS from Seagate's ATA and SCSI interfaces because the F10 BIOS is a graphical user interface ("GUI") that "facilitate[s] user selection of acoustic or performance seek modes" by "provid[ing] settings to the user and allow[ing] the user to alter settings." (Opp'n Mem. at 10-11 (citation omitted).) Plaintiff contends that the fact that GUIs like the F10 BIOS facilitate a user's mode selection and visually provide settings to a user "does not make the ATA or SCSI interface any less of a user interface" than the F10 BIOS. This argument must be soundly rejected. The type of user "facilitation" described by Plaintiff is

at 8; PFII ¶¶ 446-447.) Plaintiff asserts that such a construction is appropriate because an ATA or SCSI interface, like "all" the invention's intermediary layers, constitutes a "portion[] of the user interface" that "indirectly" permits the user to "communicat[e] information . . . to the CPU." (Opp'n Mem. at 8; PFII ¶¶ 446-447.)

A court's claim construction must not read any terms out of the asserted claims. *Bicon, Inc. v. Straumann Co.*, 441 F.3d 945, 950 (Fed. Cir. 2006) ("[C]laims are interpreted with an eye toward giving effect to all terms in the claim."); *id.* at 951 (rejecting proposed claim construction because effect "would be to read limitations . . . out of the claim"); *see also Aspex Eyewear, Inc. v. Marchon Eyewear, Inc.*, 672 F.3d 1335, 1348 (Fed. Cir. 2012) (rejecting district court's claim construction because it "effectively read[] the term 'free' out of the limitation"). Plaintiff's interpretation of "user interface" is untenable because its effect is to expand the "user" aspect of the term to the point of obsolescence. Under Plaintiff's construction, the term "indirectly" has no foreseeable limit; as long as a sequence of commands is initiated by a user while selecting a setting for performance or acoustic mode, then each iteration or conduit the command must go through until it effectuates the desired outcome is itself a "user interface." Under Plaintiff's construction, any interface ensnared in the entire communication sequence between the commanding user and the ultimate implementation of the user's command would separately qualify as a user interface.[14] This construction is not permissible.

The '473 patent's "user interface" element may not be construed so broadly as to be co-extensive with the invention itself; if it were, that claim element would always be satisfied by any

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an indispensable component of a user interface. The terms "indirectly" and "combination" in the "user interface" claim construction do not alter this fact.

[14] (Opp'n Mem. at 8 (quoting Plaintiff's expert) ("[the] 'multiple layers of hardware and software' . . . between the user controlling the mouse or keyboard and that device actually functioning . . . are all still portions of the user interface"); PFII ¶¶ 446-447.)

command-relaying interface, alone, once a user originated the command – no matter how far removed from the user that "interface" is – and the "user" qualification of "interface" would be divested of meaning. Nor would there be a need to identify the "user" interface in any accused product, since any and all interfaces in the chain of command would qualify. Plaintiff's attenuated interpretation of "user interface" effectively reads the term "user" out of the asserted claims and, therefore, is not consistent with this Court's claim construction. *Bicon*, 441 F.3d at 950-51; *see also Elekta Instrument S.A. v. O.U.R. Sci. Int'l, Inc.*, 214 F.3d 1302, 1307 (Fed. Cir. 2000) (concluding that ordinary meaning of claim term must apply because "any other conclusion renders the reference to [another claim term] superfluous").

The proper interpretation of this Court's "user interface" construction limits the application of "indirectly" to the manner in which a user alters disk drive parameters by communicating a command to the computer (through some combination of software, hardware, and firmware), and the manner in which the user's command – once received by the user interface – is executed.[15] "Indirectly" does *not* characterize the connection between the user and all subsequent interfaces in the chain of execution of said command.

As expressly stated by this Court, inclusion of the term "indirectly" in the claim construction was intended to protect the patent owner against potential infringers who would attempt to frustrate an otherwise direct relationship "between the user and the invention" by

[15] The language of the claims themselves supports the conclusion that a user interface, as contemplated by the claims, will not generally – if ever – be situated beyond the host processor and in the disk drive itself, as are the ATA and SCSI interfaces. At least Claim 1 of the patent locates the user interface in or near the host processor, such that a user can "work[] with" the host processor, which comports with this Court's understanding that the user interface must be located so as to be accessible to – and facilitate interaction with – the user. (*See, e.g.*, '473 Patent Claim 1, col. 43:16-31 (claiming a "[u]ser interface for operatively working with a processor to affect operation of a data storage device," with the "user interface comprising . . . means for causing the processor to output commands to the data storage device").) A court should discount claim construction arguments from the parties or their experts that are at odds with the plain language of the patent's claims, specifications, or prosecution history. *Phillips v. AWH Corp.*, 415 F.3d 1303, 1318 (Fed. Cir. 2005) (citations omitted) ("[A] court should discount any expert testimony 'that is clearly at odds with the claim construction mandated by the claims themselves, the written description, and the prosecution history, in other words, with the written record of the patent.'").

interposing, or characterizing as an interface, an intermediary structure before the site of the user's selection of the operating mode. (*Markman* Order at 19.) The term "indirectly" was *not* included to independently define as the user interface each subsequent step necessary to execute the selected mode setting.[16] To the contrary, this Court specifically identified the need to "distinguish[] the [user] interface from other types of interfaces . . . [such as one] which allows one software program to interface with another." (*Markman* Order at 19.) In short, "indirectly" preserves nothing more than the true relationship between the user and his *actual act of selection*.[17] Device-to-device communications involved in the subsequent execution of a user's selected mode do not satisfy this criteria.

Thus, a "user interface" in the context of this action may not exclude the site at which a user actually selects an operating mode, which is the only act taken by a user that is relevant to the claimed method. (*See Markman* Order at 19 (identifying "user," in the context of this action, as one who "dictate[s] what the parameters should be"), 20 (identifying "user" as one who "in this case, set[s] the drive parameters").) Plaintiff's allegations and asserted claims also confirm that the first step in the method comprising the claimed invention occurs when a user selects between quiet and performance modes of computer operation. (*See, e.g.*, Am. Compl. ¶ 6; Pl.'s Ex. 109: Am. Final Infringement Contentions at 23-27; Pl.'s Ex. 1 at 58: '473 C1 col. 1:22-44; *see also* Opp'n Mem. at 7-8.)

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[16] This same rationale applies to the claim construction's inclusion of the word "combination." That term was included to avoid the pedantic argument that a combination of procedural instrumentalities (e.g. mouse, keyboard, etc.) between the user and the point of mode selection would preclude a finding that the point of mode selection was a user interface; it shall not be used to extend the meaning of "user interface" to exclude the point where a user actually interacts with the invention. (*Contra* Opp'n Mem. at 10-11.)

[17] The use of "indirectly" does not safeguard Plaintiff's attempt to make some of the very arguments that were specifically rejected in this Court's *Markman* Order. Plaintiff's revived arguments are identical, in effect, to its previous argument that "user" should be construed to include a "device," which this Court clearly rejected for the same reasons. (*Markman* Order at 19 ("Plaintiffs' construction of 'user' . . . is too broad. It fails to give meaning to the adjective 'user,' which distinguishes the interface from other types of interfaces used in the computing field . . . .").)

Plaintiff makes several unsuccessful arguments that it asserts "preclud[e] summary judgment that the accused drives' ATA and SCSI interfaces are not 'user interfaces' as defined by the Court." (Opp'n Mem. at 7.) First, Plaintiff proffers the opinion of its expert that the ATA and SCSI codes in the accused drives constitute "user interfaces" that "allow[] the user to 'indirectly' control the seek time or acoustic noise level of the drive . . . . via programs and subprograms that implement the ATA/SCSI standards." (Opp'n Mem. at 7-8; *see also* Phinney Decl. ¶¶ 179-190.) Plaintiff's expert suggests that the ATA and SCSI interfaces are "user interfaces" because "the user dictates drive parameters through settings provided by the ATA and SCSI interfaces" and that "the disk drives themselves . . . provide settings in the ATA and SCSI interface that allow a user to dictate . . . [drive] parameters." (Decl. of Dr. Joshua Phinney ¶¶ 180, 187.) Plaintiff's expert acknowledges, however, that the user does not actually make a setting *selection* by means of interacting with the disk drive. (Phinney Decl. ¶ 188 ("the very essence of the phrase user interface as construed by the Court" is that the "settings (e.g. performance or quiet mode) are to be set by a source outside of the drive; i.e. the user").)

Plaintiff's expert advocates a construction of the "user interface" limitation that is decidedly different than the one this Court reached in its *Markman* Order. (Am. *Markman* Order at 1.) An expert's opinion as to claim interpretation may not supplant that of the court; the federal courts retain the exclusive authority to construe patent claims as a matter of law. *See AWH Corp.*, 415 F.3d at 1318 (citations omitted) (reiterating construing courts' authority to disregard expert opinion that is in conflict with written record of patent); *see also Markman,* 517 U.S. at 372 ("the construction of a patent, including terms of art within its claim, is exclusively within the province of the court").[18]

[18] Nor do such statements by an expert transform the task of claim construction into a question of fact. *Lighting Ballast Control LLC v. Philips N. Am. Corp.*, 744 F.3d 1272, 1284 (Fed. Cir. 2014) ("[T]he elaboration of experts or

Plaintiff relies on an incorrect interpretation of the "user interface" limitation in its contention that the ATA and SCSI interfaces on the disk drives are "indirectly" "user interfaces." This interpretation effectively reads "user" out of the limitation. The undisputed facts establish that the ATA and SCSI interfaces on the disk drives cannot, on their own, satisfy the "user" element of "user interface," properly construed. The ATA and SCSI interfaces, and therefore the disk drives by themselves, cannot support a finding that the accused products infringe the "user interface" element in asserted claims 8, 9, and 11-15. (*Contra* Pl.'s Ex. 3 at 3, Table 1.)[19] Defendants' motion for summary judgment of non-infringement of the "user interface" limitation is therefore GRANTED.

C. The "Commands" Limitation

This Court constructed the term "commands" to mean "input signals to the data storage device" that have been "shaped by a processor."[20] (*Markman* Order at 22, 24.) "Shap[ing]," as used herein, refers to "[t]he method of altering the inputs to a system." (*Markman* Order at 2.) "Shaping input signals," or commands, was constructed to mean "applying a transformation to a signal." (*Markman* Order at 28.) The undisputed evidence demonstrates that the F10 BIOS user interface does not issue "shaped" commands as required under the "commands" limitation of the asserted claims and, therefore, the F10 BIOS does not infringe the '473 patent.

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tutorial explanation of technical subject matter does not convert patent claim construction into a question of fact."); *Arthur A. Collins, Inc. v. N. Telecom Ltd.*, 216 F.3d 1042, 1046 (Fed. Cir. 2000) (citations omitted) ("[F]raming the expert's conclusion as an assertion that a particular critical claim limitation is found in the accused device" is "insufficient to raise a genuine issue of material fact.").

[19] Without the foregoing argument, Plaintiff has provided evidence of infringement of the "user interface" element only with respect to Compaq's F10 BIOS utility, discussed *infra*. As noted below, Plaintiff's inclusion of the SeaAAM and SeaTools utilities in its user interface submissions was improper. (*See infra* n.21.)

[20] In construing the "commands" claim term, this Court considered Defendants' proposed construction (defining "command" as a "shaped input signal" that is "produced by the 'processor'" and "can cause an action in the 'data storage device'") and Plaintiffs Convolve and MIT's statements at argument about construction of the term (agreeing with Defendants' construction of commands, except contending that they must be output from somewhere other than the disk drive, which would not include the controller). (Defs.' '473 Claim Constructions at 53; *Markman* Hr'g Tr. 272:17-273:22, 268:6-9.)

Plaintiff accuses Defendant Compaq's F10 BIOS utility, a user interface present in certain of the accused computers, of direct and indirect infringement "in combination" with Seagate's ATA disk drives.[21] (*See, e.g.*, Pl.'s Ex. 109 at 23, 25; Pl.'s Ex. 3 at 3, Table 1l; *see also* MSJ Mem. at 5.) Specifically, Plaintiff alleges that the F10 BIOS utility is the means by which certain Compaq computers provide for user "select[ion] between quick and quiet modes." (Pl.'s Ex. 109 at 3-4.) Plaintiff claims that, in combination with Seagate's ATA disk drives and "any other hard disk drive that changes seek trajectory shape in response to the F10 BIOS Utility performance/quiet command," the F10 BIOS infringes Claims 1, 3, 4, and 7-15 of the '473 patent. (Pl.'s Ex. 109 at 3-4.)

Defendants move for summary judgment of non-infringement with respect to the F10 BIOS on the ground that the commands issued by that interface are not commands "shaped by a

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[21] In its submissions on this motion, Plaintiff includes Seagate software programs SeaAAM and SeaTools in its discussion of user interfaces that work with the accused drives on Compaq computers. (Opp'n Mem. at 10-11; PFII ¶ 452.) Defendants contest Plaintiff's inclusion of these programs because Plaintiff "never identified SeaAAM or SeaTools in its infringement contentions." (Reply Mem. at 8.) The only user interface Plaintiff identified in its '473 Amended Final Infringement Contentions was the F10 BIOS. (Pl.'s Ex. 109 at 3-4, 23-54.) Plaintiff may not seek to avoid summary judgment by pointing to allegedly infringing products that were never accused in any of its infringement contentions, nor were they the subject of discovery in this case.

Moreover, the evidence demonstrates that the SeaAAM and SeaTools utilities were not included as components in the actual accused devices; they were only available for download as separate products. (PFII ¶ 516 ("SeaTools Enterprise Edition was available for downloading from Seagate's website after the '473 patent issued."); Phinney Decl. ¶ 235 ("Though seemingly not currently available on Seagate's website, a copy of the utility can be found by typing 'SeaAAM' in an Internet search engine.").) As such, neither utility may support a claim of direct infringement absent evidence that Defendants exercised "control or direction" over users who might download these separate utilities, and there is no such evidence here. *See Muniauction, Inc. v. Thomson Corp.*, 532 F.3d 1318, 1329-30 (Fed. Cir. 2008) (citation omitted) ("[W]here the actions of multiple parties combine to perform every step of a claimed method, the claim is directly infringed only if one party exercises 'control or direction' over the entire process such that every step is attributable to the controlling party. . . mere 'arms-length cooperation' will not give rise to direct infringement by any party.").

Plaintiff's separate allegations that Defendants provided the SeaAAM and SeaTools utilities in order to induce infringement (*see* Opp'n Mem. at 14) must also fail because this Court finds that there was no direct infringement of the '473 patent. *See Epcon Gas Sys., Inc. v. Bauer Compressors, Inc.*, 279 F.3d 1022, 1034-35 (Fed. Cir. 2002) (citations omitted) ("It is well settled that there can be no inducement of infringement without direct infringement by some party. Upon a failure of proof of direct infringement, any claim of inducement of infringement also fails."); *see also Limelight,* 134 S. Ct. at 2117 (internal quotation marks and citation omitted) ("[O]ur case law leaves no doubt that inducement liability may arise if, but only if, there is direct infringement."). Therefore, the F10 BIOS is the only accused user interface (external to the disk drive itself, *see* Part III.B, *supra*) on which Plaintiff may rely in this case.

processor," and thus do not meet the required claim limitation. (MSJ Mem. at 18-20; Reply Mem. at 9-10; Tr. 13:12-14.) Plaintiff contends that "the F10 BIOS does not have to shape the output seek current directly" to fit within this Court's "commands" construction because the transmission of generic commands to the disk drive satisfies the applicable claim construction as well. (Opp'n Mem. at 13.)

The parties do not dispute that the F10 BIOS interface does not generate shaped commands. (*See, e.g.*, Opp'n Mem. at 12; Reply Mem. at 9-10; Defs.' Ex. 5: July 1, 2008 Dep. of Shukri Souri at 324:19-21 (Plaintiff's expert testifying that the F10 BIOS does not output seek current).) The parties' disagreement turns on the scope of this Court's claim construction, i.e., whether the term "commands" was construed to include both shaped and unshaped, or generic, commands. Thus, contrary to Plaintiff's assertions (Opp'n Mem. at 13), this issue is appropriate for summary judgment. *Gen. Mills*, 103 F.3d at 983; *accord Mantech*, 152 F.3d at 1371.

Defendants submit that this Court's construction requires that "commands" within the claim limitation be "shaped by a processor," and sent to the data storage device as "shaped input signals" from the processor that performed the shaping. (Tr. 13:12-14; Reply Mem. at 9-10; DF ¶ 32; *Markman* Order at 24.) Defendants contend that because Plaintiff has conceded that commands issued by the F10 BIOS are not shaped as required by the asserted claims, the F10 BIOS cannot infringe the '473 patent, and summary judgment of non-infringement with respect to the F10 BIOS is warranted. (Reply Mem. at 9; Tr. 12:8-11, 13:14-15, 15:10-15; *Uniloc*, 632 F.3d at 1301 (quoting *Lemelson*, 752 F.2d at 1551 ("The plaintiff bears the burden of showing that each and every claimed element of the patent, or its equivalent, is present in the accused device.").)

In response, Plaintiff asserts that the "commands" claim element is satisfied by the F10 BIOS as a result of its transmission of unshaped, "generic" commands to the processor on the disk drive, which device subsequently shapes the commands. (Opp'n Mem. at 13.) Alternatively,

Plaintiff states that whether the F10 BIOS commands are shaped is irrelevant to any finding of infringement, as the accused products are alleged to infringe the patent "regardless of the presence of the F10 BIOS" because the disk drives themselves constitute user interfaces that generate shaped commands or input signals.[22]

Defendants challenge Plaintiff's assessment that the construed claim language allows for the inclusion of unshaped, or generic, commands. (Reply Mem. at 9.) Defendants assert that Plaintiff misconstrues this Court's claim construction and derives its interpretation of "commands" from an inapplicable section of the *Markman* Order. (Reply Mem. at 9; Tr. 13:15-18; *see* Opp'n Mem. at 13; PFII ¶ 437, citing *Markman* Order at 22 (construing "data storage device" claim element).)

Plaintiff's interpretation of the applicable claim construction is in error; this Court previously held that, unlike the specification, the asserted claims require commands – not in the generic sense – but in the form of shaped input signals. (*Markman* Order at 22-24.) This Court expressly distinguished the specification's "more general use" of (unshaped) "commands" from the "context-specific" (shaped) use in the claims themselves. (*Markman* Order at 22.) Plaintiff bases its F10 BIOS argument on the claim construction's discussion of the "more general" usage of "commands" in the specification, without acknowledging the distinction made by this Court in the preceding and following lines of its order. (*See* Opp'n Mem. at 12-13; *Markman* Order at 22

[22] (*See* Opp'n Mem. at 12; PFII ¶ 434 ("Compaq computers containing accused Seagate drives are themselves accused of '473 patent infringement, regardless of the presence of the F10 BIOS feature."), ¶ 613 ("Compaq computers containing the JIT [SCSI] Drives are accused of infringing the '473 patent regardless of the presence of the F10 BIOS setup utility."), ¶ 448 (asserting that the ATA interface in each ATA drive and the SCSI interface in each SCSI drive satisfies the "user interface" limitation of the asserted '473 patent claims), ¶ 452 (stating that SeaAAM, SeaTools and F10 BIOS utilities are "user interfaces" used in conjunction with the accused drives), ¶¶ 461-477 (alleging that all accused ATA drives are equipped with an ATA interface), ¶¶ 478-489 (asserting the accused SCSI drives are all equipped with a SCSI interface); *see also, e.g.*, Pl.'s Ex. 3 at 132 ("Furthermore, the Court's construction of 'user interface' is met not only by the ATA interface . . . but also by the F10 BIOS on the Compaq computer system."); *see also* Tr. 64:4-8; discussion at Part III.B, *supra*.)

(emphasizing distinction between the "context-specific use within one claim" and "a more general use in the specification," and finding that "[c]laim 10 refers to a specific kind of 'command,' one that has been shaped by a processor").) Plaintiff's reliance on the usage of generic "commands" in the invention's preferred embodiment (as expressed in the specification) cannot overcome the controlling usage of shaped "commands" in the claims themselves. *Laitram Corp. v. NEC Corp.*, 163 F.3d 1342, 1347 (Fed. Cir. 1998) ("Laitram IV") ("[I]t is the *claims*, not the written description, which define the scope of the patent right.").

This Court construed, in no uncertain terms, the relevant claim limitation. (*Markman* Order at 23-24 (construing "outputting commands to the data storage device").) In the specific context of the asserted claims, "commands" was construed to mean: "input signals to the data storage device" that have been "shap[ed]" by the "disclosed method" in the invention, the *"result"* of which is then "sent (as output) from the processor performing the shaping to the data storage drive (as input)." (*See Markman* Order at 24 (emphasis added).) This construction unambiguously requires the claims' "commands" to be shaped when issued from the processor in order to satisfy the claim limitation at issue here. Applying the correct construction of this claim element, Plaintiff's concession that the F10 BIOS commands are not shaped when issued is fatal to its F10 BIOS infringement claims. *See Uniloc*, 632 F.3d at 1301; *Laitram Corp. v. Rexnord, Inc.*, 939 F.2d 1533, 1535 (Fed. Cir. 1991) ("[T]he failure to meet a single limitation is sufficient to negate infringement of the claim.").

Because it is undisputed between the parties that the F10 BIOS does not issue "shaped" commands, the F10 BIOS cannot be said to issue "commands" under the properly construed limitation in the asserted claims. The F10 BIOS therefore does not infringe the claimed method.

As there is no other user interface that has been properly identified and accused by Plaintiff,[23] this finding of non-infringement with respect to the F10 BIOS leaves Plaintiff's allegations devoid of a basis upon which to allege direct infringement of the "user interface" claim element, which is required by each asserted claim. (*See* Pl.'s Ex. 1, cols. 43:15-46:14; Pl.'s Ex. 109 at 23-54; Pl.'s Ex. 3 at 3, Table 1.) Plaintiff's allegations of indirect, or induced, infringement must also fail because Plaintiff is unable to prove direct infringement of the '473 patent. *Limelight*, 134 S. Ct. at 2117. Therefore, because Plaintiff has not provided this Court with evidence sufficient to establish infringement of the "commands" limitation by the F10 BIOS, or of the "user interface" element with respect to any accused product, Defendants are entitled to summary judgment of non-infringement as to all asserted claims (1, 3, 4, and 7-15).

IV. Intervening Rights

Even if Plaintiff had cited to evidence sufficient to avoid summary judgment, patent infringement liability is precluded by intervening rights arising from the December 2, 2008 substantive amendment to the asserted claims.

Defendants move for summary judgment dismissal of Plaintiff's lawsuit on the ground that Defendants acquired intervening rights upon the filing of the PTO's First Reexamination Certificate. Defendants base this argument on the fact that the PTO rejected Plaintiff's claims upon reexamination, and required Plaintiff to substantively amend the '473 patent before the certificate of patentability – declaring all claims allowable as amended – could issue. (*See* MSJ Mem. at 38-41; Reply Mem. at 18-19.) Plaintiff does not dispute that the '473 patent was amended during the First *Ex Parte* Reexamination, but contends that the amendment was "clarifying" as opposed to "substantive," such that intervening rights did not attach. (*See* Opp'n Mem. at 31-33.)

[23] Neither the ATA and SCSI interfaces, nor the SeaTools and SeaAAM utilities, can satisfy the required "user interface" element of the asserted claims in this case. (*See supra* Parts III.B.)

The parties do not dispute that Defendants' alleged infringement occurred in 2001 and 2002. Because the December 2, 2008 amendments to claims 1, 3, 4, 7-10, 14, and 15 of the '473 patent were required by the PTO to distinguish prior art before it would allow reissuance of the patent, the amendment was substantive in nature. Therefore, intervening rights attached on December 2, 2008, and Defendants are not subject to liability for any alleged infringement of the '473 patent prior to that date. Defendants' motion for summary judgment on this ground is therefore, independently, GRANTED.

A. Intervening Rights[24]

Reexamination proceedings "permit a patentee or other interested person to obtain review and[,] if necessary[,] correction of the claims resulting from the initial examination of the patent."

[24] Plaintiff argues that Defendants' intervening rights argument must fail because it is an affirmative defense that Defendants did not plead in their Answer and failed to amend their pleadings to include. (PFII ¶¶ 304-306; Opp'n Mem. at 31.) However, the defense of absolute intervening rights, which Defendants assert here, is not waived even when it is not raised until after the liability stage at trial. *See BIC Leisure Prods., Inc. v. Windsurfing Int'l, Inc.*, 1 F.3d 1214, 1221-22 (Fed. Cir. 1993) (finding that district court did not err in admitting defendant's intervening rights defense, despite the fact that it was not asserted in defendant's pleadings nor litigated during the liability stage of trial). Moreover, a district court has significant latitude in determining whether to allow claims and defenses, particularly where, as here, Plaintiff has not suffered any prejudice because the defense of intervening rights was asserted shortly after the December 2008 amendment to the patent was made (*see* Feb. 27, 2009 Defs.' Mots. for Summ. J., ECF Nos. 906-909; Aug. 16, 2011 Mem. Decision and Order at 46). *See, e.g., Kruse Tech. Partnership v. Volkswagen AG*, 544 F. App'x 943, 952-53, 956 (Fed. Cir. 2013) (finding it within district court's discretion to grant or deny leave to amend infringement contentions based upon considerations of prejudice); *see also BIC Leisure Prods.*, 1 F.3d at 1217, 1222 (allowing intervening rights defense at damages phase of trial because plaintiff had ample notice of the defense through prior deposition testimony, negating any prejudice, and the defense was an important part of the merits of the action).

Plaintiff also repeatedly asserts – with respect to the intervening rights ground for summary judgment and others – that this Court should be compelled or persuaded by decisions of a Magistrate Judge in the Eastern District of Texas, who presided over *Convolve Inc. v. Dell, Inc., et al.*, No. 2:08-CV-244 (E.D. Tex., filed June 18, 2008), and findings by the jury in that case. (*See, e.g.*, Opp'n Mem. at 1-2, 4-8, 10, 15, 19, 22-25, 29, 31, 33; PFII ¶¶ 276-303.) That litigation was an action brought by Plaintiff in this case over the same '473 patent, but against different defendants (Dell Inc., Western Digital Corp., Hitachi Global Storage Technologies, Inc., and Hitachi Ltd.), which defendants are represented by different counsel, and in which – as Plaintiff concedes (Opp'n Mem. at 10) – the Texas magistrate judge adopted a different claim construction for "user interface" than that adopted by this Court. (*Compare* Am. *Markman* Order at 1 *with Convolve v. Dell Markman* Order at 16, No. 08-cv-00244-RSP, ECF No. 211 (E.D. Tex. Jan. 5, 2011).) Despite Plaintiff's contentions that the "same" arguments were made in the Texas case as in this case (Opp'n Mem. at 1-2, 4-8, 10, 15, 19, 22-25, 29, 31, 33), it is highly unlikely—and this Court finds no basis for presuming—that those arguments were made in exactly the same way, nor could they have been based on the same facts, circumstances, accused products, and alleged infringing conduct. Therefore, this Court finds no reason to consider the determinations made by the judge or jury in the Eastern District of Texas case applicable, persuasive, or compelling, and declines to further address Plaintiff's arguments on this point herein.

Bloom Eng'g Co. v. N. Am. Mfg. Co., 129 F.3d 1247, 1249 (Fed. Cir. 1997). The reexamination statute requires that, when a party's appeal or time for appeal has been exhausted, "the [Director of the PTO] will issue and publish a certificate canceling any claim of the patent finally determined to be unpatentable, confirming any claim of the patent determined to be patentable, and incorporating in the patent any proposed amended or new claim determined to be patentable." 35 U.S.C. § 307(a). If a patent claim is canceled or amended during reexamination, and reissued in a form that is not "substantially identical" to its original counterpart, there can be no liability for alleged infringement of that claim that pre-dates issuance of the reexamination certificate. 35 U.S.C. §§ 307, 252; *Bloom Eng'g Co.*, 129 F.3d at 1250. This is the doctrine of intervening rights.

A new or amended claim incorporated into a patent following reexamination "will have the same effect as that specified in section 252 for reissued patents." 35 U.S.C. § 307(b). Under Section 252, the issuance of a reissued patent effectuates the surrender of the original patent, and the reissued patent nullifies any pending litigation or preexisting causes of action based on the original patent, unless the claims of the original and reissued patents are "substantially identical." 35 U.S.C. § 252. Whether claims are "substantially identical" turns on "whether . . . amendments to the claim language [] effected substantive changes in claim scope." *Marine Polymer Techs., Inc. v. HemCon, Inc.*, 672 F.3d 1350, 1363 (Fed. Cir. 2012). A court determines whether a claim's scope has been substantively changed by conducting "an overall examination of the written description, the prosecution history and the language of the respective claims." *Laitram IV*, 163 F.3d at 1348 (citing *Laitram Corp. v. NEC Corp.*, 952 F.2d 1357, 1362-63 (Fed. Cir. 1991) ("Laitram I")).

But for those claims that are reissued in substantially identical form, amended claims of a patent "can not be enforced against infringing activity that occurred before issuance of the reexamination certificate." 35 U.S.C. § 252; *Bloom Eng'g Co.*, 129 F.3d at 1250; *Fresenius USA,*

Inc. v. Baxter, Int'l, Inc., 721 F.3d 1330, 1340 (Fed. Cir. 2013) ("[I]f the original claim is cancelled or amended to cure invalidity, the patentee's cause of action is extinguished and the suit fails."). Instead, when substantive changes result from reexamination of a patent, "any person . . . who, prior to the grant of reissue, made, purchased, offered to sell, or used . . . anything patented by the reissued patent" acquires the protection of intervening rights and is immune from liability for alleged infringing conduct that occurred prior to the reissuance of the patent.[25] 35 U.S.C. § 252; *Fresenius*, 721 F.3d at 1339 ("Even if the claim is amended during reexamination to render the claim valid, no suit can be maintained for the period prior to the validating amendment."). In such a circumstance, infringement liability and damages are limited to the period following issuance of the reexamination certificate. *Seattle Box, Inc. v. Indus. Crating & Packing, Inc.*, 731 F.2d 818, 827-28 (Fed. Cir. 1984).

Whether the claims of a patent have been substantially amended as a result of reexamination is a question of law to be decided by the Court. *See Westvaco Corp. v. Int'l Paper Co.*, 991 F.2d 735, 741 (Fed. Cir. 1993); *see also AIA Eng'g Ltd. v. Maotteaux Int'l S/A*, 657 F.3d 1264, 1271-72 (Fed. Cir. 2011). "This rule flows from the general principle that 'the interpretation and construction of patent claims, which define the scope of the patentee's rights under the patent, is a matter of law, exclusively for the court.'" *Laitram IV*, 163 F.3d at 1346-47 (citation omitted).

B. The December 2008 Amendment

In the First *Ex Parte* Reexamination requested by Seagate, the PTO reexamined claims 1, 3, 4, and 7-15 of the patent and, on November 27, 2007, initially rejected all twelve of those claims as being anticipated by the Koizumi patent (U.S. Patent No. 5,982,570). (Defs.' Ex. 38 at 1, 7.)

[25] For patent claims that *are* reissued in substantially identical form, however, the exception to the grant of intervening rights applies. Within this exception, the reissued patent operates as a seamless continuation of the original patent, and does "not affect any action [previously] pending nor abate any cause of action [previously] existing." 35 U.S.C. § 252; *see also Kaufman Co. v. Lantech, Inc.*, 807 F.2d 970, 978 (Fed. Cir. 1986).

On June 16, 2008, following Plaintiff's request for reconsideration (Pl.'s Ex. 122; Defs.' Ex. 46), the PTO issued a Final Office Action in which it maintained its rejection of those '473 claims as anticipated by Koizumi. (Defs.' Ex. 47 at 2-7.) Plaintiff subsequently obtained a July 15, 2008 Interview with the PTO and submitted an "Amendment After Final and Interview Summary" following that conversation. (Pl.'s Ex. 11; Defs.' Ex. 48; *see also* Pl.'s Ex. 9: July 16, 2008 PTO Interview Summary.)

Plaintiff's Interview Summary included proposed amended claim language for the twelve '473 claims rejected by the PTO. (Pl.'s Ex. 11 at 2-6; Defs.' Ex. 48 at 2-6.) The amended language added the word "seek" before every instance of "acoustic noise" in the claims, in order to distinguish the type of acoustic noise targeted by the claimed '473 method from the "spindle" acoustic noise targeted by the method disclosed in the Koizumi patent. (Pl.'s Ex. 11 at 2-6, 9-13; Defs.' Ex. 48 at 2-6, 9-13.) In the Interview Summary, Plaintiff described each claim amendment as "clarify[ing]," contending that a person having ordinary skill in the art would have known that the original claims were "always" "implicit[ly] and inherent[ly]" limited to "seek" acoustic noise. (Pl.'s Ex. 11 at 7-13; Opp'n Mem. at 31-32; Defs.' Ex. 48 at 7-13.)

On December 2, 2008, the PTO issued the First Reexamination Certificate, accepting Plaintiff's proposal to amend the '473 claims and specify that the claimed method applies only to "seek" acoustic noise as sufficient to distinguish the '473 patent from the prior art in Koizumi. (Pl.'s Ex. 12 at 3; *see also* Defs.' Ex. 49 at 3-5 ("Prior art Koizumi discloses that noise attributed to the spindle is reduced by selecting a quite [sic] mode, but does nothing to . . . reduc[e] the *seek* noise for selected frequencies as now clearly required by [the amended claims].").) With Plaintiff's amendment, the PTO Reexaminer found all previously rejected '473 claims to be "patentable as amended." (Defs.' Ex. 45: First Reexam. Certificate, col. 1:18-19.)

C. The December 2008 Amendment Was Substantive

Defendants argue that Plaintiff's amendment of the '473 claims narrowed or limited those claims so as to constitute a substantive alteration of the patent, thus entitling Defendants to the protection of intervening rights. (MSJ Mem. at 38-41; DF ¶¶ 77-90.) Plaintiff disputes that the intervening rights doctrine applies, and contends that the claim amendments were merely clarifying in nature, as it was "inherent" in the original version of the patent that all '473 claims pertained only to "seek" acoustic noise. (Opp'n Mem. at 31-33; PFII ¶ 311.) Analysis of the original and amended claims, as well as consideration of the additional factors outlined by the Federal Circuit in *Laitram IV*, reveals that the December 2008 amendment was substantive in nature.

1. The Amendment Was Required for Reissuance of the Patent

The PTO rejected reexamined claims 1, 3, 4, and 7-15 on November 27, 2007 as unpatentable due to anticipation by prior art Koizumi, and the PTO maintained its rejection on the same ground on June 16, 2008. (Defs.' Exs. 38, 47.) The examiner found that, "[s]ince Koizumi teaches that unwanted acoustic noise is reduced when silent mode is selected, and that the seek trajectory shape is changed, i.e. altered, to become flatter . . . [Koizumi] anticipates the ['473] claim based on the broadest reasonable interpretation of the language of the claims."[26] (Defs.' Ex. 47 at 7.) In rejecting the claims, the Reexaminer noted and conscientiously addressed each distinction proffered by Plaintiff between Koizumi and the '473 patent. The Reexaminer concluded, however, that none of these distinctions – including Plaintiff's arguments concerning

[26] *Compare* language excerpted from representative Claim 11 in the original '473 patent, requiring: "[a] disk drive operatively controlled by a user interface, said user interface providing settings capable of altering one of a seek time of the disk drive and acoustic noise level of the disk drive . . . the disk drive comprising means for outputting commands to alter seek trajectory shape by shaping input signals to the means for performing the seek operation to reduce selected unwanted frequencies . . . in accordance with the altered settings in the user interface." (Pl.'s Ex. 1, col. 44:47-60.)

spindle noise – were apparent from the language of the '473 claims. (Defs.' Ex. 47 at 4 ("[Convolve's] interpretation . . . can not be gleaned from the language of the claims as they presently exist in the '473 patent."); *see also* Defs.' Ex. 47 at 7 ("[Convolve has] set forth narrow arguments . . . that are more specific than required by the broad limitations of [the '473] claims.").) Ultimately, Plaintiff overcame the PTO's rejection of its patent based on Koizumi only by amending the rejected claims.[27] (Defs.' Ex. 49.)

The PTO Reexaminer certified reissuance of the rejected claims only *after* Plaintiff added the term "seek" to "acoustic noise," explaining in his statement of reasons for patentability that, since Koizumi "disclose[d] that noise attributed to the *spindle* is reduced by selecting a quite [sic] mode," the '473 claims, "*[a]s now amended*," were sufficient to distinguish the claimed method from that disclosed in Koizumi. (Defs.' Ex. 49 at 3 (emphasis added).) It was only *after* receiving the proposed amendment that the Reexaminer found that the claimed '473 method of "[reducing] the *seek* acoustic noise level" was "*now clearly required* by [the reexamined] claims." (Defs.' Ex. 49 at 3 (final emphasis added).) In pertinent part, the PTO Reexaminer emphasized that the designation of the patent's targeted acoustic noise as "seek" acoustic noise finally distinguished the claimed method from prior art: "[T]he prior art of record does not suggest or render obvious that a user interface controls the seek time and subsequently outputs commands to a data storage drive, in combination with the claimed features specifically requiring that a seek trajectory is altered by shaping the input signals to reduce selected unwanted frequencies of the *seek* acoustic noise by altering the setting at the user interface." (Defs.' Ex. 49 at 3-4 (emphasis in original).)

[27] The reexamination process is formulated to result in this outcome for imprecisely claimed inventions; patent holders are permitted to amend their claims in response to an adverse PTO decision, in order to reflect their "actual contribution to the art," without suffering the effects of a permanent revocation of patent protection. *In re Yamamoto*, 740 F.2d 1569, 1571-72 (Fed. Cir. 1984) ("[Patent owners'] interests are not impaired" by the PTO's obligation to give claims their "broadest reasonable interpretation consistent with the specification" during reexamination proceedings, because they are able to "obtain[] appropriate coverage for their invention" by "correct[ing] errors in claim language and adjust[ing] the scope of claim protection as needed.").

Having incorporated Plaintiff's amendment into the claim language, the PTO reversed its prior decisions and allowed the previously rejected claims as patentable over Koizumi's prior art. (First Reexam. Cert., col. 1:18-19; Pl.'s Ex. 9 at 2.)

The Federal Circuit has held that the allowance, upon amendment, of previously rejected claims is a "highly influential piece of prosecution history" in determining whether a patent's claims have been substantively changed by an amendment. *Laitram IV*, 163 F.3d at 1348 (finding that amendment substantively changed claims because "[m]ost significantly, . . . [the amendment] resulted in the allowance of claims that had been rejected in the reexamination proceeding over prior art"). Plaintiff acknowledged the Federal Circuit's conclusion in *Laitram IV* that "it is difficult to conceive of many situations in which the scope of a rejected claim that became allowable when amended is not substantively changed by the amendment," *id.*, and pointed only to *Kaufman Co. v. Lantech, Inc.* as an example of a case in which an amendment made to distinguish a patent from prior art was determined not to be substantive in nature. (June 3, 2014 Oral Arg. Tr. 57:10-22.) *Kaufman* does not support Plaintiff's contention on this point.

Plaintiff accurately reports that the *Kaufman* Court determined the patent claim amendments in that case to be "without substantive change." (Opp'n Mem. at 32-33; Tr. 57:21; *see Kaufman*, 807 F.2d at 977.) However, the claims of the patent at issue in *Kaufman* were never rejected, or found to be unpatentable, over prior art. To the contrary, the *Kaufman* claims were amended "notwithstanding" the fact that "[a]ll of the reexamined claims were found to be patentable over numerous prior art references." *Kaufman*, 807 F.2d at 972. Thus, the outcome in *Kaufman* is consistent with the proposition that where – as here – a patent's claims, having previously been rejected as unpatentable over prior art, only become allowable once amended, those amendments are properly deemed to be "substantive " and not "clarifying."

It is implausible that a claim insufficient to sustain patentability – such that the PTO would withdraw patent protection unless the claim is modified, and restore patent protection only when amendment is made – could be "clarifying" in nature or effect. It is difficult to argue that an amendment is "clarifying" and not "substantive" when the PTO declared the reexamined claims invalid without the amendment. The PTO's sustained rejection, until amendment, of the original '473 claims distinguishes this case from *Kaufman* and supports the conclusion that the amendment constituted a substantive change to the asserted claims.

2. The Content of the Amendment Was Not Implicit In the Original Claims

Plaintiff argues that the December 2, 2008 amendment was not substantive because the limitation that the claims target only "seek" – and no other type of – acoustic noise was implicit, or inherent, in the claims as originally patented. (Opp'n Mem. at 31-32; PFII ¶¶ 311-312, 318.) Plaintiff submits that the patent's specification (PFII ¶¶ 311, 331-332), the parties' understandings during patent prosecution (PFII ¶¶ 337-339) and claim construction (PFII ¶¶ 320-324), the opinions of its experts (PFII ¶ 319) and Defendants' experts (325-330), and the PTO Reexaminer's single use of the word "clarifying" in reference to the amendment (PFII ¶¶ 308-309) compel a finding that the amendment itself was not substantive. (Opp'n Mem. at 31-33.) Plaintiff's arguments are unavailing. The claim language itself is the most significant interpretative guide for the courts, and the terms of the original '473 claims are unambiguous. Nor do other indications of the terms' meaning mandate a finding that the amendment was anything other than substantive.

a. The Amendment Was Not Implied By the Patent Specification

It is well-settled that "it is the claims, not the written description, which define the scope of a patent right." *Laitram IV*, 163 F.3d at 1347. While a court may consider a patent's prosecution history, specification, prior art, and other pertinent information for context, determination of whether a claim amendment is substantive is "circumscribed by the well-established principle that

a court may not import limitations from the written description into the claims." *Id.* (citing *Electro Med. Sys. v. Cooper Life Scis., Inc.*, 34 F.3d 1048, 1054 (Fed. Cir. 1994) ("[C]laims are not to be interpreted by adding limitations appearing only in the specification.")); *see also Hill-Rom Servs., Inc. v. Stryker Corp.*, No. 2013-1450, 2014 WL 2898495, at *2 (Fed. Cir. June 27, 2014) (citation omitted) ("While we read claims in view of the specification, of which they are a part, we do not read limitations from the embodiments in the specification into the claims."). Thus, Plaintiff's contention that the '473 patent specification "evidences" that the acoustic noise targeted in the original claims was limited to "seek" acoustic noise is not a permissible interpretation.

Moreover, review of the specification language excerpted by Plaintiff does not support a limited definition of "noise," even if Plaintiff's specification argument were persuasive: the excerpt is consistent in referring specifically to "seek" *time* but only generically to "noise level," e.g. "a seek time and a noise level," "a relatively high noise level/low seek time," "disk drive noise level and seek time," "both the seek time and noise level parameters." (PFII ¶ 331.) This excerpt demonstrates that Plaintiff clearly knew how to specify the "seek" limitation when it so desired. The specification language therefore does not support Plaintiff's assertion that the specification and the original claims inherently targeted "seek" acoustic noise, even if such a limitation were permitted to be read from the specification into the claims themselves. *Schreiber Foods, Inc. v. Beatrice Cheese, Inc.*, 31 F. App'x 727, 730 (Fed. Cir. 2002) (citation omitted) ("The interpretative process forbids importing limitations from the specification into the defining language of the claims."); *cf. Kaufman*, 807 F.2d at 977 (finding that amendment language[28] was already effectively in both the specification and the claims, to the point where the amendments were "unnecessary" and "redundant" with the claim language).

[28] The amendments to the claims in *Kaufman* added the word "rotationally" to "interconnected," and specified that "the downstream roller means rotates faster than the upstream roller means." *Kaufman*, 807 F.2d at 972-73.

b. The Amendment Was Not Implied By the Prosecution History of the Patent

Plaintiff argues that the parties' representations during patent prosecution[29] and claim construction, and the documented opinions of their experts during those times, demonstrate that the patent claims were always understood to be limited to "seek" acoustic noise. (*See* PFII ¶¶ 319-330, 337-339, 325-330.) But the understandings of the parties, and statements of their experts in the context of litigation, cannot import limitations into the claims that are not contained in the language of the claims themselves.[30]

Even if this were not the case, the representations and opinions cited by Plaintiff do not clearly demonstrate that the patent's original claims were inherently limited to "seek" acoustic noise. In many instances, a statement that Plaintiff asserts pertains only to seek acoustic noise, actually does not contain the "seek" modifier in front of the "acoustic noise" term at all. (*See, e.g.*, PFII ¶ 322, stating that Defendants represented to this Court that the patent's methods "trade *seek* speed for *seek* acoustics," though Defendants' actual language reads "trade-off between speed and noise," and does not use the term "seek" other than to qualify the terms "speed" and "operations";

[29] The prosecution history of a patent consists of the entire record of proceedings in the Patent and Trademark Office. This includes all express representations made by or on behalf of the applicant to the examiner to induce a patent grant, or, as here, to reissue a patent. Such representations include amendments to the claims and arguments made to convince the examiner that the claimed invention meets the statutory requirements of novelty, utility, and nonobviousness. Thus, the prosecution history . . . limits the interpretation of claims so as to exclude any interpretation that may have been disclaimed or disavowed during prosecution in order to obtain claim allowance." *Standard Oil Co. v. American Cyanamid Co.*, 774 F.2d 448, 452 (Fed. Cir. 1985).

[30] Proposed claim constructions by the parties may be informative as to the parties' understandings of the claim language, but they are not binding on a court. *Praxair, Inc. v. ATMI, Inc.*, 543 F.3d 1306, 1323–24 (Fed. Cir. 2008) ("Because the court has an independent obligation to construe the terms of a patent, we need not accept the constructions proposed by either party . . . ."). Moreover, assertions by a party's expert, while helpful to a court's technical understanding of a patent or the usage of a technical term in the pertinent field, may not supplant a court's determination that a particular claim construction is warranted based on the presence or absence of language in the written record of the patent itself. *See Lighting Ballast*, 744 F.3d at 1284-85 ("[E]xperts in the science or technology may assist the court in understanding the meaning and usage of a claim term, but this does not morph the question [of claim construction] into one of fact."); *AWH Corp.*, 415 F.3d at 1317-18 (extrinsic evidence, including expert and inventor testimony, "can shed useful light on the relevant art," but it is "less significant" and "less reliable than the patent and its prosecution history in determining how to read claim terms"); *Laitram IV*, 163 F.3d at 1346, 1349 (finding that intervening rights attached despite "uncontroverted expert testimony" that amended claim was not substantive change); *Key Pharms v. Hercon Labs. Corp.*, 161 F.3d 709, 716 (Fed. Cir. 1998).

compare Plaintiff's characterization of specification language, Part III.C.2(a), *supra*.) Instead, this characterization relies on Plaintiff's own inference and interpretation. This evidence is insufficient to overcome the other evidence before this Court of the circumstances under which the amendment was made.

The claims of a patent "serve both a definitional and a [public] notice function." *Werner-Jenkinson Co. v. Hilton David Chem. Co.*, 520 U.S. 17, 33 (1997). In order to effectively serve both of these functions, claims that do not otherwise indicate they are subject to a limitation – such as one targeting a particular type of acoustic noise over another – cannot privately be limited based on the parties' alleged understandings of the claims' scope, or an expert's testimony in the context of litigation. *See Vectra Fitness, Inc. v. TNWK Corp.*, 162 F.3d 1379, 1384 (Fed. Cir. 1998) (citation omitted) ("The public is entitled to rely upon the public record of a patent in determining the scope of the patent's claims."); *Vitronics Corp. v. Conceptronic, Inc.*, 90 F.3d 1576, 1583 (Fed. Cir. 1996) ("[W]here the public record unambiguously describes the scope of the patented invention, reliance on any extrinsic evidence is improper."); *see also AWH Corp.*, 415 F.3d at 1318.

The positions of the parties during claim construction proceedings, whether Plaintiff's or Defendants' or a view that is jointly held, are not part of the patent prosecution history. *Standard Oil Co.*, 774 F.2d at 452. As such, these views and statements do not supersede a determination by the PTO – such as the one by the Reexaminer here – that a limitation is not reflected in the actual language of the claims.[31] Even statements that *are* part of the prosecution history do not

[31] Furthermore, if the parties' statements during claim construction proceedings were relevant to this determination, the proposed construction of "acoustic noise" that Plaintiff submitted to this Court made no attempt to limit the term to "seek" acoustic noise. (Pl.'s '473 Claim Constructions at 7, (defining "acoustic noise" as "[n]oise in the acoustic spectrum, usually measured in decibels").) Nor did it include the term "seek" in any defined claim term incorporating "acoustic noise." (*See, e.g.*, Pl.'s '473 Claim Constructions at 6-8.) This is so even though Plaintiff limited other, comparable terms in its proposed constructions, by qualifying them with "seek." (*See, e.g.*, Pl.'s '473 Claim

affect the scope of a patent's claims if they are not clear and unmistakeable and made for the purpose of obtaining claim allowance. *3M Innovative Properties Co. v. Tredegar Corp.*, 725 F.3d 1315, 1322 (Fed. Cir. 2013) ("This court does not rely on the prosecution history to construe the meaning of the claim to be narrower than it would otherwise be unless a patentee limited or surrendered claim scope through a clear and unmistakable disavowal."); *AWH Corp.*, 415 F.3d at 1312. Absent a "clear and unmistakable disavowal" by Plaintiff, limiting the scope of "acoustic noise" to exclude spindle and other acoustic noise during prosecution of its patent, "acoustic noise" maintains its ordinary meaning. *3M*, 725 F.3d at 1324-26 (finding that, absent "exclusionary language" or a clear and unmistakable disavowal, ordinary meaning of claim term applied and invoked the "full breadth of [the] claim scope").

The only evidence of an express patent prosecution disavowal advanced by Plaintiff is embodied in an April 2, 2001 fax to the PTO, which Plaintiff asserts establishes that it "specifically stated that *all* claims of the '473 patent were directed to controlling *seek* acoustic noise." (PFII ¶¶ 337-338.) But this claim is belied by both the excerpt[32] quoted by Plaintiff and the unambiguous purpose of the faxed document. First, the fax language quoted by Plaintiff does not use the term "seek acoustic noise." It, again, discusses a "seek operation" and "seek trajectory," but only general "acoustic noise." (PFII ¶ 338.) This cannot necessarily be interpreted to mean "seek acoustic noise," particularly since Plaintiff itself characterized Koizumi as addressing "acoustic noise" in the context of a "seek operation." (Pl.'s Ex. 127 at 6 ("with respect to seek operation . . . Koizumi is concerned with acoustic noise").)

Constructions at 8 ("seek time"), 16 ("seek trajectory"), 22 (defining claim element using qualified term "seek time," but unqualified term "acoustic noise level").)

[32] "As stated above, all of the independent claims have been amended herein to state that the noise to be reduced during a seek operation is acoustic noise. Thus, as now claimed, it is the acoustic noise level of the data storage device that is controlled by changing seek trajectory shape to reduce unwanted frequencies by shaping input signals to the data storage device." (PFII ¶ 338 (quoting Pl.'s Ex. 127: Apr. 2, 2001 Fax [Requesting Reconsideration of Mar. 29, 2001 Rejection]).)

Second, the document Plaintiff cites as the "4/2/01 PTO Amendment" was submitted by Plaintiff as part of a request that the PTO reconsider and reverse its rejection, due to anticipation by the combination of prior art Rowan (U.S. Patent No. 5,986,426) and Koizumi, of certain claims in Plaintiff's patent application. (Pl.'s Ex. 127 at 4-8; Pl.'s Ex. 4: Mar. 29, 2001 Office Action.) The April 2, 2001 amendment submission proposed adding the term "acoustic" before every instance of "noise" in the patent application, and expressly stated that it was amending the claims in Plaintiff's patent application to specify that the '473 patent targeted "acoustic noise" and not "electrical noise," as in the Rowan patent. (Pl.'s Ex. 127 at 4 ("The pending independent claims have been amended herein to state explicitly that the noise controlled [by Convolve's invention] is acoustic noise as opposed to electrical noise.").) The amendment submission does not employ the term "seek acoustic noise" in any instance. Though not part of the amendment, Plaintiff went on to distinguish Rowan as "altering control of only the spindle motor to reduce acoustic noise." (Pl.'s Ex. 127 at 6.) Plaintiff contended that "the combined teachings of Koizumi and Rowan" did not suggest "alter[ing the] acoustic noise level of a data storage device by changing seek trajectory shape to reduce unwanted frequencies." (Pl.'s Ex. 127 at 6.) With the addition of "acoustic" before the term "noise," the original patent examiner allowed the claims and granted the '473 patent.

The 2001 amendment cannot establish that the term "seek" was thereafter implicitly incorporated into the original claim language. In 2007 and 2008, the PTO Reexaminer considered this prosecution history and *nevertheless* determined that the reexamined claim language must be rejected, on the grounds that it was insufficiently specific to disclose all of the invention's allegedly required elements, or to distinguish it from Koizumi. (Defs.' Ex. 47 at 2-7, 11-12.) In light of this determination, and the subsequent December 2, 2008 amendment – required for patentability –

that added the word "seek" to "acoustic noise," Plaintiff's prosecution history argument is unavailing.

These considerations weigh against a finding that statements by the parties or their experts rendered the "seek" limitation implicit in the original claims.

c. The Reexaminer's Characterization Does Not Render the Amendment Implicit

Plaintiff repeatedly seeks to bolster its argument that the substance of the December 2008 amendment was already implicit in the original claims by citing to the PTO Reexaminer's single use of the word "clarifying" in describing the amendment.[33] (Opp'n Mem. at 31-32; PFII ¶¶ 308-309; Tr. 49:7, 50:21-22, 52:6; *see* Pl.'s Ex. 9 at 4.) However, against the abundance of evidence that the amendment was substantive in nature, Plaintiff relies too heavily on the Reexaminer's isolated statement. In the context in which the amendment was made, the Reexaminer's characterization is flatly undermined by the PTO's actions rejecting the patent's claims – twice – during the same reexamination. In relevant part, the amendment was deemed necessary by the PTO both to distinguish the '473 patent from prior art (Koizumi) and to permit reissuance of the patent, neither of which factors support a determination that the amendment was merely "clarifying." *See, e.g.*, *Laitram IV*, 163 F.3d at 1348. Moreover, Plaintiff has not set forth any evidence that the PTO Reexaminer's single use of the term "clarifying" in this isolated instance was a term of art. Given that the normal principles of claim interpretation render the claim amendment substantive, Plaintiff's reference to the Reexaminer's isolated use of the term

[33] The PTO summarized the conclusion of the post-rejection Interview it granted Plaintiff as follows: "PTO representatives agreed [with arguments presented by Convolve] that while in Koizumi the reduced noise appeared to be related to spindle noise, the independent claims of the '473 patent did not clearly make the distinction that the reduced selected unwanted frequencies were specifically directed to targeting the reduction of seek noise as argued by [Convolve]. The PTO representatives indicated, however, that claim amendments clarifying that seek noise is reduced by the input shaped signals would be favorably considered in distinguishing the '473 claims over Koizumi."

"clarifying" is insufficient to merit an alternate conclusion. *Accord, e.g.*, *Cobra Int'l Inc. v. BCNY Int'l, Inc.*, 864 F. Supp. 2d 1328, 1340 (S.D. Fla. 2012).

3. The Amendment Narrowed the Scope of the Claims

As the content of the amendment was not implicit in the original patent claims, this Court must determine whether the amendment substantively changed the scope of the claims. *Bloom Eng'g Co.*, 129 F.3d at 1250-51 (considering "whether the scope of the claims of the . . . patent in suit was substantively changed"). The Federal Circuit has concluded, in similar cases, that an amendment substantively narrows the scope of a patent's claims when a claim term is changed to exclude situations that were ostensibly included in the original language of the claim. *See, e.g.*, *Institut Pasteur v. Focarino*, 738 F.3d 1337, 1343 (Fed. Cir. 2013); *Laitram IV*, 163 F.3d at 1349; *Bloom Eng'g Co.*, 129 F.3d at 1251. Here, because the plain language of the original claims ("acoustic noise") ordinarily includes "seek," "spindle," and other acoustic noise within its scope, Plaintiff's necessary amendment, limiting its claims only to "seek" acoustic noise (and excluding "spindle" and other types of acoustic noise), substantively narrowed the scope of those claims. *See AWH Corp.*, 415 F.3d at 1312 ("[T]he words of a claim are generally given their ordinary and customary meaning.").

Adding to a claim term a new modifier that changes the term's meaning from that of the original term to a subset of the original term narrows the scope of the claim. *See, e.g.*, *Laitram IV*, 163 F.3d at 1349 ("[T]he terms 'alphanumeric characters' and 'type quality alphanumeric characters' are not synonymous, but . . . the latter is a species of the former. Accordingly, the addition of the 'type quality' limitation narrowed the original claims, substantively changing them."). It is inconsequential that the patentee may have intended for the original claim to target, in practice, only the more particular term, which may have been included in the broader term's definition. *See Institut Pasteur*, 738 F.3d at 1343; *Laitram IV*, 163 F.3d at 1349.

The *Institut Pasteur* patentee amended its claims by adding the term "chromosomal" before "DNA" in order to limit the DNA targeted by the claimed method to chromosomal DNA only. *Institut Pasteur*, 738 F.3d at 1340-41. That plaintiff contended that the original claims' requirement that the targeted DNA recombine with a plasmid that was "homologous to the sequence of a chromosome" already limited the scope of the patented method to chromosomal DNA. *Institut Pasteur*, 738 F.3d at 1343. The Federal Circuit rejected this argument, finding that, because non-chromosomal DNA could be homologous to chromosomal DNA in some situations, "the original claim covered situations where nonchromosomal DNA is the targeted DNA." *Institut Pasteur*, 738 F.3d at 1343. Thus, the Circuit held that "amending the claim to target only 'chromosomal' DNA substantively altered (narrowed) its scope." *Id.*

The *Institut Pasteur* analysis applies equally, in this case, to the '473 amendments. Plaintiff here, having amended its claims to limit the patented method's application only to "seek" acoustic noise, argues that the original claims were already implicitly limited to "seek" noise. (*See supra* Part IV.C.2.) But the original claims employ the term "acoustic noise" with no modifier, which – by its plain language – covers situations where "spindle" or other acoustic noise, as well as "seek" acoustic noise, is targeted by the claimed method. (*See* Pl.'s Ex. 1, U.S. Patent No. 6,314,473 B1 cols. 43:15-46:14.) As in *Institut Pasteur*, amending the claims to specifically target only one of these subsets of acoustic noise ("seek") substantively altered, by narrowing, the claims' scope. *Compare Institut Pasteur*, 738 F.3d at 1343. This conclusion is reinforced by the fact that, without the specific and explicit reference to "seek" acoustic noise provided by the amendment, the PTO rejected the reexamined claims. (*See supra* Part IV.C.2(c); *see also, e.g.*, Defs.' Exs. 38, 47, 49.)

D. Defendants Are Entitled to Intervening Rights

The December 2008 amendment, which narrowed the scope of the '473 patent's original claims and resulted in allowance of those claims, as amended, after prior rejections, was substantive in nature. "When a claim is substantively amended," the doctrine of intervening rights "treats the amendment as raising an irrebuttable presumption that the original claim was materially flawed, so there can be no liability for acts of infringement before the amended claim issues." *Institut Pasteur*, 738 F.3d at 1343; *Bloom Eng'g Co.*, 129 F.3d at 1249 ("[I]f the patentee later cures [an identified] infirmity by reissue or reexamination, the making of substantive changes in the claims is treated as an irrebuttable presumption that the original claims were materially flawed" and "the [reexamination] statute relieves those who may have infringed the original claims from liability during the period before the claims are validated."). The substantive amendment to the '473 patent was effective as of the date of the First Reexamination Certificate: December 2, 2008. (Pl.'s Ex. 12.) Defendants are entitled to the protection of intervening rights for any accused conduct prior to that date.[34]

The parties do not dispute that Defendants' alleged infringement occurred in 2001 and 2002, long before December 2, 2008. (*See, e.g.*, Opp'n Mem. at 30; PFI ¶ 77; PFII ¶¶ 634-643; MSJ Mem. at 38; Defs.' Ex. 14.) Because the December 2, 2008 amendments to claims 1, 3, 4, 7-10, 14, and 15 of the '473 patent were substantive in nature, intervening rights attached at that time, and Defendants are not subject to liability for any alleged prior infringement of the asserted '473 claims. Summary judgment of non-infringement for Defendants, pursuant to the intervening rights doctrine, is therefore warranted.

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[34] This result is consistent with the original purpose of the intervening rights doctrine. *Fresenius*, 721 F.3d at 1339 ("[T]he language and legislative history of the reexamination statute show that Congress expected reexamination to take place concurrent with litigation, and that cancellation [or substantive amendment] of claims during reexamination would be binding in concurrent infringement litigation.").

CONCLUSION

Defendants' motion for summary judgment is GRANTED. Plaintiff's Tenth Claim for Relief is DISMISSED in its entirety. The Clerk of the Court is directed to close the motion at ECF No. 1029 and this case.

Dated: New York, New York
July 11, 2014

SO ORDERED.

George B. Daniels

GEORGE B. DANIELS
United States District Judge

USDC SDNY
DOCUMENT
ELECTRONICALLY FILED
DOC #:
DATE FILED: 7/14/2014

UNITED STATES DISTRICT COURT
SOUTHERN DISTRICT OF NEW YORK

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CONVOLVE, INC.,

Plaintiff,

00 **CIVIL** 005141 (GBD) (JCF)

-against-

JUDGMENT

COMPAQ COMPUTER CORP. and SEAGATE TECHNOLOGY LLC,

Defendants.

----------X

Defendants Compaq Computer Corp. and Seagate Technology LLC having moved for summary judgment pursuant to Fed. R. Civ. P. 56, seeking dismissal of Plaintiff Convole, Inc's Tenth - and only remaining - Claim for Relief, and the matter having come before the Honorable George B. Daniels, United States District Judge, and the Court, on July 11, 2014, having rendered its Memorandum Decision and Order granting Defendants' motion for summary judgment, dismissing Plaintiff's Tenth Claim for Relief in its entirety and directing the Clerk of the Court to close this case, it is,

ORDERED, ADJUDGED AND DECREED: That for the reasons stated in the Court's Memorandum Decision and Order dated July 11, 2014, Defendants' motion for summary judgment is granted and Plaintiff's Tenth Claim for Relief is dismissed in its entirety; accordingly, the case is closed.

Dated: New York, New York
July 14, 2014

RUBY J. KRAJICK

Clerk of Court

BY:

Deputy Clerk

THIS DOCUMENT WAS ENTERED ON THE DOCKET ON _____

UNITED STATES DISTRICT COURT
SOUTHERN DISTRICT OF NEW YORK

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CONVOLVE, INC. and MASSACHUSETTS INSTITUTE OF TECHNOLOGY,

Plaintiffs,

-against-

COMPAQ COMPUTER CORP. and SEAGATE TECHNOLOGY LLC,

Defendants.

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MEMORANDUM DECISION AND ORDER
00 CV 5141 (GBD)

GEORGE B. DANIELS, District Judge:

Plaintiffs Colvolve, Inc. ("Convolve") and Massachusetts Institute of Technology ("M.I.T.") (collectively, "plaintiffs") bring suit, alleging that defendants Compaq Computer Corp. ("Compaq") and Seagate Technology LLC ("Seagate") (collectively, "defendants") have infringed several of their patents. Plaintiffs seek injunctive relief and monetary damages. A Markman hearing was held to address the construction of the patent claims.

FACTS

Plaintiff Convolve owns United States Patent Nos. 5,639,267 ("the '267 patent") and 6,314,473 ("the '473 patent"). Plaintiff M.I.T. owns United States Patent No. 4,916,635 ("the '635 patent"). Plaintiffs allege patent infringement, trade secret misappropriation, and breach of contract. Specifically, plaintiffs assert infringement of claims 1-4, 11, 21, and 24 of the '635 patent, claims 19, 29, 39, and 55 of the '267 patent,[1] and claims 1, 3, 4, and 7-15 of the '473 patent.

[1] The parties indicated at the Markman hearing that infringement of the '267 patent is no longer being asserted, and did not raise the issue of claim construction of the '267 patent at the hearing.

The '635 patent, entitled "Shaping Command Inputs to Minimize Unwanted Dynamics," discloses a method to reduce vibration and noise in physical systems. One example given is of a load-bearing crane which, as the load is moved, develops vibrations within the system. As the operator moves the crane, the load begins to swing. This swing and resulting vibration can increase stress on the crane, forcing the operator to wait for the load to come to rest before performing another operation, such as lowering the load to the ground. The '635 patent discloses a method for reducing unwanted dynamics, such as the swinging of the crane load, by translating the sequence of operations performed by the operator into a sequence of operations that achieves the same end position while minimizing the unwanted dynamics introduced into the system. The method of altering the inputs to a system is generally referred to within the art as "input shaping." ('635 patent Col. 1 line 29).

The '473 patent, entitled "System for Removing Selected Unwanted Frequencies in Accordance with Altered Settings in a User Interface of a Data Storage Device" discloses the application of input shaping to computer disk drives. Computer disk drives consist of platters coated with a magnetic substance, and a sensor attached to an arm which scans over the platters as they rotate. The spinning of the platters and movement of the arm introduce vibrations into the disk drive. The arm must be precisely positioned over the platter to accurately read the data contained therein, and vibration increases the time for the arm to reach the correct location. Performance of hard drives can be increased by spinning the platters or moving the arm more rapidly, at the cost of increased vibration. As disk drive capacity increases, the arm must become increasingly precise. All of these factors indicate the desirability of eliminating vibration in disk drives. The '473 patent translates the signals sent to the disk drive into a sequence which reduces unwanted vibration caused by the movement of the arm. The patent identifies certain frequencies

which, when reduced, cause the disk drive to operate more quietly, and other frequencies that allow the arm to seek the correct position more quickly. ('473 patent Col. 7 lines 16-20).

CLAIM CONSTRUCTION

Patent infringement analysis involves two steps. In the first step the court determines the proper construction of the patent claims by establishing the scope and boundaries of the subject matter that is patented, as a matter of law. In the second step, the trier of fact compares the properly constructed patent with the alleged infringing device to determine if infringement has occurred. Claim construction is a question of law for the court.[2] See Markman v. Westview Instruments, Inc., 52 F.3d 967 (Fed. Cir. 1995), *aff'd*, 517 U.S. 320 (1996). The claims of a patent define "the metes and bounds of the right which the patent confers on the patentee to exclude others from making, using, or selling the protected invention." Corning Glass Works v. Sumitomo Elec. U.S.A., Inc., 868 F.2d 1251, 1257 (Fed. Cir. 1989). Proper interpretation looks first to the intrinsic evidence: the language of the claims themselves, the patent specification, and the prosecution history if it is in evidence. See Gart v. Logitech, Inc., 254 F.3d 1334, 1340 (Fed. Cir. 2001). The claims are at the center of the analysis. See Interactive Gift Express, Inc. v. Compuserve, Inc., 256 F.3d 1323, 1331 (Fed. Cir. 2001). There is a heavy presumption that claim terms have the plain and ordinary meaning given to them by one of ordinary skill in the art. See Bell Atl. Network Servs., Inc., v. Covad Communications Group, Inc., 262 F.3d 1258, 1268 (Fed. Cir. 2001). Where the claim language is unambiguous, the intrinsic record should only be consulted to determine whether a deviation from the plain meaning is required.[3] See Interactive

[2] The purpose of construing patent claims is to define the scope of the coverage of the claim by interpreting the words and terms of art used as they would be understood at the time the claim was made by one reasonably skilled in the relevant art. Claim construction "is the judicial statement of what is and is not covered by the technical terms and other words of the claims." Netword, LLC v. Centraal Corp., 242 F.3d 1347, 1352 (Fed. Cir. 2001).

[3] Intrinsic evidence consists of the patent itself: the claims, the specification, and the prosecution history, if in evidence. See Zodiac Pool Care, Inc. v. Hoffinger Indus ., Inc., 206 F.3d 1408, 1414 (Fed.Cir.2000).

Gift Express, Inc., 256 F.3d at 1331. Dictionaries may be used at any point in litigation to aid the court in better understanding both the technology and terminology used by those skilled in the art, but the dictionary definition cannot indicate a meaning different from the intrinsic record. See Texas Digital Sys., Inc. v. Telegenix, Inc., 308 F.3d 1193, 1202 (Fed. Cir. 2002).

Furthermore, claims must be read in light of the specification, of which they are a part. See Markman, 52 F.3d at 979. Claim terms must be constructed so as to be consistent with their use in the specification.[4] The presumption that claim terms have their ordinary meaning is rebutted when the inventor has demonstrated a clear intent to act as his own lexicographer. See C.R. Bard, Inc. v. United States Surgical Corp, 388 F.3d 858 (Fed. Cir. 2004) (providing an explicit definition or words of manifest exclusion demonstrate disavowal of claim scope). The specification also contains a preferred embodiment of the invention, which discloses the best mode of practicing the invention contemplated by the inventor. The preferred embodiment does not impart a limitation on the claims. The prosecution history, a contemporaneous record of proceedings before the Patent and Trademark Office, must also be considered if it is in evidence. Amendments made by the patentee to overcome or distinguish a reference serve to limit claim terms, as do statements made to the examiner during prosecution. However, if the applicant wishes to disclaim claim scope during prosecution, such disclaimer must be clear and unambiguous. See Invitrogen Corp. v. Biocrest Mfg., L.P., 327 F.3d 1364, 1367 (Fed. Cir. 2003).

[4] The specification acts as a dictionary when it expressly defines terms used in the claims or when it defines terms by implication. See Vitronics, 90 F.3d at 1582; see also Markman, 52 F.3d at 979. Because the specification contains a written description of the invention which must be clear and complete enough to enable those of ordinary skill in the art to practice the invention, the specification "is the single best guide to the meaning of a disputed term." Vitronics, 90 F.3d at 1582.

After the intrinsic evidence has been considered, the court may look to extrinsic evidence to guide the interpretation. Extrinsic evidence includes expert and inventor testimony, treatises, and all other evidence external to the text of the patent and the prosecution history. See Markman, 52 F.3d at 979-90.

THE '635 PATENT

The '635 patent is directed to a method for removing unwanted dynamics from a physical system. The patent discloses a method, called "shaping," which modifies inputs to a system so as to minimize those unwanted dynamics. In the preferred embodiment, a mathematical model of the system is generated, from which the response of the system to an input can be determined. ('635 patent Col. 4 lines 63-69). Based on this model, a sequence of inputs[5] is generated such that the unwanted dynamics of each individual input cancels out the unwanted dynamics of the others when an impulse is applied to the system. In different refinements of the system, the number of inputs in the generated sequence is increased. ('635 patent Cols. 5-7). As more inputs are added to the sequence, the ability of the model to reduce unwanted dynamics to an acceptable level is improved. ('635 patent Col. 6 lines 12-49). The ability of the model to maintain unwanted dynamics below an acceptable level is termed "robustness." ('635 patent Col. 4 lines 14-18).

The parties dispute the meaning of several terms which appear in multiple claims. Each of the terms has the same meaning unless otherwise noted. Claim 1 is cited by both parties as a representative claim. (Pls.' Claim Construction Br. For U.S. Patent No.'s '635, '267, and '473 at 37; Defs.' Responsive Claim Construction Brief for U.S. Patent Nos. '635 and '267 at 9).

[5] The preferred embodiment discusses this sequence as "a sequence of impulses" ('635 patent Col. 4 lines 8-14), however dependent claims 2-6 disclose numerous variations on the form of the sequence.

A. CLAIM 1:

1. Input

The first element of claim 1 provides: "A method for generating an input to a physical system to minimize unwanted dynamics in the physical system response …" ('635 patent Col. 10 lines 41-42) (emphasis added).

Plaintiffs allege that the term "input" encompasses any "information that is delivered to the system from outside the system", relying on the plain dictionary definition of the term. (Pls.' Claim Construction Br. At 39). The dictionary definition of "input" is "data or similar information fed into a computer or accounting machine." Merriam-Webster's Third New International Dictionary Unabridged, Merriam-Webster, Inc., 1993.[6] Defendants respond, relying principally on the specification, that an "input" is "the second signal that is applied to a control system to cause a desired action in the control system such that the altering of the first signal to create the second signal is unaffected by the actual action of the control system." (Joint Claim Construction and Prehearing Statement at Exhibit B, '635 Patent 1). The principal distinction in defendants' definition is that the signal sent to the physical system is "an altered signal generated outside the control loop." (Defs.' Proposed Claim Construction Order for U.S. Patent Nos. '635; '267 and '473 at 10). Defendants seek to exclude situations where the input shaping is performed within the control loop. The control loop is a configuration where a system receives an input, acts in response to it, then measures whether the system reached the desired state. If the system did not respond as anticipated, then the system is adjusted repeatedly until the correct state is reached.

[6] While this definition has not been offered into evidence by either party, dictionaries are usable "As resources and references to inform and aid courts and judges in the understanding of technology and terminology . . . at any stage of a litigation, regardless of whether they have been offered by a party in evidence or not." Texas Digital Sys. V. Telegenix, Inc., 308 F.3d 1193, 1203 (Fed. Cir. 2002).

The plain meaning of "input" is consistent with its use throughout the patent. Particularly relevant are two uses in claim 11. The preamble provides: "Method for shaping an arbitrary command input to a dynamic physical system …" ('635 patent Col. 11 lines 17-19). The third element provides: "controlling the physical system based on the shaped command input …" ('635 patent Col. 11 lines 24-25). Any interpretation of the term "input" must be consistent across these uses. There is a "presumption that the same terms appearing in different portions of the claims should be given the same meaning unless it is clear … that the terms have different meanings at different portions of the claims." Fin Control Systems Pty, Ltd., v. OAM, Inc., 265 F.3d 1311, 1318 (Fed. Cir. 2001). The use in the preamble of claim 11 clearly indicates that the "input" therein is the input to the physical system that is going to be shaped, as the second element provides that the input is shaped by "convolving the impulse sequence with the arbitrary command input." ('635 patent Col. 11 lines 22-23). The use in the third element is modified by "shaped command," indicating that the input has been shaped as disclosed in the first two elements. The plain meaning of "input" offered by plaintiffs is consistent with all these uses. "Input" covers, generally, a piece of information which is delivered to a system. In the preamble of claim 11, this input is the unshaped input to a physical system which the invention addresses. In element three, it is the shaped element produced by the invention.

Defendants offer two main arguments for their proposed construction. The first is that the patent only discloses a system where the shaped command input is generated outside the control loop. (Defs.' Responsive Claim Construction at 11). An inquiry into whether or not a patent adequately discloses an invention is a question of validity. See, e.g., Moba v. Diamond Automation, 325 F.3d 1306 (Fed. Cir. 2003). It is improper to determine validity before properly constructing the claims. See Markman, 52 F.3d 967. It is apparent that plaintiffs have not

disclaimed the situation where input shaping is performed within the control loop. Whether or not they have adequately disclosed a method which can be used within the control loop is question of validity. Plaintiffs have asserted a construction that is supported by the plain language of the specification, and accordingly bear the risk that the patent will subsequently be found invalid.

Defendants' second argument is that Plaintiffs' construction "would necessarily cover an unaltered input that would result in the very unwanted vibrations the alleged inventions are intended to eliminate." (Defs.' Responsible Claim Construction at 10). This assertion lacks merit. Adopting plaintiffs' construction merely indicates that an "input" follows the plain and ordinary meaning of the term. Concerns that the patent will be broadened beyond what is claimed, "a method for generating an input … to minimize dynamics," are unfounded as infringement requires that each limitation of the claim be met, either literally or under the 'doctrine of equivalents.' See Frank's Casing Crew & Rental Tools, Inc., v. Weatherford Int'l, Inc., 389 F.3d 1370, 1377 (noting "literal infringement requires that each and every limitation set forth in a claim appear in an accused product"); Riles v. Shell Exploration and Production Co., 298 F.3d 1302, 1309 (stating "[i]nfringement under the doctrine of equivalents requires that the accused product contain each limitation of the claim or its equivalent.") An accused infringer must meet the other limitations of the claim in order to infringe, including that the method "minimize unwanted dynamics." If an input does not "minimize unwanted dynamics," then it is not covered by claim 1 because it has failed to meet all the elements of that claim.

Accordingly, plaintiffs' proposed construction for the term "input" is adopted. The term "input," as used in independent claims 1, 11, 21, and 24, and dependent claim 2, is interpreted to mean: "information that is delivered to the system from outside the system."

2. Expressions

The first element of claim 1 provides: "establishing expressions quantifying the unwanted dynamics of the physical system" ('635 patent Col. 10 lines 44-45) (emphasis added).

Plaintiffs argue that the term "expression" indicates any means of symbolizing, and so in this context, an "expression" would be anything that quantifies the unwanted dynamics of the system. (Pls.' Claim Construction Br. For U.S. Patent No.'s '635, '267, and '473 at 40). Plaintiffs base this meaning on the dictionary definition of an expression. The dictionary definition most relevant to the context of the patent is: "A sign or a character or a finite sequence of signs or characters (as logical or mathematical symbols) representing a quantity or operation." Merriam-Webster's Third New International Dictionary Unabridged, Merriam-Webster, Inc., 1993. Defendants insist that the meaning be limited to mathematical equations which are in the time domain. (Defs.' Proposed Claim Construction Order for U.S. Patent Nos. '635, '267, and '473 at 1). A mathematical equation in the time domain is one which expresses some value, here the unwanted dynamic, as a function of time.

The correct interpretation must be consistent with the use of the term in the specification. See Texas Digital, 308 F.3d at 1202. The terms "expression" and "expressing" or "expressed" appear several times in the specification: "establishing expressions quantifying the unwanted dynamics" ('635 patent Col. 3 lines 62-63); "a system's unwanted dynamic response will be expressed as a function of its transient input" ('635 patent Col. 4 lines 54-57); "[t]he same result can be obtained mathematically by adding two impulse responses and expressing the result for all times greater than the duration of the input" ('635 patent Col. 5 lines 17-21); "[e]limination of vibration after the input has ended requires that the expression for A_{amp} equal zero at the time at which the input ends…" ('635 patent Col. 5 lines 44-46); "[i]n order to quantify the residual

vibration level for a system, a vibration-error expression must be defined…" ('635 patent Col. 6 lines 1-3); "[i]t can be shown that the same expressions that guarantee zero derivatives with respect to frequency also guarantee zero derivatives with respect to damping ratio" ('635 patent Col. 6 lines 41-44); "[t]hese sequences can be obtained by expressing the same (or some other equivalent) constraint equations…" ('635 patent Col. 7 lines 10-12).

Imposing defendants' "time domain" limitation would be inappropriate. While many of the "expressions" discussed in the specification are solved for time, see, i.e., '635, Col. 5, lines 44-46; '635, Col. 5, lines 44-45, all of these examples occur in the preferred embodiment of the specification. Since limitations cannot be imposed based solely on the preferred embodiment, defendants' argument requires that the patentee evinced a clear intent to act as his own lexicographer. Consistent and explicit use of a claim term in the specification to mean something other than the ordinary meaning indicates this intent. See Intellicall, Inc. v. Phonometrics, Inc., 952 F.2d 1384, 1388 (Fed. Cir. 1992) (noting "[s]o long as the meaning of an expression is made reasonably clear and its use is consistent within a patent disclosure, an inventor is permitted to define the terms of his claims.") The patentee did not consistently and uniformly use "expression" to unambiguously refer to time-domain equations, See, i.e., '635, Col. 6, lines 46-48 (referring to a graph in the frequency domain as "the vibration-error expression for the same three sequences of impulses …") The use in the specification is not sufficiently definite to demonstrate the necessary "unequivocal intent," therefore the plain and ordinary meaning is presumed.

Within the context of the specification, and to be consistent with the plain meaning, "expression" cannot include all possible methods that quantifies a dynamic. There must be a solution that minimizes that which is quantified expression. ('635, Col. 10, lines 50-52). The

only type of "expression" offered by plaintiffs which quantifies and can be solved is a mathematical characterization. (Pls.' Reply to Defs.' Responsive Claim Construction Br. for U.S. Patent Nos. '635 and '267 at 3). Plaintiff has argued that "expression" should not be limited to "equations where there must be an equal sign" (Transcript of Proceedings Held on 3/31/2004 at 262). Given the character of the invention, which is designed to meet or exceed a threshold level of unwanted dynamics, there is no reason to impose a requirement for "an equal sign." Accordingly, the term "expression," as used in independent claim 1 is interpreted to mean: "a mathematical characterization that quantifies."[7]

3. First Constraint

The second element of claim 1 provides: "establishing first constraints bounding the available input to the physical system" ('635 patent Col. 10 lines 46-47) (emphasis added).

Plaintiffs argue that the "first constraint" imposes a limit on the "input" generated by the method such that it does not exceed the capabilities of the physical system. The method transforms each input into a sequence of impulses in a way that vibration is reduced. There is no certainty that the physical system is capable of responding to the new sequence of impulses. Defendants argue that the constraint is "a limit on the size of the input." (Defs.' Responsive Claim Construction Brief for '635 and '267 Patents at 15). The term "first constraints" is defined by the language of the specification as the physical limits of what input the system can receive. ('635 patent Col. 7 lines 17-39). Defendants' reading is only justified if the only limitations on the inputs of the system are on the size. For some physical systems this may be the case. The language of the patent itself, however, extends to any limitations on the possible inputs to the

[7] This interpretation was not offered by either party. The Court of Appeals for the Federal Circuit permits adoption of claim constructions not offered by either party when they are consistent with the standards of claim construction. See, e.g., Blistad v. Wakalopulos, 386 F.3d 1116, 1121-1123 (Fed. Cir. 2004).

physical system, and therefore "first constraint" is not solely a limit on the size of the available input.

Accordingly, the term "first constraint" as used in independent claim 1 is interpreted to mean: "a limit on the input based on the physical system."

4. Second Constraint

The third element of claim 1 provides: "establishing second constraints on variation in system response with variations in the physical system characteristics." ('635 patent Col. 10 lines 48-49) (emphasis added).

Plaintiffs argue that in this context "second constraints" refer to robustness. It is undisputed that robustness refers to the ability of the model of the physical system to successfully reduce unwanted dynamics in the physical system when the model is not exact. (Pls.' Claim Construction Br. For U.S. Patent No.'s '635, '267, and '473 at 9; Defs.' Responsive Claim Construction Br. for '635 and '267 Patents at 16). The model of the physical system which quantifies the response of the system to an input will only eliminate all dynamics when the model is exact. An inexact model can be due to operation of the physical system in an environment which can influence its behavior, such as variation in temperature, humidity, or precision of manufactured components of the system. In the crane example, the addition of wind to the system could cause the load to swing in ways that the model cannot anticipate. Plaintiff argues that the term should be given the meaning "constraints on the range of response over a range of differences in the physical system." (Pls.' Claim Construction Br. at 41). Defendants respond that the only valid interpretation of the term is that derivatives of specific time domain equations are set to zero. (Defs.' Responsive Br. for '635 and '267 at 16). This definition is based on an example in the preferred embodiment, where the model for the physical system is expressed as a

system of equations. ('635 patent Cols. 5-6). The "time domain equations" referred to by defendants are a set of equations added to the system which constrain the solutions to the system.

Since there is no plain and ordinary meaning for the term "second constraints," its meaning must be found in the specification. The term is defined at the outset to be "variation in system response with variations in system characteristics." ('635, Col. 4, lines 4-5). The preferred embodiment describes the "second constraint" as an additional constraint where the derivatives of the physical response to an impulse are taken with respect to frequency. ('635, Col. 6, lines 12-49). Second constraints are limitations imposed on the "expressions" described in part A.2, *supra*. Expressions are not restricted to equations in the time domain. The expression modeling the physical system could exist in, *i.e.*, the frequency domain. It is nonsensical to impose a constraint on a variable which is not in the equation. Moreover, restricting the term "second constraints" to setting derivatives of an equation to zero ignores the breadth claimed in the patent. The specification contemplates imposing constraints on the expressions modeling the physical system. The full specification, not just the preferred embodiment, breathes meaning into the claims. See Amhil Enters. v. Wawa, Inc., 81 F.3d 1554, 1559 (Fed. Cir. 1996) (refusing to limit the claim to the preferred embodiment since "[a] preferred embodiment, however, is just that, and the scope of a patentee's claims is not necessarily or automatically limited to the preferred embodiment. The entire specification, including all of the claims, the prosecution history, and the prior art may all affect the interpretation ultimately placed on claim language.") It would therefore be inappropriate to restrict the meaning of "second constraints" to defendants' interpretation, which emphasizes the preferred embodiment over the specification as a whole, and would be incompatible with the meaning of the term "expression."

Accordingly, the court finds the term "second constraint" as used in independent claim 1 is interpreted to mean: "variation in system response with variations in system characteristics."

5. Minimize

The term "minimize" appears in both the preamble and the fourth element of claim 1: "finding a solution which is used to generate the input which minimizes the value of the expressions while satisfying the first and second constraints …" ('635 patent Col. 10 lines 50-51) (emphasis added).

Plaintiffs argue that the term "minimize" should be understood to mean "reduce to a minimum." Defendants argue that "minimize" should be "reduce to zero." Neither party has indicated that this term is used in any way other than it's ordinary meaning. The dictionary definition of "minimize" is "to reduce to the smallest possible number, degree, or extent." Merriam-Webster's Third New International Dictionary Unabridged, Merriam-Webster, Inc., 1993. Plaintiffs assert that within the context of the claim, "minimize" does not require reduction to zero. In support of their argument, plaintiffs recite the claim language that expressions are "minimized" subject to the constraints in the other elements of the claim. The constraints, as constructed *supra*, impose strict requirements on the input generated. Physical systems have a range of inputs which they are designed to receive. The input must be within this range ('635 patent Col. 7, lines 36-39) ("If at any time during the convolution, the actuator limit is exceeded, the sequence is unacceptable."), and within the range of tolerances the system permits ('635 patent Cols. 5-7). Within these constraints, and subject to real world conditions, the claimed method cannot necessarily eliminate all vibrations. (Decl. of Dr. Bell ¶ 20-21). See also '635 patent Col. 6, lines 8-11 ("Acceptable response is defined as less than 5% of total move size residual vibration.")

Defendants correctly indicate that the abstract of the patent states an objective "to eliminate unwanted dynamics", and a disclosed method in the specification which describes amplitudes of undesired vibrations as being reduced to zero. ('635 patent abstract; Col. 5, lines 44-61). Reducing unwanted dynamics to zero is only one step of the method taught by the invention. The abstract provides "A sequence of impulses is determined which eliminates unwanted dynamics of a dynamic system." ('635 patent abstract). This "sequence of impulses" is not the "input which minimizes the value of the expressions." In the preferred embodiment, the method taught determines how to translate an arbitrary input into another input. If the model is perfect with respect to the real-world operating environment, the patent contemplates eliminating all residual vibration. The imposition of the first and second constraints, above, are specifically imposed because of the difficulty of formulating a model which can capture every variation of the system's environment. See '635 patent Col. 5 lines 67-68 ("The two-impulse input, however, cancels vibration only if the system natural frequency and damping ratio are known exactly.") Interpreting "unwanted dynamics" to incorporate a threshold for acceptable residual vibration is consistent with the specification and the awareness of this difficulty. The disclosed method establishes a model which, in an idealized and abstracted world, eliminates a dynamic, such as vibration, from the system. ('635 patent Col. 5-6, lines 67-3) (noting that "vibrations [are canceled] only if the system natural frequency and damping ratio are known exactly.") The preferred embodiment specifically accommodates for uncertainty in the natural frequency of the system, and to variations in the damping ratio. This is exactly what is contemplated by the "first constraints" and "second constraints" in the '635 patent claims.

Defendants concede that they have no support for the assertion that reducing resulting vibrations to zero is possible.[8]

Reading a limitation into the claims which is so substantial as to exclude the preferred embodiment, when an alternative interpretation is clearly consistent with the language of the specification, is unwarranted. See Vitronics Corp. v. Conceptronic, Inc., 90 F.3d 1576, 1583 (Fed. Cir. 1994). The preferred embodiment contemplates a model where unwanted dynamics are reduced as much as possible, but with a tolerance for error. This tolerance would not be necessary if the invention reduced unwanted dynamics to zero in every instance. Presumably this is why plaintiffs opted for a broader term, encompassing solutions where the input is reduced as much as possible subject to constraints, but not necessarily to zero.

Accordingly, the term "minimize" as used in independent claims 1 and 11 is interpreted to mean: "reduce to a minimum."

6. Find A Solution

The third element of claim 1 provides: "finding a solution which is used to generate the input which minimizes the value of the expressions …" (emphasis added).

Plaintiffs assert that the term "finding a solution" means "determining an answer." Defendants initially contended that "finding a solution" means "the sequence of impulse signals or finite duration pulses that sets the expressions of the amplitude of the resonant vibration equal to zero" (Defs' Responsive Brief for '635 and '267 Patents at 18), but conceded plaintiffs'

[8] Mr. Akerley, attorney for defendant Seagate, adduced at the Markman hearing:

> MR. AKERLEY: . . . I'm not going to stand here and tell you that we can ever reduce those vibrations to an absolute zero.
> THE COURT: . . . what you're arguing that the plaintiff got a patent for, you're saying to me is impossible?
> MR. AKERLEY: No.
> THE COURT: Any of your experts opine that they know of such a system that reduces vibration to zero?
> MR. AKERLEY: No.
> Transcript of Markman Hearing at 131.

definition at the Markman hearing (Transcript of Proceedings Held on 3/30/2004 at 176). Accordingly, the term "finding a solution," as used in independent claims 1 and dependent claims 2-4, is interpreted to mean: "determining an answer."

THE '473 PATENT

The '473 patent is generally directed to a system for reducing unwanted dynamics in disk drives. Dynamics can arise in a disk drive due to the movement of the drive arm, an internal mechanism, over the platters within the disk containing the data. Reducing these dynamics can provide faster seek time, by reducing the time it takes for the drive arm to settle over a specific location of the platter, or lower noise level since noise in hard drives is caused by vibration. The '473 patent discloses an application of the methods for shaping inputs to a disk drive, and providing a user interface to select between a faster seek time or lower noise level. As for the other two patents, '267 and '635, each term has the same meaning in all the allegedly infringed claims unless otherwise noted.

A. CLAIM 10:

1. User Interface

The first element of claim 10 provides:

> providing a user interface for controlling one of a seek time of the data storage device and an acoustic noise level of the data storage device; (emphasis added)

There are two disputes over the term "user interface." The first dispute is whether a "user interface" is limited to being either a graphic user interface (GUI) or electromechanical switches, or whether a "user interface" more broadly encompasses any means to alter the drive performance parameters. The second dispute is whether the "user interface" can only be used by the human end-user of the system. Plaintiffs assert that a "user interface" broadly encompasses

any means to alter the parameters. They further contend that a "user interface" can more generally be used by any person or other system which is capable of setting the parameters.

Within the relevant art[9], there are distinctions between a "user interface" and a "graphic user interface." The dictionary meaning of "User interface" is "the means of communication between a human user and a computer system, referring in particular to the use of input/output devices with supporting software. Examples include the graphical user interface (GUI) and command-line interface (CLI)." A Dictionary of Computing, Oxford University Press, 1996. Defendants assert that the specification indicates that "user interface" should be construed as "a graphic user interface ('GUI') of a type common to windowing operating systems such as Microsoft Windows or electro-mechanical switches." ('473 patent Col. 6:44 – 9:44). This fails to distinguish between a "user interface" and a "graphic user interface". Defendants claim the specification defines the term "user interface" to be synonymous with "graphical user interface":

> [A]s an alternative to the GUI, or to supplement the GUI, the disk drive may include one or more electro-mechanical manual switches for controlling all or part of the drive's operation in the manner set forth above.
> ('473 patent Col. 9:38 – 42).

This language, however, clearly indicates the breadth of the term "user interface" to include both a GUI or electromechanical switches. This language indicates that a GUI is one type of "user interface," and an electro-mechanical switch is another, albeit simpler, type of "user interface." The "alternative to the GUI" and "supplement the GUI" language indicates that the electro-mechanical switch is not intended to limit the definition of "user interface," but rather demonstrates the range of user interfaces

[9] The '473 patent discloses an invention for improving the performance of computer disk drives. The relevant art here is the field of computer engineering.

encompassed by the invention. See Johnson Worldwide Assocs. v. Zebco Corp., 175 F.3d 985, 991 (Fed. Cir., 1999) ("Varied use of a disputed term in the written description demonstrates the breadth of the term rather than providing a limited definition.") Defendants' construction would require that "user interface" ensnare both a complex and simple user interface, but not the spectrum of user interfaces in between. The inventor did not demonstrate a manifest intent to disclaim every type of user interface not disclosed in the specification.

Plaintiffs' construction of "user" as "a person or device that uses the user interface" is too broad. It fails to give meaning to the adjective "user," which distinguishes the interface from other types of interfaces used in the computing field, for example, an advanced programming interface (API) which allows one software program to "interface" with another. The plain meaning of "user interface" requires a user, and the term "interface" typically indicates a means by which anything can interact with a device. Plaintiffs maintain that the term "user" cannot be limited to "a person" because this would exclude the situation where a person indirectly uses the interface. They argue, in essence, that any device can be broken down into a series of simpler devices. A potential infringer could, therefore, circumvent the patent by placing an intermediary device between the user and the invention. For instance, when using a GUI, the user typically positions the cursor on the screen using a mouse. A potential infringer could claim that the user is interfacing with the mouse, and the mouse is interfacing with the computer, thereby avoiding infringement. To avoid such pedantic arguments by accused infringers, the term is constructed specifically to include circumstances where a person has, at some point, dictated what the parameters should be. A patent cannot be constructed to deprive

a claim term of all meaning, and plaintiffs' construction of "user interface" would render "user" meaningless.

Defendants also contend that the user of the "user interface" must be the human end-user of the drive. They claim that the description of the GUI in the specification compels an interpretation imposing the end-user restriction. However, the user can be any person who wants to make use of the device; in this case, setting the drive parameters. The plain meaning of "user" does not require an individual who is the end-user of a product. Even the word "end-user" militates against the proposed construction: "end" modifies "user," so in it's regular usage "user" must mean something other than end-user. To impose a definition more limited than the normal meaning, there must be a clear intent on the part of the author to use the more limited definition. Johnson Worldwide Assoc., 175 F.3d at 990 (stating that anything other than the "ordinary and accustomed meaning" inheres only "if the patentee has chosen to be his or her own lexicographer by clearly setting forth an explicit definition for a claim term"... [or]... "the term or terms chosen by the patentee so deprive the claim of clarity that there is no means by which the scope of the claim may be ascertained from the language used.")(internal citations omitted). Defendants do not assert that the term end-user appears in the patent, nor does any language limiting the potential user of the product appear.

Claim terms are to be given their normal broad meaning absent an explicit disavowal of scope. See Novartis Pharm. Corp. v. Eon Labs Mfg., 363 F.3d 1306, 1314 (Fed. Cir. 2004). The "Windows-like operating system," one of the types of user interfaces defendants claim fits under their definition, is still a user interface when it is used by a technician configuring the computer before sale. There is no contemplation

within the patent that only the end-user of the drive be able to use the interface, and defendants' examples also militate toward no limitation based on the type of user.

Defendants contend that plaintiffs' proposed construction could be read to include disk drives that have been irrevocably configured at the factory. This meaning is beyond the scope of a "user interface." A user interface enables the alteration of parameters of the system. Drives manufactured in such a way as to only be capable of a one-time setting, which is then fixed in the hardware, do not possess a capability to alter the parameters. They only have a capability to set the parameters once. This is beyond the ordinary meaning of "user interface" in the art.

Accordingly, the term "user interface," as used in independent claims 1, 10, 11, and dependent claims 4, 12, and 13, is interpreted to mean:

> "hardware, firmware, or a combination thereof that allows a person, directly or indirectly, to alter parameters."

2. Data Storage Device

The first element of claim 10 also provides:

> … for controlling one of a seek time of the data storage device and an acoustic noise level of the data storage device; (emphasis added)

The term "data storage device" is used several times in claim 10. The interpretation of this term is linked with the interpretation of "outputting," below. Plaintiffs assert that the data storage device comprises the electromechanical components of the disk drive that perform commands specified by a controller. Defendants assert that "data storage device" should be understood to mean a hard disk drive, including

controller electronics. Defendants' construction would exclude from the scope of the claim those devices where shaped commands were generated within the drive itself.

The meaning adduced by both parties to "data storage device" is that it is a disk drive. Plaintiff states that those skilled in the art of control systems typically use a term to refer to that which is controlled, and that therefore what a layperson considers a disk drive would be characterized by a control engineer as a disk drive and a controller. (Pls.' Claim Construction Br. For U.S. Patent No.'s '635, '267, and '473 at 26). The specification supports such a construction. The patent in Col 10:1-21 describes a preferred embodiment of the control of a disk drive. Included in this description is the possibility that the processor controlling the disk drive is located in the PC, or, "alternatively, a separate controller dedicated to the disk drive which receives commands from [that] processor." '473 patent Col 10:6-8. Defendants claim that the specification discloses only two possible structures which can control the disk drive: the first is a processor within the PC, and the second is a controller which receives "commands" from that processor. (Defs.' Responsive. Claim Construction Br. for '473 Patent at 5). Since the third element of claim 10 uses the term "command" to refer to shaped inputs, defendant infers that the commands must be shaped by the processor located within the PC. Defendant combines a context-specific use within one claim with a more general use in the specification. The term "command" as it is used in the specification refers to signals communicated from a keyboard or mouse (Col. 6:19), to a signal which will be shaped (Col. 8:12), and to signals in a disk drive generally (Col. 2:22-28). Claim 10 refers to a specific kind of "command," one that has been shaped by a processor. The command referred to in Col. 10:6-8 could therefore be a signal which has been shaped by a disk

drive engine running on a processor in the PC, or an unshaped signal from the PC which will be shaped by a processor dedicated to the disk drive and not located in the PC. Defendants argue that since "disk drives," as lay people use the term, commonly include on-board electronics dedicated to controlling the drive, a construction that permits on-board electronics to send "commands" is not supported. Such a configuration is within the scope of the claim. Accordingly, the term "data storage device," as used in claim 10, is interpreted to mean:

> "a computer disk drive, including all electronic and mechanical components, which receives shaped commands from a processor which may be integrated into the drive."

3. Outputting Commands to the Data Storage Device

The third element of claim 10 provides: "outputting commands to the data storage device causing the data storage device to alter seek trajectory …" (emphasis added).

The parties dispute whether the underlined portion of the claim imposes a limitation that the commands must be generated in the computer. Plaintiffs asserts that the commands can originate from any source. Defendants seek to exclude from the scope of the claims situations where electronics located within the disk drive itself perform a shaping method on commands sent to the data storage device. The specification discloses in the preferred embodiment a software application, the disk drive engine, which "generates and outputs commands to the disk drive." ('473 patent, Col. 6 lines 43-45). This application is executed either on the main processor of the computer of which the disk drive is a component, or "a separate controller dedicated to the disk drive which receives commands" from the main processor of the computer. ('473 patent, Col. 10 lines 6-8). Defendants' argument depends in part on their construction of data storage device to include any electronics built into a commercially packaged disk drive. The

construction of "data storage device" adopted is consistent with the claim language requiring that commands be "output" to the data storage device. This reduces the question to the source of any "output."

Defendants are correct that plaintiffs do not provide any guidance regarding the source of the "commands" being "output." In order for the claim to be self-consistent, the "commands" must be the "input signals to the data storage device." The dictionary definition of "output" is "the result of data-processing activity when it is presented external to the system … it may be ready for input to another system or process…" A Dictionary of Computing, Oxford University Press, 1996. Within the context of the invention, the disclosed method for shaping inputs is performed. The result of this method, in the form of "commands," are sent (as output) from the processor performing the shaping to the data storage device (as input). The word "output" when applied to a signal does not inherently require that the signal be sent from a different device than that receiving the signal. A feedback system "outputs" a signal to itself, which it then uses as an input.

Accordingly, the term "output," as used in independent claims 1, 7-11, and 14-15, is interpreted to mean: "sending a command to a device, which may originate from within the device."

4. By Shaping Input Signals and Selected Unwanted Frequencies

The third element of claim 10 also provides:

> "… causing the data storage device to alter seek trajectory shape by shaping input signals to the data storage device to reduce selected unwanted frequencies from a plurality of frequencies…" (emphasis added)

The two underlined terms are in dispute. Plaintiff argues that the term "shaping" includes frequency-based filtering, and that "selected unwanted frequencies" can be some or all of the unwanted frequencies. Defendant insists that filtering, which is found in prior art references, cannot be encompassed by the invention. They also argue that the term "selected" precludes selection of all unwanted frequencies.

Defendants' assertion that including filtering in the term "shaping" would result in invalidity is premature. The specification unambiguously indicates that shaping includes conventional filtering techniques. ('473 patent, Col. 22:60 – 67). The patentee's offered construction does not conflict with the explicit language of the claim, and follows from the plain meaning of the term. Rhine v. Casio, 183 F.3d 1342, 1346 (Fed. Cir. 1999) (the court should "sustain the patent and the construction claimed by the patentee himself, if this can be done consistently with the language which he has employed.") This construction may later be found invalid, but it is inappropriate to argue invalidity during claim construction. Rhine v. Casio, 183 F.3d 1342, 1346 (Fed. Cir. 1999) (defendant "cannot avoid a full-blown validity analysis by raising the specter of invalidity during the claim construction phase.")

Accordingly, the term "shaping" as used in claim 10 is interpreted to mean: "applying a transformation to a signal."

The third element of claim 10 also provides: "shaping input signals to the data storage device to reduce selected unwanted frequencies" ('473 patent Col. 44 lines 43-45) (emphasis added).

Plaintiffs assert that "selected unwanted frequencies" should be interpreted to mean some unwanted frequencies, and could include, but need not include, all unwanted frequencies. (Pls.' Claim Construction Br. For U.S. Patent No.'s '635, '267, and '473 at 29). Defendants respond

that selected cannot encompass all unwanted frequencies. (Defs' Responsive Brief for '473 Patent at 24).

Neither party has presented any special meaning of the term "selected" in the art. The dictionary definition most relevant to the context of the patent is "choose from a number or group." Merriam-Webster's Third New International Dictionary Unabridged, Merriam-Webster, Inc., 1993. Plaintiffs note particularly that when the method reduces certain specific unwanted frequencies, such as would be the case if less than all unwanted frequencies are selected, other unwanted frequencies may also be reduced. (Transcript of Markman Hearing on 3/31/2004 at 278). As a natural consequence of the robustness built into the system, plaintiffs maintain, when any specific frequency is reduced, there will be collateral reductions in other frequencies. (Transcript of Markman Hearing at 279). These arguments do not directly address the question of "selection" of frequencies. A method which reduces frequencies other than those selected is not excluded from the patent since there is no limiting language requiring that only specific frequencies are reduced.

Defendants agree on the ordinary meaning of the term "selected" (Transcript of Markman Hearing at 254), but assert that the prosecution history of the '473 patent discloses a surrender of any method where all unwanted frequencies are reduced. In an interview on May 9, 2001, the PTO asserted that U.S. Patent 6,011,373 (hereinafter "McConnell patent") teaches selection by the user between fast response time and noise reduction mode. Plaintiffs amended the language "reduce unwanted frequencies" to "reduce selected unwanted frequencies from a plurality of frequencies" in the '473 patent. The PTO rejected the "reduce unwanted frequencies" language since "McConnell et al teach that the user can select between the fast response time and noise reduction modes.

However, McConnell et al can't reduce selected unwanted frequencies …" (Akerley Dec. Exh. V, PLFS-C 008898). The McConnell invention "allow[s] the user to select a command input from a given group of command inputs … by ranking the importance of three characteristics … response time, robustness, and noise generation potential." (McConnell patent Col. 11 lines 21-25). Whereas the '473 patent identifies specific unwanted frequencies to reduce, and generates a command input which reduces them, the McConnell patent takes a set of pre-determined command inputs, categorizes these commands by the three characteristics above, and applies the input best suited to the user's preference.

Amendments made during prosecution are a guide to understanding the language of the patent, although they do not "enlarge, diminish, or vary the limitations in the claim." Markman, 52 F.3d at 980. Plaintiffs did not give up any claim to a reduction of all unwanted frequencies. The amendment made to overcome rejection by the PTO clearly indicates that the '473 patent is differentiated from the McConnell patent by the fact that the McConnell patent does not perform selective reduction of unwanted frequencies. The McConnell patent applies methods known to reduce all frequencies, and picks one based on the user specified criteria. The term "selected" was imposed to distinguish the '473 patent from the McConnell patent, and it is a significant distinction that the '473 patent targets specific frequencies to reduce as opposed to indiscriminately reducing all frequencies. The fact that under this interpretation the '473 patent could result in a reduction of more than the selected frequencies is unimportant. The inventor has disclosed a method which provides that certain targeted frequencies will definitely be

reduced, which the PTO considered sufficiently novel in light of the prior art to grant a patent.

Accordingly, the term "selected unwanted frequencies" as used in claim 10 is interpreted to mean: "at least the chosen unwanted frequencies."

CONCLUSION

Based on the foregoing, the term "input" means "information that is delivered to the system from outside the system"

The term "expression" means "a mathematical characterization that quantifies."

The term "first constraint" means "a limit on the input based on the physical system."

The term "second constraint" means a "variation in system response with variations in system characteristics."

The term "minimize" is interpreted to mean "reduce to a minimum."

The term "find a solution" is interpreted to mean "determining an answer."

The term "user interface" is constructed to mean "hardware, firmware, or a combination thereof that allows a person, directly or indirectly, to alter parameters."

The term "data storage device" is constructed to mean "a computer disk drive, including all electronic and mechanical components, which receives shaped commands from a processor which may be integrated into the drive."

The term "outputting commands" is constructed to mean "sending a command to a device, which may originate from within the device."

The term "shaping input signals" is constructed to mean "applying a transformation to a signal."

The term "selected unwanted frequencies" is interpreted to mean "at least the chosen

unwanted frequencies."

Dated: New York, New York
August 9, 2005

SO ORDERED:

GEORGE B. DANIELS
United States District Judge

UNITED STATES DISTRICT COURT
SOUTHERN DISTRICT OF NEW YORK
----------x

CONVOLVE, INC. and MASSACHUSETTS INSTITUTE OF TECHNOLOGY,

Plaintiffs,

-against-

COMPAQ COMPUTER CORP. and SEAGATE TECHNOLOGY LLC,

Defendants.

----------x

MEMORANDUM DECISION AND ORDER
00 CV 5141 (GBD)

GEORGE B. DANIELS, District Judge:

On August 9, 2005 this Court issued a Memorandum Decision and Order after holding a Markman hearing to address the construction of the patent claims in the above caption case. Defendants' Compaq Computer Corporation ("Compaq") and Seagate Technology LLC ("Seagate") (collectively, "defendants") moved for reconsideration and reargument of this Court's August 9, 2005 Decision and Order ("Order") pursuant to Civil Rule 6.3 of the Rules of the United States District Courts for the Southern and Eastern Districts of New York ("Local Rule 6.3") on the grounds that this Court failed to consider the Federal Circuit's en banc decision in Phillips v. AWH Corp., 415 F.3d 1303 (Fed. Cir. July 12, 2005, revised July 14, 2005) (en banc).

Specifically, defendant Compaq seeks reconsideration of the construction of two terms in the '473 Patent: (1) "user interface;" and (2) "shaping input signals" by reducing "selected unwanted frequencies." Compaq argues that the Court, at plaintiffs' urging, relied too heavily on dictionary definitions when constructing these claims and therefore ran afoul of the holding in Phillips. Defendant Seagate advances a similar argument in its motion which asks the court to

reconsider its claim construction with respect to six different terms: (1) "expressions;" (2) "second constraints;" (3) "minimizes;" (4) "user interface;" (5) "data storage device;" and (6) "outputting commands." Defendants have offered no new arguments nor have they articulated in what manner the Court's claim construction is erroneous.

Contrary to defendants' assertions, this Court considered Phillips which was decided four weeks prior to the issuance of this Court's Order and which was specifically raised in briefing by defendant Compaq by letter dated July 29, 2005 and by defendant Seagate by letter dated August 1, 2005. Consistent with Phillips, this Court stated at the outset that: "[p]roper interpretation looks first to intrinsic evidence: the language of the claims themselves, the patent specification, and the prosecution history. . .[t]he claims are at the center of the analysis" (internal citations omitted). Accordingly, in construing each term or phrase at issue, this Court first focused on intrinsic evidence in reaching each of its conclusions.

Defendants' also incorrectly assert that this Court's use of dictionary definitions during claim construction led it to rely "too heavily" on such extrinsic evidence in violation of Phillips' holding. Phillips expressly states that: ". . .we do not intend to preclude the appropriate use of dictionaries. . . .[which] are often useful to assist in understanding the commonly understood meanings of words and have been used by both our court and the Supreme Court in claim interpretation." 415 F.3d at 1322 (internal citations omitted). In keeping with Phillips' holding, this Court's Order did not utilize dictionary definitions and extrinsic evidence in a vacuum; rather, this Court considered dictionary definitions when offered by the parties' themselves as correct definitions, as well as, to help it understand the commonly understood meaning of certain words used in the patents' themselves. See 415 F.3d at 1319 (stating that extrinsic evidence, though useful, should be "considered in the context of the intrinsic evidence").

Because the Court considered the Phillips decision, defendants' motions have failed to meet their burden under Local Rule 6.3. See In re Health Mgmt. Sys., Inc. Secs. Litig., 113 F. Supp. 2d 613, 614 (S.D.N.Y. 2000) (internal citation omitted) (stating "reconsideration. . . is an extraordinary remedy to be employed sparingly in the interests of finality and conservation of scarce judicial resources); see also Shrader v. CSX Transp., 70 F.3d 255, 257 (2d Cir. 1995) ("[t]he standard for granting such a motion is strict, and reconsideration will generally be denied unless the moving party can point to controlling decisions or data that the court overlooked – matters, in other words, that might reasonably be expected to alter the conclusion reached by the court"). Moreover, Rule 6.3 is not a vehicle for "reargu[ing] those issues already considered when a party does not like the way the original motion was resolved," In re Houbigant, Inc., 914 F. Supp. 997, 1001 (S.D.N.Y. 1996), nor "does it mean the parties get a 'do over.'" Metropolitan Opera Ass'n, Inc. v. Local 100, 2004 U.S. Dist. LEXIS 17093, at *4 (S.D.N.Y. Aug. 27, 2004).

Nothing in this Court's Order is inconsistent with Phillips; nor would reconsideration of anything in Phillips lead this Court to reach a different result. Accordingly, defendants' motions for reconsideration and reargument of this Court's August 9, 2005 Memorandum Decision and Order are denied.

Dated: New York, New York
December 7, 2005

SO ORDERED:

George B. Daniels

GEORGE B. DANIELS
United States District Judge

U.S. DISTRICT COURT FILED DEC - 8 2005 S.D. OF N.Y.

UNITED STATES DISTRICT COURT
SOUTHERN DISTRICT OF NEW YORK

----------x

CONVOLVE, INC. and MASSACHUSETTS INSTITUTE OF TECHNOLOGY,

Plaintiffs,

-against-

COMPAQ COMPUTER CORP. and SEAGATE TECHNOLOGY LLC,

Defendants.

----------x

ORDER

00 CV 5141 (GBD)

#439

GEORGE B. DANIELS, District Judge:

This Court issued an order denying defendants' motions for reconsideration and reargument of this Court's August 9, 2005 decision and order in the above captioned case.

Accordingly, the clerk of the court is directed to remove the defendants' motions for reconsideration and reargument, documents # 406 and # 426, from the Court's docket.

Dated: New York, New York
December 7, 2005

SO ORDERED:

George B. Daniels

GEORGE B. DANIELS
United States District Judge

MICROFILM NOV 8 2005

U.S. DISTRICT COURT FILED JAN 17 2006 S.D. OF N.Y.

UNITED STATES DISTRICT COURT
SOUTHERN DISTRICT OF NEW YORK

Doc # 442

CONVOLVE, INC. and MASSACHUSETTS INSTITUTE OF TECHNOLOGY,

Plaintiffs,

-against-

COMPAQ COMPUTER CORP. and SEAGATE TECHNOLOGY LLC,

Defendants.

ORDER

00 CV 5141 (GBD)

GEORGE B. DANIELS, District Judge:

Plaintiffs have requested that "software" be added to the construction of the claim term "user interface."

The defendants have not responded to this application.

Unless the defendants state some objection within thirty day of this order, the term "user interface" is constructed to mean: "*software*, hardware, firmware, or a combination therof that allows a person, directly or indirectly, to alter parameters."

Dated: New York, New York
January 13, 2006

SO ORDERED:

George B. Daniels

GEORGE B. DANIELS
United States District Judge

MICROFILM JAN 17 2006 3:30 PM

U 7199104

THE UNITED STATES OF AMERICA

TO ALL TO WHOM THESE PRESENTS SHALL COME:

UNITED STATES DEPARTMENT OF COMMERCE
United States Patent and Trademark Office

August 19, 2009

THIS IS TO CERTIFY THAT ANNEXED HERETO IS A TRUE COPY FROM THE RECORDS OF THIS OFFICE OF:

U.S. PATENT: *6,314,473*
ISSUE DATE: *November 06, 2001*

By Authority of the
Under Secretary of Commerce for Intellectual Property
and Director of the United States Patent and Trademark Office

E. BORNETT
Certifying Officer

US006314473B1

(12) **United States Patent**
Singer et al.

(10) **Patent No.: US 6,314,473 B1**
(45) **Date of Patent: Nov. 6, 2001**

(54) **SYSTEM FOR REMOVING SELECTED UNWANTED FREQUENICES IN ACCORDANCE WITH ALTERED SETTINGS IN A USER INTERFACE OF A DATA STORAGE DEVICE**

(75) Inventors: **Neil Singer**, Armonk, NY (US); **Mark Tanquary**, Needham; **Kenneth Pasch**, North Eastham, both of MA (US)

(73) Assignee: **Convolve, Inc.**, New York, NY (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **09/262,781**

(22) Filed: **Mar. 4, 1999**

Related U.S. Application Data

(60) Provisional application No. 60/109,145, filed on Nov. 20, 1998, and provisional application No. 60/077,292, filed on Mar. 5, 1998.

(51) **Int. Cl.**[7] **G06F 3/00**; G11B 15/46; G11B 21/02; G11B 5/596

(52) **U.S. Cl.** **710/5**; 318/560; 360/73.01; 360/75; 360/78.07

(58) **Field of Search** 360/31, 75, 69, 360/73.01, 78.07; 318/560, 561; 710/1, 5, 15

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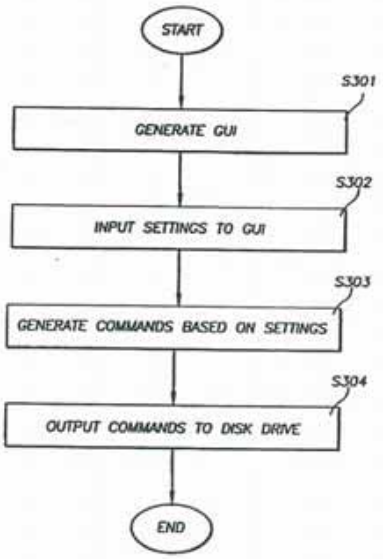
"High-Speed/Low-Power Selectable Optical File", 2244 Reserarch Disclosure, Jul. 1990. No. 315.*

Primary Examiner—Thomas Lee
Assistant Examiner—Chun Cao
(74) *Attorney, Agent, or Firm*—Choate, Hall & Stewart

(57) **ABSTRACT**

Techniques are provided herein for reducing vibrations in various modes of a dynamic system. One such technique comprises incorporating vibration limiting and sensitivity constraints into a partial fraction expansion equation model of the system so as to reduce vibrations to specific levels. Another technique comprises shaping a command determined using the partial fraction expansion equation model to produce a desired output. The entire command may be shaped or only selected portions thereof which produce vibrations. Another technique involves commanding in current to produce saturation in voltage. By doing this, it is possible to command voltage switches. The times at which the switches occur can be set to reduce system vibrations. Other techniques are also provided. These include varying transient portions at the beginning, middle and/or end of a move and using Posicast inputs, among others.

15 Claims, 28 Drawing Sheets



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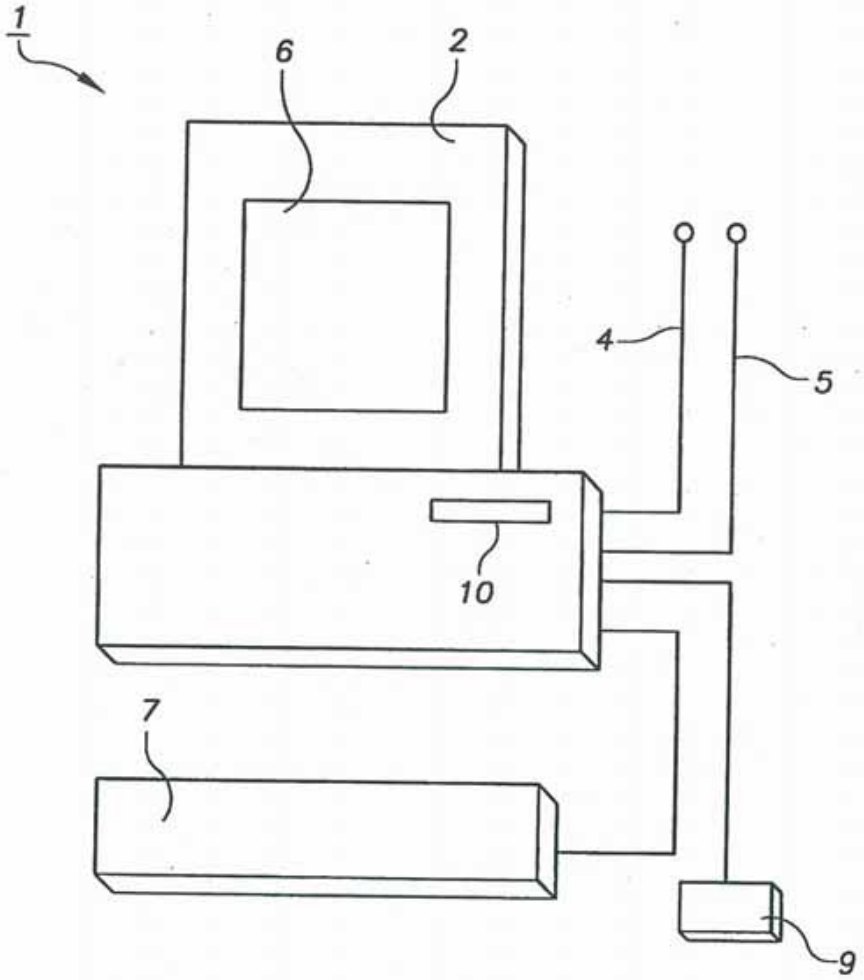
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FIG. 1



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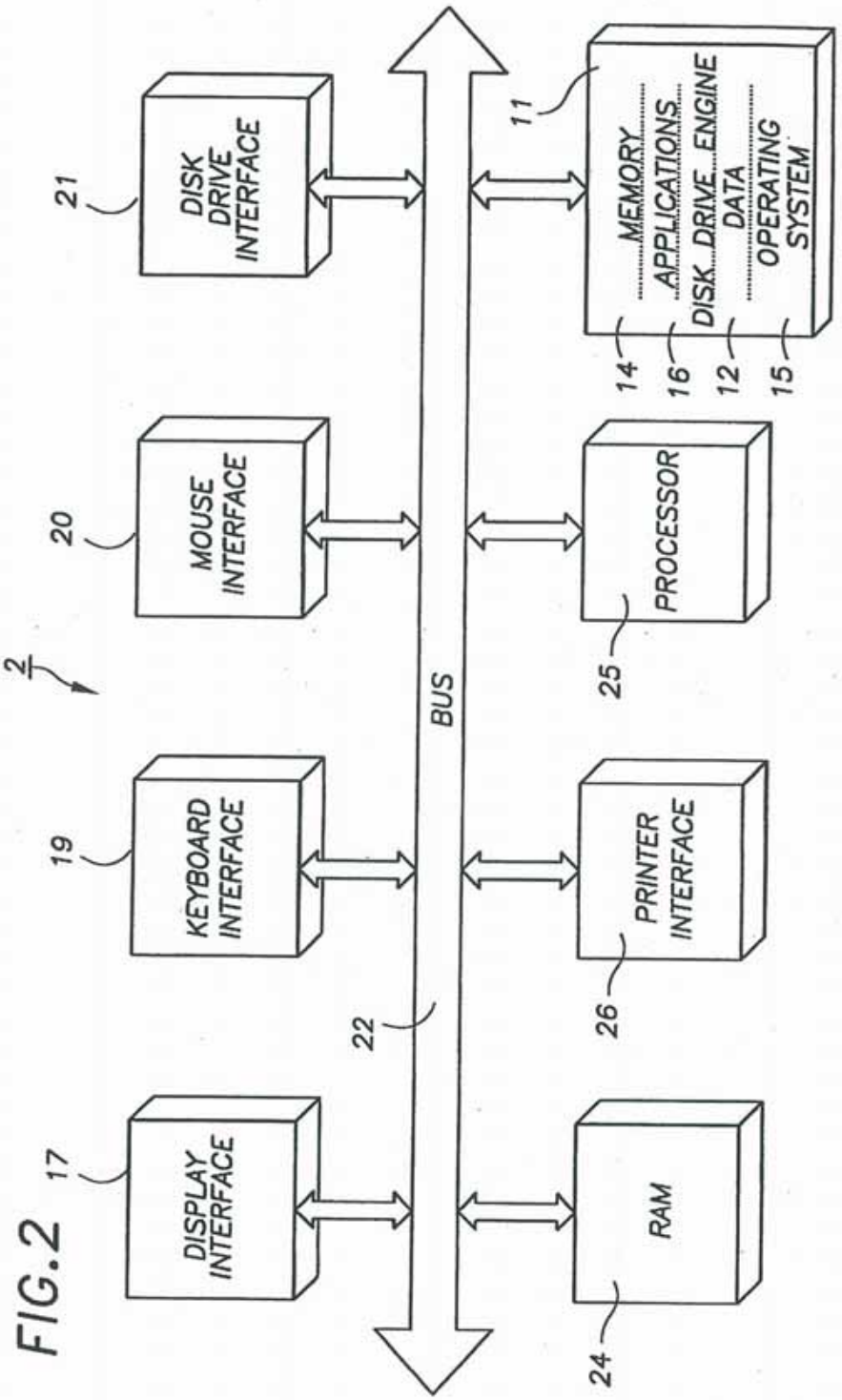
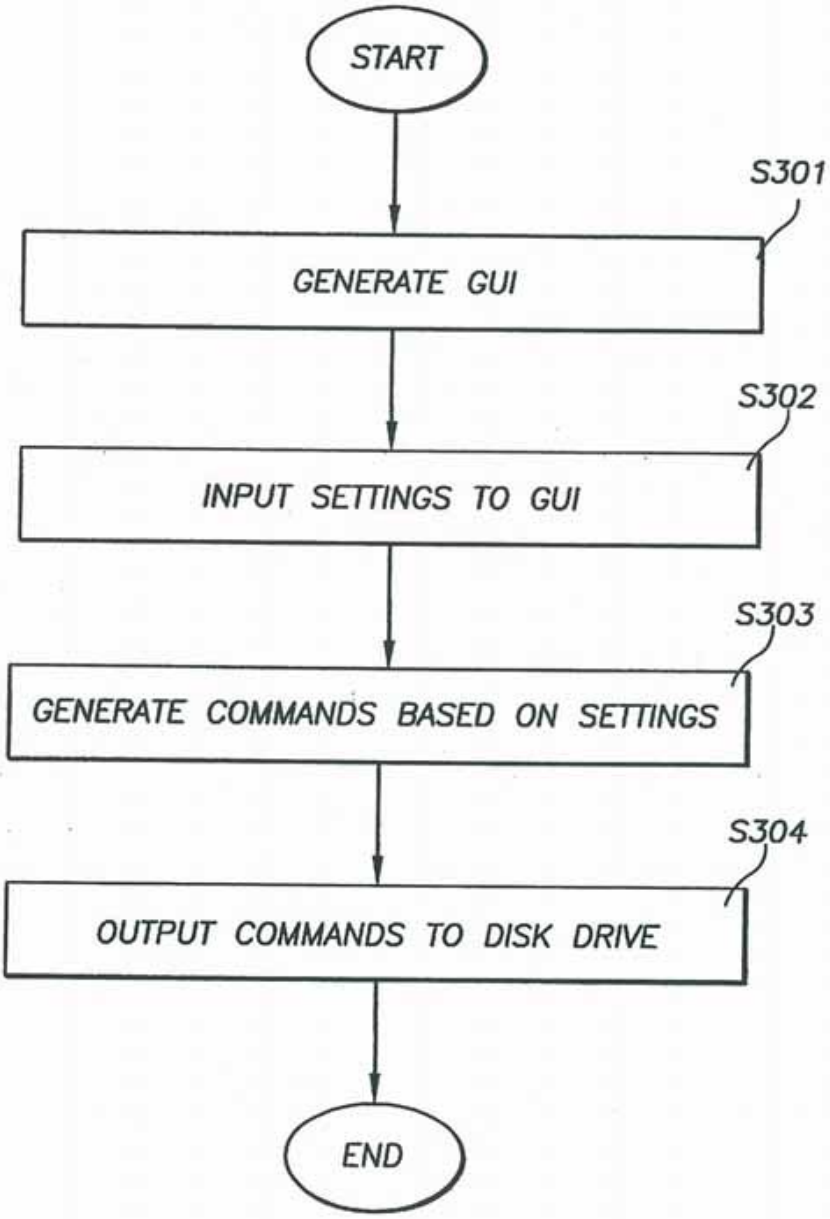


FIG.2

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FIG.3



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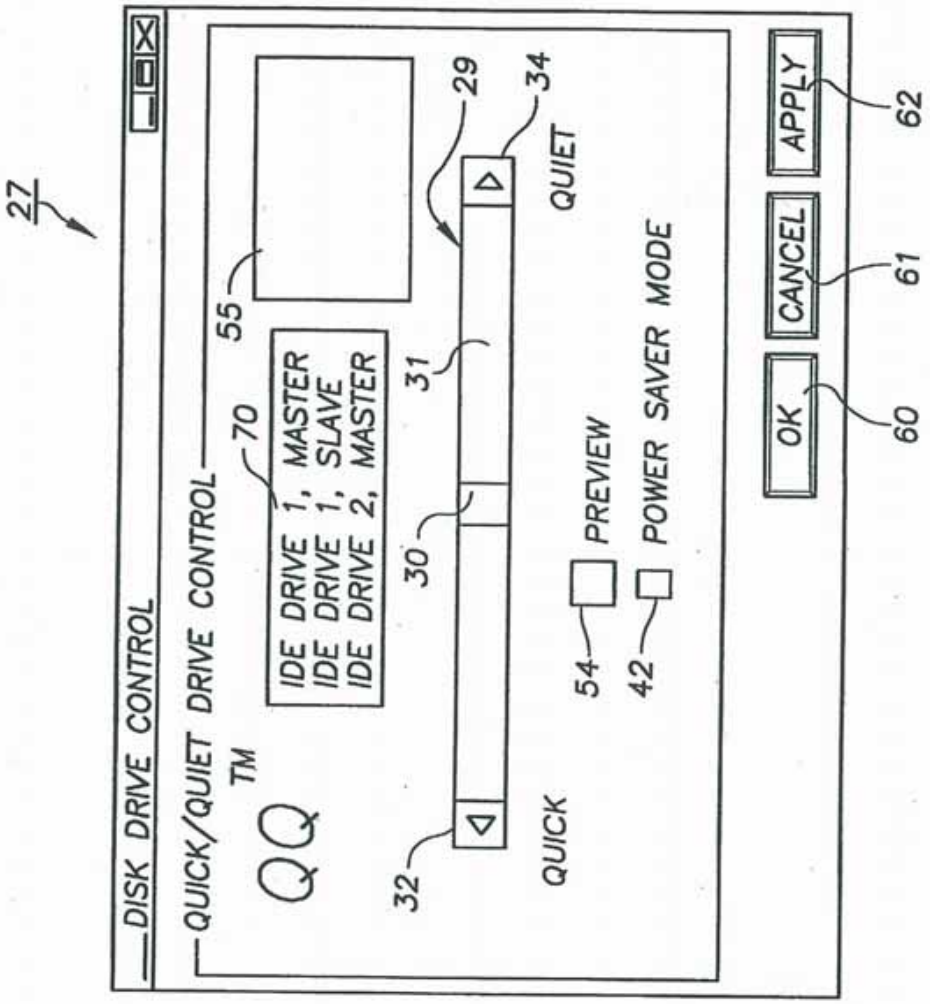


FIG. 4

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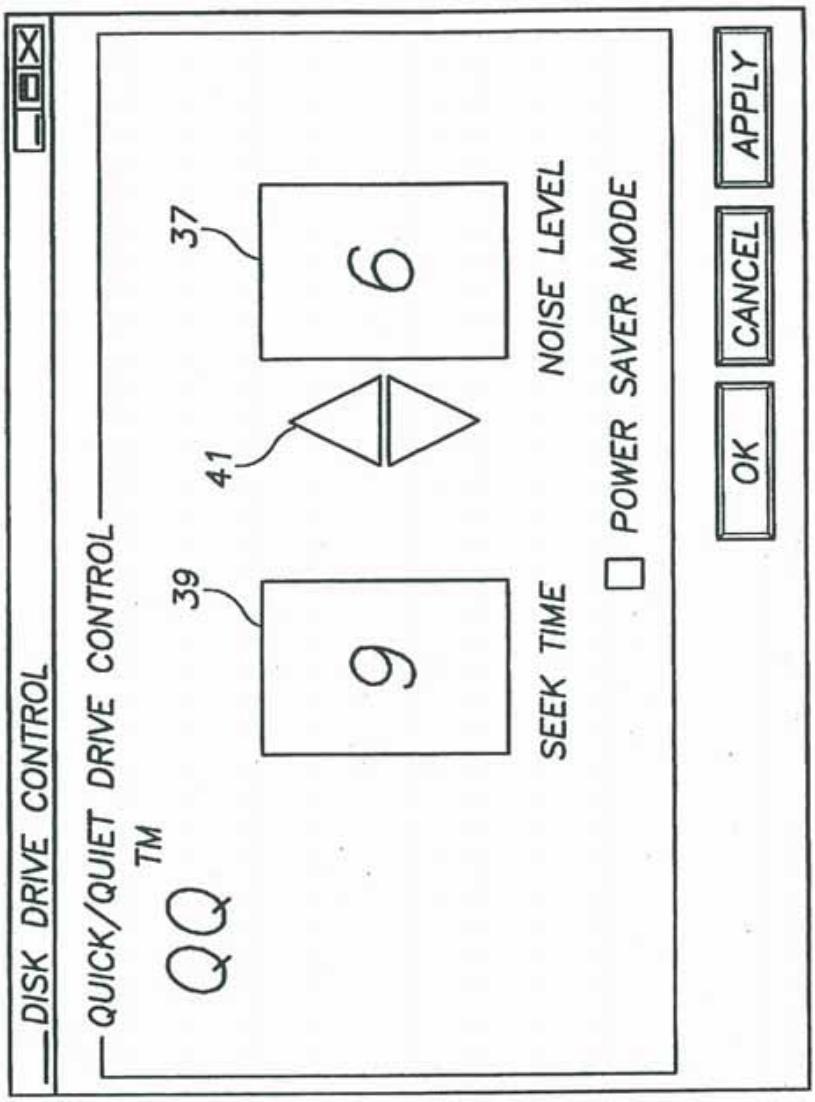


FIG.5

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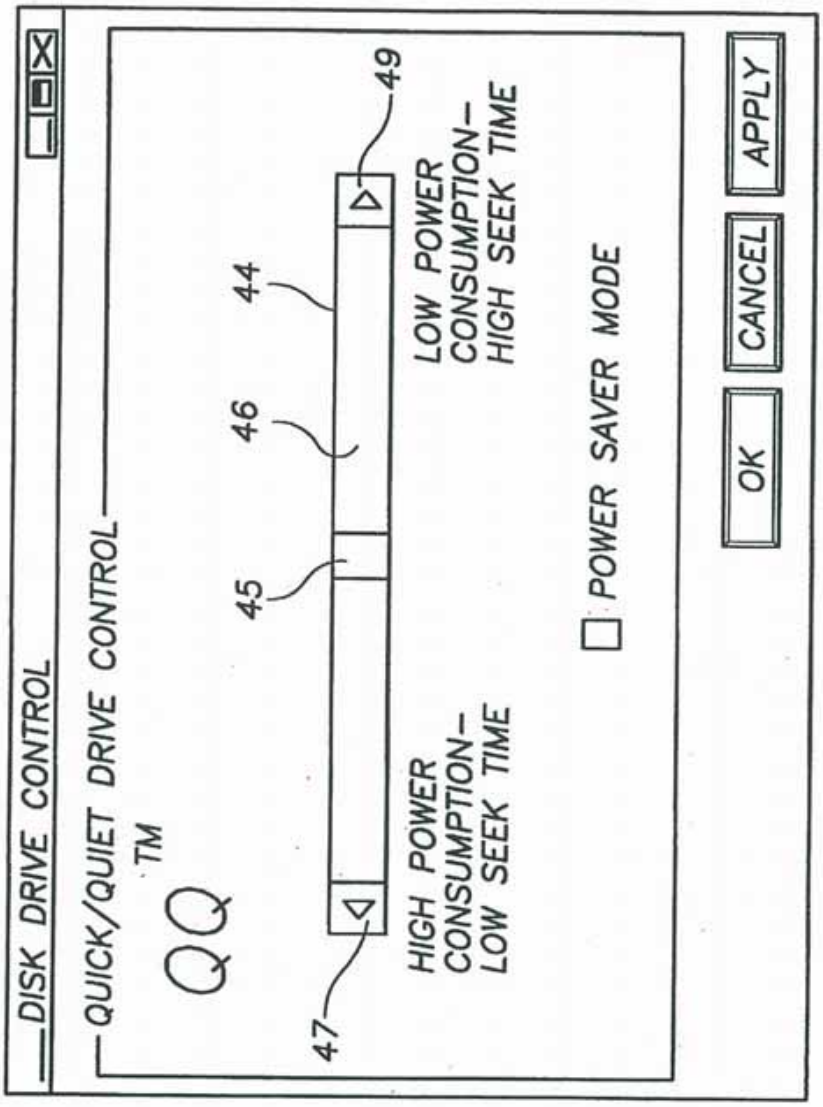


FIG. 6

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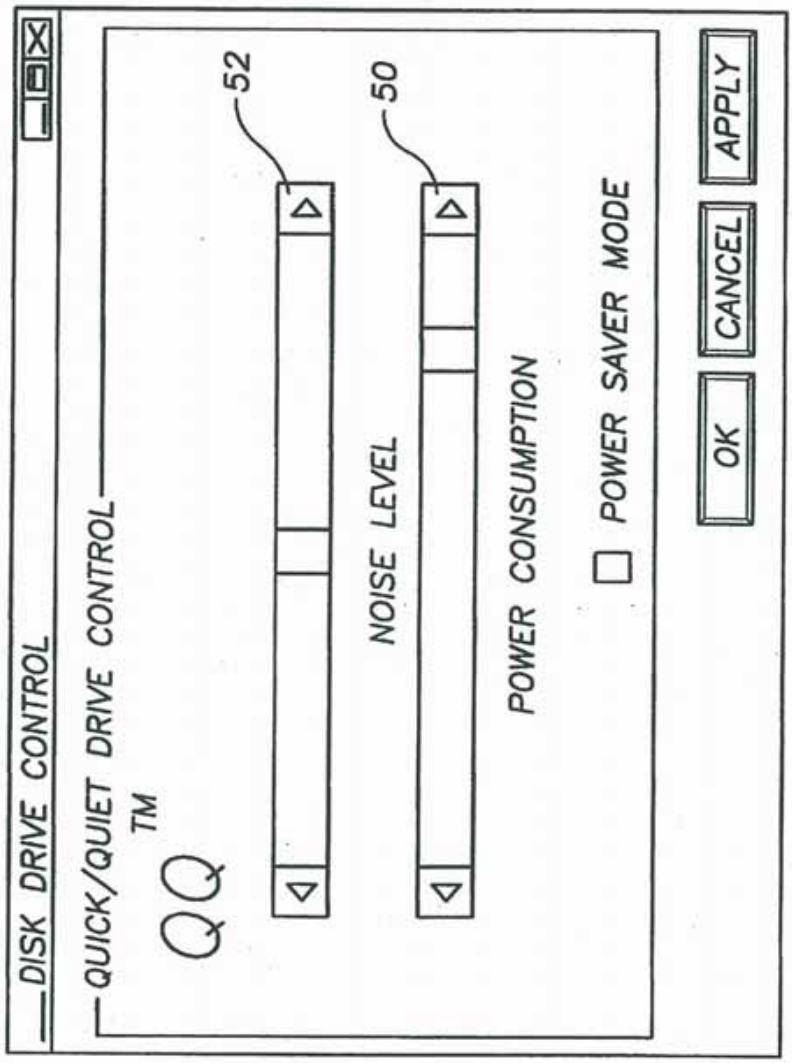


FIG. 7

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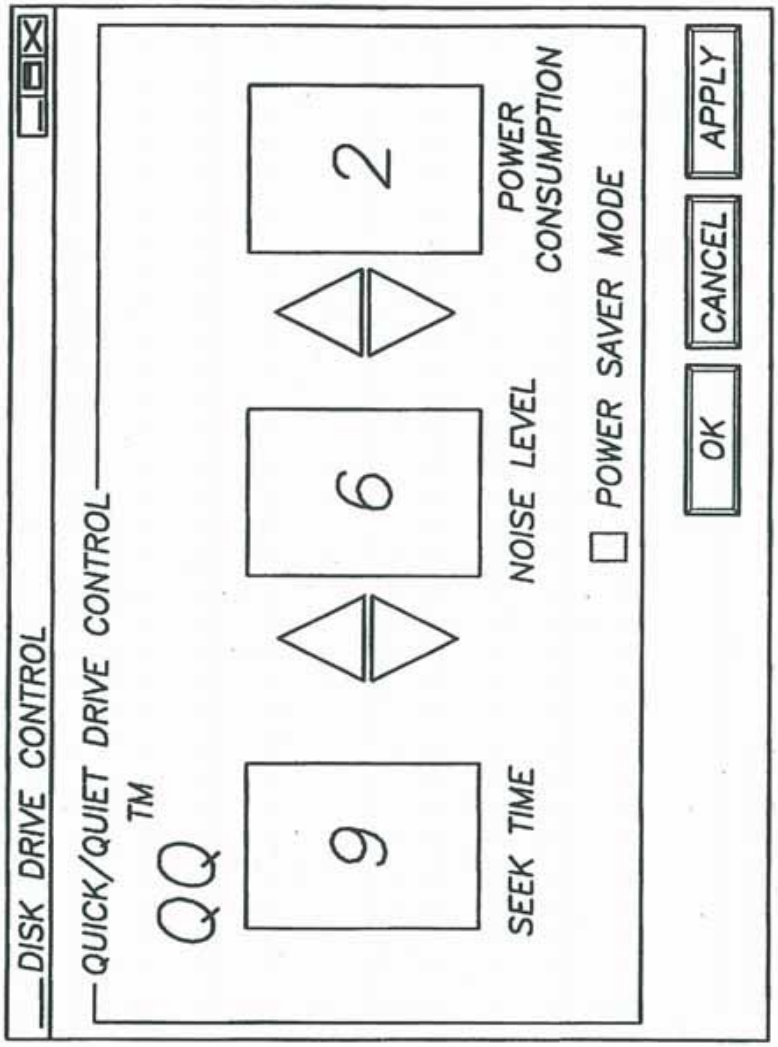


FIG. 8

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FIG.9

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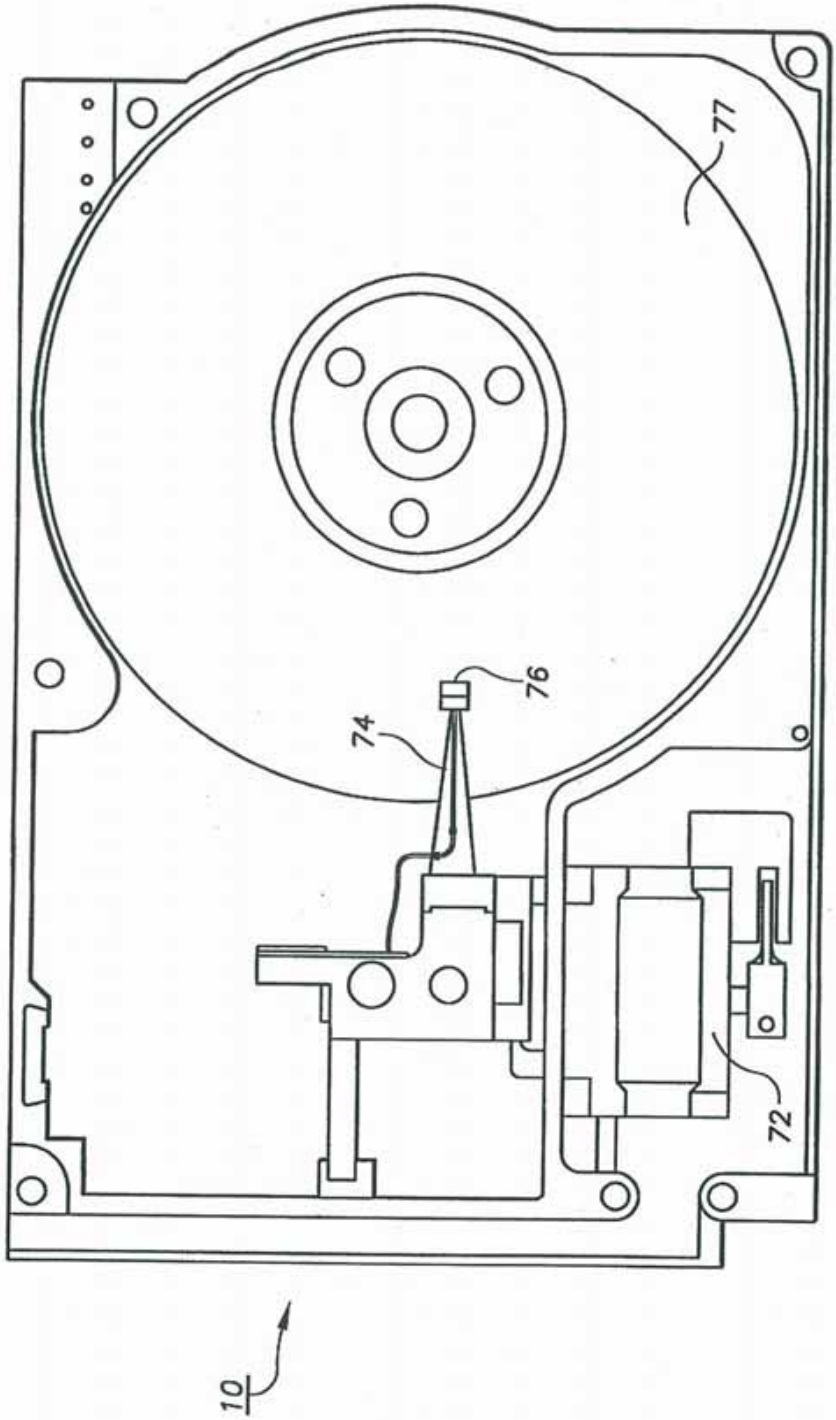
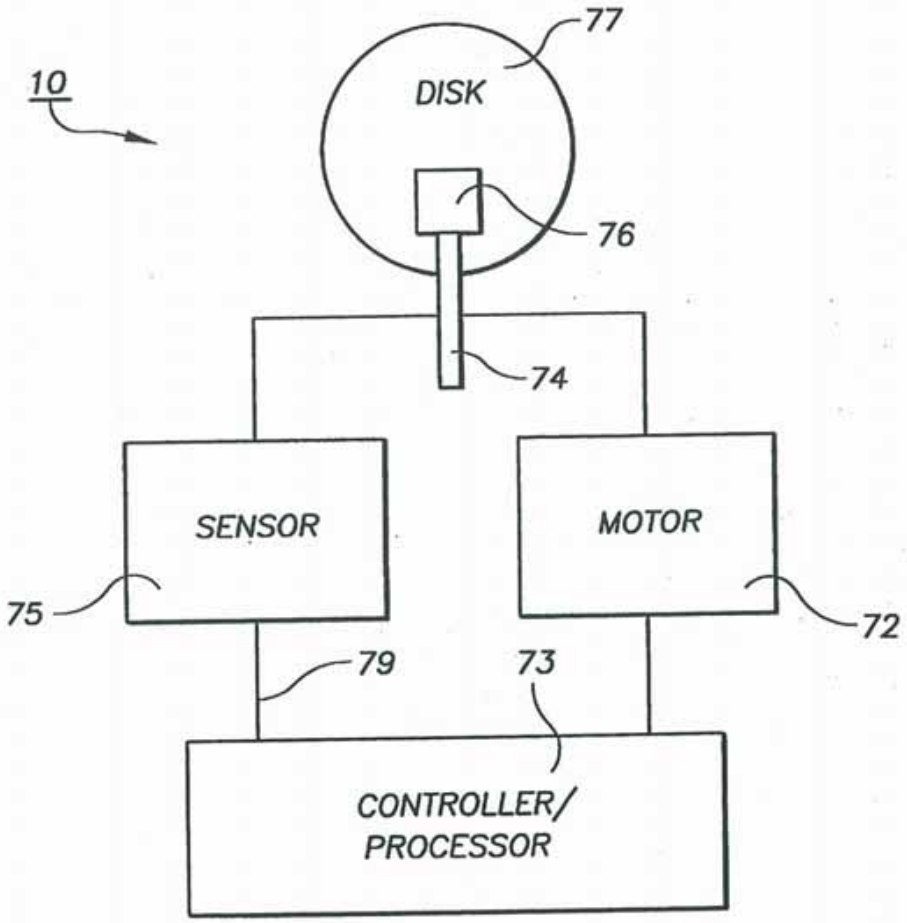


FIG. 10A

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FIG. 10B



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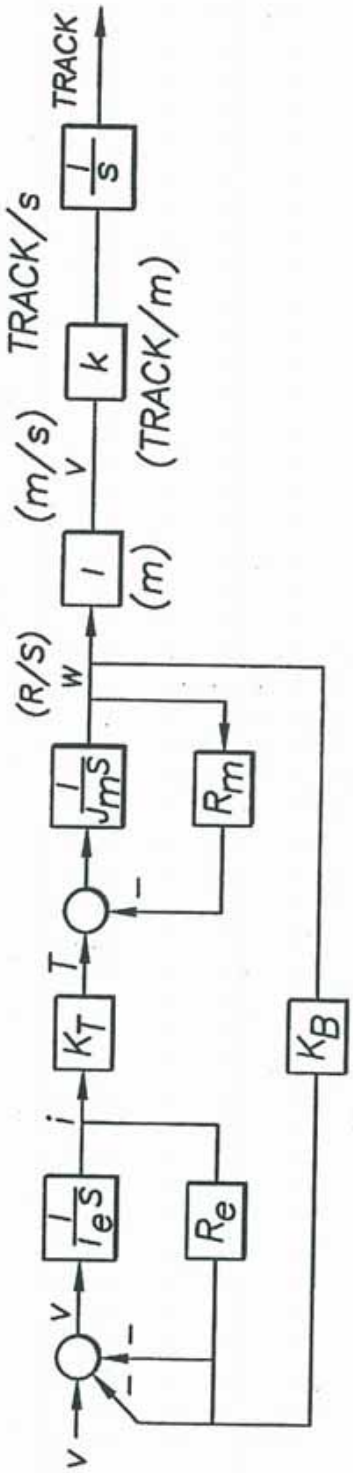


FIG. 11

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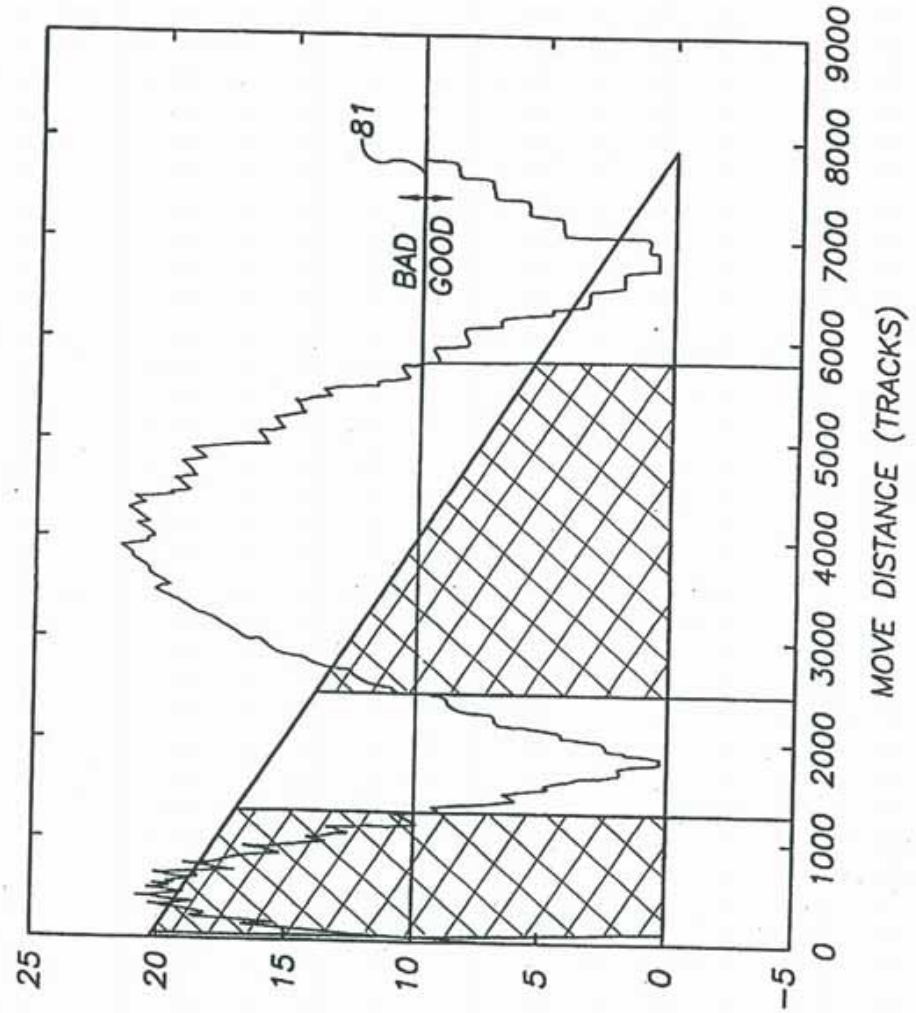


FIG. 12

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FIG. 13
PRIOR ART

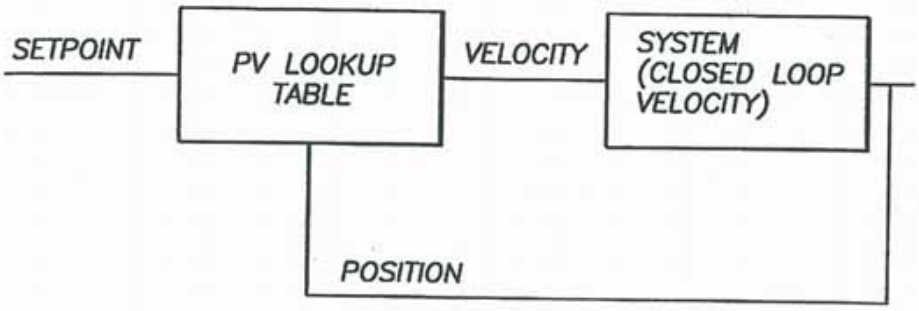
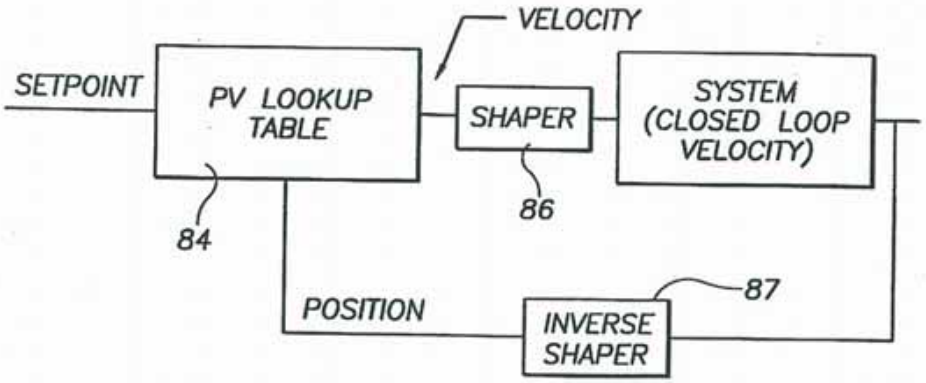


FIG. 14



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FIG. 15

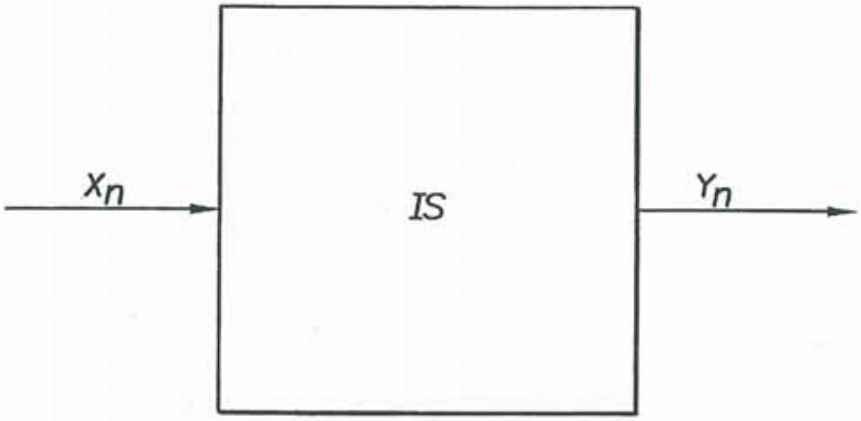
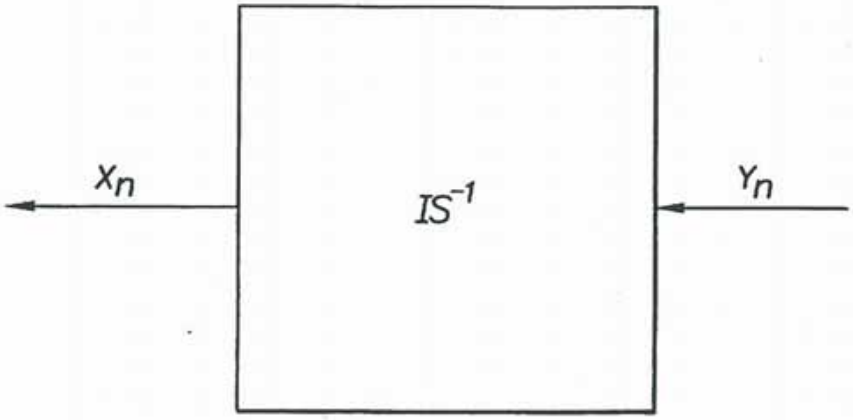


FIG. 16



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FIG. 17

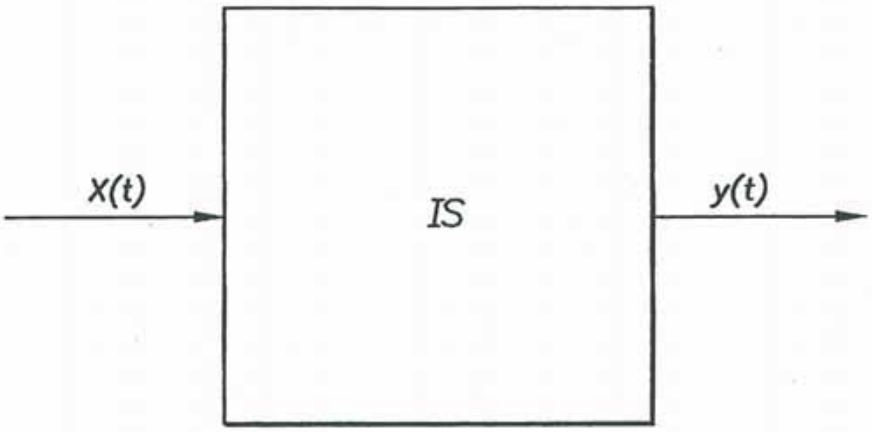
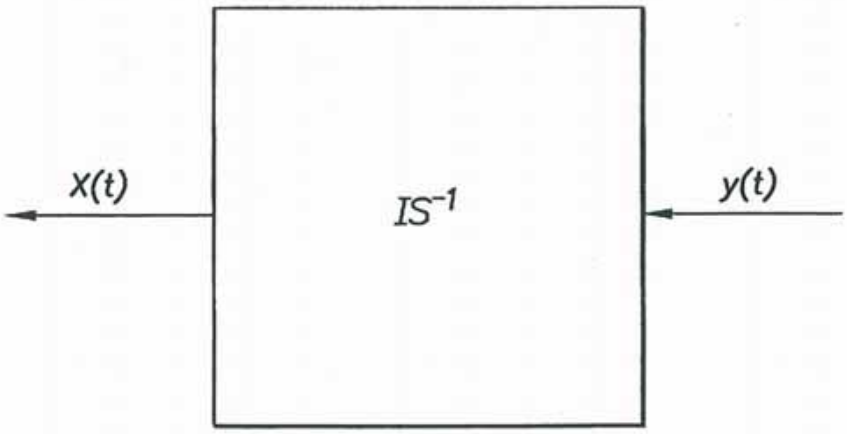


FIG18



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FIG. 19

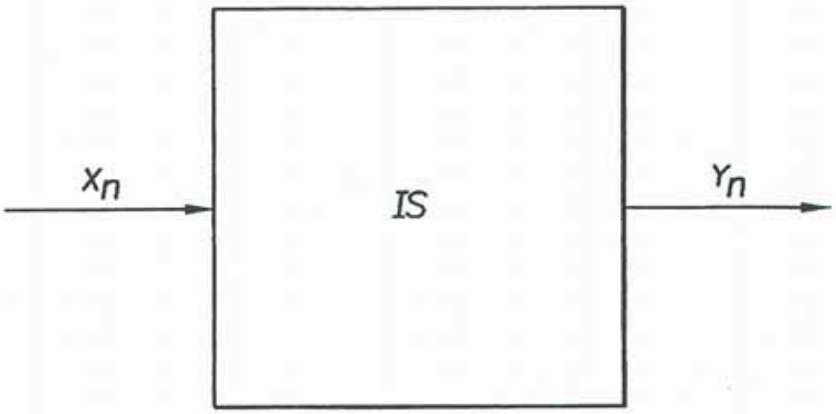
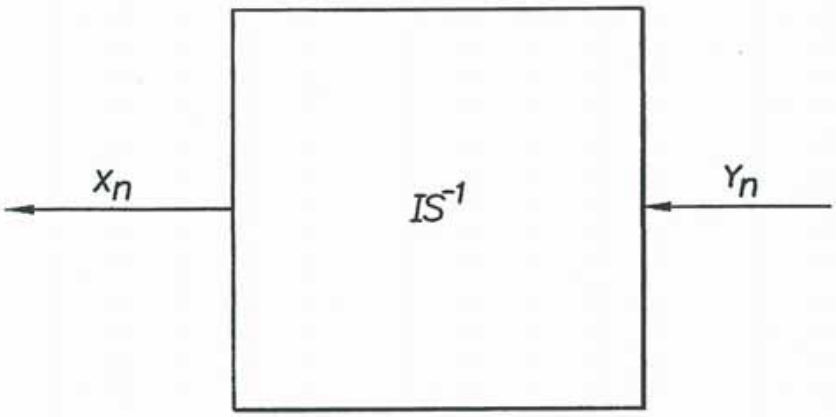


FIG20



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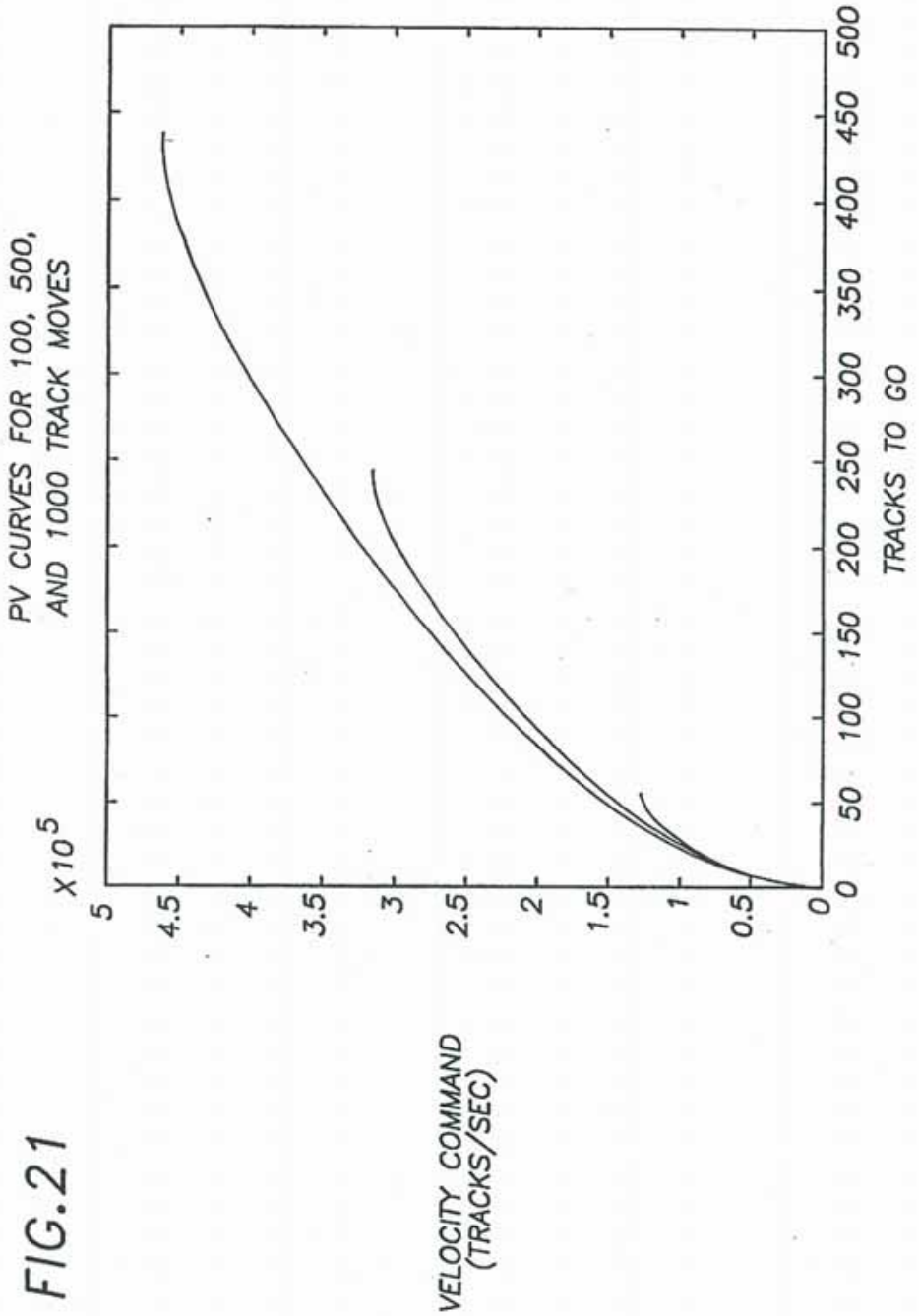


FIG. 21

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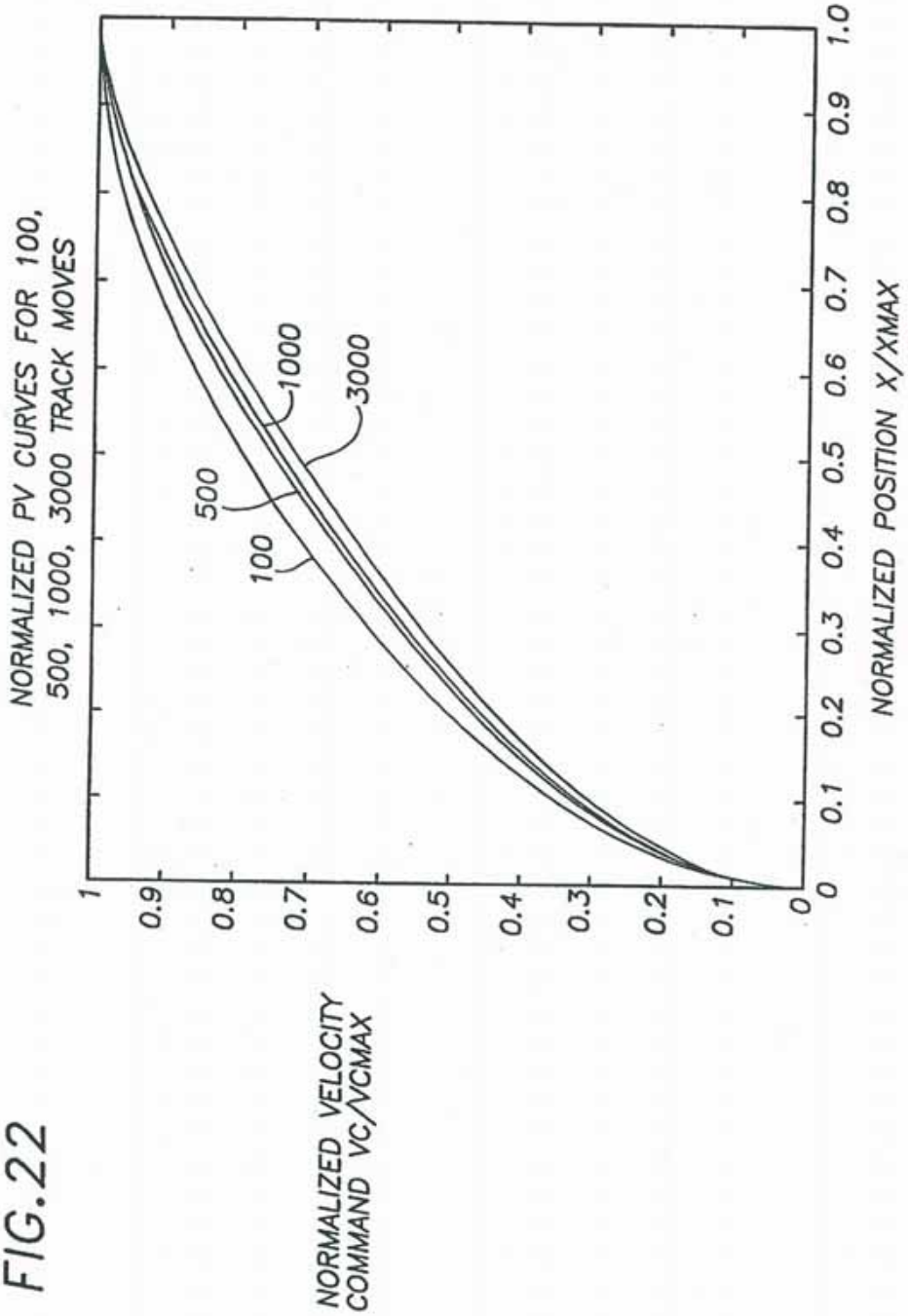


FIG. 22

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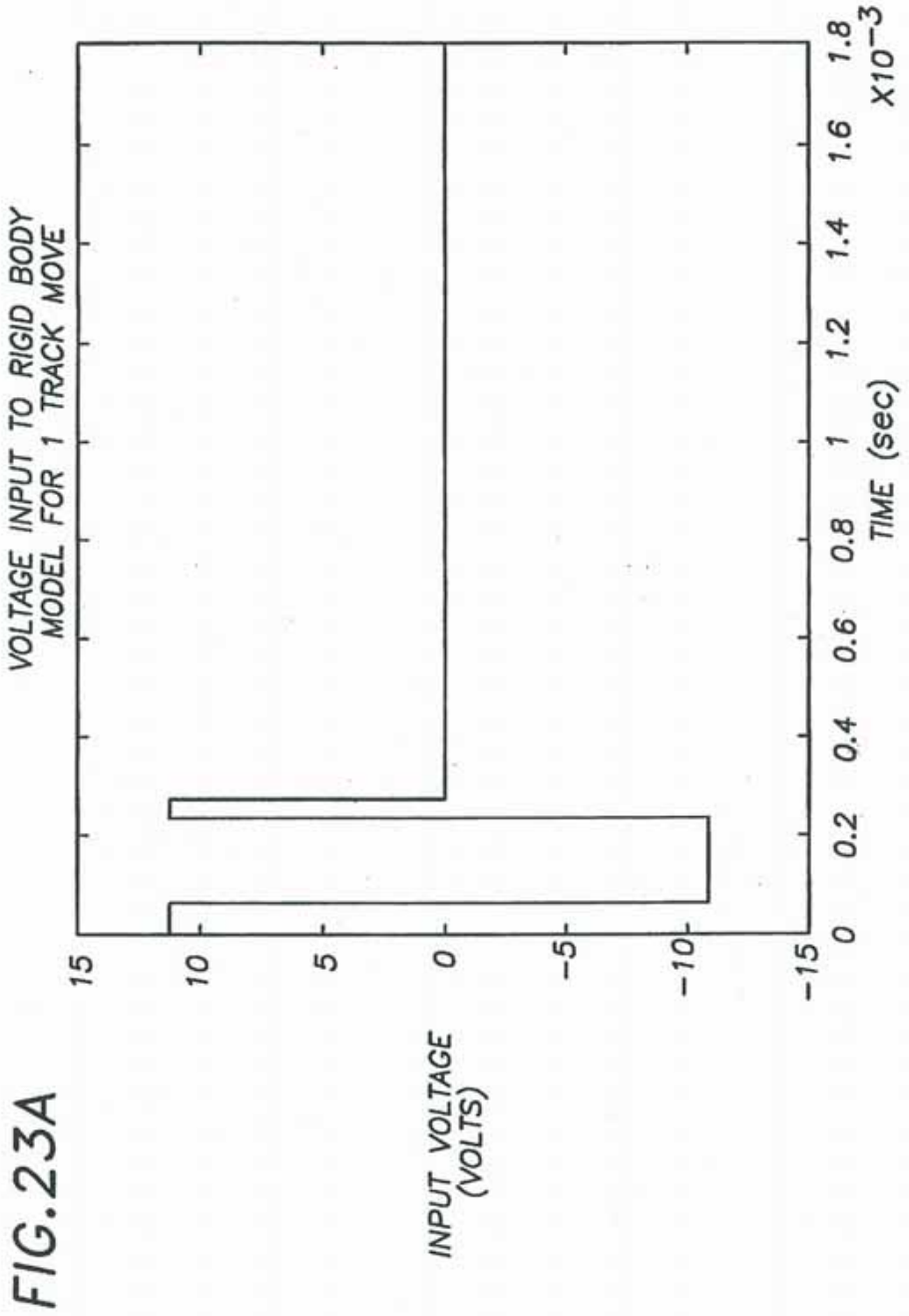


FIG. 23A

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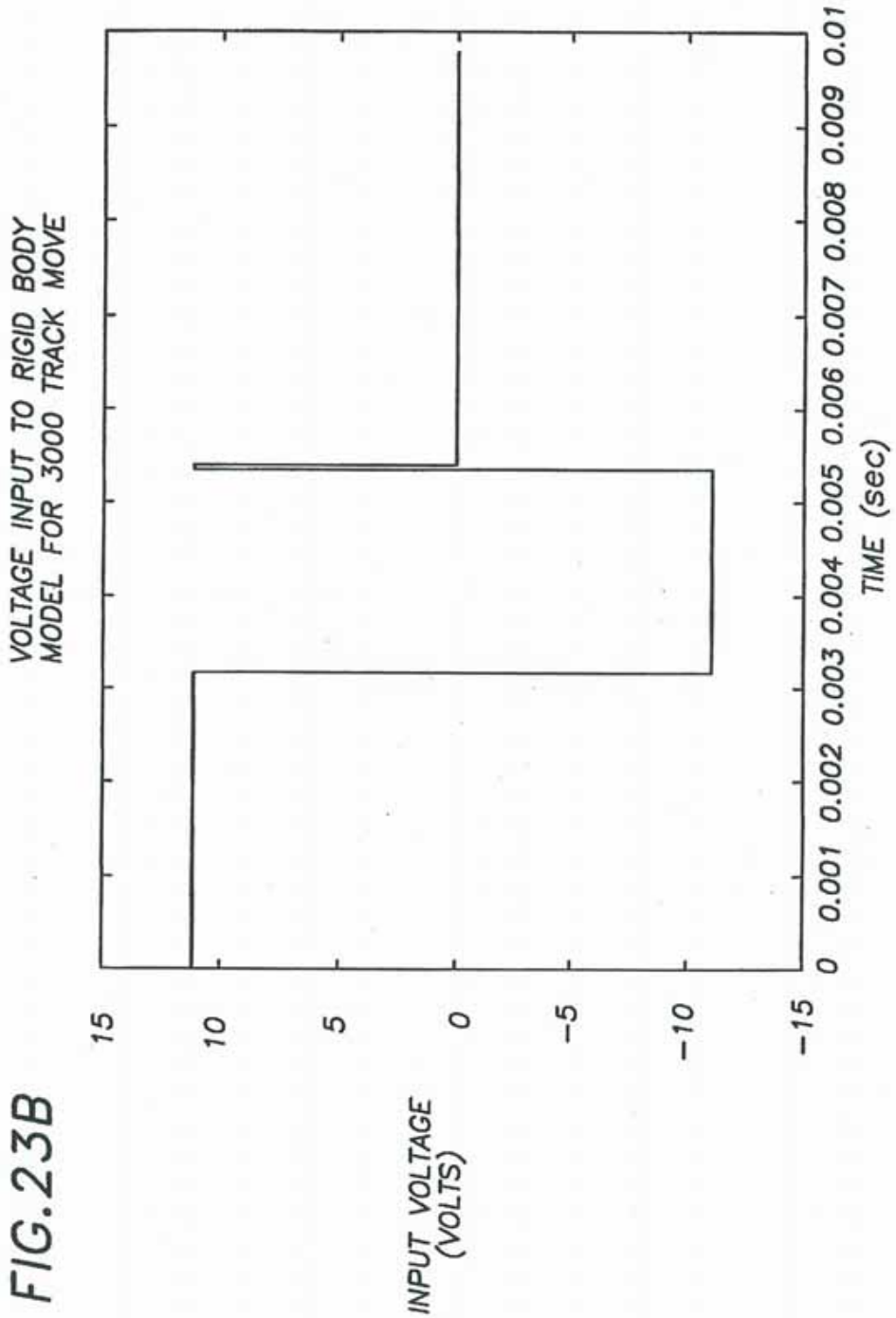


FIG. 23B

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FIG.24

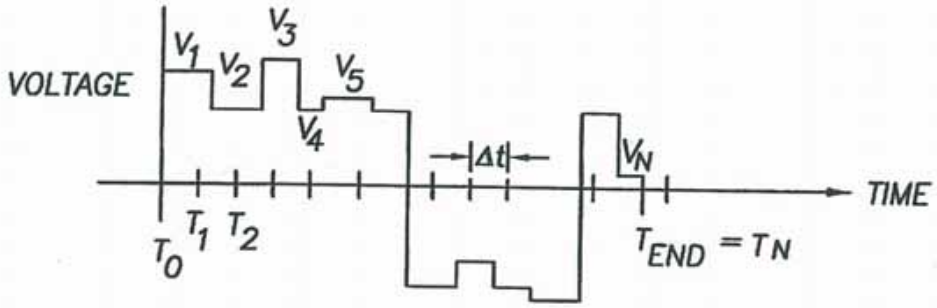


FIG.25

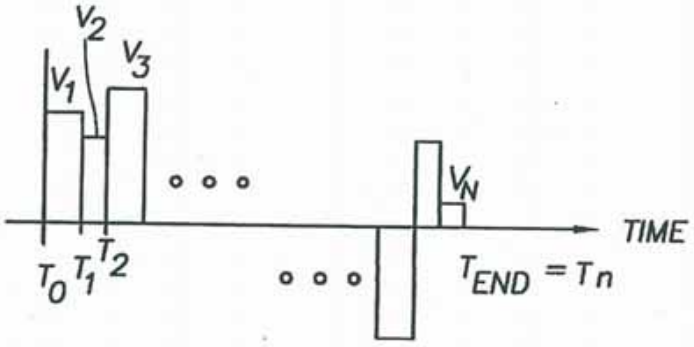
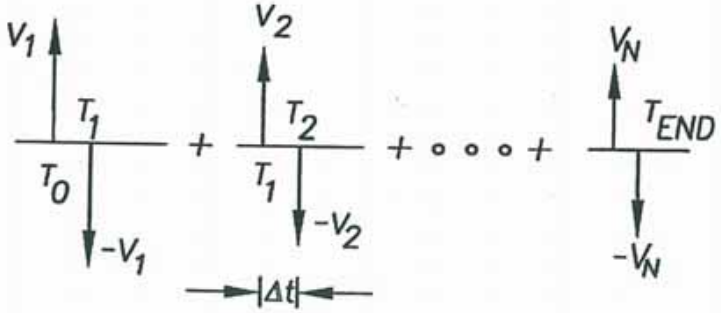


FIG.26



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FIG.27

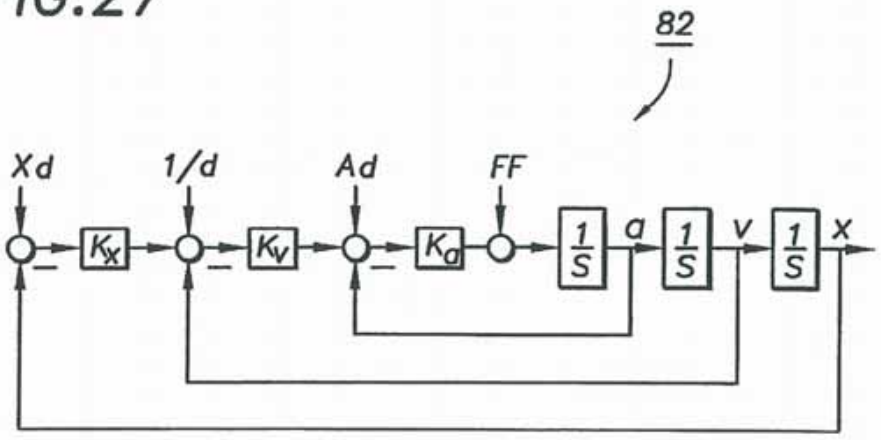
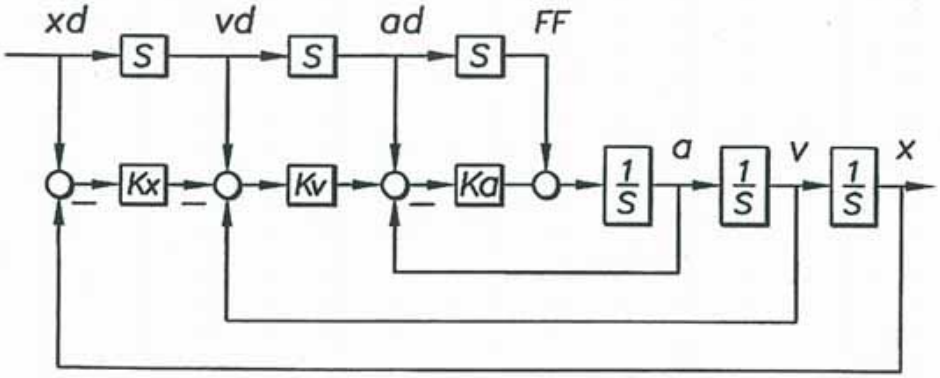


FIG.28



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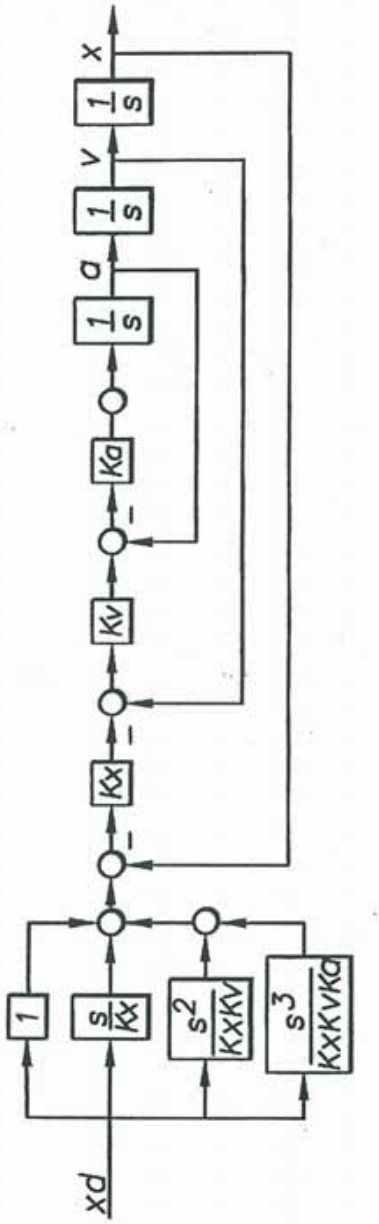


FIG.29

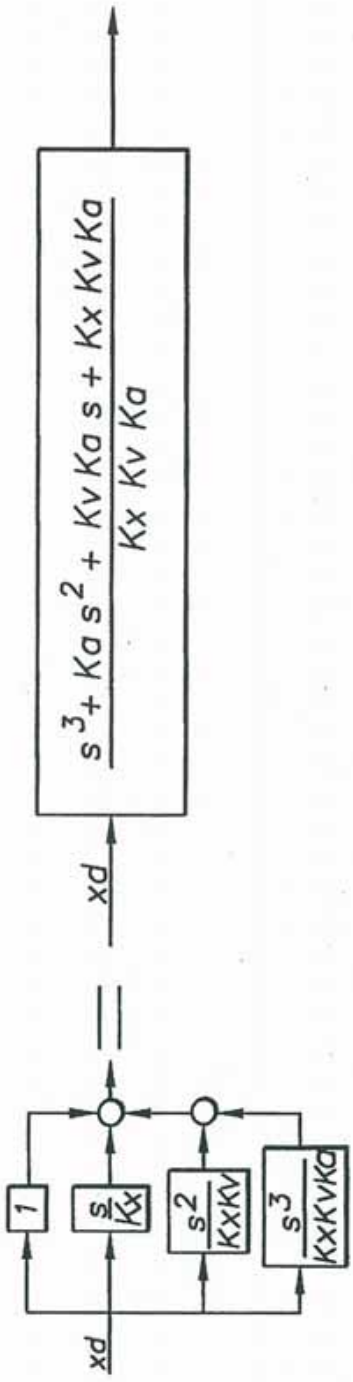


FIG.30

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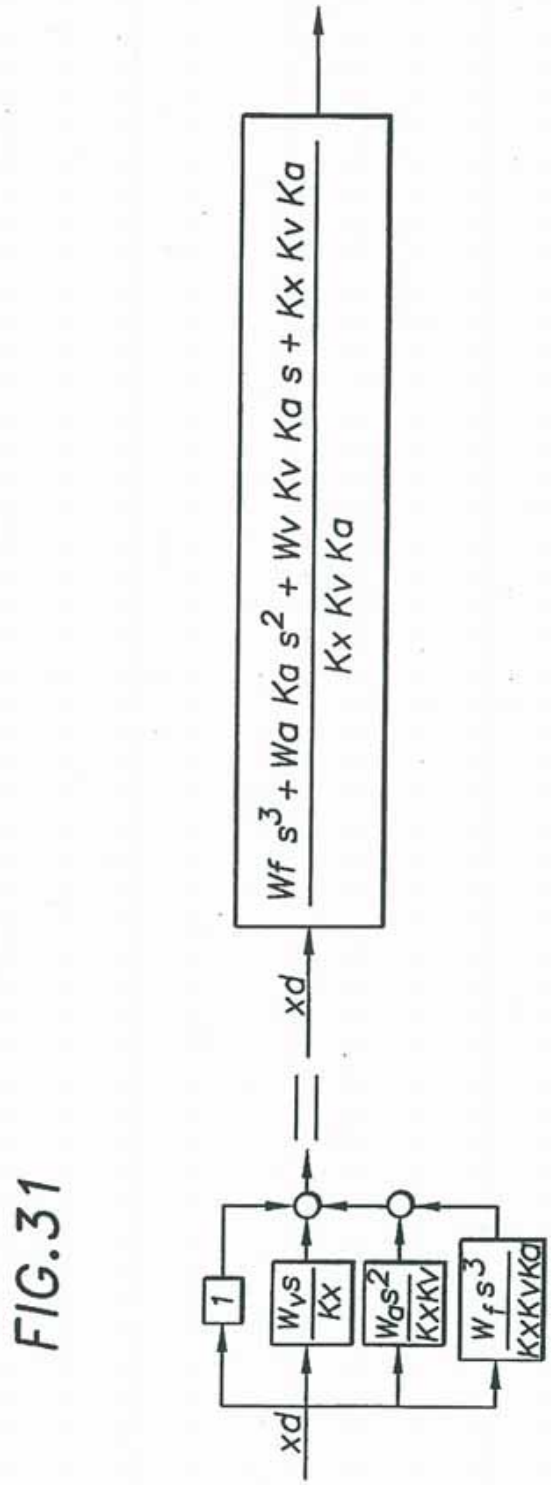


FIG. 31

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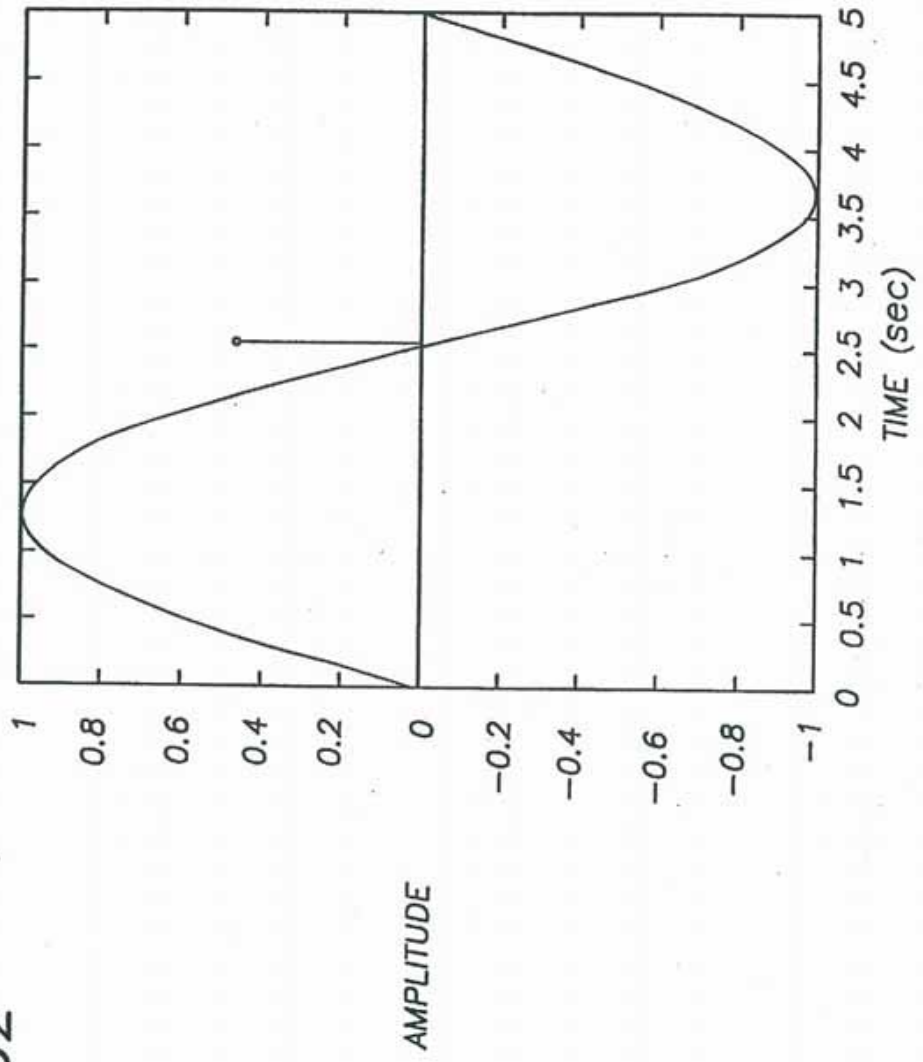


FIG. 32

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FIG.33

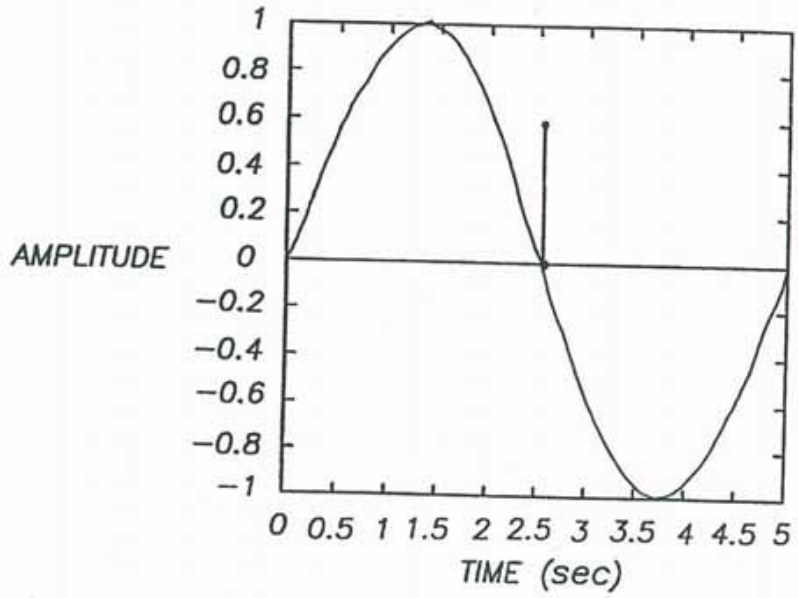
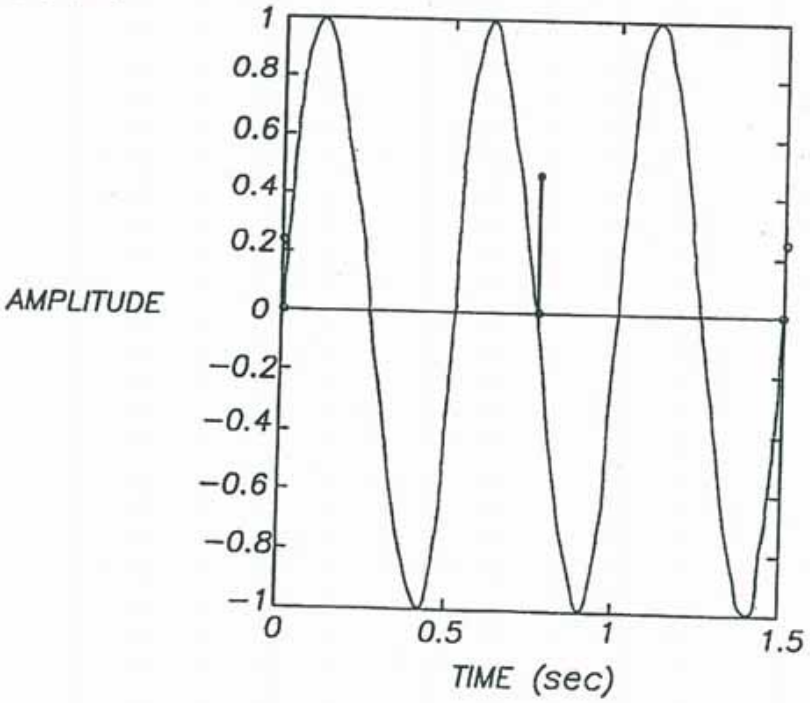
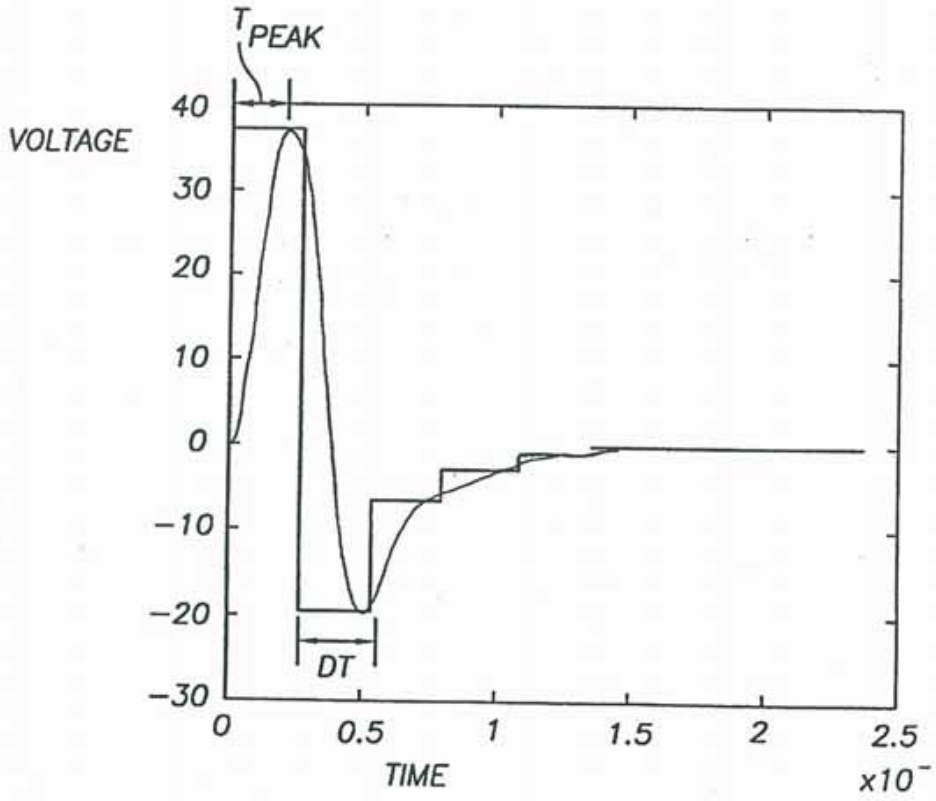


FIG.34



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FIG.35



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SYSTEM FOR REMOVING SELECTED UNWANTED FREQUENICES IN ACCORDANCE WITH ALTERED SETTINGS IN A USER INTERFACE OF A DATA STORAGE DEVICE

This application claims priority to U.S. Provisional Patent Application No. 60/109,145 filed Nov. 20, 1998 and U.S. Provisional Patent Application No. 60/077,292 filed Mar. 5, 1998.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention is directed to altering inputs to, and generating feedforward signals for, a dynamic system so as to reduce unwanted vibrations in the system. The invention has particular utility in speeding up computer disk drives by reducing unwanted vibrations which, if unchecked, could lead to disk read/write errors or excessive noise.

2. Description of the Related Art

Movement in dynamic systems typically results in unwanted vibrations that are both mechanical and acoustic in nature. These vibrations can have a detrimental affect on the operation of such systems. One dynamic system that is particularly sensitive to unwanted vibrations is a computer disk drive.

A computer disk drive includes an actuator arm having a head mounted at a distal end of the arm for reading from, and writing to, tracks on a magnetic disk. This head is moved by the arm from track-to-track on the disk. Vibrations in the system result from this movement. That is, the head and actuator arm vibrate after reaching a nominal final position. Reading and writing cannot take place by the disk drive until these vibrations go below a certain level; otherwise read/write errors occur. These vibrations may also cause noise.

The period during which the disk drive waits for these vibrations to reach an acceptable level (i.e., the settling time) increases the disk drive's seek time. The drive's seek time comprises the time it takes for the drive's head to come to rest at a position where the head can perform a read/write operation on a particular track. The increase in seek time can be especially acute in cases where the track-per-inch density of the magnetic disk is high. That is, because tracks in these disks are relatively close together, even small vibrations in the head can seriously affect the accuracy of the disk drive and/or increase noise in the drive. Since even small vibrations cannot be tolerated, the settling time is further increased, thereby further increasing the drive's seek time.

Conventional attempts at addressing the foregoing problems in both disk drives and dynamic systems in general have fallen short of satisfactory. That is, such attempts are too computationally intensive to be practical, have failed to provide sufficient reduction in vibrations for use in high accuracy positioning equipment such as computer disk drives, produce sub-optimal trajectories, and/or are overly sensitive to system parameter variations.

Other related problems also plague conventional disk drives. For example, in conventional disk drives, two different controllers are used to position the drive's head on a track. A first controller controls the drive's head to reach a predetermined position near to a final position, at which point a second controller takes over. This second controller moves the head into the final position and regulates the head on a track. Switching between these two controllers increases settling time and, as a result, increases seek time.

Also, in conventional disk drives, little or no control over vibrations is included in the derivation of these controllers. Consequently, conventional disk drives may not be able to discern important variations during motion transients.

In view of the above, there exists a need for a way to control computer disk drives and, more generally, dynamic systems, which reduces both mechanical and acoustic vibrations to an acceptable level without undue computational effort and without a substantial reduction in movement speed.

SUMMARY OF THE INVENTION

The present invention addresses the foregoing needs by providing methods of controlling movement in a dynamic system so as to reduce mechanical and/or acoustic unwanted vibrations in the system. These methods are relatively easy to perform, produce good results, and have few adverse side effects, thereby making them a significant improvement over the prior art.

In one aspect, the invention determines which parameter will cause a dynamic system to saturate. For example, in the case of a computer disk drive, current commands control the system. However, voltage is the fundamental limiting parameter of the system, since voltage supplied by the drive's power supply limits the amount of current in the system. In this aspect, the fundamental limiting parameter is used to generate a command for the system which reduces vibrations without causing the system to saturate. In the specific case of a disk drive, the fundamental limiting parameter (i.e., voltage) is also used to generate current commands that do not exceed the voltage limitations of the system.

In another aspect of the invention, a disk drive system is modeled using partial fraction expansion equations. The digital form of those equations is as follows:

$$Finalpos = \sum_{i=1}^{N} V_i A \Delta t$$

$$0 = \sum_{i=1}^{N} V_i \frac{Ab}{b-a}\left(e^{-a(T_{end}-T_i+\Delta t)} - e^{-a(T_{end}-T_i)}\right)$$

$$0 = \sum_{i=1}^{N} V_i \frac{Aa}{a-b}\left(e^{-b(T_{end}-T_i+\Delta t)} - e^{-b(T_{end}-T_i)}\right),$$

where Finalpos is a final position of the system, A is a scaling factor, a and b are inverse time constants, t_{end} is the time at which a move is completed, V_i are voltage inputs to the system, T_i are the times at which V_i are input, and Δt is a time interval at which V_i are input. Using the above equations, system inputs which produce reduced vibrations can be determined. These equations are particularly powerful when used to solve for a system input in terms of its fundamental limiting parameter. Additional constraints may also be included in the above equations in order to provide a more accurate model of the system.

In still another aspect of the invention, techniques are provided for reducing system vibrations in its various modes. These techniques may be used alone or in conjunction with the concepts set forth above. One such technique comprises incorporating vibration limiting and sensitivity constraints into the partial fraction expansion equation model so as to reduce vibrations to specific levels. Another technique comprises shaping (e.g., convolving or filtering) a

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command determined using the partial fraction expansion equation model to produce a desired output. The entire command may be shaped or only selected portions thereof which produce vibrations. Selective shaping is preferred since it reduces seek time relative to shaping the entire command. Another technique involves commanding in current to produce saturation in voltage. By doing this, it is possible to command voltage switches. The times at which the switches occur can then be set to reduce system vibrations. Other techniques are also provided. These include varying transient portions at the beginning, middle and/or end of a move and using Posicast inputs, among others.

In still another aspect, the invention determines an input to the system that will result in limited (or reduced) vibrations, and uses that input as a feedforward trajectory for the system. Several approaches are provided for generating the input, including performing an optimization method on the partial a fraction expansion equations. In one approach, the problem of generating an input is separated into a rigid mode problem and a flexible mode problem. Specifically, terms associated with the rigid mode of the system are determined from the partial fraction expansion equations, and terms associated with oscillating or flexible modes of the system are determined based on a system analysis. The rigid body terms are solved for an input which drives the system so as to satisfy its rigid body constraints. This input is then shaped using, e.g., an Input Shaper™ designed to compensate for the flexible modes of the system. Using this approach, the computational difficulty of obtaining a solution is reduced relative to the optimization approach, while still providing an adequate reduction in levels of vibrations in relevant modes of the system. Another approach to generating the input involves creating a closed-loop model of the system. An input which results in reduced vibrations may then be generated based on this model. In still another approach, voltage switch times for a bang-bang input that reduces vibrations are determined based on the partial fraction expansion equations. Input Shaping™ may then be applied to that input so as to provide a further reduction in vibrations.

In other aspects of the invention, various position-velocity ("PV") table formulations are provided for reducing system vibrations. In one approach, a trajectory which reduces system vibrations is generated in accordance with one or more of the techniques set forth above, and that trajectory stored in a PV table. The trajectory can then be used to control movement of the system. In another approach, a shaper is provided at the output of a PV table, and its inverse is provided along the system's feedback path. This arrangement reduces system dynamics via the feedforward direction, and restores loop stability in the feedback direction. In still another approach, an N (N>2) dimensional PV table is used to control a system, in which velocity is a function of position and one or more other variables, such as movement distance, resistance, temperature, etc. In yet another PV approach, current commands are shaped at transition(s) (e.g., at deceleration) so as to yield desired levels of vibrations. During non-transitional states, a trajectory in a PV table is followed.

While the above-summarized methods significantly enhance the operation of dynamic systems, such as computer disk drives and other data storage devices, it is also preferable to allow end-users some control over the system's operation. For example, a user may want a disk drive that has a relatively low seek time (i.e., a disk drive that is fast), but may not care about acoustics. Similarly, the user may be more focused on acoustics than on seek time. Thus, there exists a need for a way by which an end-user can control operation of a disk drive. In particular, there exists a need for a simple way to control operation of the disk drive, which permits the user to select operational parameters, such as seek time and acoustic levels, in addition to other features.

The present invention addresses these needs by providing a GUI and/or mechanical switch(es) through which an end-user may alter operational parameters of a disk drive, including, but not limited to, the drive's seek time, noise level, and power consumption. By providing these features, the invention enables the user to customize operation of a disk drive relatively easily without requiring significant hardware and/or software modifications.

This brief summary has been provided so that the nature of the invention may be understood quickly. A more complete understanding of the invention can be obtained by reference to the following detailed description of the preferred embodiments thereof in connection with the attached drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a perspective view of a computer system through which the present invention may be implemented.

FIG. **2** shows the architecture of the computer system.

FIG. **3** shows process steps for generating a graphical user interface in accordance with the invention.

FIGS. **4** to **9** show graphical user interfaces that can be generated by the invention.

FIG. **10A** is a cut-away view of a disk drive that is controlled by the present invention.

FIG. **10B** is a block diagram of circuitry for controlling the disk drive in accordance with the invention.

FIG. **11** is a feedback diagram of a computer disk drive.

FIG. **12** shows a plot of "good" moves versus "bad" moves for different movements made by a computer disk drive.

FIG. **13** is a feedback diagram of a prior art disk drive system.

FIG. **14** is a feedback diagram of a disk drive system in accordance with the present invention.

FIG. **15** is a block diagram showing the relationship between an input and an output of a finite impulse response filter shaping technique.

FIG. **16** is a block diagram showing the relationship between an input and an output of a finite impulse response filter inverse shaping technique.

FIG. **17** is a block diagram showing the relationship between an input and output of a tapped continuous delay line filter shaping technique.

FIG. **18** is a block diagram showing the relationship between an input and an output of a tapped continuous delay line filter inverse shaping technique.

FIG. **19** is a block diagram showing the relationship between an input and an output of an infinite impulse response filter shaping technique.

FIG. **20** is a block diagram showing the relationship between an input and an output of an infinite impulse response filter inverse shaping technique.

FIG. **21** shows examples of trajectories in a position-velocity table used in embodiments of the present invention.

FIG. **22** depicts parameterization of trajectories in a position-velocity table in accordance with the present invention.

FIGS. **23A** and **23B** show optimal rigid body voltage commands for 1 and 3000 track moves, respectively, for a disk drive system.

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FIG. 24 shows a digitized input voltage waveform.

FIG. 25 shows the waveform of FIG. 24 conceptualized as a series of pulses.

FIG. 26 shows each of the pulses of FIG. 25 represented as a pair of impulses.

FIG. 27 shows a block diagram of a feedback system.

FIG. 28 shows application of a Laplace differentiation operator to inputs to the system shown in FIG. 27.

FIG. 29 shows scaled versions of the inputs of FIG. 28.

FIG. 30 shows a reduction, using block diagram algebra, of the inputs shown in FIG. 29.

FIG. 31 shows a reduction of the inputs shown in FIG. 30.

FIG. 32 shows a plot of impulses of a three pulse shaper together with a sine wave representation of undamped vibration.

FIG. 33 shows a plot of digital pulse spacing for the three pulse shaper together with a sine representation of undamped vibration.

FIG. 34 shows pulse spacing for a three pulse shaper and a sine wave representation of vibration.

FIG. 35 shows a voltage pulse response of a dynamic system.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The present invention comprises computer-executable code (i.e., computer-executable process steps) for controlling operation of a disk drive or, more generally, any dynamic system. For the specific case of a disk drive, the invention includes code which generates a GUI, which accepts inputs into that GUI, and which outputs commands to a disk drive causing the disk drive to conform its operation to the GUI inputs. The invention can be used in any type of computer/disk drive system, such as a desktop computer, laptop computer, or the like. For the sake of brevity, however, the invention will be described in the context of a desk-top computer system only.

FIG. 1 shows a representative embodiment of a computer system 1 on which the invention may be implemented. As shown in FIG. 1, personal computer ("PC") 2 includes network connection 4 for interfacing to a network, such as the Internet, an ATM network, or the like, and fax/modem connection 5 for interfacing with other remote devices such as a digital camera, digital video camera, and the like. PC 2 also includes display screen 6 for displaying information to a user, keyboard 7 for inputting text and user commands, mouse 9 for positioning a cursor on display screen 6 and for inputting user commands, and disk drive 10 for reading from and writing to floppy disks installed therein. PC 2 may also have one or more peripheral devices (not shown) attached thereto for inputting text, graphics, images, or the like, and/or for outputting images.

FIG. 2 shows the internal structure of PC 2. As shown in FIG. 2, PC 2 includes memory 11, which comprises a computer-readable medium such as a computer hard disk. Memory 11 stores data 12, applications 14, and operating system 15, among other things. In preferred embodiments of the invention, operating system 15 is a windowing operating system, such as Microsoft® Windows98 or Microsoft® Windows NT; although the invention may be used with other operating systems as well. Among the applications stored in memory 11 is computer code to implement the present invention, namely disk drive engine 16. Alternatively, disk drive engine 16 may be stored in a read-only memory ("ROM"), or the like, together with other operational firmware for disk drive 10. In brief, disk drive engine 16 is comprised of computer-executable process steps which, inter alia, generate a GUI for controlling operation of disk drive 10 and output commands to disk drive 10 causing disk drive 10 to conform its operations to settings in the GUI. A more detailed description of disk drive engine 16 is provided below

Also included in PC 2 are display interface 17, keyboard interface 19, mouse interface 20, disk drive interface 21, computer bus 22, RAM 24, processor 25, and printer interface 26. Processor 25 comprises a microprocessor or the like for executing applications, such those noted above, out of RAM 24. Such applications may be stored in memory 11 (as noted above) or, alternatively, on a floppy disk in disk drive 10. Processor 25 accesses applications (or other data) stored on a floppy disk via disk drive interface 21.

Application execution and other tasks of PC 2 may be initiated using keyboard 7 or mouse 9, commands from which are transmitted to processor 25 via keyboard interface 19 and mouse interface 20, respectively. Similarly, application execution may be initiated remotely via, e.g., network interface 4 and a network interface card (not shown). Output results from applications running on PC 2 may be processed by display interface 17 and then output via network interface 4 or, alternatively, displayed to a user on display 6. To this end, display interface 17 preferably comprises a display processor for forming video images based on video data provided by processor 25 over computer bus 22, and for outputting those images to display 6. Output results from other applications running on PC 2 may be provided to an attached printer via printer interface 26.

Turning to disk drive engine 16, this application comprises computer code to control operation of disk drive 10 either according to one of a plurality of well-known conventional methods or according to one or more of the proprietary methods described herein. Disk drive engine 16 further includes code for generating a GUI for interactively controlling at least one of a seek time, a noise level, and a power consumption of a disk drive. The GUI includes a controller that is operated by a user so as to alter settings in the GUI for one or more of these parameters. Thereafter, disk drive engine 16 generates and outputs commands to the disk drive causing it to conform its operation in accordance with the altered settings in the GUI.

1.0 User Interface

FIG. 3 is a flow chart for controlling operation of a disk drive using disk drive engine 16. To begin, step S301 generates a GUI and displays that GUI to the user via display 6. FIG. 4 shows such a GUI, labeled 27. GUI 27 includes a window 70 for selecting a disk drive to be controlled. That is, although the computer system shown in FIG. 1 includes only one disk drive, many systems include more than one disk drive. Window 70 provides a way for a user to select which disk drive to control. FIG. 9 is a close-up view of window 70. A disk drive can be selected simply by pointing and clicking on that drive in window 70. The selected drive is then highlighted, as shown.

As shown in FIG. 4, GUI 27 also includes controller 29. Controller 29 is used to alter a seek time and a noise level of disk drive 10. In this particular embodiment, controller 29 comprises a sliding bar 30 which moves along a continuum 31 between a relatively high noise level/low seek time ("Quick") end 32 and a relatively low noise level/high seek time ("Quiet") end 34. Disk drive noise level and seek time vary inversely along the continuum, meaning that, as the noise level of the disk drive progressively increases, the seek

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time of the disk drive progressively decreases. Likewise, as the noise level of the disk drive progressively decreases, the seek time of the disk drive progressively increases. By moving sliding bar **30**, it is possible to vary both the seek time and noise level parameters simultaneously.

In the preferred embodiment of the invention, sliding bar **30** moves between discrete positions on continuum **31**, meaning, e.g., between a first position corresponding to high noise level/low seek time ("Quick") end **32**, a second position corresponding to a mid-point between the two ends on continuum **31**, and a third position corresponding to low noise level/high seek time ("Quiet") end **34**. Alternatively, there may be more than three discrete levels or noise and seek time may vary continuously between the two ends of continuum **31**.

The level of noise in a disk drive is due to vibrations at particular frequencies, such as 6.6 KHz, 6.0 KHz, 5.0 KHz, 4.2 KHz, and 1.3 KHz. On the other hand, mechanical vibrations, which reduce seek time, result from vibrations at different frequencies, such as 3.3 KHz. By moving the sliding bar of controller **29** along the continuum, an end-user is effectively determining which of the above frequencies should be reduced and/or how much the reduction should be. For example, in a case that Input Shaping™ (described below) is used to reduce vibrations, by moving sliding bar **30**, the user effectively selects one or more shaping functions for reducing vibrations at specific frequencies, and causes disk drive engine **16** to convolve those functions with the appropriate disk drive inputs in order to implement the desired vibration reduction.

In GUI **27** the noise level and seek time vary inversely along continuum **31** such that there is an effective trade-off between seek time and noise level, meaning that as seek time increases, noise level decreases and vice versa. These variations are not necessarily linear; although they may be. As an alternative to sliding bar **30**, the GUI may include boxes into which discrete noise levels and/or seek times are entered. For example, as shown in FIG. **5**, the GUI may include entry box **37** into which a noise level value is entered and display box **39** which displays a corresponding numerical value of the seek time. In this case, the GUI preferably also includes up/down arrows **41** which are used for selecting the various noise level values. On the other hand, these values may be input directly via mouse **9** and keyboard **7**. As another alternative, the seek time may be settable via entry box **37** and the corresponding noise level displayed via display box **39**. In either case, the numerical value displayed in the display box is calculated by disk drive engine **16** based on the value set in the entry box.

Returning to FIG. **4**, GUI **27** may also include a second controller, such as check box **42**. This controller causes the disk drive to enter a power-saving mode. The power-saving mode comprises a state during which the disk drive reduces its power consumption by a predetermined amount. The power-saving mode may be set in conjunction with varying the seek time and the noise level. That is, in the power saving mode, the set seek time and noise level are achieved using less power than would otherwise be required. This is achieved, e.g., by convolving one or more predetermined functions with a command input to a voice coil motor in the disk drive.

On the other hand, a reduction in power consumption may be achieved via a controller, such as controller **44** shown in FIG. **6**. Controller **44** comprises a sliding bar **45** which moves along a continuum **46** between a relatively high power consumption/low seek time end **47** and a relatively low power consumption/high seek time end **49**. As was the case above, sliding bar **45** may move between discrete values along the continuum. Thus, in this embodiment, disk drive power consumption and seek time vary inversely along the continuum, meaning that, as the power consumption of the disk drive progressively increases, the seek time of the disk drive progressively decreases. Likewise, as the power consumption of the disk drive progressively decreases, the seek time of the disk drive progressively increases.

By moving sliding bar **45** it is possible to vary both seek time and power consumption simultaneously. For example, varying power consumption may be achieved by convolving one or more predetermined functions with a command input to a voice coil motor in the disk drive. Selection of the predetermined functions is performed based on the settings of the sliding bar. Of course, the functions may be set in other ways as well (as is the case throughout this application). For example, the functions may be selected from predetermined trajectories in a position-velocity ("PV") table, as described herein below.

FIG. **7** shows yet another alternative configuration for the GUI. As shown in FIG. **7**, the GUI could include separate controllers **50** and **52** for reducing both power consumption and noise level, respectively, as a function of seek time. Thus, (i) as noise level increases, seek time decreases, and vice versa, and (ii) as power consumption increases, seek time decreases, and vice versa. The sliding bars shown in FIG. **7** preferably have all the characteristics of that shown in FIG. **4**. As shown in FIG. **8**, numerical values for noise level and power consumption may be implemented, as in FIG. **5**. Here, a numerical value is calculated for seek time as well based on the noise level and power consumption settings, and displayed in the GUI as shown.

Returning to FIG. **4**, GUI **27** may also include a preview controller, shown at **54**, to cause the disk drive to operate using parameter(s) set by controller **29**. This preview controller may comprise a button or the like, which a user can click on, and which causes the disk drive to operate in a "preview" mode. The preview mode may cause the disk drive to seek between various tracks on a disk so that the user can experience the noise level and seek time settings in the GUI. If these levels are unacceptable, the user may then revise the GUI inputs, and preview the drive's operation based on such newly-set inputs. This process can be repeated as often as desired until the user achieves the desired settings. Preview mode may also be pre-set to execute automatically each time the GUI settings are altered.

GUI **27** may also include one or more display areas **55**, as shown in FIG. **4**. These display areas may provide a numerical indication of the noise level of the disk drive, its seek time, and/or its power consumption rate. Display areas such as these are generally most beneficial in cases where parameters are set using a sliding bar, as is the case, for example, in FIGS. **4**, **6** and **7**. Likewise, a display area may be provided which informs the user of the amount of hours that a computer (e.g., a laptop) can operate with an existing power supply. To determine this value, disk drive engine **16** monitors the computer's power supply directly, or estimates the amount of power left based on the total time the computer has been running with the present supply, as well as other relevant parameters.

Returning to FIG. **3**, following step **S301**, in which a GUI is displayed, processing proceeds to step **S302**. In step **S302**, the user inputs desired settings into the GUI. These settings, of course, will depend upon the available options in the GUI, examples of which are described above. For instance, the user may input some combination of a new seek time, power consumption rate, noise level, etc. Step **S302** may be per-

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formed locally or remotely via network interface **4**. That is, the GUI may be displayed on a remote networked PC, and the settings therefor applied to the local PC. In any event, once the new parameter setting are input in step **S302**, they may be confirmed via "OK" button **60**, canceled via "Cancel" button **61**, or applied to the disk drive via "Apply" button **62**. The difference between "OK" button **60** and "Apply" button **62** is that "OK" button **60** merely stores the new settings in memory (e.g., memory **11**), whereas "Apply" button **62** applies the settings to the disk drive, overriding any previous hardware or software settings.

Next, in step **S303**, commands (e.g., electrical signals) are generated for controlling disk drive **10** in accordance with the settings set in the GUI. Exactly how these commands are generated may vary, depending upon the way in which the disk drive is controlled. Assuming, for illustration's sake, that the disk drive is being controlled via Input Shaping™, step **S303** comprises convolving various inputs to the disk drive with predetermined functions which are selected based on settings in the GUI in order to produce disk drive inputs that achieve the results specified in the GUI. These functions may be stored, e.g., in memory **11** or in another memory on the system. Sections 2 to 11 below describe a variety of methods that may be used to control operation of the disk drive, any of which may be used in step **S303** based on the GUI setting and other factors.

Once the necessary commands have been generated, processing proceeds to step **S304**, wherein these commands are provided to control operation of the disk drive. Thereafter, a user may again alter the drive's operation simply by calling up a GUI using, e.g., mouse **7**, and entering desired operational parameters. Following step **S304**, processing ends.

At this point, it is noted that the GUI is not limited to the combinations of features shown in the figures. That is, a GUI may be generated in step **S301** with includes any one or more of the foregoing features, subject to certain constraints inherent in the system. Likewise, additional features not described herein, but which are well known to those skilled in the art, may also be included in the GUI. As an alternative to the GUI, or to supplement the GUI, the disk drive may include one or more electro-mechanical manual switches for controlling all or part of the drive's operation in the manner set forth above. For the purposes of the present invention, a "jumper" is considered to be within the definition of electro-mechanical manual switch.

2.0 System Control

The following control methods are preferably implemented via computer-executable process steps in disk drive engine **16** so as to effect high-speed moves in a disk drive, such as drive **10**. However, it is noted that these methods are not limited to use with disk drives. Rather, the methods described herein can be used to control any type of dynamic system which moves from one state to another state. In fact, any unwanted dynamic behavior that can be quantified in a mathematical expression can be reduced by the present invention. For example, using the present invention, a disk drive in a Redundant Array of Independent Drives ("RAID") can be commanded to move in less time than has heretofore been possible without substantially exciting neighboring drives and while simultaneously reducing acoustic vibrations that result in noise. The designer simply need select which vibrations or dynamic behavior is troublesome, identify constraints and, using the technology presented herein, choose from among several approaches for generating optimal or near optimal moves that reduce those vibrations or dynamic behavior. As used herein, the term "vibrations" can refer to mechanical and/or acoustic vibrations that cause noise.

FIGS. **10A** and **10B** show close-up views of disk drive **10**. As shown, disk drive **10** includes voice coil motor **72** having a rotor (not shown), actuator arm **74**, sensor **75**, and head **76**. These components are controlled via disk drive engine **16**, or portions thereof, running on a controller/processor **73**. This processor may comprise processor **25** set forth above or, alternatively, a separate controller dedicated to the disk drive which receives commands from processor **25**. Head **76** reads to, and writes from, tracks (not shown) on magnetic disk **77** installed in drive **10**. Actuator arm **74**, on which head **76** is mounted, controls the motion of head **76** between the tracks on magnetic disk **77**. Motor **72** drives actuator arm **74** in accordance with control signals received from processor **73**. These control signals are generated based, at least in part, on a desired position of head **76** and an actual measured position of head **76** provided via signal **79**. Movement of head **76** from an initial position to the desired position occurs within the device's seek time. The seek time for disk drive **10** comprises the time it takes for head **76** to move from an initial position to rest at a position where head **76** can perform a read/write operation on a particular track of magnetic disk **77**.

The seek time for computer disk drive **10** can be reduced by commanding a component in disk drive **10**, such as head **76**, to move from one location to another while satisfying constraints on mechanical vibrations, acoustic vibrations, drive mounting vibrations, or any combination of constraints, physical limitations, and/or parameter variations. Several different methods for reducing such vibrations are described below in detail. One such technique involves altering system inputs that are specified as a function of time. Another technique involves generating a position-versus-velocity (hereinafter "PV" or "position-velocity") table using dynamic elements, e.g., constraints or the like, so as to produce PV table trajectories which result in reduced vibrations. In this regard, the terms "input" and "trajectory" may refer to either a reference command for a controller to follow or a feedforward signal within the controller. Still another technique involves modifying the current industry-standard PV table so that an improved PV table is constructed and used. Several methods for generating PV tables are also provided, together with ways to use an Input Shaper™ in combination with a PV table in order to reduce unwanted vibrations. Also presented are several modifications to the foregoing embodiments which have differing levels of optimality and ease of implementation.

Processor **73** determines which of these techniques to apply based on a variety of factors, such as user inputs to the GUI and the identity of the disk drive. For example, time can be traded off against amount of vibration reduction and robustness to parameter variation. In a given application, the amount of vibration reduction required to make end-of-move conditions acceptable can be a function of the movement distance or other parameter. When this is the case, it is advantageous to trade-off shaping time against shaper effectiveness (meaning amount of vibration reduction) such that (i) vibrations, both mechanical and acoustic, are reduced to an acceptable level (not excessively attenuated), and (ii) shaping time is less than it would be if the vibration were excessively attenuated. When more vibration reduction is required, a longer shaper can be used; when less vibration reduction is required a shorter shaper can be used; and when no vibration reduction is required, then no shaper (zero length) can be used. In this example, shaper selection was from among a discrete collection of shapers. It is also possible to use a single adjustable shaper, e.g. one in which the time interval between pulses is shortened; resulting in a desired shorter shaping time and reduced vibration reduction.

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3.0 Fundamental Limiting Parameter

One of the techniques utilized by the present invention is a method for commanding systems that saturate in an optimal manner while still reducing unwanted dynamics. Since all systems saturate in some manner, a method for setting up a command profiling approach is presented herein which first determines a fundamental limiting parameter for the system, second applies either a command shaping or whole-trajectory-generating technique to that parameter, and third schedules the shaped command to be output to the system.

The fundamental limiting parameter of a system is the parameter that causes the system to saturate. In the case of a computer disk drive, current commands control the system. However, the fundamental limiting parameter is voltage, since voltage supplied by the drive's power supply limits the amount of current in the system. By identifying the fundamental limiting parameter of a system in this manner, and processing that parameter in accordance with the techniques provided herein, it is possible to provide for greater control over system movement than has heretofore been possible.

In this regard, there are several disadvantages to not using the fundamental limiting parameter for command profiling. First, there is no a priori way to generate a command signal that does not saturate the system. If the system is allowed to saturate a signal at any time after any command profiling technique is applied, the vibration (or unwanted dynamics) reduction benefit of command profiling will be degraded. The amount of degradation depends on how much the signal is saturated. Therefore, sub-optimal trajectories often result. As examples, optimal rigid body voltage commands for a disk drive system for 1 and 3000 track moves are shown in FIGS. 23A and 23B, respectively (see section 6.3 below for a discussion of rigid vs. flexible system modes). The optimal current command that corresponds to this voltage is highly complex because it depends on the state of the system (in this case, velocity, due to the back EMF of the drive's motor). Any simple current command would necessarily be sub-optimal if the designer is to guarantee that the system is not to saturate. Section 3.1 below describes how this is achieved.

For optimal moves, the system should be commanded with inputs that take the system to saturation limits without exceeding these limits. The second disadvantage of not choosing the fundamental limiting parameter is that these saturation limits cannot be determined without including the entire system dynamics. Therefore, the solution to the problem is significantly more complex. Additionally, once vibrational constraints are included in the problem, the solution increases yet again in complexity. Once the proper selection of a fundamental limiting parameter is made, an input that approaches saturation without unknowingly trying to exceed the limit can be generated.

Another approach to handling the presence of nonlinearities, such as saturation, along the feedforward path is to place a shaping module after the nonlinear element. For example, if a signal can saturate along the feedforward path, the signal should be saturated before the shaping operation. In the case of a digital-to-analog conversion ("DAC") saturation, the output of the feedforward calculations might need to be limited to plus or minus 16,000 counts. If a shaping technique is to maintain the vibration reducing benefits, the output should be limited to 16,000 counts and then shaped.

Still another approach to handling saturation of a parameter, while maintaining the vibration reduction benefits of the various techniques presented herein, is to pre-saturate a signal. One condition under which this would be necessary is if the saturating element is outside of the control of the designer (e.g., the saturation occurs in a hardware amplifier). In this case, it is impractical to perform shaping after saturation. Under this condition, the signal should be pre-saturated and then shaped. Pre-saturation involves determining a mathematical expression for the condition under which the system will saturate during a move, and saturating the signal before it is shaped.

This approach of placing the shaping operation after any nonlinear block is applicable to the technique of putting Input Shapers™ and Inverse Shapers™ in a loop, as presented in section 9 below. All of the same rules apply in that any saturation or nonlinear operation must occur outside the path between the Shaper™ and Inverse Shaper™. If the loop is cut open and all of the dynamic elements between the Shaper™ and Inverse Shaper™ are extracted, the dynamic elements must all be linear (or nearly linear); otherwise the effect of unwanted dynamic reduction is degraded. Additionally, the pre-saturation technique can be used in situations in which saturating elements must necessarily be between the Shaper™ and Inverse Shaper™.

3.1 Using the Fundamental Limiting Parameter While Generating Feedforward Signals in a Different Parameter

In a disk drive, current is usually commanded to a transconductance amplifier. The fundamental limiting parameter for a disk drive is voltage. It is, however, possible to generate current commands that maintain a limit in voltage. This section explains how to generate such commands.

The first method for generating a current command that does not exceed the voltage limitations of the system is to solve a set of equations directly for the command input which, in this case, is the feedforward signal to the transconductance amplifier. The following equation is used to generate an input that takes the system to zero final velocity:

$$\sum_{i=1}^{N} A_i = 0, \tag{1}$$

where the A's comprise the amplitudes of the current commands at time interval i, and N comprises the last time interval. The following equation determines the velocity, v, at each time interval i

$$v_i = C_{vscale} \sum_{j=1}^{i-1} A_j, \tag{2}$$

where A comprises the current inputs and C_{vscale} comprises a disk-drive-dependent constant. The final desired position/state of the system, P_{final}, is determined as follows

$$P_{final} = \sum_{j=1}^{N} v_i. \tag{3}$$

The voltage limit constraint, V_{lim}, comprises the maximum voltage that is being commanded (usually the drive supply voltage). For a disk drive, this is usually on the order of 12V. V_{lim} limits the A value by the following equation:

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$$-V_{lim} < \sum_{i=1}^{j} A_{j-i+1} R_i < V_{lim}, \; j = 1 \rightarrow N, \tag{4}$$

where R_i is the pulse response of the amplifier and drive system to the voltage command. The voltage pulse response may be determined by outputting a unit pulse to the amplifier connected to the disk drive and measuring the voltage response of the amplifier. The values of R_i are chosen by means of a multiple step process outlined below.

In this regard, FIG. 35 shows a voltage pulse response from a computer simulation. The smooth curve is the continuous voltage response. The "square step" curve represent the system's digital sampling rate (or output rate, see section 7.1 below), DT. The first peak occurs T_{peak} after the initial pulse is issued to the system. The first value of R is determined by measuring this peak value and setting the first R equal to this peak value. All subsequent values of R are determined by sampling in DT intervals after this initial peak. The step curve in the figure shows the actual values for this particular example. In this case, a complex voltage curve is reduced to a relatively small number of sample points to be used in one of the several solution techniques described herein.

Alternatively, the pulse response R can be computed as a calibration step in the disk drive or generated at design time. All of the required information for generating an optimal current command is included in this pulse response (except for slew rate limits discussed below). The amplifier is reasonably linear, therefore, saturation of the amplifier is easily predicted from the pulse response. Also, the pulse response may be altered as a function of a measured or estimated parameter change.

The effect of the back EMF of the drive's voice coil motor on the above calculation may be notable. If the voltage pulse response R is calculated analytically (or from a model), the voltage is constant and non-zero at steady state because the system reaches a finite velocity from a pulse in acceleration. In FIG. 35, the pulse response achieves a small positive value (which cannot be seen on the plotted resolution). Experimentally, friction and flex circuit spring effects eliminate this constant velocity and cause the drive's head to stop moving. In this case, a constant term in consistent units equal to $K_{BEMF}C_{VSCALE}$ should be added to the voltage pulse response R so that it includes the effect of back EMF and allows for a more aggressive command.

An example computer code written in GAMS that may be used to solve equations 1 to 4 above for values of A is provided below in Appendix B. By solving the set of equations in Appendix B, a time optimal, unshaped current command can be generated. This set of equations can be solved in many different ways. For example, the entire set can be solved as a constrained optimization in which the goal is to generate the minimum time solution. This may also be performed without optimization by solving for a feasible solution (the first step of a Simplex solution, for example) and then reducing the length, N, of the solution vector until no answer can be found (a binary search may be used here). Another method is to determine a function that predicts the length of the solution and then, without any iteration, find a feasible solution. One such prediction function comprises the switch time equations set forth in Appendix A, described below. Another approach is to fit a curves to such a solution. In this case, an exact answer is not needed so long as the curve prediction functions overestimate the solution lengths and never underestimate the solution lengths.

It is also possible to solve for an optimal, unshaped command in real-time which is not in the system's fundamental limiting parameter. For example, we can solve for current (A) by setting a final value of the fundamental limiting parameter, here voltage (V), as follows (of course, the invention is not limited to use with current and voltage, any parameters can be used). This approach is based on the fact that the maximum current command output value is related to previous output values by the following relationship:

$$A(i) = \frac{V_{max} - \sum_{j=2}^{i} A(i+1-j)R(j)}{R(1)}, \tag{5}$$

where R is the voltage pulse response and V_{max} is the maximum voltage V_{lim} on acceleration (or any condition under which $A_{i+1} > A_i$) and $-V_{lim}$ on deceleration (or any condition under which $A_{i+1} < A_i$). Equation 5 assumes that the back EMF of the drive's voice coil motor is already included in R(j). The back EMF term may be added to R(j) as set forth above, if needed. Equation 5 can be further simplified since the R(j) values become insignificant after only a few samples. Consequently, an efficient approximation would only use a few samples of the R(j) series. If samples are dropped for an efficient approximation, the back EMF of the drive's voice coil motor times the number of dropped samples may be added to equation 5 to achieve an even more accurate result if that value is deemed significant.

A rigid body current command can be generated from equation 5 in a step-by-step fashion, where each response depends only on previous values. First the system is accelerated. Each current step is computed from equation 5. Next, the system is decelerated. This deceleration may be to zero for a constant velocity coast in the middle of the move or it may be a transition to negative deceleration and then to a stop. Deceleration is computed from equation 5 by reversing the sign of V_{max}. Under coast conditions, a second deceleration phase will be started (again using equation 5 with a negative value for V_{max}). Lastly, when deceleration is complete, the transition back to zero current is governed by equation 5 with a positive value, once again, for V_{max}.

The only unknowns in the previous equations are the times at which to transition between regions. There are several ways to solve these problems. Shaped™ switch times derived in section 6.9 below may be used as reasonable estimates for the transition times; although any curve fit or lookup table would also suffice. This lookup is especially useful given that on many disk drives, one current profile is often currently used and scaled for a range of seek distances. Additionally, using this approach the final position will not be exact and a zero velocity must be guaranteed. The problem of zero velocity means that an additional constraint must be used in computing the final values. Equation 5 defines the limit on the current value; therefore, in deceleration, for example, any value more negative than that value may be used without exceeding the limit. As a result, the final values can be chosen so that the sum of the current values equals zero (no residual velocity). The distance traveled will be incorrect (but very close). The last step is to scale the waveform linearly by the percentage error so that the final value is correct. This operation can even be performed as part of the next step, which is the shaping operation. The shaper can be scaled and then convolved with

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the rigid body current command. Another option is to increase the value of N, thus adding extra points, and directly solving for the extra A(i) values such that velocity equals zero and position equals "final position".

There are many variations to the above approach which may yield fewer computations. Also any vibration suppression technology can be subsequently applied to the rigid body current command. Furthermore, V_{max} may be changed as the calculation progresses to optimize scaling. For example, with the knowledge that the current command is to be shaped (and thereby reduced in magnitude) a more aggressive value (higher V_{max}) can be computed.

Physical amplifiers have finite limits on the rate at which the voltage can change. The pulse response calculated above does not include such limits. It should be noted that a constraint on the rate of change of voltage in the current amplifier can be added to the equation set during numerical solution in the same manner as all of the other constraints. The slew rate becomes important when rapid transients of the input are allowed. The slew rate equation is simple. For example, an amplifier chip may limit at 1.25 volts per msec. The voltage constraint used in calculating the input is the minimum of either the voltage generated from the Voltage Limit Constraint above or (old_voltage+(A(I)-A(I-1))* Volt_Rate_Limit) with the correct unit conversions.

3.2 Rescaling of Current Inputs

The current commands generated in the previous section are completely scaleable. If for example, a 5 track seek has been created by generating an optimal current command and subsequently shaping it, a 4 track, shaped move can be made by simply rescaling the input by ⅘. The move time will be the same as that of a 4 track seek, however, the computation is simple. The point is that shaped moves can be scaled in amplitude and they will continue to reduce vibrations and acoustic noise.

4.0 Partial Fraction Expansion Equation System Model

Once a parameter in the system, such as the fundamental limiting parameter, has been identified, an input to the system in terms of that parameter can be generated. In order to generate an input which results in reduced system vibrations, it is first necessary to generate a set of simple equations that define the system. The first step in generating such system equations is to write the transfer function for a simple model of the system.

FIG. **11** shows a third order model for a disk drive system such as that shown in FIGS. **10**A and **10**B. For system **80** shown in FIG. **11**, a voltage V is input so as to control movement of head **9** to a particular track on a recording medium. To this end, blocks in system **80** convert voltage V into a current i, convert current i into torque τ, convert torque τ into frequency ω, convert frequency ω into velocity v, convert velocity v from meters-per-second into tracks-per-second, and convert tracks-per-second into a location of a particular track on a recording medium such as a magnetic disk.

To generate a set of equations for system **80**, the transfer function H(s) therefor must first be determined. The transfer function H(s) for system **80** is as follows:

$$H(s)=\frac{K_t lk}{(L_e s^2 J_m+(L_e R_m+R_e J_m)s+R_e R_m+K_t K_b)s}. \quad (6)$$

where K_t is the motor torque constant, K_b is the back EMF constant, l is the actuator arm radius, k corresponds to track density on a recording medium, L_e is the inductance of a voice coil in the motor, J_m relates to inertia of the motor's rotor, R_m corresponds to an amount of viscous friction in the motor, and R_e corresponds to an amount of electrical resistance in the system.

Next, H(s) is written as an equivalent transfer function in terms of three parameters, namely A, a and b, as follows:

$$H_{eq}(s)=\frac{Aab}{s(s+a)(s+b)}. \quad (7)$$

where A corresponds to a scale factor and a and b correspond to inverse time constants. Specifically, in terms of the parameters in equation 6, A is defined as follows:

$$A=\frac{K_t lk}{R_e R_m+K_t K_b}. \quad (8)$$

Variables a and b correspond to two solutions in s, namely s_1, and s_2, to the following quadratic characteristic equation from equation 6:

$$L_e J_m s^2+(L_e R_m+R_e J_m)s+R_e R_m+K_t K_b=0. \quad (9)$$

After writing H(s) in terms of the equivalent transfer function $H_{eq}(s)$, a modal analysis or a partial fraction expansion is then performed on $H_{eq}(s)$ so that each pole of the system is in a separate term. A partial fraction expansion for $H_{eq}(s)$ is follows:

$$H_{eq}(s)=\frac{A}{s}+\frac{Ab}{(-b+a)(s+a)}+\frac{Aa}{(-a+b)(s+b)}. \quad (10)$$

Each term of the expression for $H_{eq}(s)$ in equation 10 can then be written as follows:

$$F_1(s)=\frac{A}{s} \quad (11)$$

$$F_2(s)=\frac{Ab}{(-b+a)(s+a)}$$

$$F_3(s)=\frac{Aa}{(-a+b)(s+b)}.$$

From equations 11, a time domain response of each term to a unit step (e.g., to a unit voltage) input can be determined. This time domain response is as follows:

$$F_1(t)=At \quad (12)$$

$$F_2(t)=\frac{Ab}{a(-b+a)}-\frac{Ab}{e^{at}a(-b+a)}$$

$$=\frac{Ab}{a(-b+a)}*(1-e^{-at})$$

$$F_3(t)=-\frac{Aa}{b(-b+a)}+\frac{Aa}{e^{bt}b(-b+a)}$$

$$=\frac{Aa}{b(-a+b)}*(1-e^{-bt}).$$

System response to a unit impulse can also be obtained by differentiating the above "step response" equations with respect to time.

To solve equations 12 for a system input, values must be determined for $F_1(t)$, $F_2(t)$ and $F_3(t)$. Examination of the expressions for $F_1(t)$, $F_2(t)$ and $F_3(t)$ reveals that the expressions for $F_2(t)$ and $F_3(t)$ vanish as "t" approaches infinity in

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a case that the input to the system is zero, which is the case at the end time of a move (hereinafter referred to as time "t_{end}"). Since the input is zero at time t_{end}, responses of $F_2(t)$ and $F_3(t)$ decay after time t_{end}. Accordingly, in order to solve for a system input that will move the system to the correct location in a rest state, $F_2(t)$ and $F_3(t)$ should be set to zero at time t_{end}. Furthermore, since the input is zero after time t_{end}, the value of $F_1(t)$ stops changing at time t_{end}. The above two conditions are equivalent to zero velocity and zero acceleration (or current) at the end of the move.

Thus, in the equations for $F_1(t)$, $F_2(t)$ and $F_3(t)$, in a case of zero velocity and acceleration at the end of a move, only the term involving $F_1(t)$ contributes to the final position. An expression can then be written including the response of each mode, namely $F_1(t)$, $F_2(t)$ and $F_3(t)$, at a time corresponding to an end of the move, namely t_{end}, for a voltage V_0 input at t_0 and having transitions at t_1 and t_2. To this end, $XF_1(t_{end})$ set forth below defines the contribution of $F_1(t)$ to the position at time t_{end}, $XF_2(t_{end})$ set forth below defines the contribution of $F_2(t)$ to the position at time t_{end}, and $XF_3(t_{end})$ set forth below defines the contribution of $F_3(t)$ to the position at time t_{end}

$$XF_1(t_{end})=V_0F_1(t_{end}-t_0)-2V_0F_1(t_{end}-t_1)+2V_0F_1(t_{end}-t_2)$$

$$XF_2(t_{end})=V_0F_2(t_{end}-t_0)-2V_0F_2(t_{end}-t_1)+2V_0F_1(t_{end}-t_2)$$

$$XF_3(t_{end})=V_0F_3(t_{end}-t_0)-2V_0F_3(t_{end}-t_1)+2V_0F_1(t_{end}-t_2) \quad (13)$$

Thus, the total movement distance at time t_{end} is expressed as

$$XF_1(t_{end})+XF_2(t_{end})+XF_3(t_{end}). \quad (14)$$

As noted above, the expressions for $F_2(t)$ and $F_3(t)$ vanish as "t" approaches infinity in a case that the input is zero, i.e., at the end of a move. Thus, in equations 13, only the term involving $F_1(t)$ contributes to the final position as time approaches infinity. This results in the following three constraint equations that must be satisfied in order for a third order system to reach its desired final position in substantially minimal time, with substantially zero velocity and acceleration

$$XF_1(t_{end})=\text{Finalpos}$$

$$XF_2(t_{end})=0$$

$$XF_3(t_{end})=0, \quad (15)$$

where Finalpos denotes the end (or "final") position of the system. These equations correspond to rigid mode motion constraints since they achieve a final position in the third order model with substantially zero velocity and acceleration.

A digital model of the response of a disk drive system to a unit impulse may be derived based on the foregoing. FIG. 24 shows a digital voltage input waveform. The waveform of FIG. 24 can be conceptualized as a series of pulses as shown in FIG. 25. Each of these pulses can be represented as a pair of impulses, as shown in FIG. 26. A first digital constraint is formed by realizing that the system's final position, Finalpos, is proportional to the area enclosed by the voltage waveform, i.e., the integral of the voltage waveform. The area of the voltage waveform can be determined by inspection of the waveform shown in FIG. 24. Specifically, the area is determined as follows

$$Finalpos=\sum_{i=1}^{N} V_i A\Delta t, \quad (16)$$

where "$V_i\Delta t$" corresponds to an area of a pulse "i". Negative values of V_i subtract from the overall sum.

The remaining two digital constraints can be formed using the impulse summation form of the voltage waveform shown in FIG. 26. Specifically, as noted above, the impulse response of the system can be determined by taking the derivatives of step response equations. For $F_2(t)$ and $F_3(t)$ above, the impulse response equations are as follows:

$$\frac{d}{dt}(F_2(t))=\frac{Ab}{b-a}e^{-at} \quad (17)$$

$$=F_2'$$

$$\frac{d}{dt}(F_3(t))=\frac{Aa}{a-b}e^{-bt}$$

$$=F_3'.$$

In accordance with constraint equations 12, the response of the series of impulses of the voltage summation form of the voltage waveform, evaluated at time t_{end}, is set to zero in order to form the second and third digital constraints, as follows:

$$0=\sum_{i=1}^{N} V_i(F_2'(T_{end}-T_i+\Delta t)-F_2'(T_{end}-T_i)) \quad (18)$$

$$=\sum_{i=1}^{N} V_i\frac{Ab}{b-a}(e^{-a(T_{end}-T_i+\Delta t)}-e^{-a(T_{end}-T_i)})$$

$$0=\sum_{i=1}^{N} V_i(F_3'(T_{end}-T_i+\Delta t)-F_3'(T_{end}-T_i))$$

$$=\sum_{i=1}^{N} V_i\frac{Aa}{a-b}(e^{-b(T_{end}-T_i+\Delta t)}-e^{-b(T_{end}-T_i)}).$$

Thus, partial fraction expansion equations corresponding to a digital model of the response of a disk drive system to a unit impulse comprise:

$$Finalpos=\sum_{i=1}^{N} V_i A\Delta t \quad (19)$$

$$0=\sum_{i=1}^{N} V_i\frac{Ab}{b-a}(e^{-a(T_{end}-T_i+\Delta t)}-e^{-a(T_{end}-T_i)})$$

$$0=\sum_{i=1}^{N} V_i\frac{Ab}{a-b}(e^{-b(T_{end}-T_i+\Delta t)}-e^{-b(T_{end}-T_i)}),$$

where Finalpos, A, a, b and t_{end} are as previously defined, V_i are voltage inputs to the system, T_i are the times at which V_i are input, and Δt is a time interval at which V_i are input.

Equations 19 can be used to solve for system inputs V_i which result in substantially zero velocity and acceleration at the end of a move. These equations can be solved in a number of ways. For example, the equations can be solved using a linear programming method, either on their own or in conjunction with a variety of other constraints. Examples

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of such constraints include vibration constraints and physical constraints such as power consumption or heat buildup, etc. Also, the continuous form of the equations can be solved for voltage switch times, as described in more detail below.

5.0 Generating "Good Moves"

The techniques set forth in sections 3 and 4 above determine inputs to a system that utilize substantially the full capabilities of the system actuators and that reduce system vibrations (both mechanical and acoustic). Several techniques can be used, either alone or in conjunction with the techniques presented above, to generate (or enhance) system inputs to reduce system vibrations even further.

For the purposes of the subject application, a "good move" is defined as a movement of a system component along a trajectory from an initial position to a nominal final position, such that, at the time the component reaches its nominal final position, the component is vibrating at or below an acceptable level, possibly subject to one or more predetermined constraints. In the context of computer disk drives, this means that, as soon as the drive's head reaches its nominal final position, the head is ready to perform a read/write operation to a recording medium. A good move is also one in which acoustic noise excited by the move is at or below an acceptable threshold. In contrast, a "bad move" is, for example, a move in which the component is vibrating at an unacceptable level when the component reaches its nominal final position. In the context of computer disk drives, this means that at the time the drive's head reaches its nominal final position, the head is vibrating at a level which is too high to perform a read/write operation accurately. A bad move is also one in which the acoustic noise excited by the move is above an acceptable threshold.

A powerful result of the approach outlined herein is that a rigid body command may be calculated by one of a number of techniques including equations 19 or the current mode technique of section 3.1. Next, other dynamics, such as flexible modes, acoustic modes or other dynamic effects can be subsequently corrected by the various methods set forth below. For disk drives, the process comprises, e.g., determining, over a population of drives and for each move length (or range of move lengths), which frequencies can be heard and which effect settling time. Then, moves may be generated that limit the amplitude of those frequencies or some subset thereof. Frequencies that only appear in a subset of the drives may also be included or turned-on selectively. The effects of the selected frequencies can be reduced by applying any of the techniques set forth below.

5.1 Vibration Limiting and Sensitivity Constraints

This technique for generating a good move incorporates physical constraints into a system model. One such model comprises partial fraction expansion equations 19 derived above. To generate a good move in accordance with this technique, the first step is to choose one or more physical constraints. Examples of physical constraints include constraints that limit vibration (both mechanical and acoustic) and constraints for insensitivity to parameter variations.

Constraints for insensitivity to parameter variations can be added to the system equations in several ways. For example, derivatives of the partial fraction expansion equations can be taken with respect to a particular parameter and then added to the constraint equations. This technique is set forth in detail in U.S. Pat. No. 5,638,267, issued to Singhose et al. on Jun. 10, 1997, the contents of which are hereby incorporated by reference into the subject application as if set forth herein in full, and in U.S. Pat. No. 4,916,635, issued to Singer et al. on Apr. 10, 1990, the contents of which are also hereby incorporated by reference into the subject application as if set forth herein in full. Additionally, a sampling technique can be used to set a series of constraints for different values of a given parameter so as to limit the solution for a variation in that parameter. For example, using this technique, 10% insensitivity at 1000 Hz can be achieved by setting constraints at 900 Hz, 920 Hz, etc. up to at least 1100 Hz. One variation of this technique is set forth in U.S. Pat. No. 5,638,267.

In accordance with the invention, constraints can be chosen so as to reduce system vibrations by substantially 100% or to limit reduction in system vibrations to a percentage which is less than 100%, say, between 50% to 70%. Which constraints are used to reduce system vibrations by such amounts can be determined experimentally or by running a computer simulation for the system. Choosing constraints that reduce system vibrations by less than 100% (e.g., a range of 50% to 70%) is particularly useful in cases where excessive vibrations do not occur in the system and in cases where large reductions in vibrations, including noise-inducing vibrations, are not required. In these cases, since the constraints are more relaxed, the resulting system input is shorter in duration. As a result, the system moves faster than it would otherwise. In general, there is a trade-off between move time and the use of stringent constraints. That is, while the use of more stringent constraints may further reduce vibrations, move time is slowed as a result of their use.

Vibration constraint equations may also need to be scaled in order to achieve desired vibration reductions. Specifically, in terms of the foregoing model of a disk drive system, equations for vibration amplitude are relative. This is because the rigid mode equations do not take into account flexible body equations (described below in section 6.3). If a full set of equations (i.e., both rigid and flexible body equations) were derived for the system, and then a partial fraction expansion applied thereto, the coefficients of the vibrational terms would scale to the problem. However, since the equations were derived separately and later combined using the techniques described herein, the relative scaling is not known for the equations given above, and the problem must be scaled manually. In the case of zero vibrations, no scaling is necessary. For any other case, one of several scaling methods may be used. For example, an arbitrary gain may be selected and a resulting sequence applied to the system. The resulting vibrations can then be measured and the vibration constraint equations multiplied by a ratio of a predicted vibrational level divided by an actual measured vibrational level.

By way of example, consider the fourth order transfer function shown below in equation 20. The transfer function corresponds to the position response of a simple mass-spring-mass system to a force input.

$$H(s) = \frac{C}{s^2} * \frac{\omega^2}{s^2 + 2\zeta\omega s + \omega^2} \tag{20}$$

The first term of the transfer function, namely

$$\frac{C}{s^2}, \tag{21}$$

corresponds to the rigid body motion, while the second term, namely

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$$\frac{\omega^2}{s^2+2z\omega s+\omega^2}, \quad (22)$$

corresponds to a vibratory mode with undamped natural frequency "ω" and damping ratio "z". When transfer function 20 is expanded in a partial fraction form, the following three terms result:

$$H(s)=\frac{-2zC}{\omega s}+\frac{C}{s^2}+\frac{C(-\omega+4z^2\omega+2zs)}{\omega(s^2+2z\omega s+\omega^2)}. \quad (23)$$

The third term from equation 23, namely,

$$\frac{C(-\omega+4z^2\omega+2zs)}{\omega(s^2+2z\omega s+\omega^2)}, \quad (24)$$

corresponds to the transfer function of the vibratory mode, and should be compared to the second order vibratory term included in the original transfer function. Using inverse Laplace transformation, the time domain impulse response of the vibratory mode is determined as

$$\frac{-Ce^{-z\omega t}\sinh\left(\omega\sqrt{-1+z^2}\,t\right)}{\omega\sqrt{-1+z^2}}+ \quad (25)$$

$$\frac{2Cz^2e^{-z\omega t}\sinh\left(\omega\sqrt{-1+z^2}\,t\right)}{\omega\sqrt{-1+z^2}}+\frac{2Cze^{-z\omega t}\cosh\left(\omega\sqrt{-1+z^2}\,t\right)}{\omega}.$$

Using suitable trigonometric identities, the time domain response of the vibratory mode in equations 25 can be simplified as follows:

$$\frac{-Ce^{-z\omega t}\sin(\omega_d t)}{\omega_d}+\frac{2Cz^2e^{-z\omega t}\sin(\omega_d t)}{\omega_d}+\frac{2Cze^{-z\omega t}\cos(\omega_d t)}{\omega}. \quad (26)$$

or, after collecting terms, to:

$$Ce^{-z\omega t}*\left[\frac{(2z^2-1)\sin\omega_d t}{\omega_d}+\frac{2z\cos\omega_d t}{\omega}\right], \quad (27)$$

where "ω_d" is the damped natural frequency

$$\omega_d=\omega\sqrt{1-z^2}. \quad (28)$$

The impulse response expression derived above can be used directly to form a quantified constraint equation; i.e. the magnitude of the constraint equation can be set to be less than or equal to an actual vibration level in position.

It should be noted that the general form of equation 27 is a phase shifted sine wave of frequency ω_d. The sine wave is further subject to a decaying exponential envelope with time constant

$$\frac{1}{z\omega}. \quad (29)$$

Equation 27 can be rewritten again, including the phase shift ϕ and scale factor C_1, as follows:

$$C_1e^{-z\omega t}\sin(\omega_d t+\phi). \quad (30)$$

This form of equation 27 should be compared with the expression for the impulse response of an isolated second order system (as defined by the second term of the original transfer function H(s)

$$\left(\frac{\omega^2}{s^2+2z\omega s+\omega^2}\right) \quad (31)$$

shown below:

$$\frac{\omega}{\omega_d}*e^{-z\omega t}\sin(\omega_d t+\phi). \quad (32)$$

Since we are only concerned with the magnitude of the residual vibration, phase shift ϕ is of no importance, and the expression for the isolated second order system can be used in the formulation of quantified constraints if the scale factor ω/ω_d is replaced by C_1. Parameters C_1, $z\omega$ and ω_d can be determined experimentally by (i) subjecting the actual system to an impulse input, and from experimental data, (ii) estimating the period of vibration and computing ω_d as follows

$$\omega_d=\frac{2\pi}{\tau}, \quad (33)$$

where τ is the period, (iii) estimating the decay envelope to determine $z\omega$, and (iv) estimating actual amplitude to determine C_1.

After constraints have been chosen based on the foregoing criteria, a trajectory is digitized and is then solved for each trajectory command value in time subject to the chosen constraints. Digitization of the trajectory results in simpler, and often linear, equations that can be solved readily for the complete system trajectory. The invention, however, is not limited to solving the system equations in this manner. That is, any known technique for solving the system equations can be employed in the context of the present invention. The digitization rate used is a factor that contributes to the successful implementation of the invention. This issue is discussed in section 7.1 below.

5.2 Input Shaping™

This technique for generating good moves uses Input Shaping™ and its substantial equivalents. One example of Input Shaping™ comprises convolving a function with a system input in order to reduce unwanted system vibrations. Examples of system inputs include current and voltage. Specific Input Shaping™ methods are set forth in detail in U.S. Pat. Nos. 5,638,267 and 4,916,635, which were incorporated by reference above.

In accordance with this technique, an input to a system, such as a voltage command or a velocity, is shaped in order to produce a desired output. For example, the input may be Input Shaped™ by convolving the input with an impulse sequence which reduces unwanted vibrations in the system, including its flexible modes. Alternatively, the input may be shaped using any one or more of the filtering techniques presented herein, or using any other known command profiling techniques.

5.3 Filtering

In addition to Input Shaping™, as noted above, any type of conventional shaping method can be used to generate an input that results in a good move. For example, it is also possible to generate a good move by filtering a trajectory with infinite impulse response ("IIR") or finite impulse response ("FIR") filters, including filters where there are zeros near poles of the system, such as those described below.

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5.4 Least Squares Solution to Frequency Sampling

A conventional least squares approach can also be used to generate an input that results in a good move for a computer disk drive system. An example of such an approach is provided in U.S. Pat. No. 5,638,267. This approach may also be used to limit high mode excitations.

5.5 Selective Shaping™

Input Shaping™, filtering, and the like can increase seek time in some cases. However, the length of an Input Shaper™ is directly related to the period of the vibration being reduced. At low frequencies, i.e., long periods, the increase in seek time caused by an Input Shaper™ can be a substantial percentage of the total seek time. This is of particular significance in relation to computer disk drives. That is, in computer disk drives, relatively low frequency vibrations can occur due to compliance of the drive's mounting in its enclosure. For example, a 200 Hz mounting resonance will have a period of 5 ms. In this case, a three-pulse Input Shaper™ will also have a period of 5 ms. Thus, if the computer disk drive has an average seek time of 10 ms, the drive's average seek time will increase by 50% if the Input Shaper™ is applied to all moves.

In view of the foregoing, it is advantageous to apply Input Shaping™ selectively. This is possible because not all moves result in unwanted vibrations. That is, some moves are inherently good, meaning that they produce relatively few vibrations, and some moves are inherently bad, meaning that they produce excessive vibrations. By evaluating constraint equations for a given move, whether that candidate move is good or bad can be predicted in advance. That is, a move can be evaluated to determine whether the move excites greater than a predetermined level of vibrations in the system. Input Shaping™ can then only be applied to moves that excite greater than the predetermined level of vibrations. Thus, only those moves exciting greater than the predetermined level of vibrations, e.g., the bottom 30% of the moves, need be Shaped™.

By virtue of the foregoing, the present invention provides the advantages flowing from using Input Shaping™ with less of an increase in seek time than would otherwise be achievable. Moreover, in accordance with the invention, a level of Input Shaping™, or the numbers and types of constraints, may be altered depending upon how good or how bad a move is, i.e., depending upon the level of vibrations that the move excites. For example, if a move only requires minimal Input Shaping™, lengths of impulse sequences used to Input Shape™ the move may be reduced.

In the context of computer disk drives, for a given frequency of interest, a measure of the goodness of a move can be evaluated by examining a superposition of components of an input at the frequency of interest. An example of such a superposition is shown in the graph of FIG. 12, in which the frequency of interest is 200 Hz, and in which a good move/bad move threshold is labeled 81. By examining threshold 81, it is evident that movement distances within a range around 1800 tracks and 7000 tracks are inherently good moves. On the other hand, movement distances requiring vibration reduction are identified in FIG. 12 by cross-hatching. For these movement distances, the amount of vibration reduction required is determined by taking a ratio of a move's goodness level to the good/bad threshold. The magnitude of the Input Shaper™ required for each movement distance is determined based on this ratio.

Specifically, the magnitude of an Input Shaper™ response can be equated to a desired reduction in vibrations ("mag") to derive an expression for a modified Input Shaper™. The expression for the period, τ, of a modified two-pulse Shaper™ is as follows

$$\tau = \frac{\arccos(2mag^2 - 1)}{2\pi f}. \quad (34)$$

It is noted that the above expression is closed form and, therefore, is suitable for on-line, real-time implementation. For unity magnitude Shapers™ (mag=1) in which no vibration reduction occurs the foregoing expression yields

$$\tau = 0, \quad (35)$$

and the two pulses are co-incident at time t=0. For zero magnitude Shapers™ (mag=0) in which 100% vibration reduction occurs, the foregoing expression yields

$$\tau = \frac{1}{2f}, \quad (36)$$

or ½ period. At intermediate values of mag, the expression yields intermediate values of the Shaper™ period τ. For example, when mag=0.5,

$$\tau = \frac{1}{3f}. \quad (37)$$

At this point, it is noted that although two and three impulse Input Shapers™ are described above, the invention can use Input Shapers™ having more than three impulses as well as to shapers designed using other techniques. It is also noted that although the invention has been described with respect to Input Shaping™, any shaping technique may be used. For example, moves that are considered bad moves could be selectively shaped using an FIR filter, an IIR filter, any shaper, or even just extended in some arbitrary way to achieve the goals of the present invention. In addition, constraints, such as vibration limiting constraints or the like, may be selectively added to the system equations based on whether a move has been identified as good or bad, and the resulting set of equations can be solved for a complete move trajectory. The moves also may be solved off-line and tabulated to achieve the same benefit.

5.6 Voltage Control by Forcing Switch Times

Disk drives operate in a current command mode, meaning that their operation is controlled by current commands. Since saturation is in voltage, conventionally there is no way to determine if a particular current command will saturate the system (notwithstanding section 3.1 above). Accordingly, commanding the system in current can fail to produce a desired movement. The invention addresses this problem by commanding a current that is guaranteed to saturate a voltage input to the system. In this way, the invention is able to command voltage in either direction. That is, it is possible to provide current commands to the system, but actually to be commanding voltages switches.

In more detail, many disk drive systems utilize a closed-loop current control system to control current through a voice coil motor. A closed-loop controller in such a system makes it possible to specify a current command that, when applied to the motor, results in a constant torque. Specifically, the closed-loop controller adjusts the voltage through the motor to maintain a desired current level. However, there are limitations to such a controller. Specifically, the maximum voltage available to the controller is limited by the power supply used in the disk drive. Thus, if the voltage required to achieve a particular current

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is above the power supply's maximum voltage, the controller will saturate at the maximum voltage and the desired current will not be achieved.

While the foregoing may be perceived as a drawback, it can actually be an advantage, since the saturation can be used to operate the current controller in an alternative mode in which power supply voltage is simply applied to the motor's terminals. That is, the controller is operated as an open-loop voltage switching system, instead of as a closed-loop current control system. As a result, it is possible to create an alternative formulation for control strategies and motion profiles. This technique of using current control to command voltage has the additional benefit that voltage commands can be used during disk drive seek; however, a normal current command mode is still available for tracking without changing any system hardware.

Use of the open-loop voltage control technique described above may require a series of precisely-timed commands to achieve vibration suppression effects. Section 7.1 below presents a variety of techniques for implementing such precisely-timed commands. If the commands are not in the fundamental limiting parameter of the system, then section 3.1 may also be used to generate such commands. If the commands are in the fundamental limiting parameter, then the techniques of sections 4 and 5 can be used.

In this regard, the fundamental limiting parameter is often not used to command the system due to hardware constraints (e.g., the tracking controller in a disk drive system is designed for current, not voltage, commands). In the case of a disk drive, by modifying the drive's amplifier, it is possible to use voltage commands during one mode of operation, e.g., drive seek operations, and to switch to current commands during another mode of operation, e.g., drive tracking operations. Thus, for example, the techniques of section 3.1 can be used during a tracking operation and the techniques of sections 4 and 5 can be used during a seek operation.

5.7 Other Techniques

In addition to the foregoing techniques, other techniques may also be used to generate (or enhance) an input to produce a good move. For example, it is possible to adjust any of the above techniques using real-time identification of any system parameters. Specifically, a system parameter, such as temperature or resistance, may be identified, and that parameter addressed when generating a good move. Additionally, symmetric and multi-step (i.e., Posicast) inputs can be used to generate a good move. As set forth in section 11 below, transient portions of the input or feedforward signal at the beginning, middle and/or end of a move may also be varied in order to reduce vibrations resulting from the move. Additional constraints may also be added to the system in order to control vibrations. For example, these constraints can be symmetric and can be a function of time or position and/or can relate to thermal limits, current limits, duty cycle, and/or disk drive ZV constraints. Moreover, it is noted that since each transition of an input corresponds to a complete move in and of itself, any of the above techniques for generating a good move set forth above can be performed in real-time, and the Shaping™ and filtering methods described above can be performed only on the rapid transient portions of the move. See section 11 below.

The Shapers™ and filters described above are preferably stored in a memory as computer-executable process steps, and executed by a processor in the system. However, the invention can also be implemented in a fuzzy logic controller by embedding either an Input Shaper™ or direct solutions to systems of constraint equations in a fuzzy logic block. Similarly, the invention can be implemented in a neural network controller that can be constructed by imbedding either an Input Shaper™ or direct solutions to systems of constraint equations into a neural network. Both the fuzzy controller and the neural network PV controller can be designed to handle non-linear system parameter variations which enter into equations for a system.

6.0 Controlling Trajectory as a Function of Time

This aspect of the invention is directed to a control technique for a, reducing unwanted vibrations in a dynamic system by controlling a trajectory which is specified as a function of time. More specifically, in this aspect of the invention, an input that corresponds to a good move is used as feedforward trajectory for the system. Any of the above techniques for generating inputs corresponding to a good move may be used to modify inputs in the following control system. However, for the sake of brevity, only Input Shaping™ will be described in detail. Moreover, although the invention can be used to control any dynamic system, a description will be provided only for a computer disk drive system, again for the sake of brevity.

6.1 Optimization

One approach to generating an input that will result in a fast response in a computer disk drive is to perform an optimization using partial fraction expansion equations 19. To perform the optimization, these equations are augmented by including a set of constraints to address vibrations in various modes of the system. In addition, constraints may be added for vibrations in modes that are near a predicted vibrational mode and for real world conditions, such as voltage limits. A digital formulation of the problem can then be modeled so as to make all of the constraints linear, thereby simplifying their solution. The digitization rate may be selected using the techniques presented in section 7.1.

The invention is not limited to methods for performing optimization described herein. Rather, any optimization technique may be used. For example, other methods for implementing optimization which can be used in conjunction with the present invention include off-line computation and use of efficient linear solving codes on the disk drive controller. It is also possible to generate a series of solutions off-line and to fit curves to the solutions. Appendix C shows a set of linear equations written in GAMS that can be solved for ZVD constraints on a problem in which voltage is the commanded input.

6.2 A Related Approach

The partial fraction expansion model of a disk drive system shown above can also be used in conjunction with Input Shaping™ in order to generate system inputs. For example, in an article entitled "Fast Servo Bang-Bang Seek Control" by Hai T. Ho, ©1997, IEEE, the contents of which are hereby incorporated by reference into the subject application, it was demonstrated that near the end of a move, the instantaneous state of a system can be measured. Inputs to the system can then be calculated so as to bring the system to its final location with limited vibrations. The flaw in this technique, as presented in the article, is that exact solutions to the disk drive system equations could not be obtained because a second order system model was assumed. Since a disk drive system is more accurately modeled as a third order system, this technique could result in inputs which did not sufficiently limit vibrations or which resulted in the system reaching a nominal final position without coming to rest. By use of the partial fraction expansion model presented in section 4, a more precise solution to the system equations can be obtained, thereby resulting in relatively fewer vibrations when the system reaches its final location. Moreover, insensitivity constraints can be added to the

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foregoing equations by a variety of techniques, e.g., by sampling (as discussed in section 6.7), by taking derivatives (as discussed in U.S. Pat. No. 4,916,635), or any other approach, thereby leading to robust solutions of the equations and still fewer resulting vibrations.

6.3 Rigid and Flexible Mode Problem

Another approach which uses Input Shaping™ in conjunction with the partial fraction expansion model of section 4 is to separate the problem into a rigid mode problem and a flexible mode problem. Examination of modal terms associated with a disk drive reveals terms similar to a third order system, e.g., $F_1(t)$, $F_2(t)$ and $F_3(t)$ from equations 12, plus additional terms associated with oscillating or vibrational modes, e.g., $F_4(t)$, $F_5(t)$, etc. (not shown). The present invention separates these terms into two sets. The first set, which defines the rigid mode of the system, includes the third order system modal terms, i.e., $F_1(t)$, $F_2(t)$ and $F_3(t)$. The second set, which defines the flexible modes of the system, includes the other modal terms, i.e., $F_4(t)$, $F_5(t)$, etc. The partial fraction expansion equations in section 4 can be solved for inputs which drive the system so as to satisfy rigid body motion constraints $F_1(t)$, $F_2(t)$ and $F_3(t)$ and thereby achieve a final position with substantially zero velocity and acceleration. However, vibrations resulting from the other modes, namely $F_4(t)$, $F_5(t)$, etc., can still be problematic.

More specifically, the partial fraction expansion equations cannot be solved for an input which reduces vibrations in the flexible modes without adding additional constraints for each additional mode. However, adding additional constraints increases the complexity of obtaining the solution. Additionally, if curve fit or empirical solutions are to be obtained, the solution is increasingly more complicated for each additional constraint that is imposed. Therefore, in order to reduce vibrations in the flexible modes without substantially increasing the complexity of obtaining a solution, the present invention first solves the rigid mode equations in order to determine system inputs. Next, the determined system inputs are shaped using an Input Shaper™ designed for the flexible modes of the system. For example, the Input Shaper™ may be designed based on frequency and damping ratios of $F_4(t)$, etc. above.

The partitioning of $F_1(t)$, $F_2(t)$ and $F_3(t)$ into the rigid mode and $F_4(t)$, $F_5(t)$, etc. into the flexible mode is merely an example of one way to partition the system's modeled modes. The invention is not limited to such definitions. In fact, the partitioning of modes can vary depending upon the system under consideration as well as various other factors. For example, it is possible to derive a second order system input based on a system model that includes only $F_1(t)$ and $F_2(t)$ in the rigid mode and that includes $F_3(t)$, $F_4(t)$, etc. in the modes that are addressed using Input Shaping™. Such a formulation would be of particular advantage in the case where $F_3(t)$ corresponds to a system's electrical time constant, since Input Shaping™ could be used to correct variations in the system's electrical time constant.

6.4 Center of Mass

In the rigid mode of a system, problems may arise because various components of the system are moving relative to one another. For example, in the case of a computer disk drive, vibrations may be induced in the system because the motor's rotor is moving out of phase with an endpoint, such as the read/write head. This will cause problems during feedback if a rigid body model is assumed. That is, if the endpoint alone is used as feedback, the deflection that is observed will be fed back and cause corrections that are not required and thus may be detrimental to system performance. To reduce such errors, the present invention estimates the center of mass of the system and uses the estimated center of mass, rather than an endpoint, as the system's feedback. One way to estimate the center of mass of the system is to calculate a state estimator using modern control techniques. A wide range of correction factors, such as a quasi-static correction factor similar to that described below, can be applied to improve the estimate of the center of mass coordinate.

The center of mass coordinate estimated above will not reflect the vibrations of the rotor nor those of the endpoint. Consequently, the rigid body behavior of the system can be decoupled from most all vibrations (including acoustics) in order to allow for more accurate feedback control than has heretofore been possible.

6.5 Quasi-Static Correction

On the other hand, if endpoint feedback, rather than center-of-mass feedback, is used in the system, vibration-reducing inputs to the system, such as those generated in accordance with the techniques set forth herein, can cause unusual side effects. That is, the component at the endpoint (e.g., the head in the case of a disk drive) does not vibrate. Rather, the component deflects during the move. The deflection is in one direction during acceleration phases and in another direction during deceleration phases. The feedback signal to the controller is measured based on this deflection. As a result, if the system controller uses this feedback signal to compare to a trajectory, the controller will detect an error even if none exists. To correct this problem, a quasi-static correction factor may be added to, or subtracted from, the feedback signal depending on the amplitude and the direction of acceleration.

6.6 Closed-loop Control

By adopting a control strategy in which a trajectory is specified as a function of time, a closed-loop system formulation can be made. As shown, for example, in FIG. 11, feedback loops may be closed around any combination of system states. In the case of a disk drive, these states include voltage, current, acceleration, velocity, and position. An input which corresponds to a good move can then be generated based on the closed-loop formulation. This "good" input, which, in the case of a computer disk drive, may be a voltage input, is used to generate feedforward signals to some or all of the closed-loops.

Feedforward trajectories for each of the parameters to be used as a feedforward term are derived from a trajectory selected as a "good" move. The technique for generating feedforward trajectories may be based on either a simple simulation of the system or the partial fraction expansion model set forth in section 4. When generating a good input, it may be desirable to compute a move assuming that less voltage (or whatever physical variable is limited by reality) is available. This increases the chances that the system will stay on a trajectory corresponding to the good move. Another approach to generating a good input is to assume full voltage (or whatever physical variable is limited by reality) and to assume safe values for the physical system parameters used in the model. In this case, full voltage would only be used if the parameters were the worst case possible. At all other nominal cases, a lower voltage would be used.

In the closed-loop control model, the feedforward terms for each loop could be replaced by only one feedforward (or input) to the outer loop, where this one feedforward term is computed as a combination of each of the other feedforward terms. Also, feedforward inputs for the system could be scaled differently for each system parameter. For example, different gains could be used for each of velocity, position, acceleration, current, and voltage feedforward terms. The

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selection of gains adds zeros to each feedforward term. Since Input Shaping™ is a method of placing zeros in certain locations using a constraint based technique, it is understood that the gains selected for the feedforward terms can be chosen to add zeros which serve to augment Input Shaping™. This technique would lower the requirements on any Input Shaper™ used, or enable fewer constraints to be used in the derivation of complete trajectories.

Shown in FIG. 27 is a block diagram of a simple system, namely system 82, that will be used to demonstrate how a collection of feedforward signals can be used to effect zeros in a transfer function. In system 82, the variable to be controlled is the output position x, there is a feedforward input FF, and there are three command inputs, namely position input x_d, velocity input v_d, and acceleration input a_d. There is also full state feedback of position x, velocity v, and acceleration a. In the ideal case, the feedforward input FF will cause the system to follow a desired trajectory (x, v, a) through state space. If the actual trajectory does not match the desired trajectory, then error terms (X_d-x), (v_d-v) and (a_d-a) will be multiplied by gains K_x, K_v and K_a to generate corrective inputs. If the inputs v_d, a_d and FF are all set to zero, the system will still "track" the remaining command input x_d, but likely with larger position error.

The command inputs, x_d, v_d and a_d, and the feedforward input FF are produced by another process and are simply inputs to the system. However, the command inputs x_d, v_d and ad are mathematically related as derivatives. Their relationship is indicated in the block diagram shown in FIG. 28 by applying the Laplace differentiation operator "s" repeatedly to the x_d input signal. It is well known that it is physically impossible to implement the zero corresponding to the "s" operator without a corresponding pole. Since the input signals v_d and a_d are actually derivatives, the use of the "s" notation in FIG. 28 is a notational convenience facilitating intuition, not a means of implementation.

By applying block diagram algebra to the block diagram shown in FIG. 28, scaled versions of all the inputs (x_d, v_d, a_d and FF) can be shown to enter the closed-loop system at a single point, as shown in FIG. 29. The combination of the three parallel inputs (to the nominal closed-loop system) shown in FIG. 29 can be reduced further using block diagram algebra as shown in FIG. 30. The numerator of the block shown in FIG. 30 is a third order zero. For this system, the zeros associated with the combination of feedforward terms exactly match (and cancel) the poles of the nominal closed-loop system. Thus these zeros serve to cancel the dynamics of the modeled system. The location of the zeros can be adjusted by including weighting factors W_v, W_a and W_f on each of the terms v_d, a_d and FF, respectively. Following through with the analogous block diagram reduction yields the result shown in FIG. 31.

By allowing additional freedom in the placement of the zeros (by adjusting weights W_v, W_a and W_f), the zeros can be placed to effect a first order cancellation of the (unmodeled, but measured) poles of the system, e.g. poles associated with vibration or other unwanted dynamic response. Since FIR input shapers can be viewed as "all zero" filters, the zeros associated with the weighted feedforward input can be used to replace or augment the action of the zeros of the FIR input shaper. Thus, since some zeros are supplied by the weighted feedforward input, a lesser number of zeros must be supplied by the shaper, and consequently, the shaper period becomes shorter. The overall time advantage lies in the fact that the zeros associated with the weighted feedforward are implemented without a time cost (i.e., without a penalty).

6.7 Additional Constraints

It is also possible to add constraints to the partial fraction expansion equations of section 4 in order to provide for relatively rapid movements of the rigid mode portion of the system. For example, it is possible to add constraints relating to insensitivity to variations in system parameters. To do this, one or more constraint equations in the continuous form of equations 19 may be differentiated with respect to the system parameter and the resultant set to zero. This ensures that the solutions to the equations are insensitive to variations in that parameter. A similar result can be obtained by solving the equations to which insensitivity is required multiple times with different values for the system parameter. For example, the second of the above partial fraction expansion equations 19 can be repeatedly solved with different torque constant values in order to assure that the solution thereto works well for a range of torque constant values. Such an equation must be given some degree of freedom by not requiring that the solution be exactly zero for all values of torque constant.

6.8 Switch Times

As noted above, the continuous form of the partial fraction expansion equations can also be solved for voltage switch times which reduce vibrations in the system. A voltage switch time corresponds to a transition time between full positive and full negative voltage inputs to the system. In solving for these switch times, if no other constraints are included, the system can be modeled using the three partial fraction expansion equations 19 shown above in section 4. Using the continuous version of these equations, it is possible to solve for three transition times, namely t_1, t_2 and t_{end}, as set forth below.

Equations 19 are nonlinear in their continuous form. However, they can be manipulated to make them easily solvable in a controller with limited computational power. Since the first equation is linear, the first equation can be substituted into the other equations, yielding two equations with two unknowns. The solution can then be obtained by performing a simple fixed-point iteration. Only a few iterations are needed to obtain a solution to machine precision. Additionally, the starting guess for the iteration can be obtained from a simple curve fit, thus further increasing the speed of the calculation process. It is also possible to generate solutions to these equations by defines switch times as a function of movement distance and then fitting the data with an empirical formula to achieve a solution that is sufficient for use in a digital controller.

To this end, an additional step that is performed in order to use the continuous switch time solution in a digital controller is to round-off the switch times to a nearest digital time spacing. However, because significant errors can be generated by rounding-off the switch times, another approach is often used. The switch times are rounded upward and the voltage levels in each region are adjusted to achieve a solution to the same equations. Alternatively, voltage levels in only a portion of the solution are adjusted in order to achieve the same result. For example, only a few digital outputs are adjusted to correct for the round-off.

The pseudo-code shown in Appendix A illustrates (i) the calculation of continuous switch times, (ii) a method of rounding the continuous switch times to discrete time intervals, and (iii) recalculation of the voltage levels to satisfy the original constraint equations including discrete switch times. In the first section of the pseudo-code, the physical system parameters (V_{max}, K_v, K_b, l, k, R_e, R_m, and J_m) are used to compute transfer function parameters (A, a, b). While in theory this step is not required (a formulation in

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the original system physical parameters could be used), the resulting equations are much more compact and more suitable for real-time implementation.

In the formulation shown in Appendix A, the accommodation of digital switch times requires that the entire voltage level of each of the three steps be modified in order to satisfy the constraint equations. Modification of the entire step resulted because of the specific formulation in terms of three steps in voltage. If the problem is reformulated, e.g. in discrete impulse response form corresponding to partial fraction expansion equations 19 (repeated below as 38 for convenience), other, more flexible modifications of the voltage wave form are possible.

$$Finalpos = \sum_{i=1}^{N} V_i A \Delta t \tag{38}$$

$$0 = \sum_{i=1}^{N} V_i \frac{Ab}{b-a}\left(e^{-a(T_{end}-T_i+\Delta t)} - e^{-a(T_{end}-T_i)}\right)$$

$$0 = \sum_{i=1}^{N} V_i \frac{Aa}{a-b}\left(e^{-b(T_{end}-T_i+\Delta t)} - e^{-b(T_{end}-T_i)}\right)$$

The pseudo-code shown in Appendix A can be used to compute the digital switch times (rounded from continuous), and the impulse response form of the constraint equations used only for the final adjustment of voltage levels. A voltage variable for the reformulated voltage adjustment problem can be formed by selecting an individual V_i, or alternatively selecting a dependent set of V_i(e.g. $V_1=V_2=V_3=V_{first}$). The three constraint equations form a linear set of three equations in the three variables and can be solved using any method suitable for linear equations. If more than three variables are chosen, then the solution will not be uniquely determined and opportunity exists for additional criteria to be used to select from among the possible solutions.

6.9 Shaped™ Switching

According to the well-known bang-bang principle, time-optimal system commands for a voltage-limited system like a computer disk drive comprise a series of full-positive and full-negative voltage commands. In such a case, the voltage levels are known, but their optimal switch times are not. Because optimal switch times for the system are unknown, it is likely that unwanted vibrations will be excited when the voltages commands are input to the system. Several techniques for reducing unwanted system vibrations can then be performed. For example, it is possible to determine a switching sequence analytically subject to various constraints, such as vibration constraints, insensitivity constraints, or any number of unwanted dynamic or physical system constraints. Additional techniques that can be used include determining switch times using any technique described herein and adjusting the switch times in real-time to take system movements into consideration.

Another effective technique for commanding a disk drive to move is to combine the benefits of a bang-bang time-optimal command with the benefits of Input Shaping™. To this end, switch times for an input to a rigid system are determined analytically, and then an Input Shaper™ is applied to the input in order to shape it so that unwanted vibrations resulting therefrom are substantially suppressed. This technique has at least two advantages. First, it is relatively easy to implement from a computational point of view because the problem is separated into two problems, namely generating a good input for a simple system and separately generating a good Shaper™ to handle flexible, and possibly some rigid, modes. Second, solutions obtained by separately Shaping™ the input are more insensitive to system parameter variations.

Shaping of the input may be performed in a manner described above using, e.g., an Input Shaper™, a filter, etc. Accordingly, a detailed description of shaping the input is omitted here for the sake of brevity. With regard to generating a good input, since voltage levels for the input are already known (i.e., the voltage levels are either full positive and full negative), the only variables that need to be determined are switch times for the voltage input. Switch times can be determined using a partial fraction expansion model of a system, such as equations 19, in which $F_1(t)$, $F_2(t)$ and $F_3(t)$ correspond to step responses to a unit voltage in each mode of the system. For a third order model such as this, three transitions between full positive and full negative are required. Switch times, namely t_1, t_2 and t_{end}, for the transitions are determined as follows.

Using equations 14, reproduced below as 39,

$$XF_1(t_{end}) = V_0F_1(t_{end}-t_0) - 2V_0F_1(t_{end}-t_1) + 2V_0F_1(t_{end}-t_2)$$

$$XF_2(t_{end}) = V_0F_2(t_{end}-t_0) - 2V_0F_2(t_{end}-t_1) + 2V_0F_1(t_{end}-t_2)$$

$$XF_3(t_{end}) = V_0F_3(t_{end}-t_0) - 2V_0F_2(t_{end}-t_1) + 2V_0F_1(t_{end}-t_2), \tag{39}$$

and constraint equations 15, reproduced below as 40,

$$XF_1(t_{end}) = \text{Finalpos}$$

$$XF_2(t_{end}) = 0$$

$$XF_3(t_{end}) = 0, \tag{40}$$

it is possible to solve for the three unknown transition times t_1, t_2 and t_{end}. A change of variables, i.e.,

$$et_1 = t_{end} - t_0$$

$$et_2 = t_{end} - t_1$$

$$et_3 = t_{end} - t_2, \tag{41}$$

further simplifies the solution for the switch times. In this case, et_1 corresponds to an elapsed time from onset of a first step until the end of the move, et_2 corresponds to the elapsed time from onset of the second step until the end of the move, and et_3 corresponds to the elapsed time from onset of the third step until the end of the move.

In view of the foregoing, equations 39 reduce to the following:

$$\text{Finalpos} = V_0F_1(et_1) - 2V_0F_1(et_2) + 2V_0F_1(et_3)$$

$$0 = V_0F_2(et_1) - 2V_0F_2(et_2) + 2V_0F_1(et_3)$$

$$0 = V_0F_3(et_1) - 2V_0F_2(et_2) + 2V_0F_1(et_3). \tag{42}$$

Since equations for $F_1(t)$, $F_2(t)$ and $F_3(t)$ contain exponential terms, a numerical solution to the above equations for $XF_1(t_{end})$, $XF_2(t_{end})$ and $XF_3(t_{end})$ is not readily available. However, certain simplifications can be made to the equations in order to provide an iterative numerical solution, and thus to allow them to be solved for transition times t_1, t_2 and t_{end} in real-time. More specifically, the duration of the third step of the input to a third order system does not vary significantly for relatively long moves. Therefore, for long moves, the third step duration is nearly independent of values of et_1 and et_2. Accordingly, the second equation (for $XF_2(t_{end})$) can be solved for et_3 using guesses for et_1 and et_2.

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The value of et_3 obtained in this manner is a close approximation to its exact value. The first equation (for $XF_1(t_{end})$) is used to eliminate et_1 from the third equation (for $XF_3(t_{end})$), whereafter the third equation is solved for et_2 as a function of et_3. The value obtained for et_2 is also a close approximation of its exact value. The first equation is then used to calculate an approximation for et_1 based on the approximate values of et_2 and et_3. If more accuracy is desired, another pass may be made through the equations. That is, the approximations calculated for et_1 and et_2 can be substituted back into the foregoing equations, and the process repeated for several iterations, where each iteration provides an increase in accuracy. In practice, four iterations through the equations resulted in 16 digit accuracy for et_1, et_2 and et_3. Once these values are determined, values for the transition times t_1, t_2 and t_{end} can be calculated using the equations shown above.

The iterative solution presented above for determining switch times will converge faster for better initial guesses of et_1 and et_2. On short moves especially, convergence can be slow if initial guesses for et_1 and et_2 are not good. Accordingly, there exists a need for a way to provide a good initial guess. One such technique is to tabulate solutions for a range of short moves. Such a table may be then used to obtain a good guess, e.g., by looking-up a guess or by interpolation. Alternatively, a curve can be fit to solutions for a range of short moves, and initial guesses determined based on the curve. For example, it has been determined experimentally that a first switch time is a monotonically increasing function of move distance. Curves for other switch times can be determined in a similar manner.

The foregoing techniques for determining switch times can be expanded to include parameters other than just movement distance. For example, if resistance change is to be included in the solution, an initial guess for a switch time value can be determined based on both movement distance and resistance. Any number of system parameters can be used in this manner to determine an initial guess. In such cases, the initial guess can be determined based on a multidimensional table which includes these parameters, or computed using an empirically generated function. Switch times can also be generated by taking into account system parameters in addition to those set forth above. In such cases, conservative parameters may be used so that the actual system will move faster than the theoretical model on which the switch times are based. That is, in this case, the feedback will scale back the output voltage and the system will almost never be commanded past saturation.

As an alternative to the above approaches which rely on an initial guess, short move solutions can be determined based on the partial fraction expansion equations. Specifically, the exponential terms of the partial fraction expansion equations can be expressed in series form. The equations can then be solved for the short move solutions to the switch time problem.

A hardware implementation of this embodiment of the invention may be dictated by the design of many disk drive controllers. Specifically, in such disk drive controllers, the update rate of a processor in the controller is not fast enough to output voltages at precise desired time intervals. Accordingly, a hardware solution may be implemented, in which each next switch time is loaded into a hardware counter chip and a high frequency clock counts intervals until the desired switch time is achieved. At such time, the output of the counter chip changes and the new voltage value is output to the disk drive system.

Still another alternative to the forgoing method for determining switch times for a system input is provided in U.S. Provisional Application No. 60/076,951, entitled "Creating Time-Optimal Commands For Linear Systems", filed on Mar. 5, 1998 and its corresponding national application filed concurrently herewith. The contents of these two applications are hereby incorporated by reference into the subject application as if set forth in full.

7.0 Shaping™ Near or Beyond Nyquist

As noted above, control techniques in which trajectory is specified as a function of time involve determining an input which will generate a good move. As also noted above, this input may be determined using any other techniques, such as Input Shaping™, filtering, etc. In addition to these techniques, the present invention also provides a technique for shaping inputs having frequencies near or beyond the nyquist frequency. Shapers™ used to perform this shaping are referred to herein as "NBN"Shapers™.

Systems that use discrete time or digital control face a fundamental limitation due to the effects of sampling. That is, the sampling theorem states that any frequencies greater than the sampling frequency (or Nyquist frequency) will be aliased to other frequencies. Therefore system feedback control cannot suppress vibrations that are at a frequency greater than the Nyquist frequency. Because Input Shaping™ is a feedforward technique, it does not have this same limitation. Input Shapers™ can be designed to suppress vibrational frequencies that are near, or even well above, the Nyquist frequency. This section will demonstrate how to design Input Shapers™ which limit vibrational frequencies that are near or above the Nyquist frequency.

As background, disk drives systems with embedded servo information have a maximum position update rate that is determined by the density of the servo information and the drive's rotation speed. To demonstrate the difficulty in solving for an Input Shaper™, an example drive is presented. Assuming that the servo information on such a disk drive is updated at 5 KHz, and the drive's first resonant mode is at 2 KHz, only 2+ servo cycles exist for each vibrational cycle. This presents a computational problem. That is, only 2 unknowns exist per servo cycle and there are many more constraints to be solved (at a minimum no vibration constraints, among others). Accordingly, the problem is over-constrained.

However, more than one cycle can be used to solve for a system input. By expanding the number of unknowns until the problem becomes solvable, a solution can be obtained. Solutions obtained are unusual because they take more than one cycle of vibration to reduce vibrations to an acceptable level. Additionally, careful attention must be paid to insensitivity constraints because NBN solutions will be less sensitive than conventional solutions since fewer cycles of vibration are allowed to occur before cancellation. An alternative to this approach is to use an output or feedforward command rate that is different from the servo rate. This technique is presented in section 7.1 below.

The basic principle of the NBN shaper can be understood by examining the design of a three pulse shaper for a continuous system with zero damping. If we assume that the system is continuous, the shaper impulses can occur at exact times. When the damping ratio is zero, the amplitudes of the impulses for a three pulse shaper are [0.25 0.50 0.25]; the first pulse occurs at time zero, the second pulse at one half period of Vibration, and the third pulse at one period of vibration. FIG. 32 shows a plot of the impulses of the three pulse shaper along with a sine wave representative of the undamped vibration. The combined plot shows the phasing of the impulses relative to the sine wave. In the continuous case, the pulses occur at the times shown in FIG. 32. In the

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digital case, the pulses are constrained to occur at integer multiples of the sample period, i.e. at the sample times. If the sample period is much shorter than the vibration period, then each of the shaper pulses can be split between the nearest sample times to achieve the same effect.

The Nyquist rate is equal to one half the sample rate and represents the lowest frequency that can be sampled by a digital system without alias. Thus, vibration occurring at the Nyquist rate is just at the theoretical limit of what input can be processed by a digital system without alias, and results in two sample points per sine wave period. Two sample points per period is exactly the ideal spacing for a three pulse shaper. FIG. 33 shows a plot of the digital pulse spacing for a three pulse shaper where the digital sample rate (4 KHz) results in the Nyquist rate (sample_rate/2=2 KHz) being equal to the vibration frequency (2 KHz). Thus, the three pulse shaper is easily implemented to attenuate frequencies at the Nyquist rate.

It is well known that vibration with frequency in excess of the Nyquist rate cannot be sampled by a digital system without aliasing, and that therefore a closed-loop digital sampled data system cannot use closed-loop control techniques to attenuate vibration at high (beyond Nyquist rate) frequency. However, the open-loop (feedforward) shaping technique can be applied to attenuate vibration at frequency well beyond the Nyquist rate. Shown in FIG. 34 is the pulse spacing for a three pulse shaper and a sine wave representative of vibration. The combined plot shows the timing of the shaper pulses relative to the phasing of the sine wave. The frequency of vibration is again 2 KHz, the sample rate for this example is 1.333 KHz, and the associated Nyquist rate is 1.333 KHz/2=0.666 KHz. The frequency of vibration is well in excess of the Nyquist rate (2 KHz/0.666 KHz=3) for this case.

Examination of the phasing of the sine wave relative to the timing of the shaper pulses reveals the same relation for the sub-Nyquist rate example as for the Nyquist rate example. That is, the first shaper pulse occurs at 0°, the second shaper pulse occurs at 180° and at each 360° thereafter, and the third shaper pulse occurs at 360° and at each 360° thereafter. Since the sine wave phase repeats each 360°, the superposition of responses yields the same result in both cases. It should be noted that the sub-Nyquist rate shaper will be more sensitive to errors in the vibration frequency estimate. The increased sensitivity is due to the fact that as more periods of vibration elapse between pulses, larger errors in phase (for a given error in frequency) will accumulate.

7.1 Effect of the Rate of Command Output

The rate that is chosen for issuing digital commands to the system is extremely important. A rate should be chosen that makes sense for the particular system being considered. In some cases, this rate is simply the servo rate of the control system. However, for disk drives, this rate must usually be higher because of the restrictions imposed by the use of embedded servo information for control. For systems in which the highest frequency of vibration to be suppressed is considerably lower than the servo rate, the servo rate is adequate for use as an output rate. For systems such as those considered in section 7.0 (such as most disk drives), the rate must be higher.

One approach is to send output commands to the system at a multiple of the servo rate. In this formulation, the output to the physical system might be performed at two, three, or more times the rate of the servo. In our example system, the servo rate is 5 KHz. The highest mode to be suppressed is 2 KHz. If the output to the system is performed at triple the servo rate (15 KHz), there are over seven digital outputs per vibration cycle; therefore, the shaping formulations become simple. Several possible architectures can be considered. Two possibilities are presented below.

In the first example, there is a separate output path from the controlling computer chip to the hardware for feedforward purposes. An example of this is a disk drive in which a voltage command can be fed forward directly to the amplifier while current commands are output by the closed-loop servo. In order to actually implement this, the following steps must be performed. At the servo rate (5 KHz), these steps comprise reading the sensors, executing the servo calculations, computing the servo output, and outputting this value to the servo output channel. At the higher rate (15 KHz), these steps comprise computing or looking-up the next trajectory value, executing the shaping method (if the correction for unwanted dynamics is not already included in the trajectory), and outputting the feedforward term to the feedforward output channel.

In the second example, there is only a single output path from the controlling computer chip to the hardware. An example of this is a disk drive in which a current is the output generated by the closed-loop servo and current is also used in the feedforward term. In order to actually implement this, the following steps are performed. At the servo rate (5 KHz), these steps comprise reading the sensors, executing the servo calculations, computing the servo output, and saving this value for use by the section below. At the higher rate (15 KHz), these steps comprise computing or looking up the next trajectory value, executing the shaping method (if the correction for unwanted dynamics is not already included in the trajectory), and adding the feedforward term to the feedforward term to the servo output computed above.

There are many related configurations which either combine the above two approaches or are variations of these approaches. One such variation uses continuous or near continuous time outputs from the feedforward term. If the control hardware for a disk drive or any other machine is constructed so that outputs can be scheduled in time, the feedforward outputs can run essentially asynchronously from the servo loop. In one such implementation, the voltages to the disk drive might be updated by a circuit at a high clock rate (e.g., 2 MHz). By loading a counter register with the time of the next voltage output, the hardware circuit can count down until the appropriate time and output the next voltage value. This enables an optimized trajectory to be computed using any of the techniques herein (or by any other process), and to be output at a rate sufficiently high so that the system can be commanded to move in an optimized (or near optimized) fashion without effecting the servo rate.

An additional variation on the approaches presented herein is to use one of the shaped switched formulations so that only full scale voltages (or any other parameter) are output. For example, it is possible to use unity magnitude Shapers™ to take a switching voltage command signal designed only for a rigid body system, and to modify the switching voltage command signal so that the switching voltage command signal moves the system with little vibration. This approach enables the circuit to become a simple counter driven switch that changes its output at a preset time.

A further variation is to use an interrupt-driven approach in which times to output values are scheduled and an interrupt is generated (using state of the art computer techniques) at the appropriate time. At the time of the interrupt, an appropriate output (or voltage switch) is provided by the controller chip or other device. Single or multiple hardware timers may be used to interrupt a DSP or

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microcontroller in the disk drive. Still another variation is to use a separate device, such as a programmable logic array, that is issued a single command which, in turn, generates a series of precisely-timed commands to the current loop. The DSP or microcontroller can be programmed in an asynchronous control loop that maintains a list of switch times and required transitions.

8.0 PV Approach

A PV table comprises a trajectory curve which defines the velocity of a system component, such as head **76**, in terms of that component's position, i.e., the distance that the component has yet to go in order to reach its final position. To use a PV table, an actual position of the component is compared to its desired position. The difference between these two values is then used to look up a velocity in the PV table for the component. Many disk drive systems rely on a PV table to determine their inputs. These inputs, however, can result in unwanted vibrations in the system. The techniques presented below can be used to reduce and/or limit such vibrations.

This aspect of the invention is a method of generating a trajectory for inclusion in a PV table which is used in controlling movement of a component in a dynamic system. The method generates a trajectory in accordance with a technique for reducing unwanted dynamics of the component, i.e., generating a good move. The trajectory is then stored in the PV table, and the component is controlled to move along the trajectory stored in the PV table.

In more detail, a good move is generated for the system using any of the techniques described in section 5 above. Specifically, the system is modeled, a "good" input is applied to the system, and the system's reaction to the good input is stored in a PV table as a trajectory for the system. In this manner, good moves can be re-cast into a PV table for a system, thereby providing a way to reduce unwanted system dynamics while staying within a PV formulation. Taking this approach one step further, a series of good moves can be generated using this technique, and the series of good moves can be stored in a series of parameterized PV tables.

9.0 PV Feedback Approach

In prior art disk drive systems, the velocity determined from a PV table is merely fed forward into the system, as shown, for example, in the conventional disk drive system diagram depicted in FIG. **13**. This could lead to unwanted system vibrations. This aspect of the invention, however, shapes the velocity before it is provided to the system and, in addition, performs inverse shaping in the system's feedback loop, thereby correcting the feedback so as not to co-opt the operation of the PV table.

FIG. **14** shows an example of a system diagram for a disk drive that is controlled in accordance with this aspect of the invention. The disk drive includes PV table **84**, shaper **86**, and inverse shaper **87**. Shaper **86** is placed in the feedforward loop following PV table **84** so as to shape the velocity output therefrom. Inverse shaper **87**, which comprises the inverse of shaper **86**, is placed in the feedback loop. The relationship between inverse shape **87** and shaper **86**, in either the time domain or the frequency domain, is as follows:

if shaper=A/B, then shaper^{-1}=B/A.

The combination of shaper **86** and inverse shaper **87** reduce unwanted system dynamics, such as vibrations of head **76**. Specifically, shaper **86** alters the velocity input to the system so as to reduce vibrations in head **76** resulting from system movement, and inverse shaper **87** operates to restore loop stability to what it was prior to insertion of the shaper **86** in the forward loop. Shaper **86** and inverse shaper **87** are not limited to the Input Shapers™ and inverse Input Shapers™ described in U.S. Pat. Nos. 4,916,635 and 5,638,635. In fact, shaper **86** and inverse shaper **87** can be any pole-zero dynamic block, IIR filter, FIR filter, tapped continuous delay line filter, or the like.

FIGS. **15** and **16** show relationships between inputs and outputs of a shaper ("IS") and inverse shaper ("IS^{-1}"), respectively, formed using an FIR filter, with A as the input. Specifically, relationships between the inputs and outputs of IS and IS^{-1} are as follows:

$$y_n = \sum_{i=0}^{N} A_i x_{n-i} \tag{43}$$

$$x_n = \frac{y_n}{A_0} - \frac{1}{A_0}\sum_{i=1}^{N} A_i x_{n-i}$$

FIGS. **17** and **18**, show relationships between inputs and outputs of a shaper and an inverse shaper ("IS^{-1}"), respectively, which are formed using a tapped continuous delay line filter. Specifically, relationships between inputs and outputs of IS and IS^{-1} are as follows:

$$y(t) = A_0 x(t) + \sum_{i=1}^{N} A_i x(t - T_i) \tag{44}$$

$$x(t) = \frac{1}{A_0} y(t) - \frac{1}{A_0}\sum_{i=1}^{N} A_i x(t - T_i)$$

FIGS. **19** and **20**, show relationships between inputs and outputs of a shaper ("IS") and an inverse shaper ("IS^{-1}"), respectively, which are formed an IIR filter. Specifically, relationships between inputs and outputs of IS and IS^{-1} are as follows:

$$y_n = \frac{1}{B_0}\sum_{i=1}^{N} A_i x_{n-i} - \frac{1}{B_0}\sum_{j=1}^{M} B_j y_{n-j} \tag{45}$$

$$x_n = \frac{1}{A_0}\sum_{j=0}^{M} B_j y_{n-j} - \frac{1}{A_0}\sum_{i=1}^{N} A_i x_{n-i}$$

To summarize, this aspect of the invention is directed to a method and corresponding apparatus for using a PV table to control a component, such as head **76**, in a dynamic system, such as disk drive **10**. The invention generates a position variable for the component and determines a velocity command for the component using the PV table, where the velocity command is determined based on the position variable. The velocity command is then shaped using an Input Shaper™ or the like in order to generate a shaped velocity command, whereafter the component is controlled to move based on the shaped velocity command. In the invention, a preset position of the component is compared to a measured position of the component in order to determine the position variable, and inverse shaping is performed on the measured position prior to comparing the measured position to the preset position.

10.0 N-Dimensional PV Table

The present invention also provides an enhanced PV table which may, or may not, be used in connection with the foregoing feedback approach and the foregoing techniques for generating good moves. As background, the same PV

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table may not produce accurate results for different distance moves, among other things. To address this problem, conventional disk drive systems typically include one, two or maybe even three PV tables, i.e., one table for short moves, one table for medium-distance moves, and one table for long moves. Which table is selected depends upon the distance of the desired move. Since only three discrete values are provided for the movement distance, the system may not reach its final destination as quickly as desired.

The present invention provides a better approach, namely to generate an N-dimensional (N>2) PV table in which velocity is a function of position and a function of a third (fourth, fifth, etc.) variable, such as movement distance, resistance, temperature, etc. This approach effectively provides increased movement speed, since the requested velocity values more closely represent physical limitations of the disk drive for substantially all movement distances. Moreover, this approach makes more sense than the conventional formulation, especially in the disk drive area, since disk drive systems are third order in nature and a conventional PV approach is second order in nature. Although the present invention may use a PV table having any number N (N>2) of dimensions, for the sake of simplicity, the examples provided herein refer usually to a three-dimensional PV table.

In order to determine trajectories for a PV table, a dynamic model of the system must be determined. An example of such a model is partial fraction expansion equations 19. A system input, which is a function of time and which will move the model a desired distance, is then generated based on the model. For example, the system input may consist of a series of switch times and voltage levels, or a digital sequence of voltage levels. The input, in conjunction with the system model, is used to simulate the desired motion of the system. Any form of the model that yields both a position and a velocity output is suitable. As an example, the third order voltage-to-position transfer function

$$H(s) = \frac{A}{s} * \frac{a}{s+a} * \frac{b}{s+b} \quad (46)$$

could be transformed and manipulated so that position and velocity are available as outputs. Using the commutative property of multiplication, the transfer function can be rearranged and then broken up to yield a "block diagram" with voltage input and position and velocity outputs as follows:

$$\text{Voltage} \rightarrow A \rightarrow \frac{a}{s+a} \rightarrow \frac{b}{s+b} \rightarrow \text{Velocity} \quad (47)$$

$$\text{Velocity} \rightarrow \frac{1}{s} \rightarrow \text{Position}$$

The above "block diagram" is then used as the basis of a computer simulation that yields the velocity and position outputs corresponding the voltage input. The integration is performed forward in time. If both the form of the input (e.g. three switch times and three voltage levels) and the model are simple, then direct analytical solution of the system model to time domain equations can be used as an alternative approach to simulation. The velocity, and position outputs of the simulation are then tabulated to form one version of the PV table.

The present invention enables three approaches to PV table generation. First, a shaped input can be integrated forward to generate a PV table—in the above block diagram a shaper would be inserted following the voltage input. Second, an unshaped input can be integrated forward and an output of the integration can be shaped and stored in a table. Third, a vibration-reducing trajectory can be computed using a constraint-based approach, this input can be integrated forward, and the output thereof stored in a table. Prior to the derivation of the partial fraction expansion equations shown above, there was no way to generate an input that was guaranteed to get the system to its final destination; therefore forward integration was not a viable approach. Reverse integration from a final condition was commonly used.

Using the generated input, system outputs are then determined over time so as to generate values of position as a function of time and velocity as a function of time. These values are then re-cast as velocity as a function of position. To generate a three-dimensional PV table, the above process is repeated for the third variable in order to generate velocity as a function of both position and the third variable. The process may then be repeated for additional variables.

Since a three-dimensional PV table may require large amounts of memory space, and therefore may not be practical in all circumstances, the present invention provides several ways in which to approximate operation of a three-dimensional PV table using a series of PV trajectories. For example, the invention generates a series of PV trajectories for various movement distances, stores these trajectories, and selects trajectories corresponding to a desired movement distance while ignoring all other trajectories. Thus, in this case, one of the series trajectories is selected from the position-velocity table based on the desired movement distance and the system is controlled accordingly.

Another way to approximate a three-dimensional PV table is to perform curve fitting on a series trajectories in a PV table, such as those shown in the PV table of FIG. 21. With regard to FIG. 21, it is noted that, in the realm of computer disk drives, an actual target velocity is typically not included in the PV table. Instead, a velocity command, comprising a target velocity plus an additional term relating to the actuator arm's effort to stay on track, is included in the PV table. With regard to curve fitting, since the curves shown in FIG. 21 are substantially regular, it is possible to parameterize the curves and to generate a function which can be used to generate a single PV trajectory to control the system.

FIG. 22 shows examples of parameterized curves which were generated from the curves shown in FIG. 21. For the example shown in FIG. 22, an estimate of curves between the lowest (3000) and the highest (100) curve could be obtained by taking a weighted average of the lowest and highest curves based on movement distance. Consequently, in this example, an entire series of curves can be estimated by taking a weighted average of only two curves and using original movement distance to adjust the weights in the weighted average. Another way to approximate a three-dimensional PV table is to generate a custom PV table for each movement distance in real-time. This can be done using the system equations 19 for a computer disk drive set forth in section 4 above.

It is also possible to modify a series of trajectories in a PV table based on measurements of system parameter variations, such as variations in temperature, resistance, etc. This is done by estimating system parameters while motion is in progress, and determining whether the system parameters have varied from predetermined system parameters. Trajectories in the PV table are then modified based on any determined system parameter variations, whereafter the modified trajectories are stored in the PV table. Any method

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of estimating the system parameters may be used in connection with the present invention, including a conventional parameter estimator. For example, as a disk drive heats up, resistance therein changes. By looking at prior move responses, it is possible to estimate the resistance, to determine whether the resistance has changed, and to recalculate the drive's PV table, if necessary.

More specifically, in a disk drive system, during a first part of a move, the system is in saturation and, therefore, the PV table is inactive. This corresponds to issuing a step command in voltage to accelerate movement as rapidly as possible. During this acceleration phase, the actual current flowing through a voice coil motor used to convert electrical energy to mechanical energy can be measured. Knowing this, it is possible to perform an energy balance calculation to determine energy losses in the system due to resistance. The energy lost due to resistance equals the energy input to the disk drive minus kinetic energy of the voice coil motor minus energy stored in the voice coil inductor. This determination is made assuming that the inertia of the voice coil motor and the inductance of the voice coil are known or can be determined.

In real-time, the following steps are performed in order to estimate resistance: (i) for each time step, measure the actual current and the actual voltage applied to the drive's voice coil motor, (ii) integrate power in the drive (determined by multiplying voltage by current) over time to determine the total energy input to the system, (iii) calculate the instantaneous kinetic energy of the voice coil motor, (iv) calculate the instantaneous energy in the motor inductance, (v) calculate the integral of drive current squared over time, (vi) determine the estimated resistance by subtracting, from the energy input, the kinetic energy and the energy in the inductor divided by the integral of the current over time. Thus, after each integration, an estimated resistance for the disk drive is calculated. This can then be used to update the PV table.

Similar energy of momentum balance equations can be used to estimate other system parameters. For example, the following equation can be used to estimate motor torque:

$$K_t = \frac{J\Omega}{\int i dt}. \quad (48)$$

This equation can be solved in real-time, and can be solved over a whole move or incrementally starting at any time during the move.

The foregoing techniques for generating PV tables can be calculated off-line, thereby making it possible to parameterize or curve-fit PV tables as a function of system parameters as well as movement distance. Consequently, it is then possible to retrieve a PV table based on movement distance and system parameters. Moreover, it is noted that an N-dimensional PV table can be used outside of the context of the vibration reduction methods described herein, and that a non-dimensional PV table can be used in connection with all aspects of the present invention. A non-dimensional PV table comprises a PV table in which the independent variable on the X-axis of the PV table has been scaled using a predetermined scaling factor. Such a factor may be, for example, a maximum number of tracks moved, or the like.

11.0 Shape on Transient ("SHOT")

Conventional implementations of the PV approach to controlling a disk drive encompass variations of the following steps: (i) ramping the current command to saturation (various techniques are used for this); (ii) commanding full, saturated current until some braking condition is satisfied, (iii) transitioning to full, saturated deceleration until the PV curve is crossed; (iv) following the PV curve until the drive is close to the final destination; and (v) turning on a terminal controller to bring the system on track. The preponderance of vibration, both mechanical and acoustic, is created by the sudden transitions at the beginning and middle of the PV move. Consequently, Input Shaping™ (or any other vibrationreducing technique) need be applied to only these portions of the trajectory.

A new sequence of operations, using SHOT, is as follows: (i) Input Shape™ the current command to saturation; (ii) command full, saturated current until some braking condition is satisfied; (iii) Input Shape™ the transition to full, saturated deceleration until the PV curve is crossed; (iv) follow the PV curve until the drive is close to its final destination; and (v) turn on a terminal controller to bring the system on track. Since the transitions to saturation are both just steps, the shaped transitions become shaped steps (or staircases).

Shaping can be rendered less effective if the input results in saturation and the command generator is unaware of the saturation. There are several methods for dealing with this situation. It is possible to command the system into saturation using estimates of when saturation should occur based on previous moves. For example, by estimating the maximum voltage and the coil resistance (or the quotient of maximum voltage/coil resistance) the maximum current in saturation can be obtained. Once the system is shaped into saturation, the saturation current can be calculated by measuring the acceleration and the velocity, since current is related to acceleration by a constant and the effective voltage is the saturation voltage minus the back EMF constant times the velocity.

Based on these calculations, it is possible to compute the actual saturation level. It is then important to command only enough of an input to keep the system in saturation and not exceed this level by too great of a value. If this value is exceeded by a considerable amount, the shaping that is applied when the command is reversed to slow the system down will be "chopped-off" at the beginning. For example, if an output command of 5 volts from a DAC will saturate the current amplifier in steady state at the current velocity, then a command of 6 volts would be undesirable. During the transition to deceleration, if this error is left uncorrected, the shaper will reduce the voltage to, e.g., 5.5 volts as the first part of the shaping process, yet the amplifier will remain saturated. Therefore, the effect of shaping is degraded.

While the SHOT technique is well suited for adding to the PV approach, it is by no means limited to PV. Any method of commanding a disk drive to move that causes significant transitions in the command to the system is a candidate for SHOT. The user need simply use shaped transitions instead of sudden or ramped transitions. The key to this approach is that while sudden transitions cause vibrations and noise, and smooth transitions often cause vibrations and noise (although less so than sudden transitions); shaped transitions can be constructed to yield any level of vibrations and noise. This makes the use of shaped transitions desirable because the effects are predictable and the move is lengthened by the minimum amount. SHOT can also be used for transitions caused by sudden gain changes as well as command changes. In this application, the gain is altered in a shaped manner from one level to another using any one of the shaping techniques described herein or from the literature.

12.0 Conclusion

At this point, it is reiterated that all aspects of the present invention can be implemented in hardware, software or a

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combination of thereof. Moreover, although the invention has been described in the context of computer disk drives, it may apply equally to other types of data storage devices (of which a computer disk drive is one), including, but not limited to, optical drives, tape drives, dual-actuated disk drives, and holographic storage devices which read from, and write to, data storage media other than magnetic disks.

The present invention has been described with respect to particular illustrative embodiments. It is to be understood that the invention is not limited to the above-described embodiments and modifications thereto, and that various changes and modifications may be made by those of ordinary skill in the art without departing from the spirit and scope of the appended claims.

What is claimed is:

1. User interface for operatively working with a processor to affect operation of a data storage device, the user interface comprising:

means for providing settings for controlling one of a seek time of the data storage device and an acoustic noise level of the data storage device in inverse relation;

means for indicang to the data storage device that one of the seek time settings of the data storage device and the acoustic noise level settings of the data storage device has been altered; and

means for causing the processor to output commands to the data storage device to alter seek trajectory shape by shaping input sigals to to the data storage dice to reduce selected unwanted frequencies from a plurality of frequencies in accordance with the altered settings in the user interface.

2. A user interface according to claim 1, comprising a sliding bar which moves along a continuum on which data storage device acoustic noise level and seek time vary inversely, the continuum including a first end comprising a high acoustic noise level/low seek time and a second end comprising a low acoustic noise level/high seek time.

3. A user interface according to claim 1 further comprising a display area which displays discrete values corresponding to the acoustic noise level and/or the seek time of the data storage device.

4. A user interface according to claim 1 comprising discrete values which are selectable to alter the acoustic noise level and/or the seek time of the data storage device.

5. A user interface according to claim 1 wherein settings in the user interace override previous settings in the data strage device.

6. A user interface according to claim 1 further comprising a preview setting, the preview setting causing the data storage device to operate an acoustic noise level set in the user interface.

7. A method of controlling operation of a data storage device, comprising:

generating a user interface, the user interface controlling one of a seek time of the data storage device and an acoustic noise level of the data storage device;

altering settings in the user interface for one of the seek time and the acoustic noise level of the data storage device in inverse relation; and

outputting commands to the data storage device to alter seek trajectory shape by shaping input signals to the data storage device to reduce selected unwanted frequencies from a plurality of frequencies in accordance with the altered set in the user interface.

8. Computer-executable process steps stored on a computer-readable medium, the computer-executable process steps to control operation of a data storage device, the computer-executable process steps comprising:

code to generate a user interface, the user interface controlling one of a seek time of the data storage device and an acoustic noise level of the data storage device;

code to alter settings in the user interface for one of the seek time and the acoustic noise level of the data storage device in inverse relation; and

code to output commands to the data storage device causing the data storage device to alter seek trajectory shape by shaping input signals to the data storage device to reduce selected unwanted frequencies from a plurality of frequencies in accordance with the altered settings in the user interface.

9. Apparatus for controlling operation of a data storage device, the apparatus comprising:

a memory which stores computer-executable process steps; and

a processor which executes the process steps so as (i) to generate a user interface, the user interface controlling one of a seek time of the data storage device and an acoustic noise level of the data storage device, (ii) to alter settings in the user interface for one of the seek time and the acoustic noise level of the data storage device in inverse relation, and (iii) to output commands to the data storage device causing the data storage device to alter seek trajectory shape by shaping input signals to the data storage device to reduce selected unwanted frequencies from a plurality of frequencies in accordance with the altered settings in the user interface.

10. Method of controlling operation of a data storage device, comprising:

providing a user interface for controlling one of a seek time of the data storage device and an acoustic noise level of the data storage device;

operating the user interface so as to alter settings of one of the seek time and the acoustic noise level of the data storage device in inverse relation; and

outputting commands to the data storage device causing the data storage device to alter seek trajectory shape by shaping input signals to the data storage device to reduce selected unwanted frequencies from a plurality of frequencies in accordance with the altered settings.

11. A disk drive operatively controlled by a user interface, said user interface providing settings capable of altering one of a seek time of the disk drive and acoustic noise level of the disk drive in inverse relation, and indicating to the disk drive that one of the seek time settings of the disk drive and the acoustic noise level settings of the disk drive has been altered, the disk drive comprising:

means for performing a seek operation, the seek operation generating a plurality of frequencies; and

means for outputting commands to alter seek trajectory shape by shaping input signals to the means for performing the seek operation to reduce selected unwanted frequencies from said plurality of frequencies in accordance with the altered settings in the user interface.

12. The disk drive of claim 11 wherein the user interface comprises discrete values which are selectable to alter the acoustic noise level and/or the seek time of the disk drive.

13. The disk drive of claim 11 wherein a setting in the user interface overrides a previous setting.

14. Computer-executable process steps stored on a computer-readable medium, the computer-executable pro-

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cess steps to control operation of a data storage device, the computer-executable process steps comprising:

code providing a user interface for controlling one of a seek time of the data storage device and an acoustic noise level of the data storage device;

code to operate the user interface so as to alter settings for one of the seek time and the acoustic noise level of the data storage device in inverse relation; and

code to output commands to the data storage device to alter seek trajectory shape by shaping input signals to the data storage device to reduce selected unwanted frequencies from a plurality of frequencies in accordance with the altered settings in the user interface.

15. Apparatus for controlling operation of a data storage device, The apparatus comprising:

a memory which stores computer-executable process steps; and

a processor which executes the process steps to control, through a user interface, one of a seek time of the data storage device and an acoustic noise level of the data storage device, so as to alter settings in the user interface for one of the seek time and the acoustic noise level of the data storage device in inverse relation, and to output commands to the data storage device causing the data storage device to alter seek trajectory shape by shaping input signals to the data storage device to reduce selected unwanted frequencies from a plurality of frequencies in accordance with the altered settings.

* * * * *

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UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 6,314,473 B1
DATED : November 6, 2001
INVENTOR(S) : Singer et al.

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

Column 3,
Line 18, delete the word "a" between the words "partial" and "fraction";

Column 29,
Line 28, the word "ad" should be change to -- a_d --;

Column 30,
Line 44, the word "defines" should be changed to -- defining --;

Column 43,
Line 22, the word "indicang" should be changed to -- indicating --;
Line 28, the word "sigals" should be changed to -- signals -- and the word "dice" should be changed to -- device --;
Line 46, the word "interace" should be changed to -- interface --;
Line 47, the word "strage" should be changed to -- storage --;
Line 50, insert the word -- using -- between "operate" and "an";
Line 65, change the word "set" to -- settings --;

Column 45,
Line 16, change the word "The" to -- the --.

Signed and Sealed this

Twenty-third Day of April, 2002

Attest:

Attesting Officer

JAMES E. ROGAN
Director of the United States Patent and Trademark Office

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(12) EX PARTE REEXAMINATION CERTIFICATE (6547th)
United States Patent
Singer et al.

(10) Number: US 6,314,473 C1
(45) Certificate Issued: Dec. 2, 2008

(54) **SYSTEM FOR REMOVING SELECTED UNWANTED FREQUENCIES IN ACCORDANCE WITH ALTERED SETTINGS IN A USER INTERFACE OF A DATA STORAGE DEVICE**

(75) Inventors: **Neil Singer**, Armonk, NY (US); **Mark Tanquary**, Needham, MA (US); **Kenneth Pasch**, North Eastham, MA (US)

(73) Assignee: **Convolve, Inc.**, New York, NY (US)

Reexamination Request:
No. 90/008,354, Dec. 1, 2006

Reexamination Certificate for:

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Filed:	Mar. 4, 1999

Certificate of Correction issued Apr. 23, 2002.

Related U.S. Application Data

(60) Provisional application No. 60/109,145, filed on Nov. 20, 1998, and provisional application No. 60/077,292, filed on Mar. 5, 1998.

(51) **Int. Cl.**
G11B 5/55 (2006.01)

(52) **U.S. Cl.** 710/5; 318/560; 360/73.01; 360/75; 360/78.07

(58) **Field of Classification Search** 710/5; 318/560; 360/75
See application file for complete search history.

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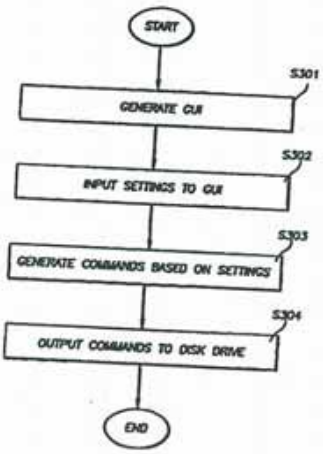
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Primary Examiner—Fred Ferris

(57) **ABSTRACT**

Techniques are provided herein for reducing vibrations in various modes of a dynamic system. One such technique comprises incorporating vibration limiting and sensitivity constraints into a partial fraction expansion equation model of the system so as to reduce vibrations to specific levels. Another technique comprises shaping a command determined using the partial fraction expansion equation model to produce a desired output. The entire command may be shaped or only selected portions thereof which produce vibrations. Another technique involves commanding in current to produce saturation in voltage. By doing this, it is possible to command voltage switches. The times at which the switches occur can be set to reduce system vibrations. Other techniques are also provided. These include varying transient portions at the beginning, middle and/or end of a move and using Posicast inputs, among others.



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EX PARTE REEXAMINATION CERTIFICATE ISSUED UNDER 35 U.S.C. 307

THE PATENT IS HEREBY AMENDED AS INDICATED BELOW.

Matter enclosed in heavy brackets [ ] appeared in the patent, but has been deleted and is no longer a part of the patent; matter printed in italics indicates additions made to the patent.

AS A RESULT OF REEXAMINATION, IT HAS BEEN DETERMINED THAT:

The patentability of claims **11–13** is confirmed.

Claims **1, 3, 4, 7–10, 14** and **15** are determined to be patentable as amended.

Claims **2, 5** and **6** were not reexamined.

1. User interface for operatively working with a processor to affect operation of a data storage device, the user interface comprising:

means for providing settings for controlling one of a seek time of the data storage device and [an] *a seek* acoustic noise level of the data storage device in inverse relation;

means for indicating to the data storage device that one of the seek time settings of the data storage device and the *seek* acoustic noise level settings of the data storage device has been altered; and

means for causing the processor to output commands to the data storage device to alter seek trajectory shape by shaping input signals to the data storage device to reduce selected unwanted frequencies from a plurality of frequencies in accordance with the altered settings in the user interface.

3. A user interface according to claim **1** further comprising a display area which displays discrete values corresponding to the *seek* acoustic noise level and/or the seek time of the data storage device.

4. A user interface according to claim **1** comprising discrete values which are selectable to alter the *seek* acoustic noise level and/or the seek time of the data storage device.

7. A method of controlling operation of a data storage device, comprising:

generating a user interface, the user interface controlling one of a seek time of the data storage device and [an] *a seek* acoustic noise level of the data storage device;

altering settings in the user interface for one of the seek time and the *seek* acoustic noise level of the data storage device in inverse relation; and

outputting commands to the data storage device to alter seek trajectory shape by shaping input signals to the data storage device to reduce selected unwanted frequencies from a plurality of frequencies in accordance with the altered settings in the user interface.

8. Computer-executable process steps stored on a computer-readable medium, the computer-executable process steps to control operation of a data storage device, the computer-executable process steps comprising:

code to generate a user interface, the user interface controlling one of a seek time of the data storage device and [an] *a seek* acoustic noise level of the data storage device;

code to alter settings in the user interface for one of the seek time and the *seek* acoustic noise level of the data storage device in inverse relation; and

code to output commands to the data storage device causing the data storage device to alter seek trajectory shape by shaping input signals to the data storage device to reduce selected unwanted frequencies from a plurality of frequencies in accordance with the altered settings in the user interface.

9. Appparatus for controlling operation of a data storage device, the apparatus comprising:

a memory which stores computer-executable process steps; and

a processor which executes the process steps so as (i) to generate a user interface, the user interface controlling one of a seek time of the data storage device and [an] *a seek* acoustic noise level of the data storage device, (ii) to alter settings in the user interface for one of the seek time and the *seek* acoustic noise level of the data storage device in inverse relation, and (iii) to output commands to the data storage device causing the data storage device to alter seek trajectory shape by shaping input signals to the data storage device to reduce selected unwanted frequencies from a plurality of frequencies in accordance with the altered settings in the user interface.

10. Method of controlling operation of a data storage device, comprising:

providing a user interface for controlling one of a seek time of the data storage device and [an] *a seek* acoustic noise level of the data storage device;

operating the user interface so as to alter settings of one of the seek time and the *seek* acoustic noise level of the data storage device in inverse relation; and

outputting commands to the data storage device causing the data storage device to alter seek trajectory shape by shaping input signals to the data storage device to reduce selected unwanted frequencies from a plurality of frequencies in accordance with the altered settings.

14. Computer-executable process steps stored on a computer-readable medium, the computer-executable process steps to control operation of a data storage device, the computer-executable process steps comprising:

code providing a user interface for controlling one of a seek time of the data storage device and [an] *a seek* acoustic noise level of the data storage device;

code to operate the user interface so as to alter settings for one of the seek time and the *seek* acoustic noise level of the data storage device in inverse relation; and

code to output commands to the data storage device to alter seek trajectory shape by shaping input signals to the data storage device to reduce selected unwanted frequencies from a plurality of frequencies in accordance with the altered settings in the user interface.

15. Apparatus for controlling operation of a data storage device, The apparatus comprising:

a memory which stores computer-executable process steps; and

a processor which executes the process steps to control, through a user interface, one of a seek time of the data storage device and [an] *a seek* acoustic noise level of the data storage device, so as to alter settings in the user interface for one of the seek time and the *seek* acoustic noise level of the data storage device in inverse relation, and to output commands to the data storage device causing the data storage device to alter seek trajectory shape by shaping input signals to the data storage device to reduce selected unwanted frequencies from a plurality of frequencies in accordance with the altered settings.

* * * * *

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U.S. DEPARTMENT OF COMMERCE
U.S. PATENT & TRADEMARK OFFICE

United States Court of Appeals for the Federal Circuit

CERTIFICATE OF SERVICE

2014-1732

I, Robyn Cocho, being duly sworn according to law and being over the age of 18, upon my oath depose and say that:

Counsel Press was retained by CADWALADER, WICKERSHAM & TAFT LLP, Attorneys for Plaintiff-Appellant to print this document. I am an employee of Counsel Press.

On **December 11, 2014**, Counsel for Appellant has authorized me to electronically file the foregoing **Corrected Brief of Plaintiff-Appellant** with the Clerk of Court using the CM/ECF System, which will send notice of such filing to the following registered CM/ECF users:

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Upon acceptance by the Court of the e-filed document, six paper copies will be filed with the Court, via Federal Express, within the time provided in the Court's rules. The brief was originally filed on December 10, 2104.

/s/ Robyn Cocho
Counsel Press

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