Magnetic and Optical Disk Control: Parallels and Contrasts

Daniel Abramovitch
Agilent Laboratories, Communications and Optics Research Lab,
3500 Deer Creek Road, M/S: 25U-9, Palo Alto, CA 94304
Phone: (650) 485-3806, FAX: (650) 485-4080, **E-mail: danny@labs.agilent.com**

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Abstract

The control of hard disks and the control of optical disks share many of the same features. However, these problems also have some fundamental differences which yield a very different set of problems for each. Recent efforts in each type of system can be seen in the context of trying to add in the best elements of the other. With this in mind, it is useful to examine these parallel problems in a tutorial fashion to understand what links and separates them and thus, when elements of one can be applied to the other.

1 Introduction

The control of hard disks and the control of optical disks share many of the same features. Both make use of spinning media to hold the data. Both make use of circular (or nearly circular spiral) tracks to encode the data. Both sets of problems include actuators that seek to a given track and then maintain the relative position in a track following mode while data is written or read. Many of the algorithms used in the control of one type of drive can be used in the other and many of the servo engineers who work on one type of drive have worked on the other. However, these problems also have some fundamental differences which yield a very different set of problems for each. These differences arise from both the physics of the problem and from the markets which drive the respective products.

Many of the recent efforts in the control loops of each type of system can be seen in the context of trying to add in the best elements of the other. With this in mind, it is useful to examine these parallel problems in a tutorial fashion to understand what links and separates them and thus, when elements of one can be applied to the other. From this it may be possible to predict where the technologies from one family of products will actually be useful in another.

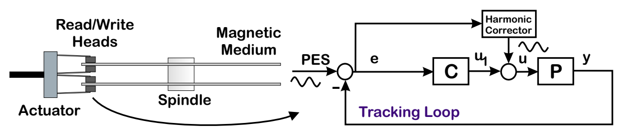

Figure 1: An overview of the magnetic hard disk servo problem.

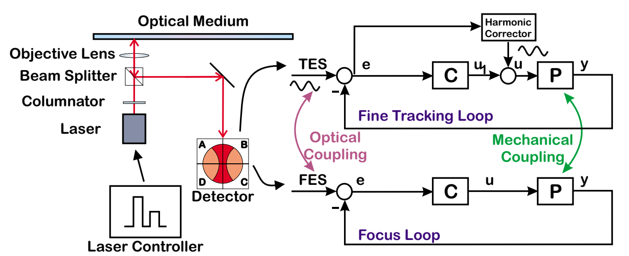

Figure 2: An overview of the removable optical disk servo problem.

The problem features of the optical and magnetic disk drive control problems are summarized in Table 1[1] . A block diagram for a typical hard disk servo problem is shown in Figure 1, while the optical servo problem block diagram is shown in Figure 2. One of the fundamental and pervasive differences between mainstream hard disk recording and mainstream optical recording is that the former is done in the near field and the latter is done in the far field. In the near field, the magnetic disk read/write head floats on an air bearing, a thin layer of air created by the spinning of the disk. As such the distance between the read/write head and the recording media is controlled with passive mechanics, negating the need for a focus loop. This in turn allows hard disk head manufacturers to shrink the size of the slider (the mechanical component containing the head) as well as the other mechanics. Thus, the main control loop in a hard disk is the

[1]Note that for the rest of this paper, the terms hard disk and magnetic disk are used interchangeably. This paper will not discuss flexible magnetic disks and will only briefly discuss near field optical recording.

	Hard Disk	**Optical Disk**
Media mechanics:	Multiple fixed disks	Single removable disk
Drive mechanics:	Excellent	Mediocre
Position Error Signals:	Mediocre SNR/Multiplexed with data	Excellent SNR/ Continuously available
Sample Rate:	Low/Medium	High
Vertical Position:	Air bearings: near field, no focus loop, multiple small heads	No air bearing: far field, focus loop,single large head
Tracking Loop:	Single medium-high frequency	Coarse (low freq.) and fine (high freq.)
Spindle loop:	low frequency	low frequency
Spindle mode:	Constant Angular Velocity (CAV)	Constant Linear Velocity (CLV) and CAV
Tracks:	circular	predominantly spiral, some circular
Applications:	Mostly random access	Mostly streaming files

Table 1: Summary of servo problem features

single, high frequency tracking loop.

On the other hand, mainstream optical drives, operating in the far field have no passive control of the distance between the read/write element and the recording media. Because of this, a vertical axis (focus) control must be applied. The size this device keeps the optical head large. Far field recording has limited the volumetric density of optical drives. Thus, optical recording has been most practical in situations where removable random access storage is important. The main control loops here are 3: a focus loop to ensure the distance between the objective lens and the media, a coarse (low frequency) tracking loop to roughly position the optical head assembly (called a sled) in the vicinity of the desired tracks, and a fine (high frequency) tracking loop to lock onto the track position.

To date, none of the attempts to apply optical recording technology to the hard disk market has been successful. Except where noted this article will restrict itself to the discussion of removable media optical storage which are far field devices.

A few more notes on the nature of this article are in order. In an attempt to stay true to a tutorial form, this article will tend to present material generally and schematically, rather than discuss a specific disk drive or set of results. The specific results will be in the reference set, which is available in an extracted bibliography of this document, available on-line [1].

2 Markets

As noted there have been several efforts over the years to replace hard disks with optical disks. To obtain the volumetric density needed to make this commercially successful, it is necessary to have multiple disks and smaller heads that fly in the near field. Unfortunately, the technical difficulties involved in doing this have doomed most efforts. The most recent examples were heavily funded startup companies with strong links to the magnetic recording industry, Quinta and Terastor. Terastor went out of business. Quinta was absorbed into Seagate. Hard disks have maintained their dominance of fixed volumetric storage while optical disks have dominated removable random access storage.

Because hard disks do not commonly deal with removable media they need only be standard at their interface to the computer (e.g. SCSI, IDE, or PCMCIA; more recently USB, IEEE 1394, and Fibre Channel). What happens inside the drive (modulo performance and reliability issues) is the designer's prerogative. On the other hand, while the optical disk drives must conform to similar computer interconnect standards, the optical media itself is made to be exchanged and are therefore based on standards. Thus, optical recording densities go up only when new standards are agreed upon and *not* simply when the technology is improved.

This has the interesting effect that patents are treated differently in the two fields. While cross licensing agreements with little or no exchange of money are the norm in the hard disk industry, the licensing of intellectual property for revenue is one of the chief business models for optical drive designers.

3 Spindle Control

Note that both optical and magnetic drives have spindle control loops. These are both relatively low frequency loops. In the case of the hard disk, the spindle control loop controls the air flow over the disk and hence is important for guaranteeing the appropriate flying height of the head, which is not an issue for optical recording. Another factor that affects the spindle loops of both drives is the concept of Constant Angular Velocity (CAV) versus Constant Linear Velocity (CLV). Optical drives that contain streaming media (such as Audio CDs or DVD videos) operate in a CLV mode. This optimizes the amount of data that can be stored on a disk surface. However, this requires the spindle to change speeds as the optical head moves from the inner diameter to the outer diameter of the disk. Computer applications deal with more random accesses and are more sensitive to performance issues. Thus, the time it takes to ramp the spindle when a CLV system is used for random access files is often prohibitive. For the most part, these drives (both optical and magnetic) operate in CAV or zoned CAV mode. (The latter keeps the spindle speed constant over several large regions of the disk.)

4 Disks, Stacks, and Formatting

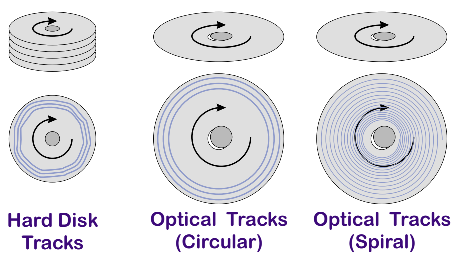

Figure 3: Tracks and eccentricity for magnetic and optical disk drives.

Hard disks are typically fixed in the drive. This means that the media remains on the spindle on which it was formatted and will never be repositioned on that spindle. As such, the format is created by servowriting: a process in which the read/write head is externally controlled to write position information magnetically on the disk surfaces. In Figure 3 the left diagram shows how a hard disk stack assembly will have individual tracks that are largely concentric with the disk spindle. However, due to the imperfect nature of the spindle and the servowriting process, the tracks themselves are noncircular. This noncircular position information is encoded at the spindle frequency, yielding a repeatable noncircular track for the disk servo to follow. Servowriting on the drive spindle tends to minimize the repeatable runout (RRO) (or at least the first harmonic). However, it is an imperfect and costly procedure. The servowritten track is strongly affected by the runout of the spindle. The servowritten track can minimize these errors by writing with multiple passes; however, these passes dramatically increase the cost of manufacturing the disk (basically related to the amount of time that expensive capital equipment is tied up).

There have been several ideas for improving on this. The first was to improve the runout of the spindles by replacing ball bearing spindles with fluid or air bearing spindles. Neither of these have caught on for the purpose of runout reduction. However, in an interesting turn of events fluid bearing spindles have started appearing in drives for acoustic noise reduction.

The center and right diagrams of Figure 3 show optical disk tracks. The center diagram shows circular tracks, much like those of a hard disk drive. The right diagram shows spiral tracks most common in streaming applications and thus found in CDs (audio, ROMs, and rewritable) as well as in DVD-ROMs. Optical disks are mastered on a precise air bearing spindle and then this master is used to create the subsequent disks. Position information is permanently encoded in the physical structure of the substrate. As the optical disk will be removed and replaced on the drive spindle, there is no way to eliminate a large repeatable first harmonic of disk runout. However, by creating the master on a very high quality spindle, the higher order harmonics can be minimized.

Another difference is in the disk diameters. Hard disks have steadily moved to smaller sizes to enable more mobile applications and improved mechanical stiffness. Typical hard disk diameters are 3.5” for desktop computers, 3” and smaller for high speed video and server applications, 2.5” for laptop computers, and 1.3” or 1” for PDAs. The need to only be standard at the external interfaces has allowed this freedom. Optical disks, on the other hand are typically 120 mm (approximately 5 1/4”) in diameter. There have been some 3.5” disks as well as the Sony MiniDisc format (2.5” magneto-optic recording), but the vast majority have stayed with the 120 mm format. The relative sized difference between 3.5” hard disks and 5.25” optical disks is shown in Figure 3.

In both sets of drives, harmonic correctors are used to minimize the effects of repeatable disk runout.

The cost of servowriting is one of the largest costs in the manufacture of a hard disk and is one of the factors pushing magnetic media makers towards permanently embossed servo information on the disk substrate. In such schemes, the magnetic media substrate is patterned in much the same way as optical media. The use of harmonic correctors makes this more practical by minimizing the effects of the disk to spindle misalignment on the control loop.

5 Actuators, Lenses, and Heads

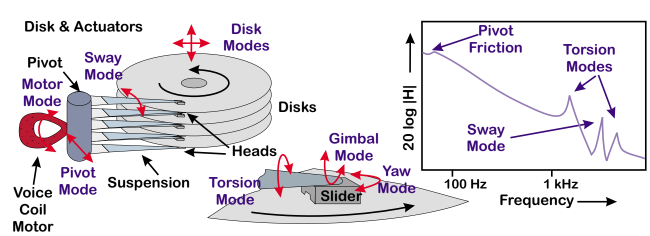

Figure 4: Modes of hard disks and actuators

Hard disks have excellent mechanics. The steady im-

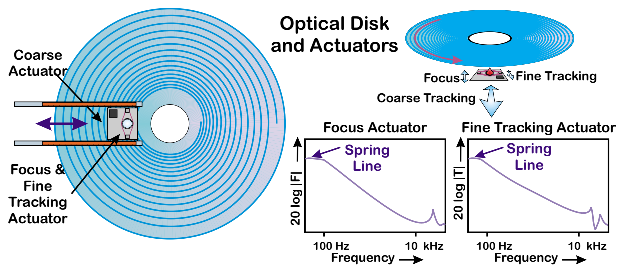

Figure 5: Optical disks and actuators.

provements in actuators have been driven in part by a desire to lower the flying height of heads (for higher linear density) and to spin the disks faster (for improved transfer rate). For the past 20 years hard disks have universally used rotary actuators for improved stiffness and smaller size. They are characterized by head stack assemblies that move over multiple disk surfaces simultaneously. To achieve these design goals, and to be able to stack more disk surfaces in the same volume, the mechanical design of the hard disk actuators have been repeatedly optimized for vibration characteristics. More recently, the increase in spindle speeds from 3600 RPM and 5400 RPM to 7200 RPM and even 10,000 and 15,000 RPM (driven by video and server applications) has increased the air flow inside the disks (windage), thereby increasing the internal disturbance of the actuators and disks, and therefore resulted in more attention being paid to the aerodynamics of the drive mechanics.

On the other hand, optical drives have not been pushed as hard on these mechanical performance issues. With only a single surface to access within a half height 5 1/2" there has been less need to shrink the size of optical mechanisms (diagrammed in Figure 5). (The glaring exception to this is in drives destined for laptop computers. These typically trade higher cost and reduced performance for smaller vertical size.) With the exception of certain early drives made by Philips, virtually all optical drives use linear actuators. This prevents a changing skew angle, which can cause different levels of cross coupling between the focus and tracking loops. The optical head remains relatively large to hold the focus and fine tracking motors. Furthermore, the lack of flying heads also imply that air turbulence is not the same major issue for optical drives that it is for hard disks.

The rotary actuators of hard disks have a large number of resonances, as diagrammed in Figure 4. However, in practice, the response of the system is dominated by 3 main resonances: typically the first and second torsion modes as well as the first sway mode or the first and second sway modes as well as the first torsion mode. Other resonances are of lesser importance because of being either farther out in frequency or because they are overlaid in frequency by the main modes. As of 1999, commercial suspensions had first and second torsional modes in the range of 1500–2500 Hz and 4800–8600 Hz, while the first sway mode was in the range of 8000-12,000 Hz. In the two stage actuators of optical drives, the bandwidth of the sled is low enough never to drive the sled resonances. The focus and fine tracking actuators have resonances in the 5-11 kHz range as shown in Figure 5.

In hard disks, friction in the rotary actuator pivot is an ongoing issue which becomes more of an issue for small disk drives with lower actuator inertia. For optical drives, the friction in the sled is mitigated by the second stage actuator of the optical disk which provides the fine tracking motion at high frequencies and thus makes this a non-issue.

The success of dual stage actuators in the tracking loops of optical disks has led to many proposals to add these to hard disks. The reasons for doing this are: (1) lowered inertia for higher bandwidth actuation, (2) lowered power requirements for high bandwidth, (3) mitigation of pivot friction effects, and (4) putting high bandwidth actuation at the end of the actuator beyond the effect of the suspension resonances.

The proposals along these lines typically consist of either micromachining a second stage onto a slider or at the gimbal (which achieves all objectives) or including piezoelectric actuation in the suspension (which achieves the third and part of the first two objectives). A more modest approach, involves adding sensors to the suspension allowing for better control through the resonances of the actuator in a manner similar to a flexible robot system. Another competing approach is stiffening the actuator with some composite material. As micromachined actuators are the only solution which solves all of the above problems, their adoption is widely considered inevitable, although the timing is a matter of lively debate.

6 Servo Signals

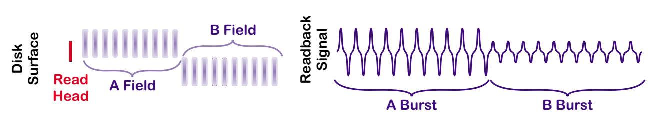

Figure 6: A simplified view of split field amplitude encoded servo fields on a hard disk and the resulting readback signals. In split field encoding the A fields and B fields are separated down the track. Amplitude/area estimates of the A and B fields, $\bar{A}$ and $\bar{B}$, are computed separately and subtracted from each other.

Magnetic disks have position information servowritten in one of two fashions: dedicated and embedded (or sectored). Dedicated servo involves reserving an entire disk surface for position information, leaving the other surfaces free to contain only user data. Embedded servo time multiplexes the servo information with the user data on each surface. Dedicated servos have the advantage

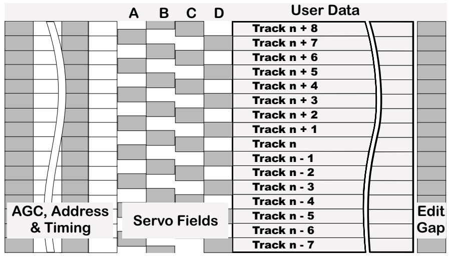

Figure 7: Simplified views of hard disk track layout. For a rewritable optical disk, the A,B,C,D servo fields would be removed.

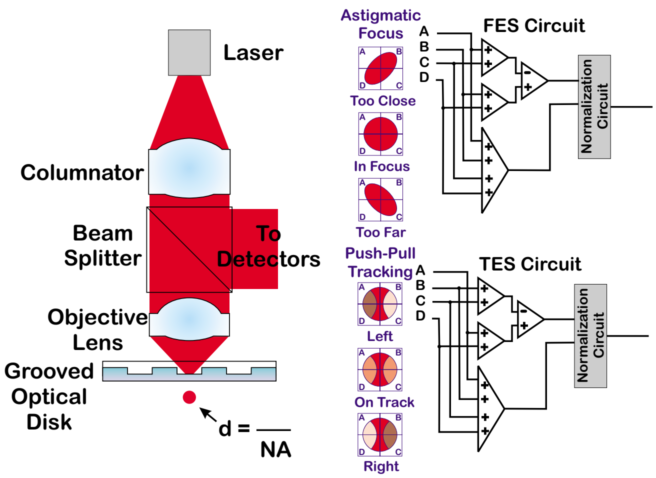

Figure 8: Optical path diagram (on left) and typical servo detectors (on right). Some typical circuits for the generation of focus error signal (FES) and tracking error signal (TES) in an optical disk drive are shown as well. Astigmatic focus uses an astigmatic lens to create a spot which is oblong on one diagonal if the objective lens is too far from the disk and oblong on the other diagonal if the objective lens is too close. Push-pull tracking detection makes use of interference patterns caused by the groove structure of the disk.

of higher sample rates and a possible savings in surface area when the total number of disk surfaces is relatively high. On the other hand, they are inappropriate for single surface systems, poor choices for single disk systems and typically have more susceptibility to thermal offsets than embedded servos. In order to minimize the effects of thermal offsets, the servo information on a dedicated servo system is usually encoded on one of the center surfaces. Embedded servos co-locate the position sensing with the control, but force the servo designers to choose between higher sample rates (desirable) and lower user data density (undesirable). However, as track densities have increased, the thermal offsets in the head stack assembly have become too large a percentage of the track to do anything other than embedded servos (co-located control).

The most common optical disk formats (CD, CD-ROM, CD-R, CD-RW, DVD-ROM, DVD+RW, DVD-RW, DVD-RAM, 5 1/4” Magneto Optic) have position information continuously available. The Focus Error Signal (FES) relies only on the distance to the disk to vary the spot size on certain portions of a split optical detector. An example of this is the astigmatic focus diagrammed in Figure 8. The Tracking Error Signal (TES) relies on physical features of the disk substrate. This “encodes” the position information in parallel with the data. For ROM formats, the position information is actually taken from the data. For rewritable optical disks, grooves are typically used to encode the tracking information.

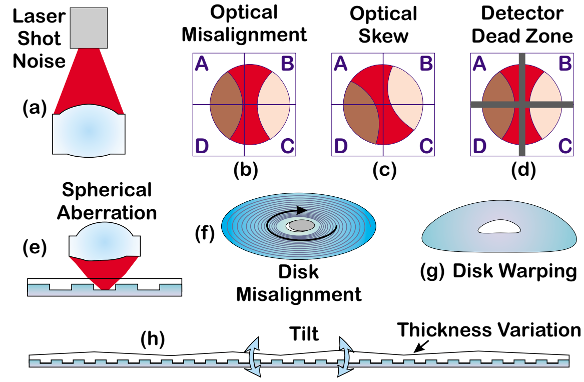

Figure 9: Sources of optical disk noises.

There are several interesting consequences to optical disks having continuous or nearly continuous tracking information. First there is no need for the servo burst information shown in Figure 7. Secondly, since position information is being read continuously, there is little or no need for AGC fields. Some optical formats have timing information at the sector boundary, but many get it from embedding an oscillation in the groove wall or extracting it from the data. The main use then of the sector boundaries in many optical disk drives is to provide addressing information and an edit gap. In ROM media, there is no physically encoded sector information although there is logical sector information. Even rewritable formats gain from this since the lack of tracking information in the header makes them shorter as shown in Figure 7. Furthermore, the sector headers can be used less frequently resulting in higher storage efficiency.

An interesting hybrid is the DVD+RW 4.7 GB format. By employing a high frequency oscillation of the groove walls and encoding the address within the oscillation, this format is able to do away with any edit gaps or address information of Figure 7 in the sectors. This allows the format to be compatible with the DVD-ROM format.

The noise sources affecting the two systems are different. For the optical disks, the error sources consist mostly of optical imperfections which show up at the optical detector. Laser noise (Figure 9a) gives a background high frequency noise which may alias into the servo frequencies. Optical misalignment and optical skew (Figure 9b&c) cause asymmetry and cross coupling between the focus and tracking error signal. The detectors are subject dead-zones between segments (Figure 9d). Lens and groove imperfections show up as spurious signals on the detectors (Figure 9e). Disk warping (Figure 9g) puts a large repetitive error into the focus loop. Disk misalignment on the spindle (Figure 9f) causes a large repetitive error at the spindle frequency into the tracking loop. Disk thickness variations and disk tilt also affect the servo signals (Figure 9h). Higher numerical aperture of the lens (NA) decrease depth of focus and increase coma nonlinearly. The latter causes problems with tilt and disk thickness variations, pushing higher density systems towards thinner protective layers and less removability.

Today's hard disks read data using Magneto-Resistive (MR) heads. The MR heads were a boon with respect to raising the bit density, but they cause all sorts of problems for servo. For hard disks, a large amount of the noise comes from media noise at the domains that define the A, B, C, and D fields. A large part of this is due to the fact that when the head is on track, it is flying over the domain sidewall edges of both the A and B fields. There are also noises and effects in the MR heads. MR heads further complicate matters by having nonlinear response in the cross track direction. Furthermore, the demodulation of these signals maps high frequency noise into the baseband where it is seen by the servo loop. Note that MR heads are read-only devices. An inductive head is still needed to write the data and this must reside on the same slider as the MR head, but cannot occupy the same position. This raises an issue with a rotary actuator. Because the heads must be offset from each other, the skew angle of the slider results in the read and write heads having slightly different angles for which they are over the track center. This means that in between reading position information and writing user data, the servo system must perform a micro-jog to shift into a position where the write head is over track center.

A consequence of the method of encoding servo signals in optical drives is that there is no tradeoff to make on user data density versus sample rate. Furthermore, the servo signals in optical disks have considerably less noise than those of magnetic disks. This has led to recent efforts to permanently encode position information in the substrate of hard disks. A major benefit of this would be dramatically lowered costs due to the elimination of the servowriting steps. The common usage of harmonic compensators makes this a reasonable proposition as the effects of large repeatable first harmonics which most likely will be introduced by this method can be removed in a fairly standard method.

The multiplexing of position information with user data on hard disks also creates a set of competing objectives. On one side is the desire for maximum data storage which would push to minimize the number of servo fields within a track. On the other side is the desire for improved performance in the control system which often requires a higher sample rate. These tradeoffs have limited the achievable sample rates to the range of 6-14 kHz. This in turn has limited the achievable tracking closed loop bandwidth to the range of 500-1000 Hz.

This has lead to a fair amount of work in multirate servos where the control output is changed at a significantly higher frequency than the sample rate of the PES. The multirate approach has also been applied to the use of auxiliary sensors in disk drives. In such cases where the sensor can sample information independently of the structure of the position information on the disk, performance can be improved by raising the sample rate of the auxiliary sensor and the update rate of the control law. These auxiliary sensors come in 3 main forms: accelerometers used for active compensation of disturbances in disk drives, current through the voice coil motor which gives an estimate of the current going through the voice coil motor, and instrumented suspensions.

Optical disks, having an essentially continuous servo signal available have had little need for multi-rate control. The sample rate of the focus and fine tracking loops are a function of the designer's discretion and the speed of the ADCs, DACs, and control law CPU. Optical disks achieve sample rates of 20-50 kHz. This, combined with the two stage tracking actuators have allowed the fine tracking loop to achieve closed loop bandwidths of 1-5 kHz. Focus loop bandwidths are typically 2-5 kHz. Thus, the use of auxiliary sensors has been minimal.

7 Application Related Issues

Because the use models for optical and hard disks are very different, the servo systems are affected in different ways. Optical disks usage in consumer electronics means that many of the applications are for streaming long files (i.e. audio or video). Hard disks have typically had larger sets of small files which are accessed in a more random fashion. The common usage of hard disks for streaming files is a more recent development (e.g. hard disk video recorders).

Streaming large files requires far less seek performance than randomly accessing small files. This favors hard disks for random access applications. However, streaming applications can use buffering of the data to avoid performance degradation caused by shock and vibration common in mobile applications. Random access applications need to neutralize the effects of shock and vibration in the servo itself, often by use of accelerometer feedforward.

Another recent issue is the audio noise that the drive spindle and actuator make in consumer applications. The sound of an actuator is most prominent when doing seeks.

Having a long streaming file contiguously written on the media minimizes this and thus, optical disks such as CDs or DVDs do not create much of a problem. Likewise, if the hard disks are written with long, streaming files, then actuator sounds will be limited. Audio spindle noise is related to the spindle speed and bearing. Optical disks being run in streaming audio or video mode rotate at relatively slow speeds. A major reason for this is the high linear bit density of optical disks. DVD-ROMS are specified to have a channel bit length of 133.3 nm which translates to 183,046 bits per inch (183 kbpi). This mark was not reached by hard disks until the late 1990s. Hard disks having relatively high spindle speeds for streaming applications (7,200–15,000 RPM), have recently incorporated fluid bearing spindles for drives intended for consumer devices.

8 Noise Sources

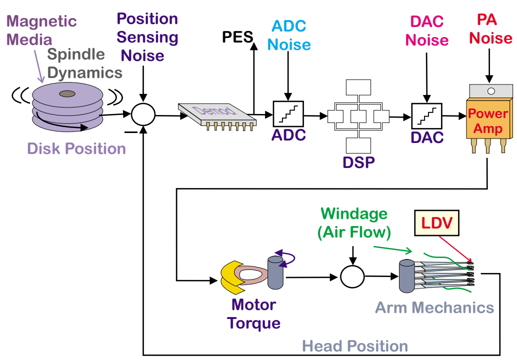

Figure 10: Generalized view of track following model.

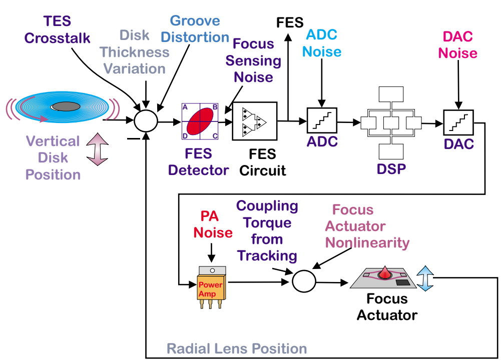

Figure 11: Focus Error Signal model block diagram for an optical disk drive.

The external disturbances affecting drives are typically in the form of environmental shock and vibration, whether from a moving vehicle, a factory floor environment, a computer under a desk being kicked, or simply the motion of a laptop computer. Internal disturbances are largely stimulated by the spindle's rotation of the disk

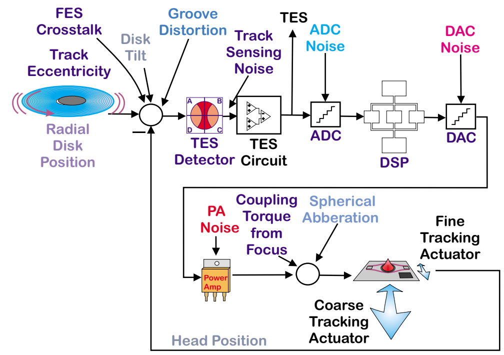

Figure 12: Tracking Error Signal model block diagram for an optical disk drive.

and the actuator's reaction forces on the drive baseplate and housing. For hard disks the disturbances are further complicated by the mechanical interface of the head and the disk through the air bearing. These disturbances affect the dynamics of the actuators and the disks and end up in the PES. The air flow can be turbulent. Its nature depends upon the disk diameter, the position and aerodynamics of the actuator, the enclosure properties, the disk materials, the air pressure in the enclosure, etc.

Optical drives are subject to coupling between the focus tracking loops. The tracking loop cannot see the grooves until the focus loop is locked and disk is in focus. The grooves show up in the focus signal. Separations of the focus and tracking signals depends upon proper alignment of the detectors. Any slight misalignment (Figure 9b&c) leads to cross coupling (as would a rotary actuator). The actuator is another source of potential coupling.

A large percentage of the internal disturbances are synchronous with the spindle frequency and its harmonics including oscillations in the disk media. Some of these are repetitive, but a large fraction of them are not. Those that are repetitive are typically dealt with by some form of harmonic cancellation, typically either repetitive control or adaptive feedforward harmonic cancellation. The spectral disturbances which are not repetitive must either be handled by the servo loop or removed by some modification to the mechanics. Mechanical methods of compensating for such problems involve changing the disk substrate, either with a stiffer material such as glass, or with an internal layer of viscoelastic damping material. The former method has the advantage of having been already tested on small form factor portable drives and the most recent high performance drives.

External shock and vibration is an issue for both hard disks and optical disks, but as mentioned in Section 7, they are often dealt with in different ways. Buffering of the data works well for streaming media such as audio CDs in a portable player or moving automobile, but disturbance cancellation is used in random access applications. Because of this, the use of accelerometers in optical disks has been limited. The use of accelerometer based compensation in hard disks is far more extensive. Typical use of accelerometers involves sensing the disturbance and moving the actuator before the error ever shows up in the position error signal. As the accelerometer and drive characteristics are subject to change, adaptive methods are often used. The use of accelerometer feedforward dramatically improves the disturbance rejection capabilities of hard disks. Cost and reliability issues for the accelerometers themselves has limited this practice. Efforts to improve the accelerometers continue, both in cost and reliability, through new micromachining methods.

Of the broadband disturbances (Figure 10), the majority is generated by air impacting on the disks and actuators (windage) and PES Noise. Unfortunately, these work against each other in the servo loop. The inherent noise in the demodulated servo signals puts a limit on how much of the windage the servo can reject without amplifying PES Noise at high frequencies. On the other hand, optical disks (Figures 11 and 12) have very low noise in their servo signals and windage is not a factor (due to slower spindle speeds and far field recording). Disturbances in such drives are more in the area of optical deformations and actuator nonlinearities.

9 Seeks

This paper has not gone into the differences in seeks in much detail, but will touch on this now. The simplest models for hard disk actuators are that of a double integrator with a saturating input. Thus, hard disks have long used something close to a bang-bang control scheme for seeks. A practical method of doing this is called PTOS (Proximate Time-Optimal Servomechanism), but the technique is as old as the original closed loop disk drive control system. Seek algorithms can been constructed to minimize residual vibration. Seek times have consistently dropped on hard disks, but not as quickly as densities have increased. Optical drives, having much larger actuators, have maintained relatively high seek times. Typical numbers for high performance optical drives have stayed up near 35 mS and above. There have been studies of how to use the movements of both the coarse and fine actuators together to improve this.

10 Closing Remarks

The purpose of this tutorial has been to show some of the similarities and differences between the control problems of optical and magnetic disk drives. This should help engineers in understanding when a technique from one set of drives is applicable to the other. Where is this going? While the future is hard to predict, here are some trends that bear watching. For hard disks, the following are likely:

- Micromachined second stage actuators solve many of the mechanical issues with disk drive actuation. While their adoption on hard disks is considered inevitable, the competing solutions of stiffening and/or instrumenting the actuator may very well be used before second stages as they can considerably extend the life of single stage actuation.
- Stiffer, smaller disks and more aerodynamic actuators are inevitable. The combination of ever lower flying heights for the sliders and tighter tolerance on servo systems means that stiffer, flatter disks will be necessary. It is likely that either glass substrates and smaller will break out of the portable drive world and become standard on hard disks for desktops.
- Alternate position encoding methods, either continuous grooved magnetic or some form of optical encoding will likely take hold to dramatically drop both PES noise and servowriting costs.
- Synchronous demodulation seems like a trivial way to improve bandwidth at the cost is more expensive electronics for servo demodulation. However, this level of electronics is already common in the read channels of disk drives. Since "silicon is cheap", especially compared to other improvements in a drive, this trend should become universal.
- Fluid bearing spindles may become standard, especially for hard disks in the consumer appliance market.

The driving force behind optical disks will continue to be removable media. However, the desire to store 2 hours (the length of a standard movie) worth of HDTV quality signals will push formats beyond the current standard of 4.7GB for DVD. The current proposals for high numerical aperture lenses and shorter wavelength lasers will narrow the servo margins on the optical disks considerably. Methods of getting around this, including making the transparent protective layer thinner and/or flying in the near field will bring forth a variety of servo and reliability issues to be resolved.

References

[1] D. Y. Abramovitch, "*References for:* Magnetic and Optical Disk Control: Parallels and Contrasts," on-line bibliography of paper, Agilent Labs, Palo Alto, CA 94304, June 2001. http://www.labs.agilent.com/personal/-Danny_Abramovitch/pubs/hd_vs_od_servo_refs.pdf.