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Fundamentals of Hard Disk Drive Acoustics

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INTRODUCTION

In the hard drive industry, drive acoustics are becoming more important than ever. With the introduction of hard drives into new emerging markets in which the consumer is more keenly aware of and sensitive to radiated acoustic noise issues, technical professionals are facing enormous challenges to meet customer demands. Drive manufacturers are under severe cost limitations, many times unable to incorporate all the noise control devices necessary to make drives as quiet as possible. Often times a trade off between performance issues and drive acoustics is required. As drives have gotten cheaper and cheaper, expectations on quietness, as well as performance, have increased. As in many other industries, the consumer views a quiet product as one of high quality. The job of meeting these increasingly difficult noise goals also falls on those manufacturers that are the end users of disk drives.

One example of this is in the area of set-top box systems, typically characterized as "smart VCR's" using the disk drive as the storage medium. Since these units are often used in consumers' bedrooms where background noise levels are much lower than the traditional office environment, the bar for low acoustic output is set very high. Radiated sound power requirements for such products are desired at levels less than 30 dBA, with seek noises virtually indistinguishable over idle conditions (less than 2 dBA louder). To accomplish this feat cost-effectively, a detailed technical understanding of drive acoustics is essential to successfully developing optimized noise control strategies. This article attempts to outline some of the fundamentals of hard drive acoustic issues confronting those working in this industry.

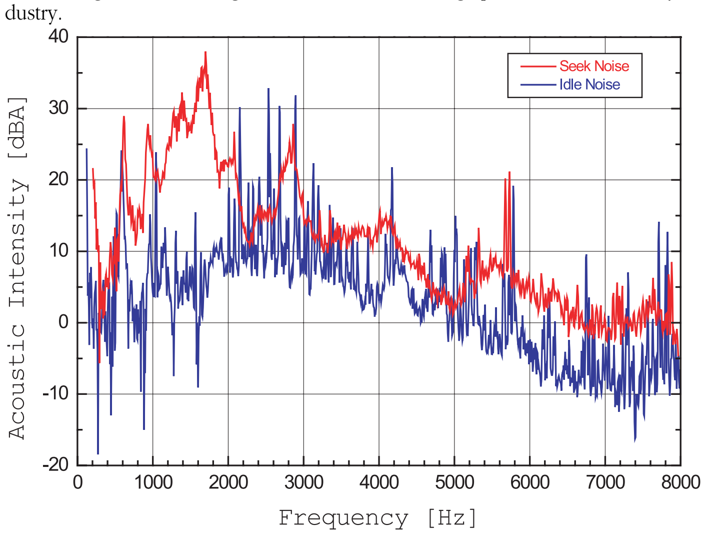

FIGURE 1
Acoustic Intensity Spectrum for a Typical Disk Drive Under Idle and Seek Operation Conditions.

DEFINITION AND CHARACTERIZATION OF DRIVE NOISE SOURCES

The spinning of the disk spindle assembly, which includes the spindle motor, bearing components, and disk stack, generates steady-state periodic tones radiated from the drive. This is referred to as idle noise as shown in Figure 1. The multiple harmonic tones are related to the spinning speed, number of bearing balls and imperfections in the bearing for a traditional ball bearing spindle motor assembly.

The idle noise source level is a function of ball bearing quality, spin speed and mass of the disk stack. Historically, hard drives became quieter with the improvement of ball bearings. As the drive spindle speed continues to increase, noise from the contact of the ball bearings in the raceway increases, making idle noise an important contributor to the overall noise level and poor sound quality. For this reason, the industry is moving toward fluid dynamic bearings for ultimate acoustic performance because they have no metal-to-metal contact. A well-designed fluid bearing can also quickly damp vibrations generated externally or internally. Fluid bearing systems are being used in the high end drives with spindle speeds at 10,000 RPM.

Seek movements of the head actuator, which includes the voice coil motor, ball bearing, and arm/suspension assembly, generate transient and discrete noises, which is referred to as seek noise also shown in Figure 1. Seek noise is normally dominated by fewer tones that are related to the structural resonances of the head actuator assembly. It should be noted that these tonal frequencies are not affected by the seek speed as they remain fixed in frequency even if the disk is operated at different seek rates.

The seek noise source level is determined by seek speed, the current profile applied to the voice coil motor, and the head actuator dynamics. To reduce these levels, changes can be made to smooth seek profile and slow the seek speed to reduce this element of the noise at the expense of drive performance. Alternatively, increasing the system damping levels of the actuator components is effective in reducing resonant behavior of key internal components in order to reduce the seek noise and maintain the drive performance. The caveat is that these add-on treatments must reside within the drive itself, and are subject to very stringent material cleanliness requirements. More will be discussed on this point under the subject of noise control options.

IDENTIFICATION OF DRIVE NOISE TRANSMISSION PATHS

The acoustic noise can be transmitted structurally and acoustically from drive noise sources. Vibrations of the spindle motor assembly and head actuator can be directly transmitted to the drive housing, which includes the cover and base plate, through screws and rigid connections, and will be amplified by resonances of the drive housing. This form of noise transmission is referred to as a structure-borne path. The noise from the disk spindle motor assembly and head actuator, which are contained in the drive housing, is also incident upon the interior housing surfaces, and transmitted through the drive housing. This is called an airborne transmission path. It should be noted that reverberation effects and acoustic resonances within the drive housing could amplify the interior noise.

Contributions of the structure-borne and airborne noise can be quantified by several techniques. One method is to eliminate the structure-borne paths by disconnecting the rigid screw supports on the cover, and isolating the disk spindle assembly and the head actuator on the base plate. Another method is to use a mini-speaker inside the drive housing to simulate drive noise sources. The speaker can be driven by a recorded noise signal to evaluate the airborne noise transmission performance of the drive housing.

The noise transmission from the base plate to the circuit board also includes a combination of structure-borne and airborne paths. The vibration of the base plate can be transmitted to the circuit board through screw mounts, and amplified by the resonances of the circuit board. The cavity between the base plate and circuit board serves as an airborne transmission path, and an acoustic amplifier due to reverberation effects.

NOISE CONTROL OPTIONS OF HARD DISK DRIVES

As discussed above, reductions in noise levels can be accomplished at the noise source level and dealing with transmission paths of the noise. The most effective method is to reduce noise source levels directly, although this is usually a difficult task. Damping treatments and isolation methods are two practical approaches in drive applications where the drive size is a main constraint. Particularly, passive viscoelastic damping treatments have been extensively used to reduce vibrations and noises in today's hard drives.

A basic understanding of the passive damping technology is essential to successfully incorporating damping materials into hard drives. Much research work has been done on the subject of passive damping in the past forty years, predominately in other industries. Work conducted in the aircraft industry is where much of the fundamental technology was developed, and it has been the automotive industry that has made these types of treatments affordable. The success of these viscoelastic-based, surface damping treatments, typically classified as constrained layer and free layer damping treatments, hinged on the development of a wide variety of viscoelastic materials that possess a variety of unique properties.

Examples of two of the most common forms of damping treatments commonly used in disk drives today are shown in Figure 2. These treatments include PCB dampers and constrained layer dampers (CLD's) for top covers. The PCB damper treatments were originally selected to provide damping to the many resonances of the printed circuit board component, which tended to act like a speaker amplifying the unwanted noise. Many of these materials were partially closed cell polyurethane foams with low air permeability behavior that created the viscoelastic damping effect in the material. Recent work has been done to also improve the acoustic absorption ability of these materials to make the treatments even more effective in reducing noise from the PCB-side of the drive. An example of one such material is the Roush Anatrol RA205TM Damped Foam.

As for the case of the top cover, some form of constrained layer damping treatment has long since been used on disk drives to eliminate resonances of the flimsy top cover components. This can be achieved in one of two ways: (1) an add-on metal layer bonded to the top cover with a viscoelastic material properly selected for the specific application, or (2) stamping the part itself from a laminated, metal composite consisting of two metal outer layers with a viscoelastic core. One such example of this material is Roush Anatrol's Dynalam™ 980 laminated metal, which is available in a wide variety of sheet metal types and thickness gage. This laminate utilizes the RA980™ damped adhesive, which has been specifically designed for the temperature and frequency range typical of disk drive applications.

One characteristic unique to viscoelastic materials is that the damping and stiffness properties are frequency and temperature dependent. This implies that the specific temperature and frequency range of a particular application must be clearly defined in order to select a material that will be properly optimized. This also assumes that the material properties have been defined in terms of the complex modulus. Through the years, Roush Anatrol has maintained an extensive database of commercially available viscoelastic materials that are used in the development of various vibration control devices for many industries. For the hard drive industry, material cleanliness is a critical issue. Typical viscoelastic materials are solvent-based polymers coated onto metal or transfer film. Much of the volatile solvents are driven off during processing, but a certain percent is retained which could leak out of the material over time (called outgassing) depositing on the disk media. Extremely low levels of outgassing performance are required when materials are used inside drives. Roush Anatrol has done much work to develop materials that possess excellent damping performance while meeting these types of environmental specifications.

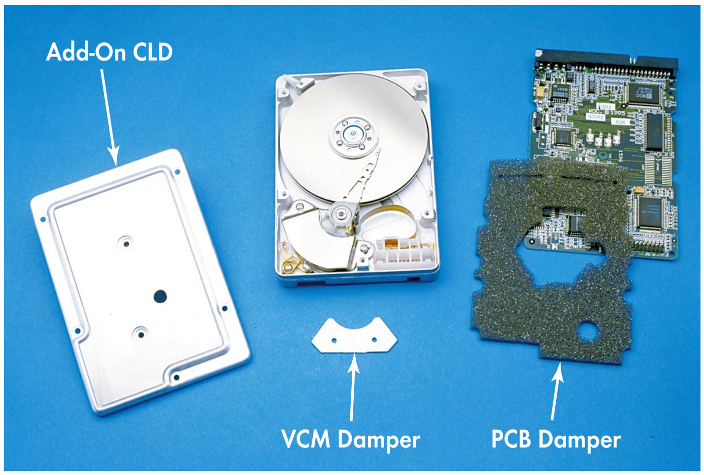

FIGURE 2
Typical Noise Control Treatments used on Disk Drives.

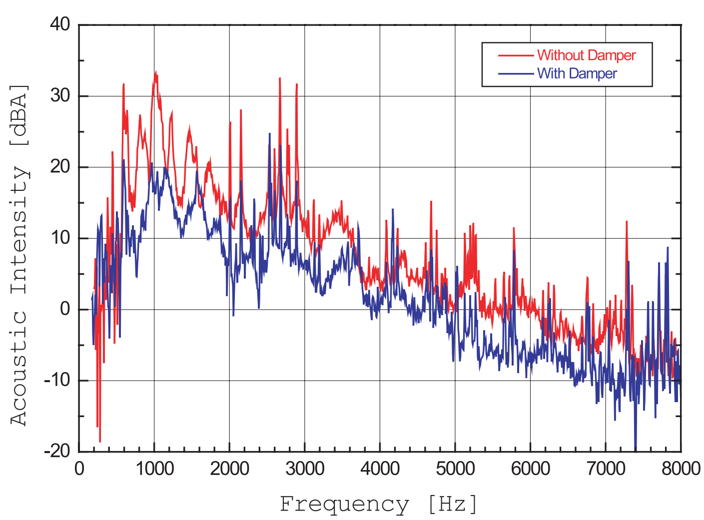

FIGURE 3
Comparison of the Idle Noise on the Cover Side with and without the Damping Treatment for a Typical Disk Drive

A well-designed damping treatment significantly reduces the noise radiated from the cover side. Figure 3 shows that the idle noise is reduced by 8.3 dBA on the damped cover side for a typical disk drive. It should be noted that the damping only reduces the resonant responses of the treated component. Therefore, the damped cover has little effect in reducing forced vibration transmitted to the top cover by way of internal resonances excited during seek operation. For example, unless specific forcing frequencies align with instabilities in the top cover, the damped cover will produce only marginal energy dissipation. The constrained layer damping treatment is rarely applied on the base plate component since it does not possess much resonant behavior.

In general, viscoelastic damping can be effective anywhere there is relative motion between components. Other forms of damping treatments have been used with much success at other locations within the drive to attack seek noise issues specifically. Viscoelastic treatments have been applied between the VCM housing and top and bottom covers to damp out resonances of this component. Add-on treatments have been applied to the read/write flexures of the arm assemblies to damp arm modes excited whenever the rotary actuated arm comes to a sudden stop. Arm assemblies themselves are being stamped out of damped laminate materials to reduce seek noise. The mounting interface between the spindle motor and the top cover are often interrupted by way of damped metal disk to provide both isolation and damping between components for structure-borne vibration from idle.

Despite the obvious challenges in dealing with viscoelastic based treatments in disk drive applications, namely the stringent cleanliness requirements and stability over the life of the product, there has been much success in reducing unwanted drive noise through these types of control methods. As drives are designed to operate at higher and higher RPM's and seek rates, and as track densities continue to increase, noise and vibration issues will continue to be an important design consideration. The challenge for companies like Roush Anatrol will be to provide these solutions to the drive industry at lower costs and ever improving performance. ■