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Seagate

TECHNOLOGY PAPER

FROM SEAGATE

Disc Drive Acoustics

Executive Summary

In the hard disc drive industry, acoustics are becoming more important than ever. Acoustics are the noises a drive produces during operation. Over time, new drives and systems have become quieter, and an even bigger effort to reduce audible noise is upon us with the introduction of disc drives into consumer electronics and other "appliance" devices. This paper outlines some of the more important issues that need to be understood when discussing acoustics specifications and requirements.

Sound is measured using a logarithmic decibel (dB) scale. Acoustic sound power measurements and specifications are much more relevant to disc drives than acoustic sound pressure, and *it is important for customers to understand which measurement system is being used and compared in any given situation* because there is no conversion or other way to relate the two.

Different markets have different requirements for **sound power** acoustics. Standard PCs (with fans) typically require drive acoustics in the sub-30-dB range for idle and can accommodate seek acoustics that are 3–4 dB higher than idle. Newer emerging markets, such as consumer electronics or internet appliances, may feature fanless products operating in very quiet environments; if so, acoustic requirements for these systems may need to be in the mid-20 dB range, with seeks less than 2 dB louder than idle.

Regardless of a drive's specifications, the most important factor to a user is how loud the drive sounds when it's built into a system. Many factors influence the overall noise or perceived noise of a system, including fans, prominent tones, structure-borne noise caused by vibrations transmitted or amplified through the system chassis, airborne noise muffled by the system case, differences between idle and seek noise, overall system design and drive mounting systems (isolators).

Seagate® has performed extensive research and development of both quieter drives and better system designs to minimize the perceived acoustics of drives and systems. We call the resulting set of features "sound barrier technology" (SBT). Seagate is leading the industry in not only providing exceptionally quiet drives but also understanding how drives sound when they are in systems, and designing methods, models and products to minimize overall system noise. These efforts are resulting in ever-quieter disc drives from Seagate and better system designs by OEMs and integrators, which ultimately results in more satisfied customers and end-users.

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How Loud Is Loud?

Sound is measured using a logarithmic decibel (dB) scale. A decibel is a unit of sound intensity. 10 decibels equal one bel. Zero dB is the threshold of human hearing. 120–130 dB is the most a typical person can tolerate. Sound pressure measures the pressure level of noise recorded by the ear. Sound power measures the average total amount of acoustic energy coming from an object.

The smallest change a typical person can detect is 3 dB sound pressure, or 1.5 dB sound power. An increase of 6 dB is a doubling of measured sound pressure, although it takes an increase of 10 dB sound pressure to sound twice as loud to a person. An increase of just over 3 dB sound power is a measured doubling, though it takes an increase of 5 dB sound power to sound twice as loud to a person.

Some typical ambient noise levels (sound pressure):

- 20–30 dB for a quiet library or whisper
- 40 dB for the average home
- 60 dB for a normal conversation
- 90 dB for a commercial truck or a train
- 120+ dB for a jet airplane or rocket taking off.

(As you know, a jet airplane sounds much more than 4 times louder than a quiet library, even though its dB value is only 4 times higher—that's because of the logarithmic scale.)

Market Segment Needs

Different Personal Storage market segments have different needs regarding system and drive noise, measured using **sound power**. For example, in a traditional PC with a fan, the fan is typically louder than the idling drive, which drowns out all but the most prominent tones (if any) and the seek acoustics. As fans and systems get quieter, *OEMs building traditional PCs are looking for drives in the sub-30-dB acoustic range at idle, and for minimal differences between idle and seek (ideally less than 3 or 4 dB).* Seagate sound barrier technology (SBT) recently lowered this bar even further, with new products in the 20 dB range.

New applications, such as small form-factor PCs, internet appliances, and consumer electronics systems (PVRs, electronic jukeboxes, etc.) may have no fans, and may be operating in quieter environments than typical PCs. For example, a PVR may be recording in the bedroom in the middle of the night, or an electronic jukebox may be playing in a family room. For such applications, the drive must be inaudible, including seeks, once it is mounted in the system. *The drives going into consumer electronics and other "quiet" systems must be in the mid-20 dB range, with seeks preferably less than 2 dB louder than idle.*

How Sound Is Measured and Reported

Sound pressure is measured using a single microphone and is highly directional. It is very subject to the influence of the environment or chamber. Furthermore, there is no way to subtract out the influence of background or reflected noise. It does not correlate well to sound power or to noise perceived by the human ear. For this reason, sound pressure specifications were abandoned by the disc drive industry several years ago.

The current disc drive industry standard for specifying acoustics is **sound power**, measured using multiple microphones (usually between 8 and 12) arranged in a sphere around the product to measure the sum of all noise from the drive. **All major computer OEMs require acoustic specifications using sound power rather than sound pressure, as it is more representative of end-user noise perception.**

Make sure that you and your customers understand the measuring system being quoted, since sound pressure measurements are significantly lower than sound power measurements. Industry standard is sound power; if a vendor promotes a sound pressure specification without saying so, it can be extremely misleading. There is no way to convert a sound pressure measurement/specification to sound power, or vice versa.

Other sound measuring units and systems are used in other industries and specialties. For example, some household devices are measured for subjective "loudness" using a unit called a "sone" or a different unit called a "phon." Devices can only be subjectively measured for "loudness."

Subjective loudness is influenced by many factors, including the frequency range of the sound, the duration of the sound impulse, and human sensitivity to various frequencies (there are different levels of sensitivity to different frequencies). That is why a prominent tone at a particular acoustic level might be perceived as loud or annoying, while a different prominent tone at the same acoustic level may not present a problem.

To account for these and other factors, sound measurements can be weighted on various scales for the mix of frequencies which are most audible to the human ear. "A", "B" and "C" weightings have internationally standardized characteristics. The A-weighting is most commonly used, since it correlates best to subjective human tests. Measurements reported using the A-weighting are often reported in dBA or dB(A), although in the disc drive industry, the A-weighting is usually assumed unless otherwise noted.

Reality Versus the Lab or Chamber

The industry-standard laboratory practice for measuring the acoustics of disc drives is to suspend the drive in a special sound-absorbing chamber (called an anechoic or hemi-anechoic chamber). The chamber eliminates or reduces reflected noise and noise from outside sources. Sound pressure measurements use a single microphone and sound power measurements use a spherical arrangement of many microphones. Prominent tones are also monitored. Results are reported using the A-weighted scale.

While this practice can accurately measure the airborne acoustic emissions from a disc drive, we all know that drives are never used while suspended in a special chamber. Rather, they are mounted in a chassis, which is in turn placed in some kind of enclosure that forms the physical system (see chassis section below).

The real question most customers want answered is, "How loud will this drive sound in my system?" Unfortunately, different drive/system combinations may yield different answers. For example, a drive that sounds quietest while suspended in an acoustic measuring chamber may actually sound louder when mounted in a system, while a drive that sounds quietest when in a system may not be the quietest when tested stand-alone. Several factors contribute to this disparity, including prominent tones, structure-borne acoustics, measuring techniques, objective measurement versus subjective hearing and so on.

Generally speaking, drives with quieter stand-alone acoustic specifications will also sound quieter in systems and vice versa. Very minor specification differences, 1–2 dB, might be indistinguishable or even reversed when the drive is in a system. Furthermore, differences of 1–2 dB are difficult for the human ear to detect. Annoying or prominent tones created by the structure-borne acoustics may also affect user perception of overall system acoustics.

Seagate follows the industry-standard process of specifying sound power acoustics (both seek and idle) for stand-alone drives. Our chamber, test methodologies and reporting all conform to the pertinent and applicable portions of various ISO, ANSI and ASTM standards. We also perform extensive subjective tests using statistically valid sample sizes to evaluate both stand-alone drives and drives inside systems. These tests are performed on both Seagate and competitors' drives in an ongoing effort to make Seagate drives with SBT as quiet and unnoticeable as possible in users' systems.

Fans or Lack Thereof, and Other Ambient Noise

Today, nearly all PCs ship with fans. A quiet fan is about 34 dB. This overwhelms most drive noise. For example, a 28 dB drive combined with a 34 dB fan will result in about 35.0 dB audible noise, while a 30 dB drive combined with the same fan will result in about 35.5 dB audible noise. This 0.5 dB is imperceptible to the user.

In the future, more PCs, internet appliances, PVRs and other consumer electronics devices will ship without fans. At that point, it will become more important for drives to perform in the sub-30 dB range.

It is also important to consider the effect of other ambient noise. A quiet room or office is generally in the 20–30 dB range and many work and home environments are considerably louder than that (think about air conditioners, heaters, traffic, office machines such as printers and copiers, voices down the hall, telephones and so forth, all adding to the ambient noise). A drive idling in the 20–30 dB range would not be noticed.

Seek Versus Idle

There are two types of acoustics measured for a stand-alone disc drive:

- Idle Acoustics: the audible noise emitted from a drive while it is spinning, but otherwise inactive
- Seek Acoustics: the audible noise emitted from a drive when the heads are moving (seeking)

Although a user may not notice a drive idling at 28 or 30 dB, he or she will certainly notice when the drive is seeking, if seek noise is considerably louder than idle noise. Many drives today have seek noise that is 4–6 dB louder than idle. This is definitely discernable to the PC user and can be quite distracting. In a CE device, such as a PVR, which could be operating in a bedroom at night, such a noise would be intolerable. Therefore, Seagate is focusing more effort on reducing seek noise, and especially, the difference between seek and idle. Seagate's goal is to reduce this delta to the sub-2 dB range using SBT. This means that as Seagate produces drives that operate ever more quietly at idle (sub-30 dB), Seagate will also be reducing the seek acoustics commensurately.

Motors and Their Effect on Drive Noise

Motor spin speed is directly related to acoustic noise: faster is usually louder if all other variables are equal. Motor spin speed is also directly related to performance: faster spinning gives better performance because of lower latency (latency is the time it takes for the drive to rotate the needed data under the read/write heads). Many design modifications can be made to both motors and other parts of the drive to make faster motors quiet, and the differences in perceived acoustic noise between various spin speeds have been diminishing.

Motors rotate on bearings. These bearings may contain metal alloy balls, ceramic balls, fluid or other materials. For many years, disc drives have relied primarily on metal alloy ball bearings; they are cost effective, reliable, durable and reasonably quiet. They can, however, become louder over time if the motor sustains knocks and bumps that could cause minor damage to the motor bearings. Such damage might not affect the drive's performance, but it could cause the drive to become noisier. Also, the balls are never perfectly round (at a microscopic level), so there is always some amount of noise and vibration associated with metal ball bearings. Ceramic balls are more costly, but they are more perfectly round and less subject to the type of damage that could result in louder drives (they can't be dented).

Finally, fluid bearings can be used for ultimate acoustic performance; the balls are completely eliminated from the bearings, which are filled with fluid instead. This results in a smoother, more perfectly-circular spin with very little vibration and nearly silent operation. Fluid bearing motors (also called fluid dynamic bearing, or FDB) have historically been more expensive than ball bearing motors, and may have other issues, as well. They need to be carefully designed and manufactured to avoid excessive power consumption, heat and fluid leakage. But they also enable additional features, such as higher areal density with more tracks per inch, and higher robustness because they are less subject to damage.

Seagate has been shipping FDB motors in its products for several years. We are currently integrating our exclusive SoftSonic™ motor in a number of products as part of sound barrier technology. Seagate's long history with FDB motor design, development and production has enabled us to drive down costs and gain valuable long-term reliability and performance data. Seagate's motor division has also made recent breakthroughs in this technology, which offer a clear advantage over competitive FDB implementations. The SoftSonic FDB motor used in Seagate's Barracuda ATA IV products, along with other SBT features, enables idle sound power acoustics of a mere 20 dB, significantly lower than any other 5400 or 7200 RPM disc drive available today.

Drive mechanics: dampening, resonances, covers, ties and number of discs

Drive mechanics have a large effect on acoustics because acoustic noise is caused by vibrations, resonances and movements. Everything from the shape of the cover to the materials used to the thickness of a piece of metal inside the drive can affect acoustics. Seagate employs extensive modeling, design principles and testing to reduce the combined effects of these components on overall drive noise. Finite Element Analysis helps Seagate model and reduce resonances. Other noise-reduction techniques include use of dampening materials on the inside and outside of the drive, use of screws or ties between the cover and motor, and choices of many other materials and designs made with acoustics-reduction in mind. Seagate's exclusive SeaShield® covers (both hard and soft) also help reduce acoustics.

The number of discs present in an HDA also affects acoustics. Generally, when there are more discs, the acoustics are higher. Quietest drives are generally single-disc drives. When comparing specifications, make sure to consider the number of discs.

Chassis: vibration, dampening, amplification and other structure-borne noise issues

The acoustic noise of a disc drive mounted in a chassis comes from two sources. The first source, *airborne acoustics,* is what all drive manufacturers currently specify as the sound power value. It is the sound that comes from the drive through the air to the observer. This value is measured with the drive suspended in space by wires. The second noise source is generated from the drive's vibration during idle and seek. This vibration energy is transmitted directly to the PC chassis structure and causes the chassis to act as a speaker. This form of noise is *structure-borne acoustics.*

When drives are mounted in a chassis (frame for a PC or other product) and enclosed in a box (plastic body of PC or other product), the vibrations that cause acoustic noise can be attenuated (reduced, muffled) or amplified. For example, the plastic enclosure tends to attenuate noise emanating from the box because it muffles airborne acoustics. The chassis, on the other hand, may pick up, redirect, or even amplify the vibrations caused by the drive, which may result in more structure-borne noise emanating from the box, or through a specific portion of the box. Seagate has considered the total effect of drives on a PC system and can show that structure-borne noise is the dominating source of disc drive-induced PC acoustics. In fact, testing has shown that changes in stand-alone drive acoustics had little effect on the overall system acoustics when drives were hard mounted in the chassis. As a result, Seagate works closely with its customers during the design and test cycle for PC chassis development, and has invested in extensive isolator design and development.

Isolators: progress and implementation update (For more detail, see Isolator Technical Paper TP-298, available at www.seagate.com/newsinfo/index.html.)

Seagate has made significant progress in the area of isolator design and development. Isolators are mounting mechanisms made of a softer material than metal; they are used to separate, or isolate, the drive from the chassis, minimizing the transmission of structure-borne vibration and noise.

At one time, years ago, isolators were thought to be impractical for disc drive mounting; the frequent long seeks could induce excessive drive motion through isolator "wind up" and "release," which caused settling problems during seeks, which could in turn reduce drive performance and/or data integrity. Current drive designs, combined with Seagate's research and development of new isolator materials and designs, have largely eliminated these issues. In typical PC applications, over 90 percent of all seeks occur within only 30 tracks, which is less than one-fourth of one percent of the drive's tracks, inducing very little motion and wind up. The materials Seagate recommends for isolators are highly damped rubber compounds, which minimize the possibilities for wind up, amplification and other unstable conditions.

Our testing indicates that WinBench scores (industry-standard drive benchmarks) are not affected by mounting drives using isolators. Further testing beyond the bounds of common disc drive functions did reveal that when performing high numbers of long seeks (long seeks are becoming more rare as track densities increase), write performance could be somewhat reduced, while read performance remains unchanged. Again, most drives perform many more reads than writes, so that overall performance, even in these extreme circumstances, is not perceivably affected.

Seagate makes its isolator designs, research results, recommendations and testing services available to customers designing chassis' with a goal of minimizing acoustic noise.

Seek performance versus acoustics: shaped seeks, slower seeks and selectable modes

Seek noise is caused by the dissipation of energy applied to the actuator to move the heads over the correct track, and by vibrations and resonances that occur in the drive as the actuator moves. There are many ways to accomplish quieter seeks. One is to simply redesign parts of the drive to dampen more noise, which reduces both seek and idle acoustics. Another is to "shape" the seeks, meaning to change the profile of current applied to the actuator so that the change in energy is smoother and less abrupt, and hence, quieter. Another is to slow down the speed of the seeks, especially the high-velocity ("long") seeks. Sound barrier technology incorporates a number of these features to reduce seek acoustics in Seagate disc drives.

Shaping or slowing seeks can impact drive performance. The extent of this impact is very dependent on the actual engineering changes, application type and performance indicator. For example, slower long (high velocity) seeks could result in a higher average seek specification, which may or may not affect performance in terms of laboratory benchmarks and real-world performance of such applications as system boot time, application start time, file load time, file save time, etc. These applications may be affected differently by the same design change; for example, boot time might take longer, while no change is recorded in WinBench results. Seagate is continuing to model and optimize quiet seeks, and may recommend different seek parameters for different applications such as CE versus traditional PC.

Conclusion

As the existing and new segments of the market continue to require quieter systems, Seagate is leading the industry in not only providing exceptionally quiet drives with SBT, but also understanding how drives sound when they are in systems, and designing methods, models, and products to minimize overall system noise. These efforts are resulting in ever quieter disc drives from Seagate and better system designs by OEMs and integrators, which ultimately results in more satisfied customers and end-users.