

# Sound Quality for Hard Drive Applications

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## Introduction

Over the past several years, the hard drive OEM's have focused on improving the radiated acoustic noise emitted from drives in response to the consumer's demand for improvements, and have made significant improvements in this area. A-weighted sound power level is commonly used to quantify the acoustic performance in the hard drive industry. For instance, acoustic requirements of a 3.5" 7200 RPM drive may need to be 32 dBA at idle mode, 38 dBA at performance seek mode, and 34 dBA at quiet seek mode. However, A-weighted sound power level is not sufficient to correctly represent the actual hearing sensation due to the very complex nature of the auditory impressions of sound.

Alternative acoustic metrics, considered within a more subjective analysis discipline known as "sound quality", are often used to better correlate to the hearing experience of customers. For instance, standard sound quality metrics such as sharpness, loudness, tonality, roughness and fluctuation strength are commonly used in the automotive industry during the development of new vehicle platforms. The use of these tools in other areas, such as the hard drive industry, is just now beginning to be employed.

With the introduction of hard drives into new consumer electronic products, such as set-top box systems, even greater reductions in overall noise level and improved sound quality characteristics are being imposed on the hard drive manufacturer. PC makers as well are beginning to include subjective-based requirements on their products in the effort to improve the perception of overall product quality. Sound quality analysis techniques will become useful tools in the development of new drives. The purpose of this article is to introduce sound quality metrics that describe the drive noise, and outline general procedures for sound quality analysis.

## Definition of Sound Quality

Sound quality can be defined as the perceptual reaction that reflects the customer's acceptability of a product's emitted sound. "Positive" sound quality means that the noise is not perceived as being annoying, and causes positive emotion with respect to the product.

"Negative" sound quality means that the noise causes an uncomfortable hearing event, and reflects poor product quality. The essence of sound quality analysis is to subjectively evaluate a sound event, and to correlate with objective measurements.

The human hearing is a very complex event due to the highly nonlinear nature of human ears. When we listen, many tasks are performed simultaneously: source direction identification, selective masking, distance estimation, noise evaluation (individual and simultaneous). A sound event includes many aspects, such as overall level, duration time, spectral contribution, temporal structure and subjective attitude. Therefore, the objective sound power measurement is sometimes different from subjective evaluation of a sound event. Psycho-acoustic measures, such as loudness, sharpness and roughness, are often used to help understand the sound quality of products.

## Sound Quality Metrics

Sound quality metrics considered for describing the hard drive noise include loudness, sharpness, tonality, roughness and fluctuation strength. It should be noted that other user-defined metrics could be developed that may better describe specific impression of sounds unique to hard drives.

*Loudness (in sone)* was determined according to Zwicker method (ISO532B), which is a more developed model of human hearing than A-weighting. The procedure is based on the distribution of the third-octave band sound pressure spectrum including masking effects and tonal components of the noise.

*Sharpness (in acum)* is defined as the ratio of high frequency level to overall level. Sounds that have higher energy in high frequencies tend to be sharper. Sharpness was determined from narrow-band sound pressure spectrum. Therefore, spectral contents and the center frequency of the narrow band sounds are important for sharpness analysis. It should be noted that sharpness does not depend on sound pressure levels. Sharpness is particularly suitable for the idle noise due to the high frequency content. An example of this phenomenon is a ball bearing type drive of poor

quality. Minor imperfections in the surface of the balls will result in discrete tones at multiples of the rotational speed, commonly referred to as bearing defect frequencies.

*Tonality (in tu)* was determined from a function specifying the fraction of the tonal components to total loudness including masking effects and hearing thresholds. Traditionally, tonality was described by “tone-to-noise” ratio, which was determined from the ratio of the sound pressure level of the tone to the sound pressure level of the noise in the critical band centered at the frequency of the tone but without the tone itself. The tone is rated as “prominent” if the tone-to-noise ratio exceeds 6 dB. It is important to note that critical bands, which are auditory band-pass filters, play crucial roles in the description of sensation we perceive with our hearing system. The width of a given critical band is approximately 100 Hz at center frequencies below 500 Hz, and 0.2(c at center frequencies above 500 Hz.

*Roughness (in asper)* is a modulation-based metric that may be described as “grating”. Roughness is generated by sounds that contain tones spaced within a critical band, amplitude-modulated tones, frequency modulation, or rapidly and repeatedly fluctuating noise. Roughness is particularly applicable for the seek noise due to the discrete, intermittent nature of the seek operation. Such things as the seek profile, or seek rate, will affect the roughness characteristics of a drive.

*Fluctuation Strength (in vacil)* was determined by integrating the temporal masking depth along the critical band based on modulation frequency. As with roughness, fluctuation strength is also an important measure for the seek noise due to the impulsive sound generated by seek operation. In some instances involving idle noise, bearing defects may cause a slight speed fluctuation, which results in a modulated noise characteristic.

### Examples of Sound Quality

To illustrate the sound quality nature of hard drives, consider two commercially available hard drives evaluated in both an idle and random seek mode of operation. Each drive was a 7200-RPM, ball bearing spindle motor, two-disk platter, 40 Gbyte style drive. Table 1 summarizes the values of various sound quality metrics measured on both drives, as well as the overall acoustic sound power levels. Since the reader does not have the ability to subjectively listen to the drives during operation, it should be noted that for idle mode, Drive B can generally be classified as having a harsher sound quality than Drive A. Furthermore, the seek speed of Drive A was altered to achieve an equivalent overall sound power level as Drive B. This was done by reducing its seek rate, thus producing a unique sound quality characteristic of Drive A, as illustrated in the figures.

Figure 1 shows a typical measurement setup used for binaural recordings of the hard drives using the Head

Drive	A		B	
	Idle	Seek	Idle	Seek
Operating Mode				
Sound Power [dBA]	32.3	39.0	29.9	38.6
Loudness [sone]	1.6	5.0	1.4	2.6
Sharpness [acum]	3.1	3.3	3.4	3.0
Tonality [tu]	0.3	0.4	0.5	0.2
Roughness [asper]	0.4	2.0	0.5	1.8
Flucuation Strength [vacil]	0.005	0.085	0.005	0.007

Table 1 — Summary of Sound Quality Metrics for Two Commercial Hard Drives

Acoustics HMSiii binaural recording system. The artificial head provides a more accurate basis for measurements because it encodes all of the information a listener will experience. The sound recording was conducted in a semi-anechoic room that has extremely low background noise.



Figure 1 — Typical Binaural Head Recording Setup for an Operating Hard Drive

Figure 2 shows the narrow-band sound pressure spectra for Drives A and B during typical idle operation. Also shown is the corresponding sharpness metrics computed as a function of time. It can be seen that Drive B is sharper than Drive A, even though the overall sound power level of Drive B is 2.4 dBA lower.

Figure 3 gives a similar example for sound quality differences between two different seek events. The nature of the seek event was manipulated between the drives to achieve similar overall sound power levels. As a result, Drive A’s seek rate was reduced, causing the intermittent seek event to be farther spaced in time, and more noticeable to the listener. This attribute is identified when comparing the loudness level between Drives A and B, in which subjectively Drive A is louder than Drive B even though the overall sound power levels are virtually identical.

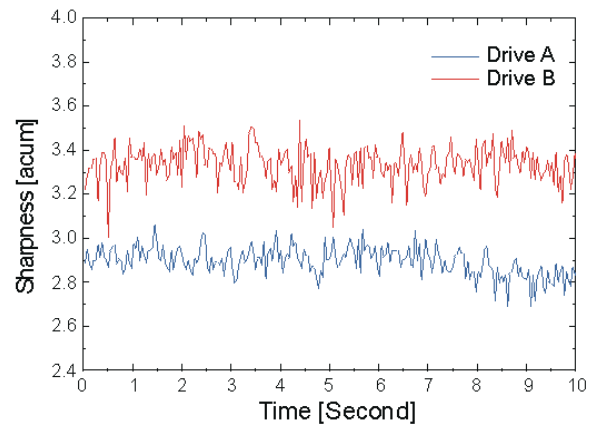
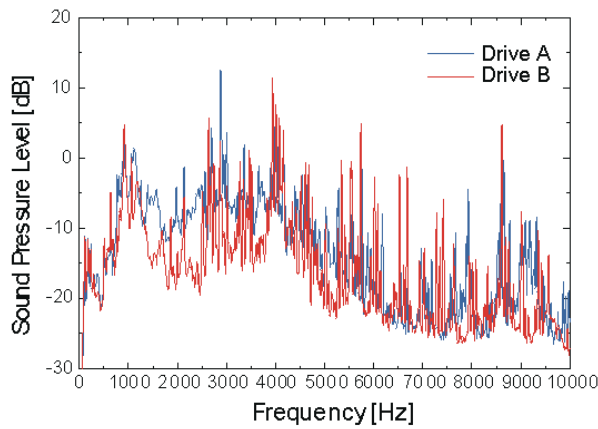


Figure 2 — Comparison of Sharpness and Sound Pressure Level at Idle Mode

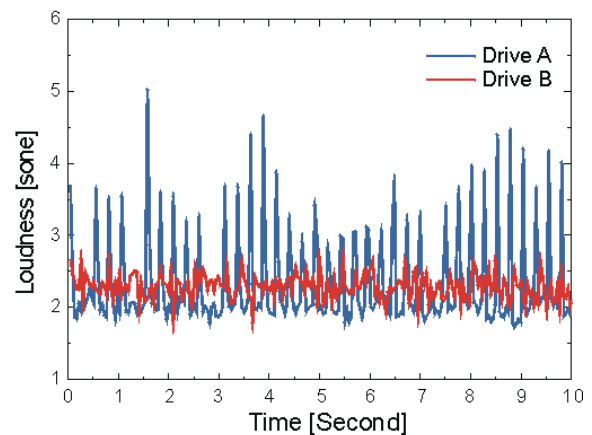
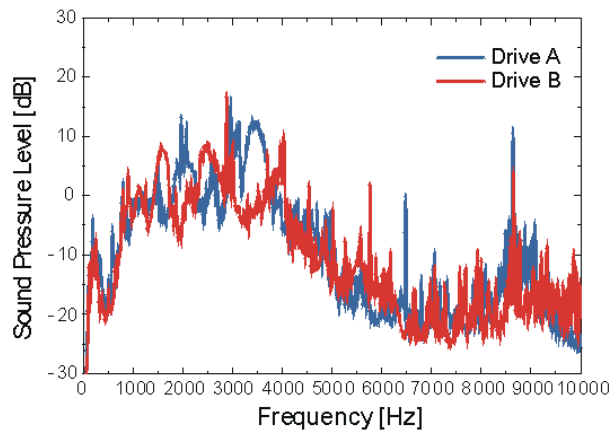


Figure 3 — Comparison of Loudness and Sound Pressure Level at Seek Mode

### General Procedures for Sound Quality Analysis

Sound quality analysis of a hard drive can be conducted using the following generalized steps.

- Use traditional quantitative tools to define the exact nature of the noise event.
  - Noise source ranking
  - Noise path analysis
  - Narrow-band frequency analysis
- Apply Artificial Head Technology by performing binaural recordings of idle and seek noise events.
- Determine traditional sound quality metrics. Loudness, sharpness, tonality, roughness and fluctuation strength can be analyzed from the recorded sounds.
- Playback while performing interactive analysis provided by a sound quality analyzer. Typical tools include:
  - Notch filters
  - Band pass filters (“Radio Tuning”)
  - Digital amplification/attenuation

Goal: Isolate subjective attributes of sound, and relate to established sound quality metrics.

- Conduct Jury Studies to subjectively identify and rank positive and negative aspects of a sound event.

The effectiveness of using traditional sound quality metrics as defined above is measured in the ability to isolate and quantify specific and unique acoustic

characteristics of the hard drive as identified during critical listening exercises and consumer jury studies. For this reason, new user-defined metrics may need to be developed that are customized for the hard drive industry.

### Conclusion

The radiated noise characteristics of products are more important than ever, as consumers have become keenly aware of such issues. The perception that a quieter, smoother running product is one of higher quality has become a reality for the typical OEM today. These subjective interpretations by the consumer affect purchasing decisions, and therefore demand the OEMs close attention to such product attributes. Conventional quantitative measurement techniques do not paint the entire acoustic picture. Sound quality attempts to take into account the human hearing factor and the psycho-acoustic nature of sound — to quantify that, which is inherently subjective. The inclusion of sound quality measurement and analysis techniques offer a more holistic approach to understanding the exact nature of a given noise event. This comprehensive understanding allows the product designer to manipulate radiated noise characteristics of the product, enhancing that which produces a “positive” sound quality reaction to the consumer, and attenuating that which connotes a “negative” reaction.