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TOWARD A VIBRO-ACOUSTIC ANALYSIS OF FDB SPINDLE MOTORS

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Introduction

With the increasing use and the rapid development of hard disk drives in the consumer electronics industry, there is a growing demand for more stringent requirements on the level of acoustic noise. This gives new challenges to the design of the hard disk drive. The acoustic noise that a drive produces comes from movement inside the drive enclosure where the spindle motor is located. One of the primary sources of acoustic noise is the spindle motor.

The acoustic noise generated in the operation of a conventional motor is originated from three sources: the electromagnetic excitation, mechanical excitation, and aerodynamic source [1]. The acoustic noise generation diagram of a motor is shown in Fig.1. Since the electromagnetic field is inherent to the operation of a motor, it creates electromagnetic excitation that causes mechanical deformation in the stator and the rotor as well. The mechanical deformation induces vibration in the motor structure and generates acoustic noise called electromagnetic noise. Moreover, the acoustic noise may originate from the vibration of mechanical components, such as bearings, and rotors, due to the mechanical excitation generated by their inherent defects, such as manufacturing defects and part installation errors. If the mass distribution of the rotor is not balanced, there will be a rotating unbalance force that creates mechanical excitation on the bearing. In addition to the electromagnetic noise and the noise of mechanical origin, spindle motors emits acoustic noise that caused by the flow of air inside and outside of spindle motors called aerodynamic noise. Usually each of these sources contributes to the generation of acoustic noise at different frequencies in the sound spectrum and to the overall sound level at different degree.

In this study, the vibro-acoustic behaviors of fluid dynamic bearing (FDB) motors for hard disk drives are investigated. Fluid dynamic bearings are becoming more used in the spindle drives. For the FDB spindle motors, the bearings have no direct metal-to-metal contact, and the rotor is supported by a liquid thin film. Thus, they produce lower acoustic noise than their ball-bearing (BB) counterpart by eliminating mechanical forces from rolling balls in the bearings. According to the use of FDB and a well balanced rotor, it may be considered that the acoustic noise caused by the mechanical source is insignificant. Furthermore, for the FDB spindle motor itself the aerodynamic noise is low due to minimal air flow.

This paper is, therefore, to investigate whether the effect of electromagnetic noise source becomes more pronounced in the FDB spindle motors. In addition, the range of frequencies that deemed important to the noise problem for the hard disk drive spindle motor is to be identified through experimental investigations.

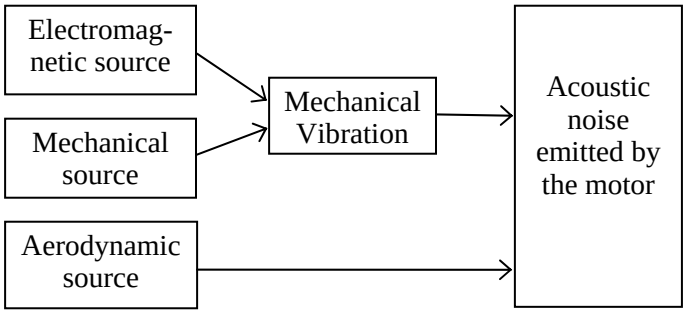

Fig.1 Acoustic noise generation in a conventional motor.

Test Set-Up and Procedures

All measurements are performed in an anechoic room on 3.5-inch FDB spindle motors with 12 poles, 9 slots, and spin speed of 7200 rpm. The motor is installed on a fixture and placed on a soft foam sheet on a table to ensure that no noise from the surroundings is produced during testing. The sound radiated by the motor at rated operating conditions, i.e. at rated supply voltage and

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speed, is measured by a microphone placed 0.30 meter away from the top of the motor. In order to investigate the contribution of the noise of electromagnetic source, the sound pressure is measured in two cases. In the first case, the measurement is done when the motor runs normally with spin speed. In this case, the noise of the motor is originated from all of the three sources: electromagnetic, mechanical, and aerodynamic sources. In the second case, the measurement is done at the moment immediately after the power supply is disconnected. Thus, there is only noise caused by mechanical excitation and aerodynamic source whereas the electromagnetic noise does not exist. In both cases, the sound pressure level with the A-weighting filter is determined with respect to the reference sound pressure of 20 μPa. The acoustic noise spectra are obtained as the sound pressure level plots covering normal audible frequency range, 20 Hz to 20 kHz, shown in Fig.2 and Fig.3 for the first and second cases, respectively.

Test Results and Discussion

The most dominant cause of acoustic noise in the FDB spindle motor can be investigated from both spectra of sound pressure of the motor in Fig.2 and Fig.3. In terms of overall sound pressure level for the entire range of frequency, the first case gives a level of 25.0 dBA while the second case gives a level of 10.3 dBA. The overall sound pressure level of the second case is 14.7 dBA less than that of the first case, and it is only 41.2% of the first case. Thus, the electromagnetic noise has a significant effect on the overall noise level in the FDB spindle motors.

Furthermore, it can be observed from Fig.2 and Fig.3 that most of the high discrete peaks in Fig.2 are not present in Fig.3 that means they disappear with power supply. Therefore, these discrete peaks are related to electromagnetic noise. Based on the results of the first case, sound level discrete peaks can be observed at 120 Hz, 240 Hz, and so on. These peaks occur at multiples of the fundamental frequency, 120 Hz, which is the rotational speed of the motor. It can be explained that the spinning motor responds to the electromagnetic excitation such that the noise spectrum frequencies appear as harmonic numbers of speed. In addition, the dominant peaks found in Fig.2 are at multiples of harmonics of 12th where this number may correspond to the numbers of pole and slot in the motor [2], or other parameters such as the supplied voltage waveform.

Upon investigation of frequency response function of the system consisting of the motor fixed on a fixture, it can be observed that the high peak in Fig.2 occurring at 4.32 kHz, or the 36th harmonic, is present because there is an electromagnetic excitation frequency that is close to the system's structural resonance frequency at 4.2 kHz.

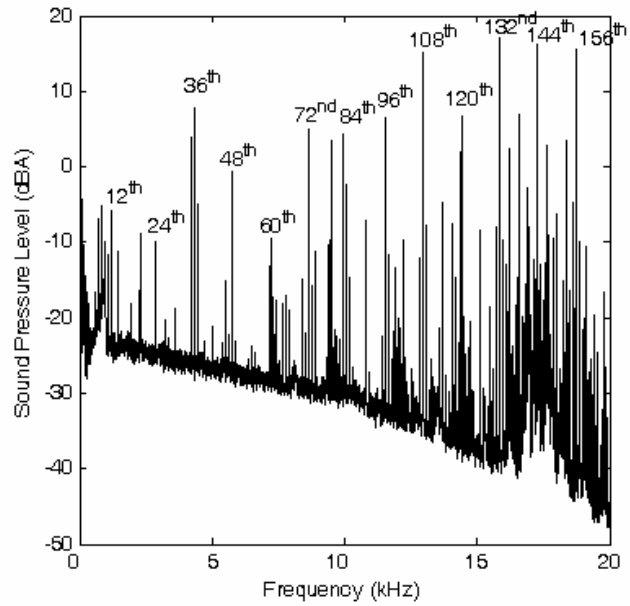

Fig.2 Sound spectrum of the motor that runs at rated speed (case 1).

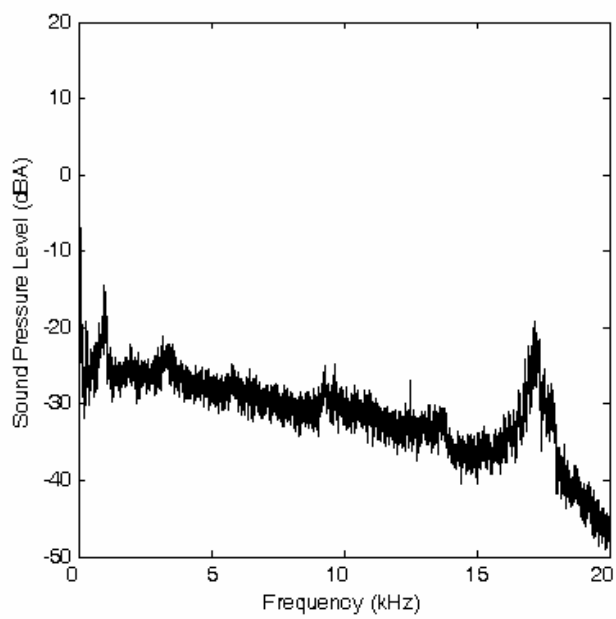

Fig.3 Sound spectrum taken from a motor immediately after the power supply is disconnected (case 2).

Although, the measurement covers the entire audible range of 20 Hz to 20 kHz, a question is what the relative contribution of each frequency range toward the overall

sound pressure level is. For the motor running normally at spin speed, the frequency of the sound spectrum shown in Fig.2 starting from 0 Hz to 20 kHz is equally divided into 4 ranges. The contribution of acoustic noise of each range to the overall sound pressure level is determined and shown in Table 1. It can be seen that the high frequency range is important as it gives the most contribution to the acoustic noise of the motor among other audible range of frequency. The noise in which frequency range is 10 kHz to 20 kHz contributes over 85% to the overall noise. This agrees with the occurrence of densely populated dominant peaks at frequencies above 10 kHz shown in Fig.2.

Table 1 Contribution of noise of each frequency range to overall noise

Frequency Range	Percentage
0-5 kHz	7.7 %
5-10 kHz	5.1 %
10-15 kHz	23.1 %
15-20 kHz	64.1 %

Even though there are only two figures shown herein, the authors carefully examined the results of the many identical motor samples. There is no distinct difference between spectra among the tested motors.

Conclusions

In the operation of FDB spindle motors, the acoustic noise caused by the electromagnetic excitation plays a significant role to the overall noise level. Therefore, to reduce the acoustic noise produced in FDB spindle motors, the causes and effects of electromagnetic excitation must be considered. Acoustic noise problem can be improved by reducing or eliminating the excitation sources and avoiding coincidence of the electromagnetic excitation and the structural resonance. In addition, it was shown that the high frequency range strongly contributes to the overall noise level. It points to possible difficulties in the analytical study of vibro-acoustic behaviors of the spindle motors where the computational complexity grows with the frequency value.

Future work

In order to minimize the electromagnetic noise, the causes of electromagnetic noise source will be examined. It may have been caused by the harmonics in the power supply waveform, the unbalanced magnetic forces on stator and rotor, etc. The dominant causes will be identified, and finally must be reduced as much as possible.

Acknowledgement

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