Two Calibration Methods of AE Measurement Channels for Slider-Disk Contact Detection[1]

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Abstract

Contacts between sliders and disks occur during normal operation in almost all current disk drives, and they can result in undesirable head crash, wear failure, power consumption, or disturbance of the MR read-back signal. The acoustic emission (AE) method has been extensively utilized in the industry to detect these contacts and even to measure the contact force, but a suitable calibration for the AE measurement channel is lacking. Here, we propose two methods for obtaining an in-situ calibration of the AE channel based on simultaneous Laser Doppler Vibrometer measurements. One is the force identification method, from which one can obtain the impact force after the AE channel is calibrated. Another is the filter method, from which one can obtain the velocity responses of the slider from AE. The two methods are successfully applied to quantitatively evaluate contact force.

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I. INTRODUCTION

Contacts between sliders and disks occur during the CSS procedure and even in the dynamic load/unload process. Likewise, contacts may occur in the normal operational state due to low flying heights and disk topography. There are several methods available for detecting the contact. The acoustic emission (AE) method has been the most extensively utilized method in the industry since it was introduced by Kita et al. [1], because of its simplicity and convenience. AE sensors can be placed either directly on top of the slider or at the base of the suspension assembly in operational drives. As long as the slider is flying there is little or no AE to be measured. However, if the slider impacts an asperity, then the slider will vibrate, and the signal can be easily detected by the sensor.

The signal from the AE sensor includes substantial noise and useless information. To reliably detect the contact several researchers [2]-[5] have proposed the use of band pass filters. Others [6]-[7] have even used the root-mean-square (rms) value of the signal after the filters in attempt to measure the contact force. However, the difficulty with this method is the lack of a suitable calibration for the AE measurement channel. Breaking a pencil lead or dropping a ball are two popular methods that are somewhat repeatable, but they can not be used for an in-situ calibration. However, in-situ calibration is very important because the AE sensor output is dependent on the travel path of the elastic waves and the structure to which the sensor is attached. Here, we propose two methods for performing in-situ calibration of the AE channel based on LDV measurements. One is the force identification method, from which the contact forces can be obtained after the

AE channel is calibrated. Another is the filter method, from which one can obtain the velocity response of the slider by use of AE. The two methods are successfully applied in detecting slider-disk contacts.

II. EXPERIMENTAL SYSTEM AND MATERIALS

Read-Rite 50% Tri-pad sliders mounted on HTI 850 suspensions, flying on a super-smooth disk with light texture, and a super-smooth disk with a bump, were used in the experiments. The TTI advanced Tribology Test System with an air bearing spinstand and two Polytec LDVs (single beam 501 and dual-beam 512) were used. The velocity range of 25 mm/s in the frequency band of 0-1500 kHz was selected. One LDV was used to measure the bump and trigger the digital oscilloscope (LeCroy 9304c). The laser beam was focused on the disk, near the trailing edge center of the slider. A very accurate trigger signal is critical for the experiment because recalled events have to be averaged. The index signal from the spindle is not accurate enough to be used in this experiment. The second LDV was used to measure the slider’s response at the trailing edge center and the trailing edge-outer rail. An AE sensor was mounted on the slider holder. The output signal of the LDV was conditioned with a band-pass filter (Krohn-Hite 3202) from 0.4 MHz to 1.5 MHz. The AE signal was conditioned with filters of the TTI system in the same frequency range. The signals were then acquired with the oscilloscope at a 20 MHz sample frequency for 10000 samples.

III. FORCE IDENTIFICATION METHOD

We can obtain the contact force by using the force identification method [8]. The contact force is identified by using the slider's responses as measured by the LDV together with the frequency response functions (FRFs) of the slider. The FRFs are synthesized by using the equation

$$H_{jk}(\omega) = i\omega \sum_{m=1}^{N_m} \frac{\phi_{mj}\phi_{mk}}{G_m\left(\omega^2 - \omega_m^2 + i2\xi_m\omega_m\omega\right)} \tag{1}$$

where ω_m and ξ_m are the measured modal frequency and the damping ratio of the slider, and G_m and ϕ_m are the modal mass and mode shapes of the slider that are calculated from a FE model of the slider. N_m is the number of modes, here limited to the first four modes of the slider. The slider's responses at steady state are measured by the LDV while the slider just contacts the disk (super-smooth disk with light texture, 8.1m/s, 0 skew). The free responses of the slider are obtained by using the random decrement method [9]. Performing the data preprocessing and parameter identification [10], we obtain the measured frequencies and damping ratios as shown in Table 1. From Table 1, we see that the calculated frequencies are close to the measured frequencies. Therefore, it is believed that the FE model is accurate, and the calculated modal mass and mode shapes are correct. Thus, the FRFs are obtained and shown in Fig. 1.

While the small trailing center pad of the slider contacts the bump on the disk (6000 RPM, 29.5 mm, 0 skew), one LDV measures the slider's response in the Z-direction, and the other LDV triggers the oscilloscope. Single shot LDV measurements usually have a very poor signal/noise (S/N) ratio. So, in our experiment, once the signals are stable, 2000 single shots of the LDV and AE signals are averaged. Very good quality averaged signals are obtained, as shown in Fig. 2. Then, the Fourier transform of the contact force F can be found from the following equation

$$F = \left([H]^H [H]\right)^{-1} [H]^H \{X\} \tag{2}$$

where *{X} is* the Fourier transform of the LDV signals (Fig, 2), and *[H]* is the FRF matrix (2×1) of the slider (Fig. 1). The identified force F is shown in Fig. 3. Having F, we can obtain the FRF of the AE measurement channel from the equation

$$T_{AE} = Y / F\,, \tag{3}$$

where Y is the Fourier transform of the AE signal (Fig. 4). The obtained AE channel FRF is shown in Fig. 5.

If we can confirm that only the small pad of the slider contacts the disk, then we can use the FRF to calibrate the AE measurements to obtain the contact force from the equation

$$F_{AE} = V_{AE} / T_{AE} \tag{4}$$

where V_{AE} and F_{AE} are the Fourier transform of the AE signal and the contact force, respectively. Figure 6 shows the measured AE signal at 8000 RPM. Using Eq. (4), we obtained the contact force from this AE signal as shown in Fig. 7.

IV. SPECIAL FILTER METHOD

If one is only interested in the slider's response, we propose another method. Similar to the previous method, the slider's response at its trailing edge center, measured by using the LDV, is X_1 (Fig. 2, Fourier transform), and the simultaneously acquired AE signals is Y (Fig. 4). Assuming the systems are linear, we have

$$X_1 = H_1 F \tag{5}$$

and

$$Y = T_{AE} F \tag{6}$$

Dividing Eq. (6) by Eq. (5), one obtains

$$H_{AE} = Y / X_1 \tag{7}$$

To suppress the noise, the following equation is suggested

$$H_{AE} = \sum \left(X_1^* Y \right) / \sum \left(X_1^* X_1 \right) \tag{8}$$

We can consider H_{AE} as the FRF of a special filter. Figure 8 shows a H_{AE} measured at 6000 RPM. Then, we can use the H_{AE} and measured AE signal Y (Fig. 6) to obtain the slider's response X_1 at 8000 RPM by using the equation $X_1=Y/H_{AE}$. The result is shown in Fig. 9. We see an almost pure response of the second mode of the slider from the AE signal. This second mode response is most useful in contact detection [5].

V. CONCLUSION

The calibration of the AE measurement channel used in slider/disk contact detection in disk drives is studied. Two methods are proposed and used to perform the in-situ calibration of the AE channel based on LDV measurements. The first is the force identification method, from which one can obtain the contact forces after the AE signals are calibrated. Another method is the filter method, from which one can obtain the velocity responses of the slider. This method is very convenient, but the result is dependent on the location of the LDV measurement. We assume the LDV is more reliable than the AE sensor, and the AE sensor is more sensitive than the LDV. After the AE channel is calibrated at a severe contact, it then can be used to detect light contacts. The major advantage of these two methods is the in-situ calibration without any modification of the system. The main disadvantage is that the contact position needs to be known and fixed.

ACKNOWLEDGMENTS

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TABLE 1

MODAL FREQUENCIES (kHz) AND DAMPING RATIOS (%)

Mode	1		2		3		4	
Measured	632.4	0.25	808.5	0.13	1149.2	0.26	1442.7	0.23
FE	624.0		824.5		1142.5		1477.1	

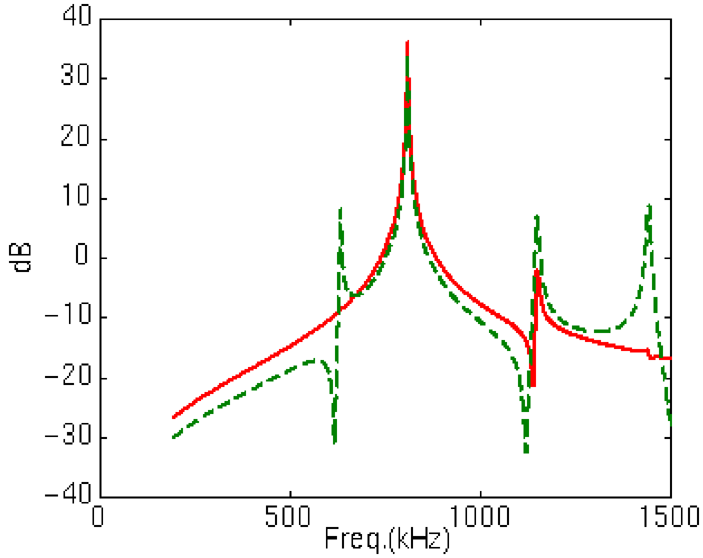

Fig. 1 FRFs of the slider (solid line – center/center; dashed line – outer rail/center)

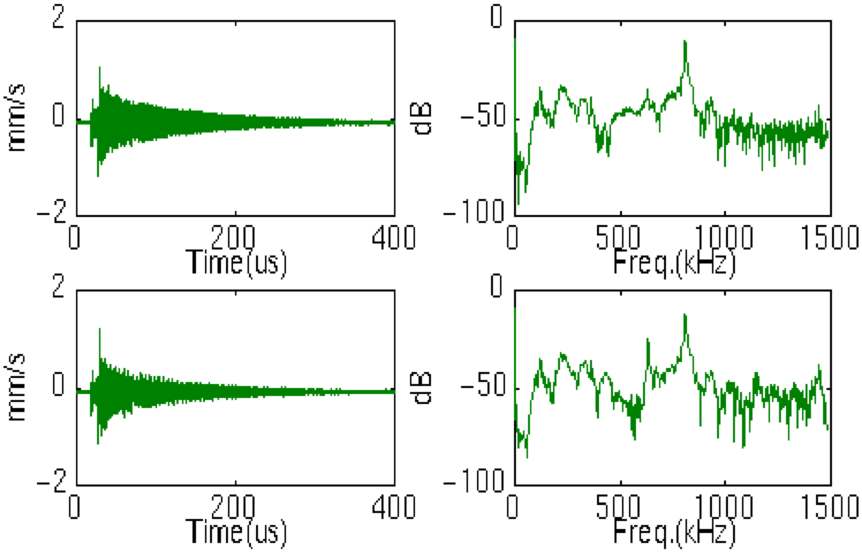

Fig. 2 Responses at the trailing edge center (upper) and outer rail (lower) of the slider measured by the LDV (6000 RPM)

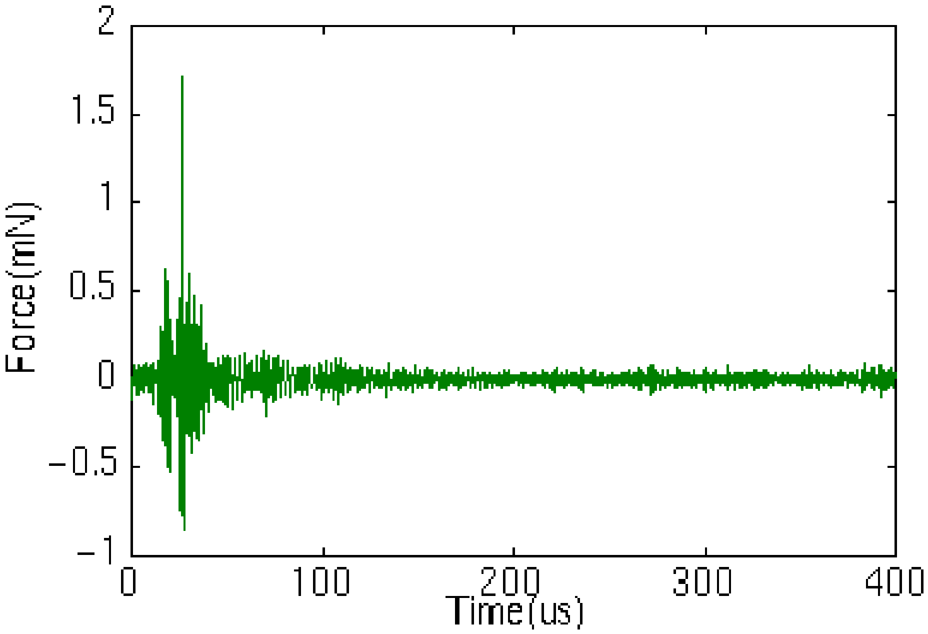

Fig. 3 Identified contact force from the LDV (6000 RPM)

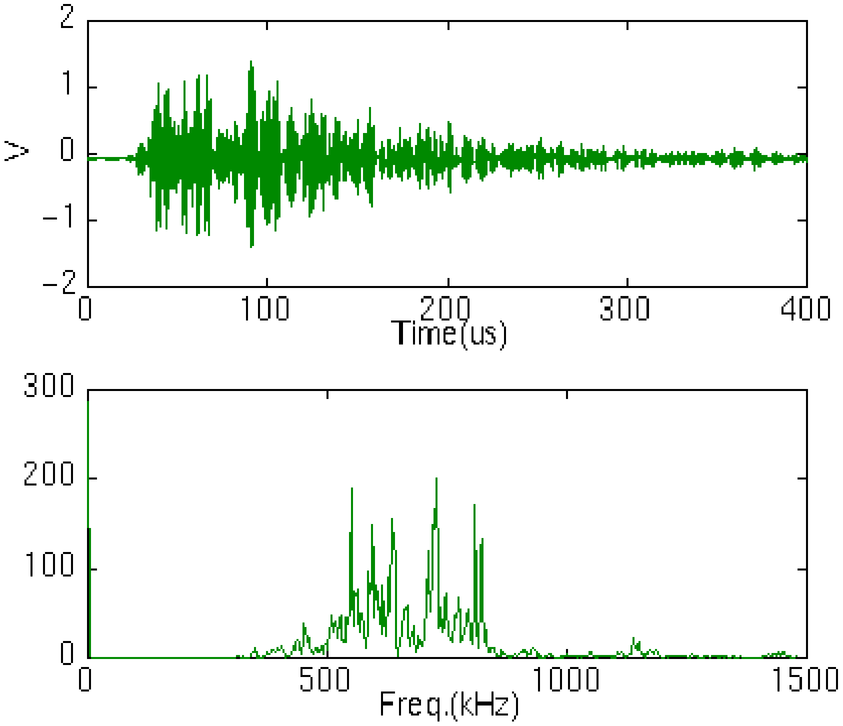

Fig. 4 Measured AE signal (6000 RPM)

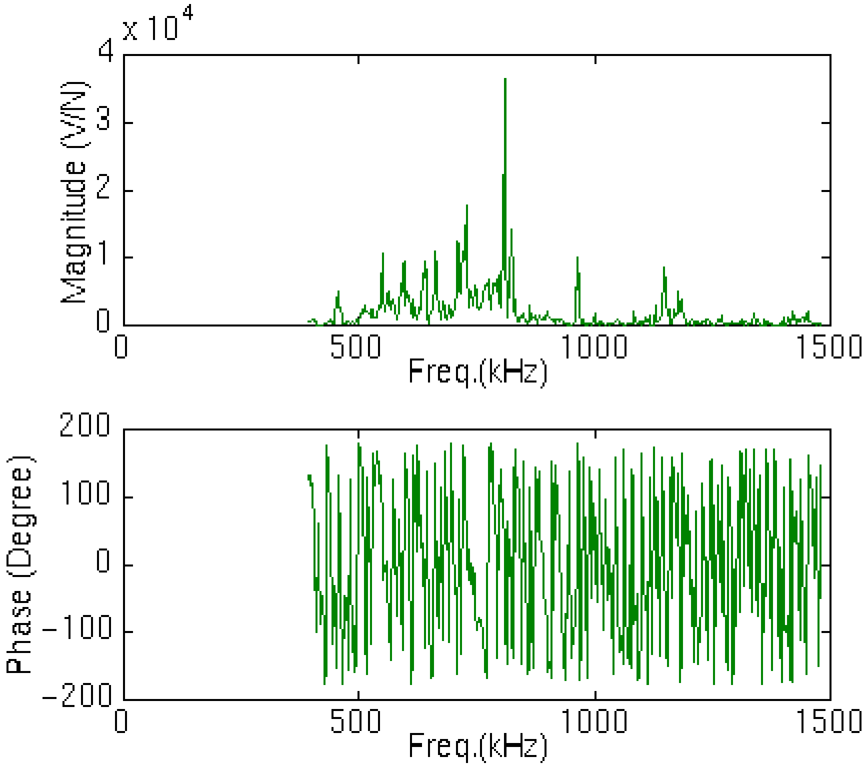

Fig. 5 FRF of the AE channel

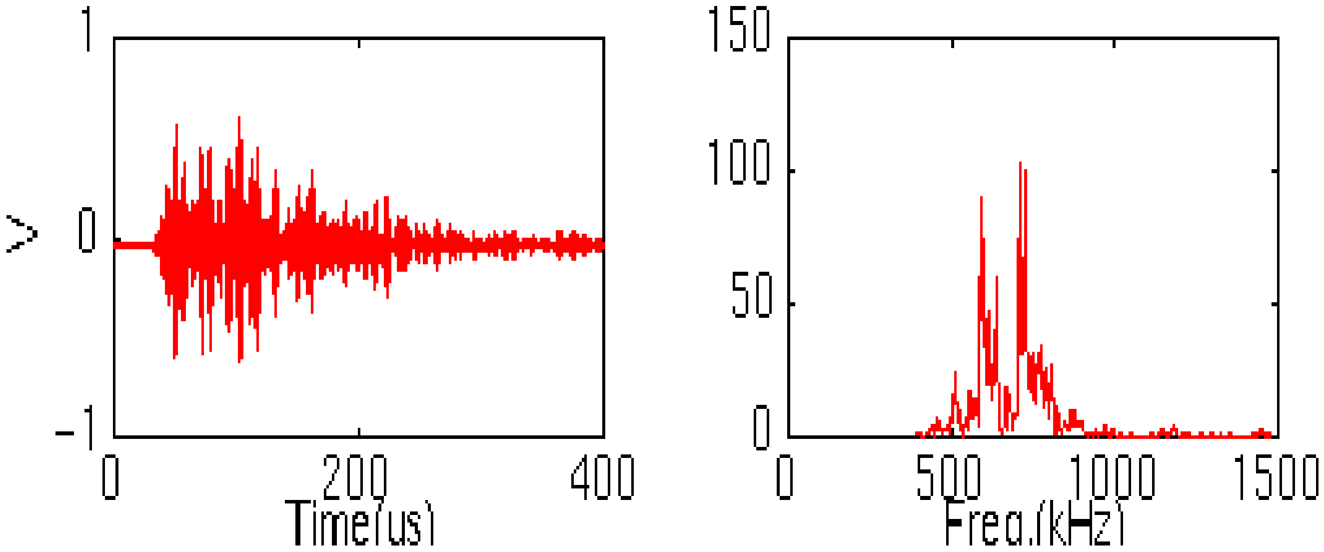

Fig. 6 Measured AE signal (8000 RPM)

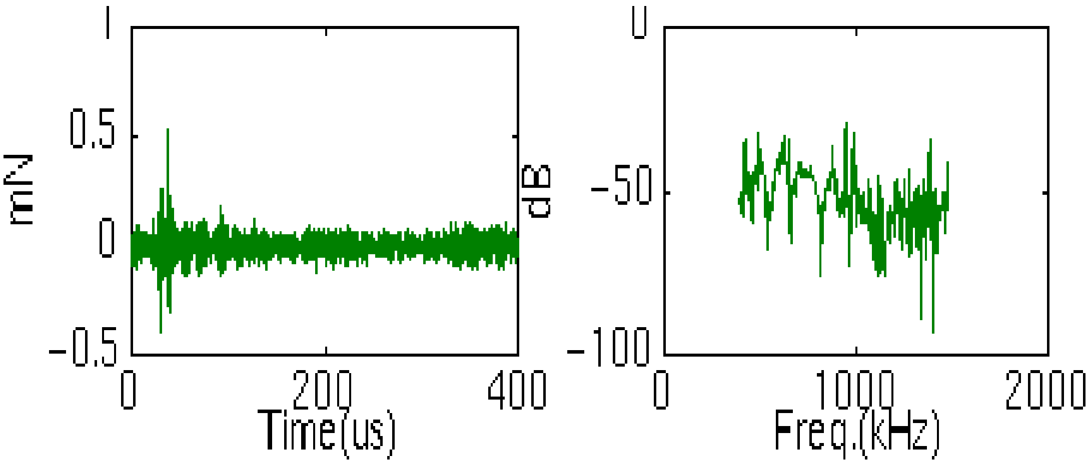

Fig. 7 Calibrated results – contact force from AE (8000 RPM)

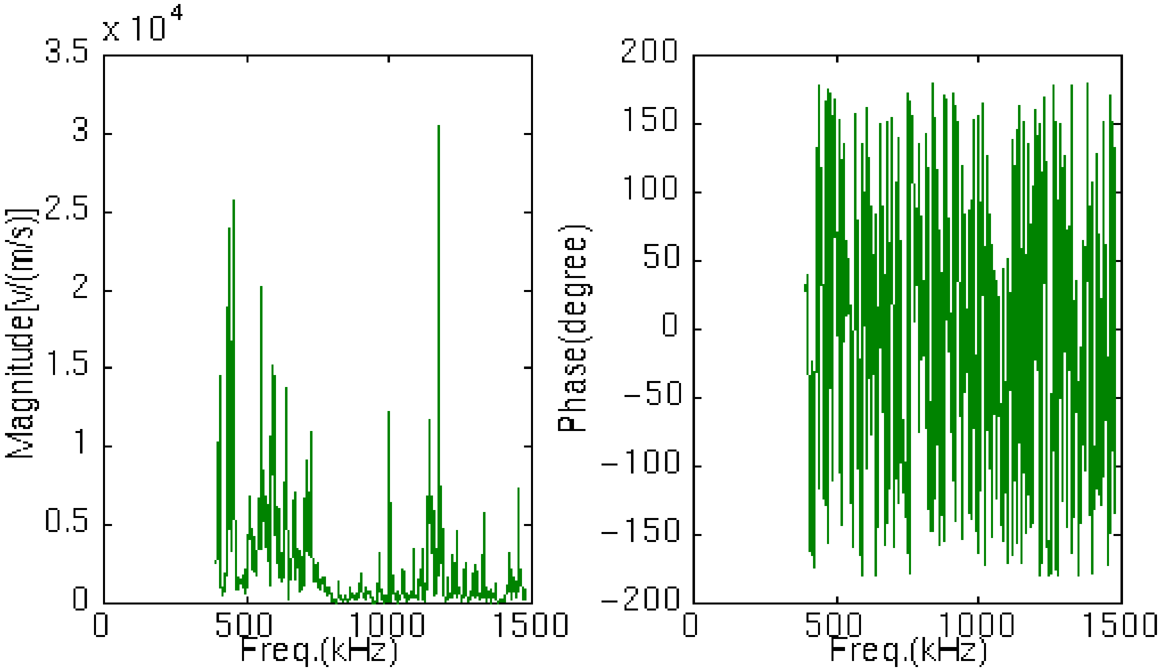

Fig. 8 FRF of the filter

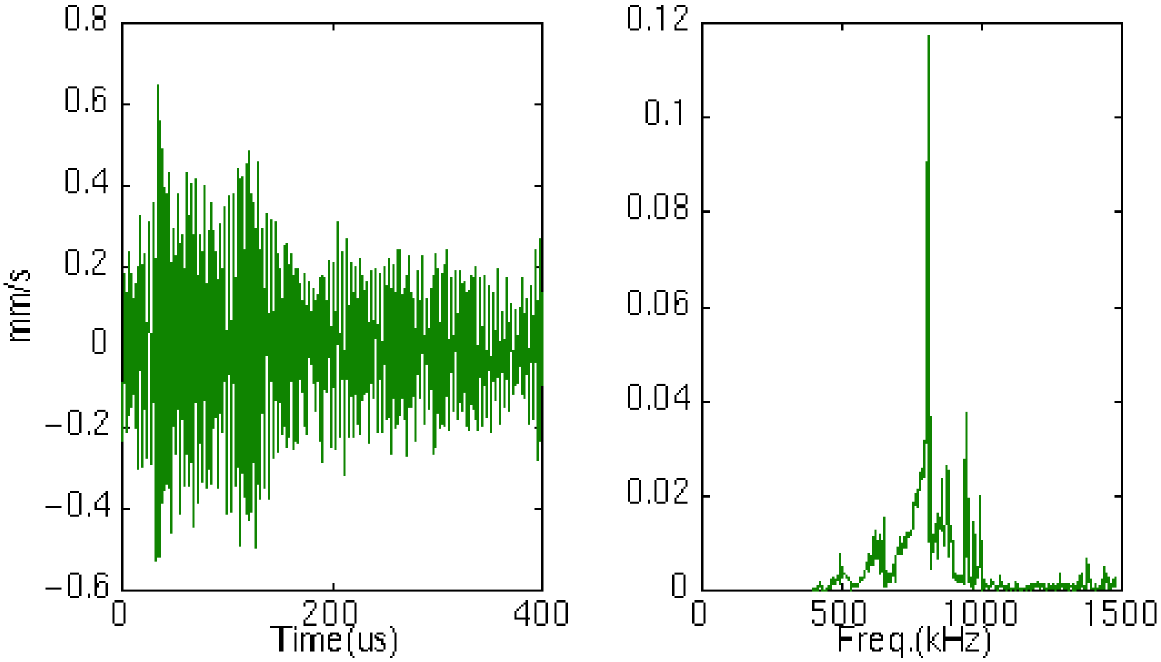

Fig. 9 Calibrated results – slider response from AE (8000 RPM)