Accelerometer mounting – comparison of stud and magnetic mounting methods

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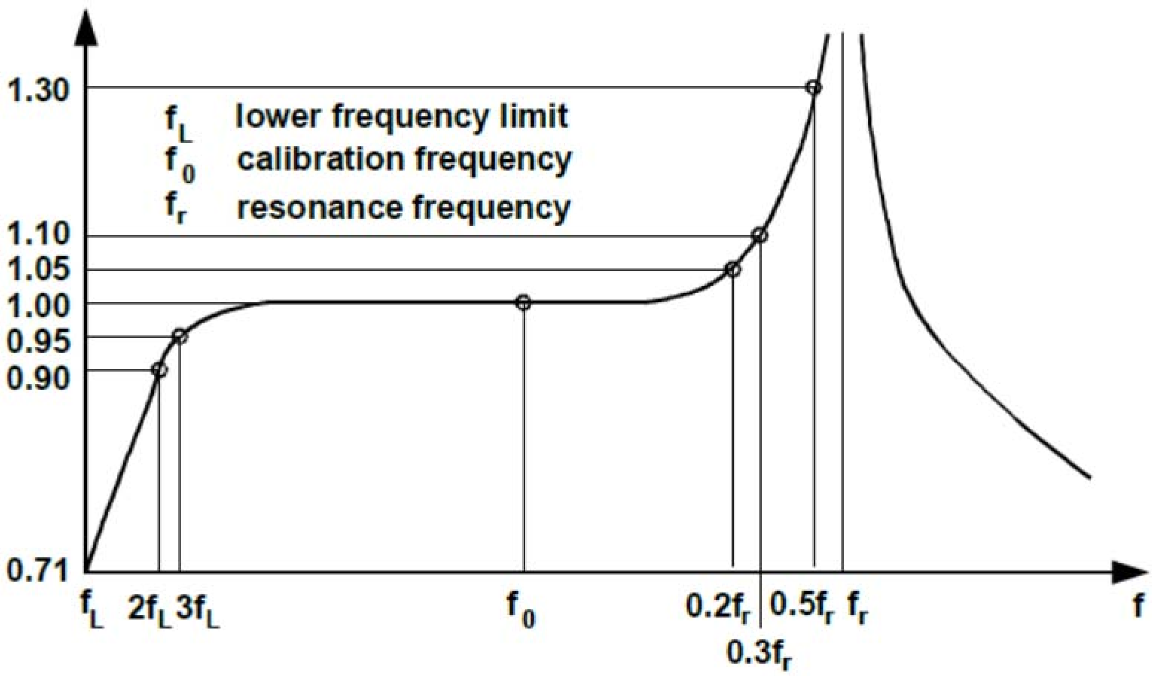
ABSTRACT

Accelerometers can be mounted to structures in a variety of ways: using studs, magnets or adhesives (including wax) are the most widely documented. It is well known that the chosen mounting method will affect the usable frequency range of the accelerometer. However, while accelerometer manufacturers specify the usable frequency range of accelerometers, these specifications usually reflect test results using stud mounting in idealised laboratory conditions. Specifications of the usable frequency range for magnetic mounting methods are limited and are often generic; typically only one magnet and accelerometer combination are presented with no commentary regarding the potential effects of the magnet's size, strength, or mass relative to the mass of the accelerometer. This paper compares the frequency response of four different accelerometers, which have been mounted to a dynamic mass shaker using stud mounts, a magnet with a flat base and a dual rail magnet.

1 INTRODUCTION

1.1 Piezoelectric Accelerometers

Piezoelectric accelerometers are widely used for measuring acceleration. Part of their appeal is a flat frequency response (if the correct accelerometer and mounting method are chosen, of course). Piezoelectric accelerometers consist of a small mass attached to a piezoelectric crystal (Crocker, 2007) which are restrained by a spring of very high stiffness (de Silva, 2005). The spring is a piezoelectric element which produces a charge proportional to the physical force exerted by the inertial forces of the mass. Consequently, piezoelectric accelerometers can be thought of as lightly damped, single degree-of-freedom systems. A typical frequency response of an accelerometer has a characteristic shape as shown in Figure 1.



Piezoelectric Accelerometers Theory and Application (Wagner & Burgemeister, 2012)
Figure 1: Characteristic shape of accelerometer frequency response

Measurements are normally confined[1] to using the linear portion of the response curve which at the high frequency end is limited by the accelerometer's natural resonance. As a rule of thumb the upper frequency limit for measurements is 20%, 30% and 50% of the resonant frequency for errors of 5%, 10% and 30% (or 3 dB) at these frequencies. Actual values depend on the particular accelerometer type and the frequencies associated with a particular error are usually supplied in the accelerometer's specifications.

1.2 Mounting Methods

The theoretically usable bandwidth may be reduced by the mounting method. As such, the method of attaching the accelerometer to the measuring surface is one of the most critical factors in obtaining accurate results at high frequencies for practical vibration measurements. Poor mounting results in a reduction in the mounted resonance frequency of the accelerometer, which can severely limit its usable bandwidth. Accelerometer manufacturers will typically describe the following mounting methods:

- Stud mounting
- Adhesive mounting (including cement and wax mounting)
- Magnetic mounting

Stud mounting is rarely used outside of regular condition monitoring applications, where a stud can be permannently installed and accuracy at high frequencies is required. For other applications such as structural damage, human comfort and ground-borne (or structure-borne) noise, drilling and threading mounting holes in the test surface is often not possible, or impractical and time consuming; in addition the very high frequencies achievable with stud mounting are often not required. For these applications, adhesive mounting or magnetic mounting methods are non-destructive and are also more convenient, and are therefore more widely used.

This paper discusses the effectiveness of magnetic mounting. Magnetic mounting is very common even on non-magnetic surfaces (eg concrete) where a thin ferrous object such as a washer can be adhered to the surface. This allows accelerometers to be moved between measurement points quickly, and reduces time spent on surface preparation and waiting for adhesives to cure between measurements.

In literature, differing information on the effectiveness of magnetic mounting can be found. Dytran (2018) notes that "in general, magnetic adapters should be used with caution and rarely trusted at frequencies above 1 kHz". Similarly, de Silva (2005) states that "the magnetic attachment method reduces the upper frequency limit to some extent (typically 1.5 kHz)". Robinson and Arlington (2018) as well as Brüel & Kjær (1982) and Broch (1984) present results for a specific accelerometer and observe the upper limit of the useful frequency range to be approximately 2 kHz. Other references for a specific accelerometer show magnets can be effective up to and above 5 kHz, including Serridge & Licht (1987), AS 2775-2004 and *Guidelines for Mounting Test Accelerometers* (2018). Serridge & Licht (1987) notes that "Considering the apparently low coupling stiffness this method gives good high frequency performance, especially on flat surfaces."

Practically, the high frequency performance of an accelerometer with a magnetic adapter will depend on the following:

- The mass of the accelerometer
- The size, strength and mass of the magnet
- The magnetic properties of the surface material
- Radius of curvature and roughness of the mating surfaces

Due to the complexity of the issues at play, accelerometer manufacturers generally do not specify the usable bandwidths for mounting methods other than stud mounting and this information is usually not readily available.

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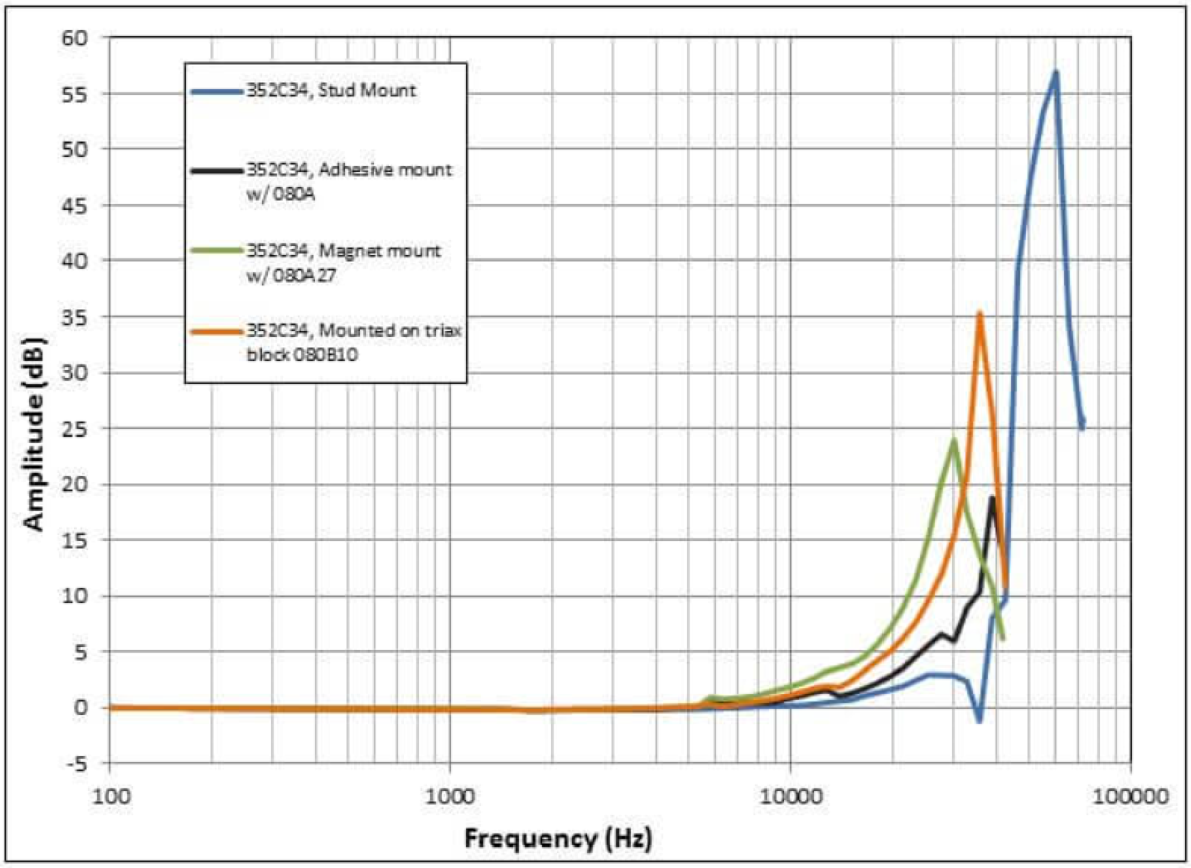
[1] The accelerometer's resonance can be within the captured frequency bandwidth as long as the magnitude and phase relationship is known, results can be compensated. However, using an accelerometer above its resonance reduces its sensitivity and likely adversely impacts on the accuracy.

Some manufacturers may publish results for one accelerometer type (such as those shown in Figure 2 below), but generally the changes in usable bandwidth have to be estimated or determined through experiment.



Guidelines for Mounting Test Accelerometers (2018)
Figure 2: Frequency response of PCB 352C34 accelerometer with different mounting techniques

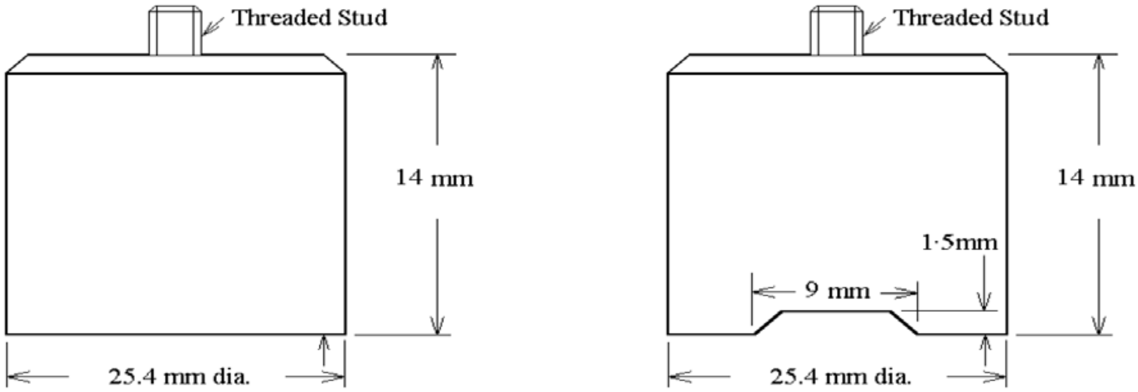
1.3 Paper Outline

The authors consider that the achievable upper frequencies (for flat and smooth mating surfaces) should be known for the type of accelerometer and magnets used prior to undertaking measurements. This is better than relying on generic graphs and significantly reduces the risk of unknown mounting resonances affecting the results.

This paper presents the frequency response of a variety of accelerometers attached with different mounting methods:

- Stud mounting
- Magnetic mounting, using a flat-based magnet with a holding force of 20 kg
- Magnetic mounting, using a dual rail magnet with a holding force of 17 kg.

Diagrams of the two magnet types are provided in Figure 3. Their masses are 64 grams and 62 grams respectively. The holding forces listed above are those specified by the manufacturer and were not verified by the authors.



Accelerometer Magnet Adapter Specification (International Scientific Instruments, 2018)
Figure 3: Accelerometer magnet adapters

The tests have been carried out using four different accelerometers. Manufacturer specifications for each accelerometer are reproduced in Table 1.

Table 1: Tested accelerometers

Manufacturer	Model	Sensitivity	Mass	Upper Limiting Frequency			Resonant Frequency
				5%	10%	3 dB	
Dytran	3055D1	10 mV/g	10 g	5 kHz	10 kHz	n/a	n/a
IMI	622B01	100 mV/g	94 g	6 kHz	10 kHz	15 kHz	30 kHz
Brüel & Kjær	4370	1 V/g	54 g	n/a	4.8 kHz	n/a	16 kHz
PCB	393A03	1 V/g	210 g	2 kHz	4 kHz	6 kHz	>10 kHz

2 TEST SETUP

2.1 Test Equipment and Configuration

Measurements were conducted using four different accelerometer models as outlined in Table 1. The three IEPE accelerometers (Dytran 3055D1, IMI 622B01 and PCB 393A03) were connected to a LMS SCADAS data acquisition module using shielded coaxial cables. The charge accelerometer (Brüel & Kjær 4370) was connected to the data acquisition system using an in-line charge to IEPE converter. Cables were secured to the mounting surface to minimise cable strain and triboelectric noise.

The test excitation signal was generated with the LMS SCADAS data acquisition module under the control of a laptop computer running LMS Test.Xpress data acquisition and control software. The excitation signal was fed to a LabWorks ET-140 dynamic mass shaker which in turn generated the testing excitation force.

The dynamic mass shaker was fitted with a 690 gram rectangular block of mild steel measuring approximately 80 mm x 50 mm x 19 mm. This material is ferrous and suitable for direct attachment of magnetic accelerometer mounts. This block was bolted to the shaker with two M4 bolts located at each end of the block. The block was oriented symmetrically on mass shaker test surface. The centre of the mounting block was drilled and tapped to suit ¼” mounting studs. The testing surface of the block was sanded smooth.

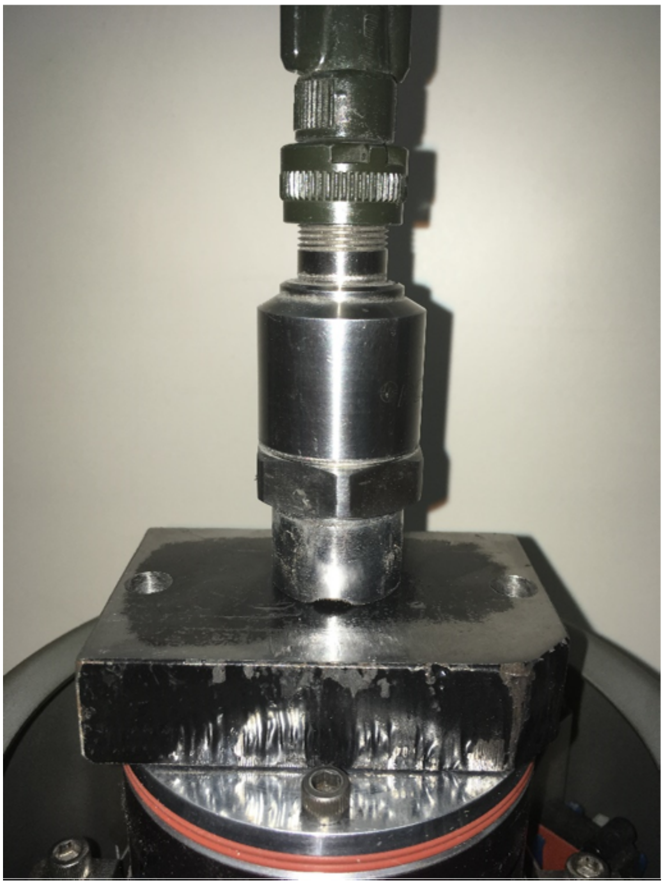


Figure 4: Test Configuration – PCB 393A03 Accelerometer on Dual Rail Magnet (strain relief not shown)

2.2 Test Procedure

One accelerometer was tested at a time with either stud or magnetic mounting methods. For each test, the shaker produced a 40 second logarithmic sine sweep excitation between 50 Hz and 8 kHz at root-mean-square amplitudes varying from approximately 2 m/s^2 to 10 m/s^2. Each measurement was recorded at a sample rate of 51.2 kHz and with a bit depth of 24.

Measurements of the sine sweep were performed three times consecutively for each accelerometer and magnet configuration. When attaching each accelerometer, the accelerometer face and testing surface was checked to be smooth and free of debris or any other elements that may affect coupling.

Each measurement included approximately 2 seconds of 'dead time' before and after the excitation signal. The measured signals were saved in lossless format within Test.Xpress software for analysis.

3 ANALYSIS

For each sweep a FFT spectrum (window length 40 seconds, no windowing function, frequency resolution 0.025 Hz) was computed. The three individual FFTs making up each configuration were checked for repeatability – frequencies at which the individual sweeps were more than 5% apart were rejected. It was found that individual sweeps for each tested configuration were within the 5% band for frequencies up to typically 6,500 Hz. In the frequency bandwidths where the attachment methods were found to be impacting on the results, the three individual sweeps of each configuration were within 1-2%.

Subsequently, average FFTs (averaged over three sweeps) were computed. The relative effect of magnet mounting to stud mounting is viewed in terms of the ratio of average FFT (dual rail magnet or flat magnet) over the average FFT for stud mounted at each frequency bin.

The results of the dynamic mass shaker testing are summarised in Figure 5 and Figure 6. The +/-5% and +/-10% ranges are highlighted. At low frequencies the ratios were found to be approximately 0.95. This apparent reduction is due to the added mass of the magnets and the results presented in Figure 5 and Figure 6 have been compensated for this effect[2].

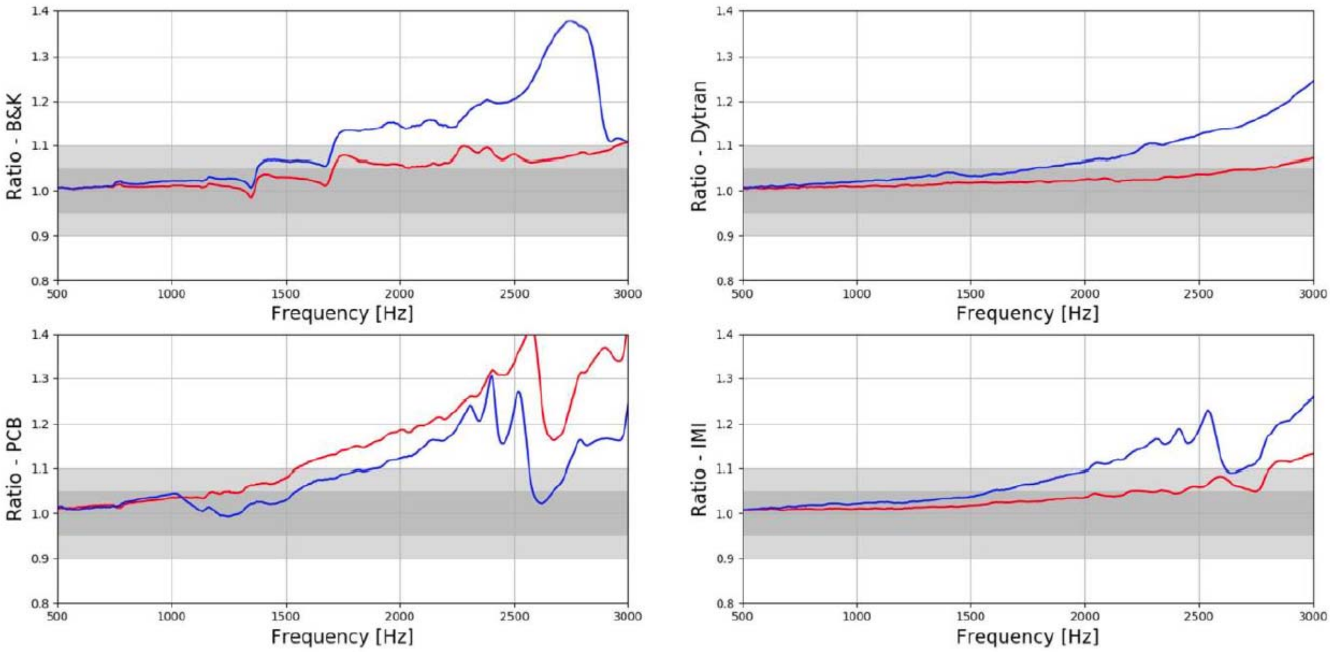


Figure 5: Dynamic Mass Shaker Results: Flat Magnet (blue) and Dual Rail Magnet (red) relative to Stud Mount, 500 Hz to 3000 Hz

[2] The moving mass without magnets ranges from approximately 1150g (Dytran) to 1360g (PCB). The majority of the mass comes from the shaker armature (453g) and the steel block (690g). The magnets weigh 62g to 64g which represents approximately a 5% increase in mass which is reflected in a 5% lower vibration level.

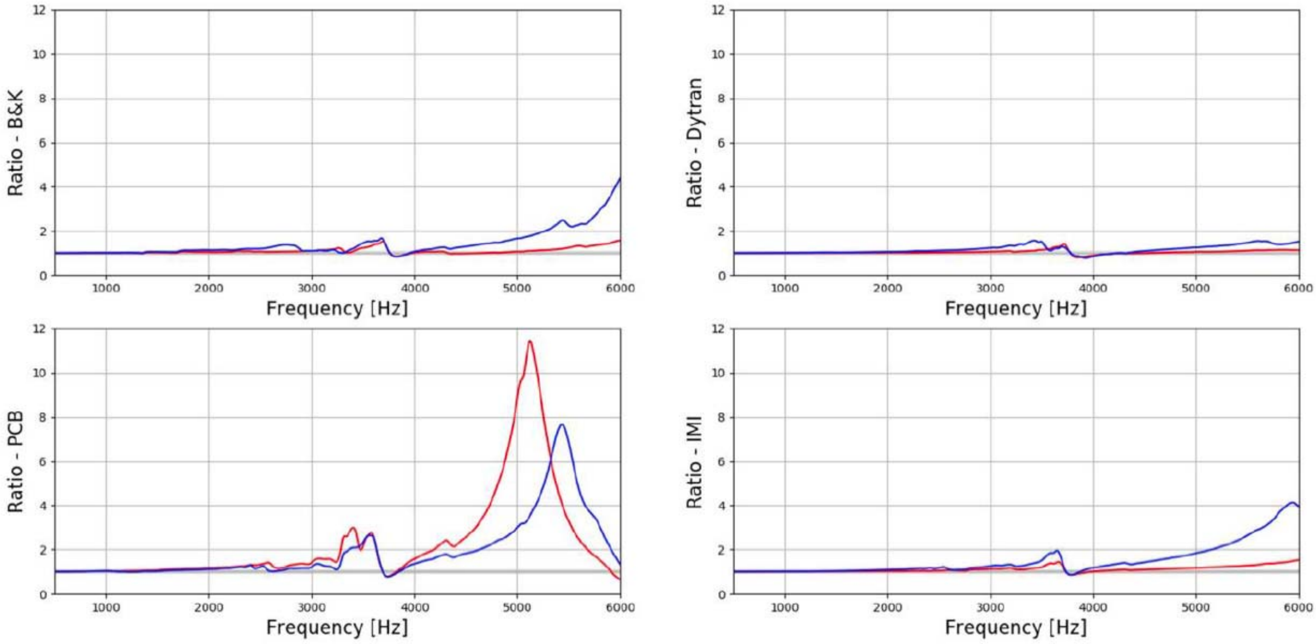


Figure 6: Dynamic Mass Shaker Results: Flat Magnet (blue) and Dual Rail Magnet (red) relative to Stud Mount, 500 Hz to 6000 Hz

Table 2 shows the frequencies where the error first exceeds the nominated 5%, 10% and 3 dB thresholds. There is a general trend of increasing usable frequency with reducing accelerometer mass. The flat magnet has a higher holding force, however, its usable frequency range is always less than that of the dual rail magnet. This could be due to the flat magnet being more sensitive to surface irregularities.

Table 2: Frequencies where error exceeds the thresholds

Manufacturer	Model	Magnet	Frequency (Hz) where threshold is first exceeded		
			5%	10%	3 dB
Dytran	3055D1	Flat	1777	2267	3292
		Dual Rail	2792	3162	3707
IMI	622B01	Flat	1597	2027	3437
		Dual Rail	2207	2817	3642
Brüel & Kjær	4370	Flat	1377	1712	3477
		Dual Rail	1712	2962	3642
PCB	393A03	Flat	997	1802	3282
		Dual Rail	1162	1537	2552

4 DISCUSSION

When viewed with respect to the 5% threshold, the frequency response of both magnets appears to be proportional to the resonant frequency of the accelerometers; as the resonant frequency decreases, the usable frequency bandwidth decreases. The accelerometer mass also influences the results, with the heavier PCB 393A03 having a lower high frequency response than the Brüel & Kjær 4370. The dual rail magnet also appears to outperform the flat magnet in every case which is unexpected considering the increased holding force of the flat magnet. This could be due to the flat magnet's increased sensitivity to surface roughness and curvature.

The results with respect to the 10% and 3 dB thresholds are more difficult to interpret. For the PCB 393A03 accelerometer, the flat magnet performs better than the dual rail magnet, and has a higher frequency range than the Brüel & Kjær 4370 with the flat magnet with respect to the 10% threshold. With respect to the 3 dB threshold, the the PCB 393A03 with the flat magnet has almost the same upper limiting frequency as the Dytran 3055D1, which is much lighter, having a smaller inertia force to magnet holding force ratio.

5 CONCLUSIONS

For accelerometers with a mass up to 210 g and magnets with holding forces of 17 kg and 20 kg mounted on a smooth steel block it was found that vibration can be measured within the 5% error range for frequencies generally up to 1 kHz. This is generally suitable for structural damage, human comfort and ground-borne noise applications. These experimentially determined values will decrease if weaker magnets are used or if the contact surface is dirty, painted or uneven, less magnetic or less flat. Where higher frequencies are required, the accelerometer and magnet combination should be carefully considered. The experiments suggest that accelerometers with high resonant frequencies used in combination with magnetic mounts may be able to achieve a suitable frequency response (with errors up to 10% and 3 dB) in the order of 2.5 to 3 kHz. However, the combined frequency response of an accelerometer, magnet, upper frequency of interest and surface properties should always be verified prior to use.

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