OPTIMAL ATTACHMENT METHODS FOR ACCELEROMETERS

William D. Marscher and Maki M. Onari
Mechanical Solutions, Inc.
11 Apollo Drive
Whippany, NJ 07981
(001) 973-326-9920
wdm@mechsol.com

Abstract: Vibration detection on stationary surfaces of machinery, such as bearing housings, is typically accomplished with accelerometers. Modern accelerometers have been engineered to have a very wide frequency range with strong sensitivity of voltage to surface acceleration. However, in order to implement this capability, the bottom surface of the accelerometer must faithfully track the actual motion of the surface that it is attached to. The ideal method would be a tight metal-to-metal connection, such as can be achieved with a well-torqued screw joint. However, this is often not practical (e.g. no surface modification allowed), or is very inconvenient (e.g. an Operating Deflection Shape requires measurements at hundreds of locations, or walk-around machinery monitoring routes on many uninstrumented machines in large plants). In such cases, diagnosticians use temporary attachment methods, such as a simple hand-pressure attachment, a magnetic base, two-sided tape of various thicknesses, a thin layer of wax, or glue-cement. The authors have studied the fidelity of each of these methods in a series of controlled experiments, and determined that all methods, up to about 1500 Hz, are adequate for characterization of machines over the typical range of significant dynamic excitation forces. For frequencies to over 10 kHz, an unexpected result was that double-sided tape provided some of the best results. All methods provided similar looking amplitude vs. frequency spectra up to about 5 kHz.

Key words: Accelerometer Attachment; Vibration Measurement; Operating Deflection Shape; Turbomachinery; Machinery Diagnostics

1. INTRODUCTION

Vibration of machinery is useful in determining whether or not a machine is experiencing distress, or perhaps has already worn certain key components such as bearings. In order to quantitatively characterize vibration, motion sensors are used. For rotor systems, these probes are typically non-contact (e.g. eddy current based) proximity probes. For stationary surfaces such as bearing housings, contact probes based on either vibration velocity ("velocimeters") or acceleration ("accelerometers") are used. Velocimeters are more limited in frequency range, and bulkier, while modern accelerometers are designed to be accurate over a wide range of about 1 Hz to over 10 kHz, with special accelerometers able to function with reasonable accuracy to as high as 50 kHz.

In all cases the accuracy and repeatability depends upon how well the base of the accelerometer is able to follow the true movement of the surface being measured. This requires a stiff attachment, one that does not allow the accelerometer surface to part from the measured surface, and that also does not allow the natural frequency of the mounted accelerometer to drift down into the intended measurement frequency range.

2. APPLICATION HISTORY

The ideal attachment in this regard has always been considered metal-to-metal contact, enforced by a screw or bolt that enforces significant compression on the interface. Testing has of course validated this as a means to achieve high fidelity of measurement, as discussed in references [1] to [7]. Depending upon the mass of the accelerometer and the stiffness of the mounting surface, this method can result in accurate and repeatable measurements to order of 50 kHz [4, 5, 6].

However, screw-on attachment of an accelerometer requires tapping of the measured surface, which may not be permitted, or may not be practical (e.g. thin surface walls). In other instances, it may be very time-consuming and inconvenient to perform such an attachment. This is the case in a typical Operating Deflection Shape (ODS) test, when hundreds of measurements on many types of surfaces are required [7]. It is also the case for walk-around routes in large plants, where technicians must measure key locations on a large number of machines in a brief period of time, as they follow their routes.

Therefore, other methods of attachment are typically used. One of the simplest and oldest is the use of hand-held pressure, by holding the accelerometer sensor base (sometimes through a needle point "stinger") firmly against the measurement location. This method is intuitively considered the least accurate attachment method, but in the authors' experience is typically more accurate than the other long-time method, a magnetic base firmly screwed onto the accelerometer base. The problem with the magnetic base is that at moderate frequency the magnetic surface can temporarily lose contact with the magnetic target surface, especially at higher acceleration G levels.

Other methods include the use of a thin layer of special sticky wax (only works for surfaces with temperatures to about 100 F), a thin layer of glue/ cement (typically cyano-acrylic "superglue"), and double-sided sticky tape on the order of 8 mils (0.2 mm) thick. Studies have been performed by various organizations, and opinion-based curves of adequate ranges for each technique are published by such standards organizations as ISO (ISO 5348[1]), Hydraulic Institute (ANSI/HI 9.6.4 [2]), and ANSI (ANSI S2.61 [3]).

3. EXPERIMENTAL SET-UP

As stated in the references, there is general agreement that a screw-on connection is the highest fidelity method of attaching an accelerometer to a machine for which vibration is to be measured. Finite element analysis confirms this conclusion, for flat-surface-on-flat-surface, where a torqued-up screw tightly compresses the two surfaces together sufficiently so that the separation force from acceleration F=ma, remains below the spring-like compression force across the surface, F=kx, where m is the accelerometer mass, k is the attachment interface stiffness, a is the acceleration being measured, and x is the compression displacement of the combined accelerometer base and measured surface material. Therefore, the author's testing used the screw attachment method as the standard against which all other methods were compared.

In the authors' experiments, a 12 inch long, 2 inch wide, 2 inch thick cantilever beam was attached to a stiff support over a 4 inch length at one end, firmly bolted to a massive slotted machine foundation plate. The beam retained 8 inches of cantilevered free length, as shown in Figure 1. The modal characteristics of the final assembly were determined by impact testing and an Operating Deflection Shape test, assisted by 3-D finite element analysis, and resulted in quantification of many natural frequency modes existed in the range of 100 Hz to 10 kHz. The test results were evaluated in the context of these modes (unavoidable in a real-life laboratory set-up), rather than assuming infinite stiffness of the attachment of the beam "fixed end" to ground, or the base of the exciter to ground. A screwed-on reference accelerometer was attached to the bottom of the free end of the beam, 2.5 inch from the beam end. The tested accelerometer/ attachment method in each test was attached to the beam, on the top side of the beam, precisely on the opposite side of the reference accelerometer, as also shown in Figure 1.

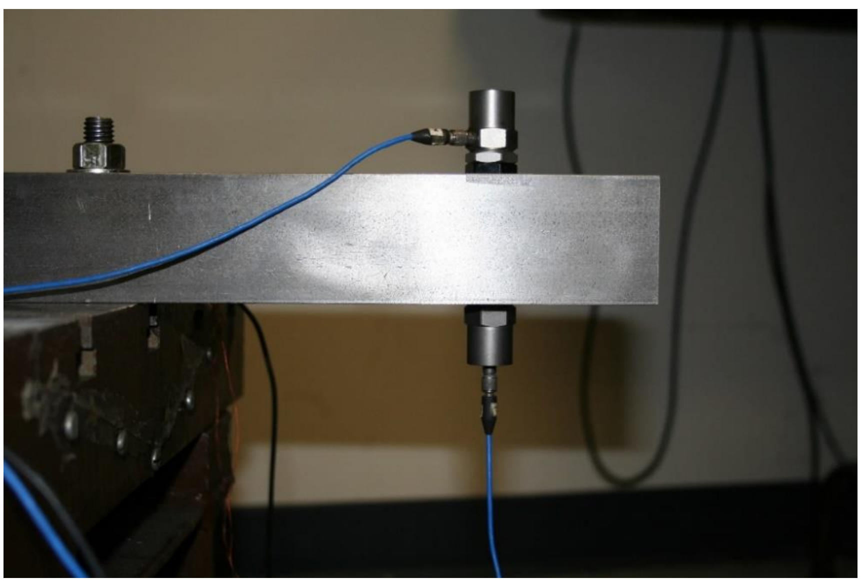


Figure 1: Acceleration attachment test set-up

The tests consisted of exciting the end of the beam with an electrodynamic shaker, with an accelerometer on its head to detect the acceleration spectrum input to the base of a stinger. For all acceleration measurements in the experimental set-up, MSI used off-the-shelf accelerometers from a major supplier. The remaining equipment consisted of a National Instruments (NI) data acquisition (DAQ) system chassis model number NI PXIe-1073 with two cards of model number NI PXIe-4497, and a Labworks ET-132-2 shaker, driven by a power amplifier PA-138, with LabView based software control custom-programed by the authors' group.

The LabView-based DAQ and FFT system was set up to read a frequency span of over 10 kHz (after anti-aliasing), a resolution of ¼ Hz, an overlap of about 90%, and an update time of 0.375 sec. The analyzer was set to Peak Averaging mode throughout a frequency sweep. The shaker was set to sweep from 100 Hz to 10 kHz frequency (later testing to 20 kHz will be reported in a future paper) at a constant rate of typically 20 Hz/s, at a nominally constant amplitude of 0.1 G at the base of the shaker stinger, where the stinger attached to the shaker head. The shaker possessed system resonances at about 4800 Hz and 8500 Hz, which resulted in increased acceleration input to the stinger of order a 1 G when the shaker was operating within several percent of those frequencies. The presence of the resonant frequencies was not observed to affect the fidelity of the results.

A 100 mV/g reference accelerometer was stud mounted to the underside of the cantilever beam. For each attachment-tested accelerometer, after acquiring data at 0.1 G excitation across the frequency range, the excitation amplitude was increased by increasing the current fed to the Power Amplifier. Three amplitudes were tested (0.1 G peak, 0.3 G peak, and 1.0 G peak) for each tested attachment and each tested accelerometer type. Specifically, the procedures were repeated with different accelerometers to ensure repeatability of the various attachment methods, or to investigate the effect of accelerometer mass on the result. Two different serial number (but same model) 100mV/g accelerometers were tested, and were then replaced with a roughly $1/10^{th}$ mass 10 mV/g accelerometer. Each specific test was repeated four times to ensure consistency. The results were found to be quite consistent, and within the range of frequency and amplitude investigated, the accelerometer size had no measurable effect. Therefore, the results reported will focus only on the effect of the attachment means.

4. EXPERIMENTAL RESULTS

A large volume of test data was acquired. The following figures show only representative results from the authors' tests. Initially, plots (Figure 2 to 5) show the raw frequency spectra from a given test, plotting the tested accelerometer and attachment as a blue line, and the reference accelerometer, bolted firmly in place to the beam, as the red line. These plots are log amplitude plots, which have the advantage of showing low amplitude and high amplitude responses on an equal basis, but can give the false impression of better percentage agreement than is actually present. Therefore, following the raw FFT plots, the results are re-plotted (Figures 6 to 12) from a statistical average of the repeatability testing, in this case in terms of the ratio of the tested accelerometer reading to that of the reference accelerometer, along with any phase difference between the two, over the tested range of frequency. This plotting method in turn can give a false impression of gross error, particularly at low amplitude anti-resonance "valleys". Taken together, however, in the authors' opinion the two sets of plots give a reasonable indication of the capability of each attachment method.

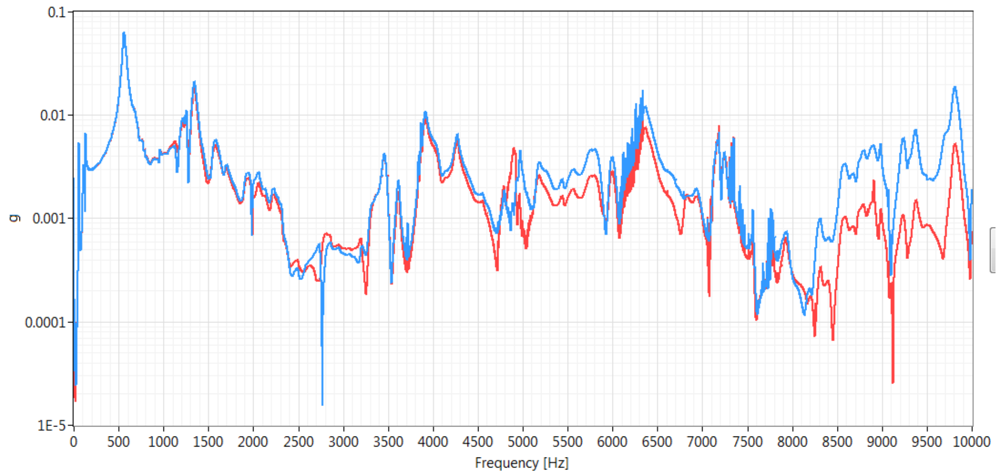


Figure 2: Acceleration attachment test raw spectra, handheld-only attachment; blue is the signal of the tested accelerometer & attachment, red is the reference accelerometer signal

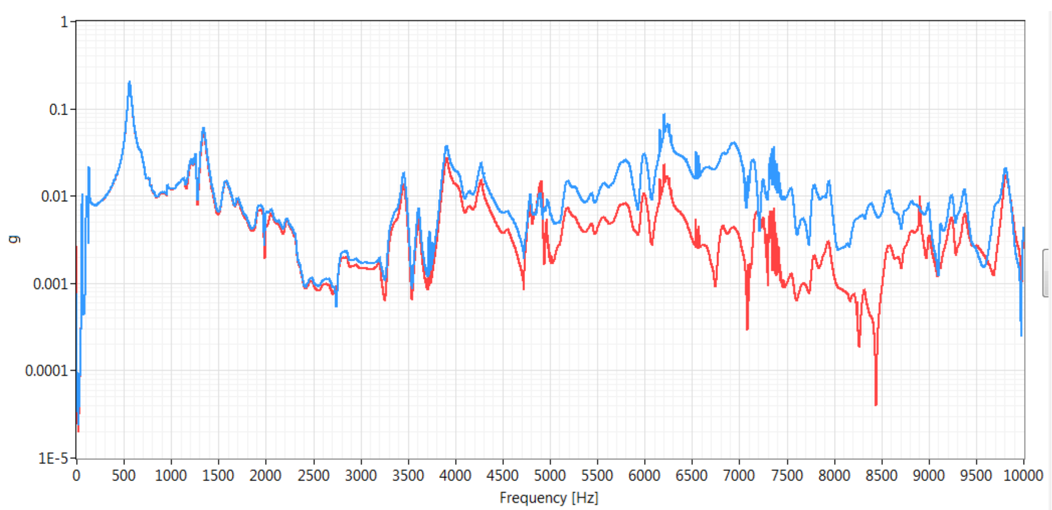


Figure 3: Acceleration attachment test raw spectra, magnet-only attachment; blue is the signal of the tested accelerometer & attachment, red is the reference accelerometer signal

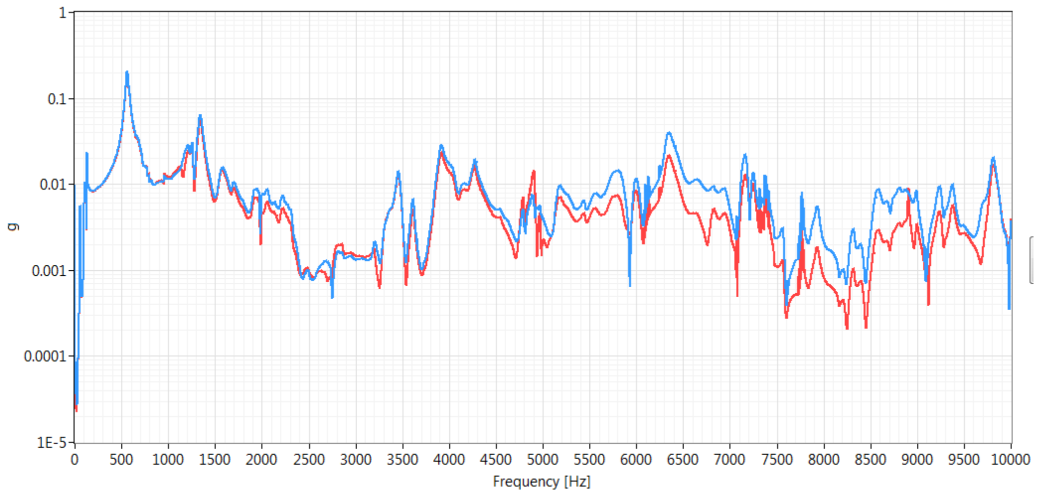


Figure 4: Acceleration attachment test raw spectra, wax-only attachment; blue is the signal of the tested accelerometer & attachment, red is the reference accelerometer signal

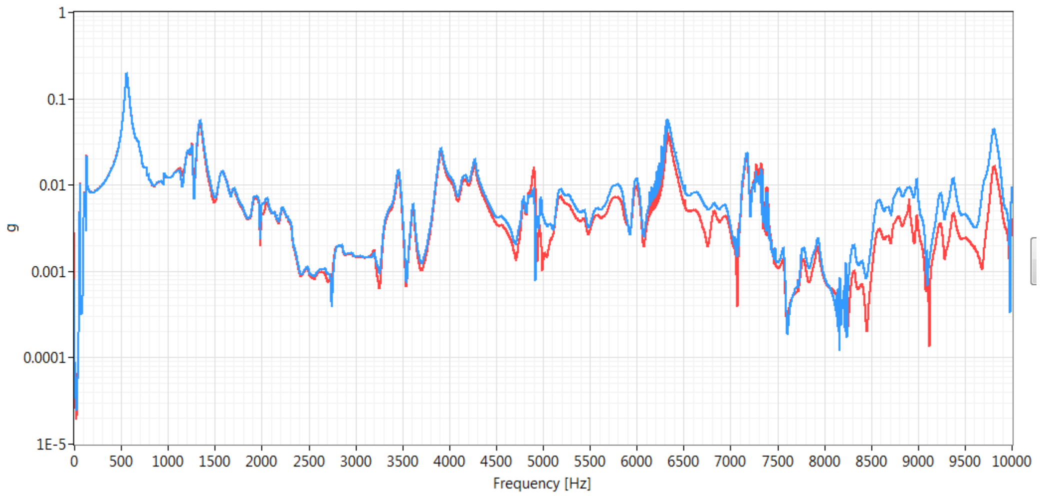


Figure 5: Acceleration attachment test raw spectra, magnet-plus-wax attachment; blue is the signal of the tested accelerometer & attachment, red is the ref. accelerometer signal

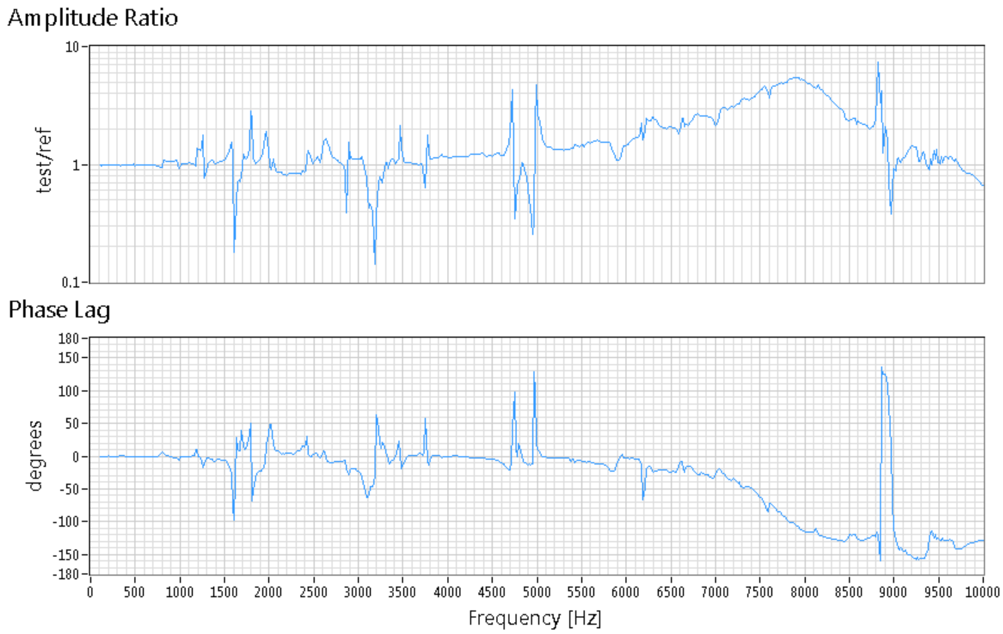


Figure 6: Acceleration attachment test comparison vs. reference, hand-held only

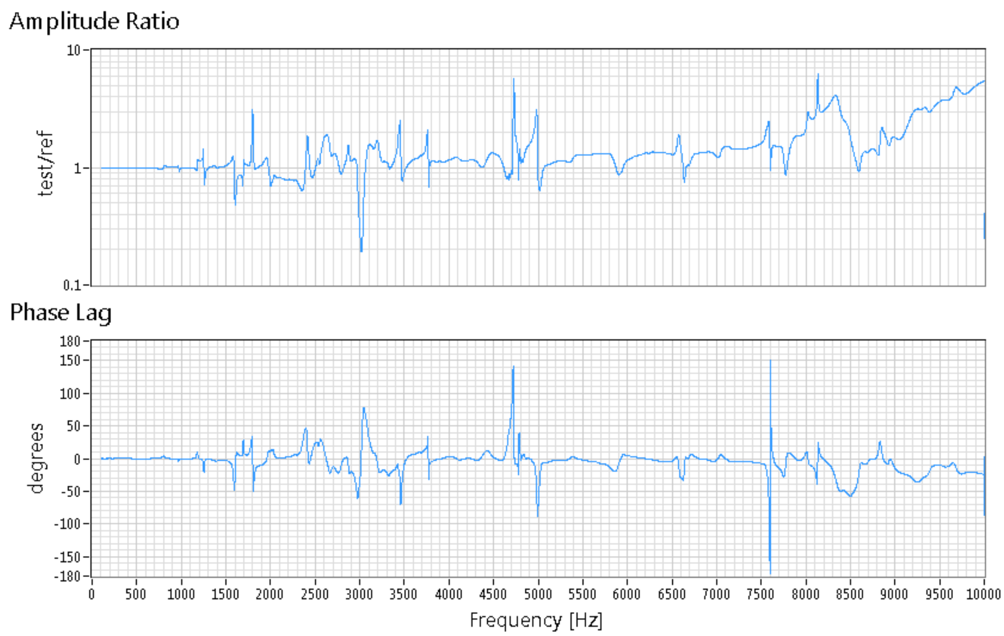


Figure 7: Acceleration attachment test comparison vs. reference, magnetic mount only

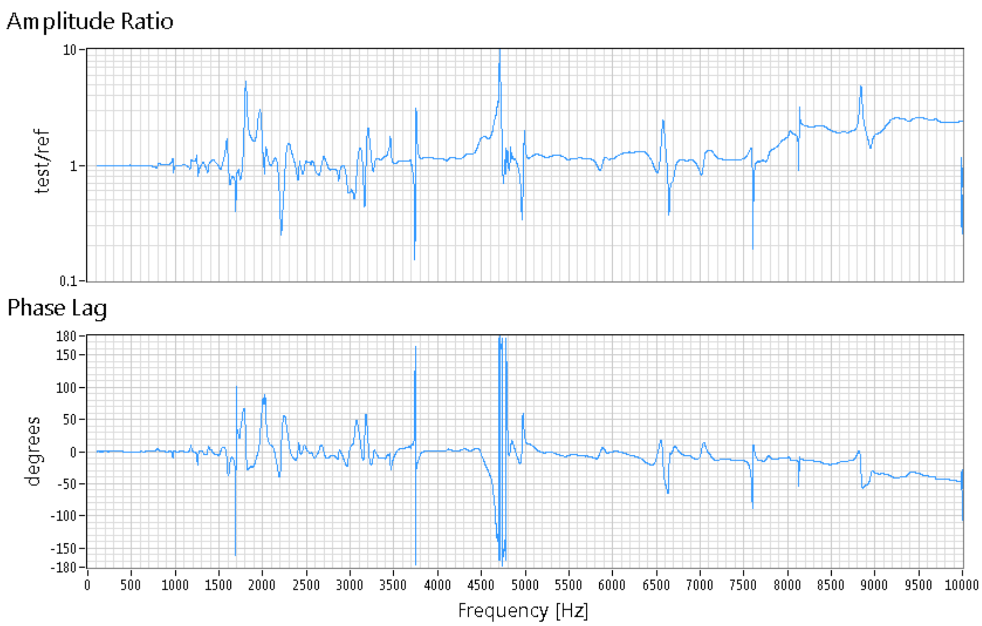


Figure 8: Acceleration attachment test comparison vs. reference, wax only

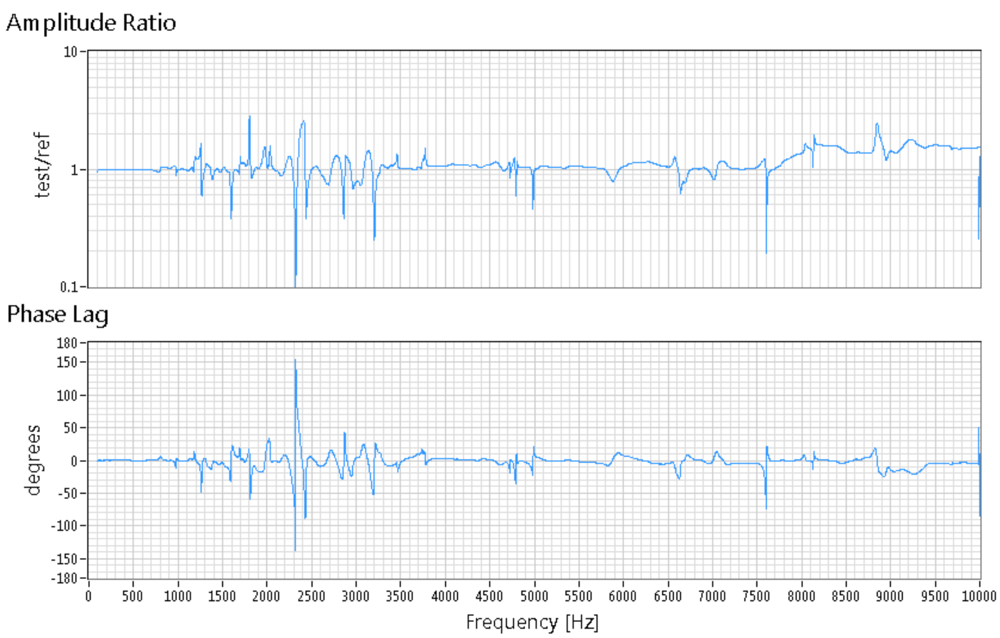
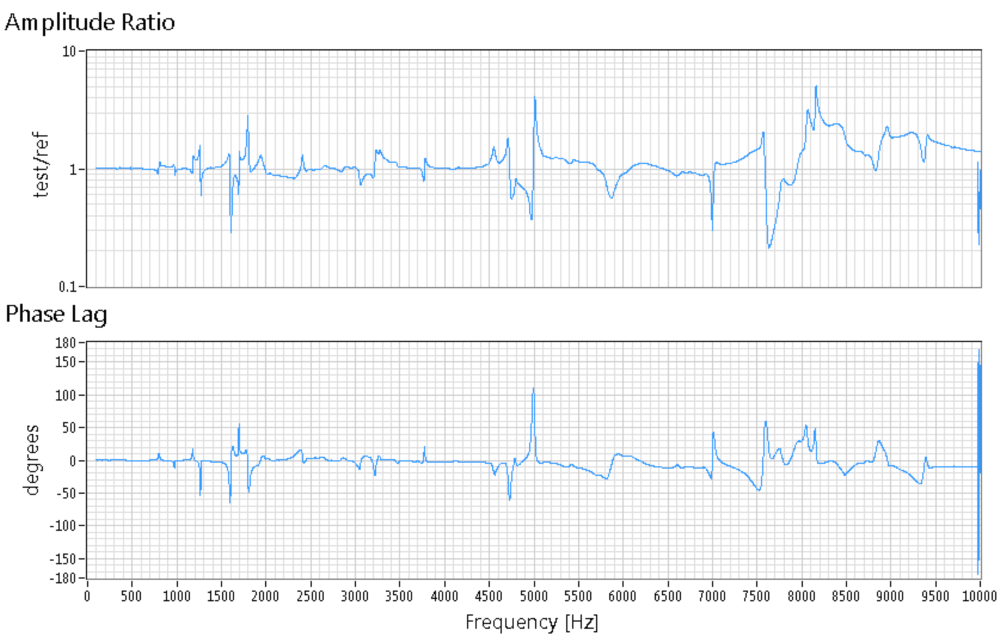


Figure 9: Acceleration attachment test comparison vs. reference, wax plus magnet mount



.

Figure 10: Acceleration attachment test comparison vs. reference, 3 mil thick tape

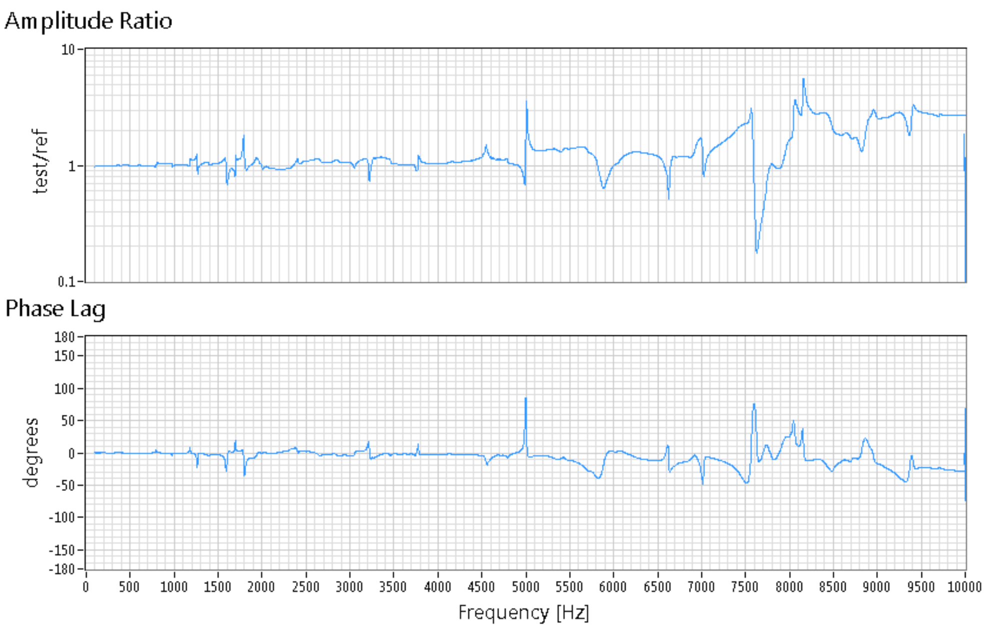


Figure 11: Acceleration attachment test comparison vs. reference, 7 mil thick tape

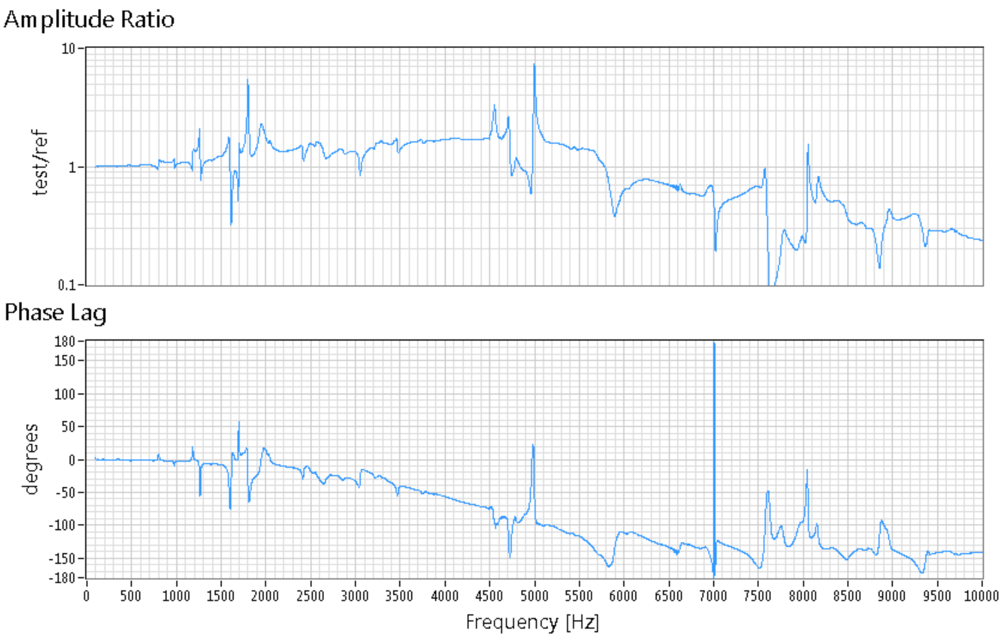


Figure 12: Acceleration attachment test comparison vs. reference, 15 mil thick tape

5. Conclusions

The test data indicated the following results:

1. In the opinion of the authors, a screw compression attachment of flat-surface-against-flat-surface is the "gold standard" of accelerometer attachment methods. This is consistent with the recommendations of international standards such as ISO and ANSI/HI.
2. All of the tested attachment techniques were found to provide accurate and repeatable results for frequencies from 1 Hz to 1.5 kHz, indistinguishable on a practical basis.
3. The best non-damaging technique of accelerometer attachment was found to be moderate thickness (7 mil, or 0.175 mm) double-sided fiber-reinforced paper tape. 50% thinner tape did not produce as high fidelity results, nor did 2x thicker tape. The 7 mil thick tape attachment method provided reasonable fidelity from 1 Hz to 7 kHz, apparently being thick enough to better fill in surface undulations than the 3 mil thick tape, but not be so thick as to lose significant stiffness though the thickness of the tape as in the case of the 15 mil thick tape. Some fidelity was lost at specific natural frequency peaks and anti-resonance "zeros", such that the reference accelerometer might report higher or lower vibration amplitude within +/-1% of such zones. Except for the highest amplification factor natural

frequencies (e.g. Q>30), the 7 mil tape provided good FFT curve shape fidelity, and practically acceptable quantitative amplitude results to 19 kHz.
4. The use of wax by itself provided results that were inferior to wax plus a magnet.
5. The lowest fidelity method was shared by magnet-alone, hand-held alone, and wax-alone. The magnet-alone was dependent on the flatness of the attachment surface. Handheld-alone was generally superior, but dependent on the firmness and steadiness of the hand holding the accelerometer. Generally, any unsteadiness in the hand holding affected frequencies at 30 Hz and below. The wax attachment was dependent to some extent on the thickness of the wax coating between the accelerometer base and the target surface.

6. ACKNOWLEDGMENTS

The authors would like to thank Senior Engineer Joseph Gruener, and co-op students Daniel Pruess and Alison Jago for their excellent work in setting up the experimental hardware, and acquiring the data associated with this IRAD project.

References

[1] ISO 5348 [2018], "Mechanical Vibration and Shock- Mechanical Mounting of Accelerometers", International Standards Organization, Geneva Switzerland
[2] ANSI/ HI 9.6.4 [2016], "Rotordynamic Pumps for Vibration Measurement and Allowable Values", Hydraulic Institute, Parsippany NJ
[3] ANSI S2.61-1989 (ASA 78-1989) [1989, Reaffirmed 2010], "Guide to the Mechanical Mounting of Accelerometers", American National Standards Institute and ASA, New York, NY
[4] Bowers, S.V., Piety, K.R., and Piety, R.W. [1990], "Real-World Mounting of Accelerometers for Machinery Mounting", 4th Incipient Failure Detection Conference, EPRI, Philadelphia PA, October 1990
[5] Peters, J. [2007], "Restrained by Resonance", Uptime Magazine, May 2007
[6] Corelli, D.A. [2015], "How Sensor Mounting Affects Measurements", Vibrations Magazine, Vibration Institute, Oak Brook IL, May 2015
[7] Marscher, W.D., and Onari, M.M., [2019], "Vibration Problems and Solutions for Turbomachinery and Centrifugal Pumps", Short Course at MFPT2019, King of Prussia PA, May 2019