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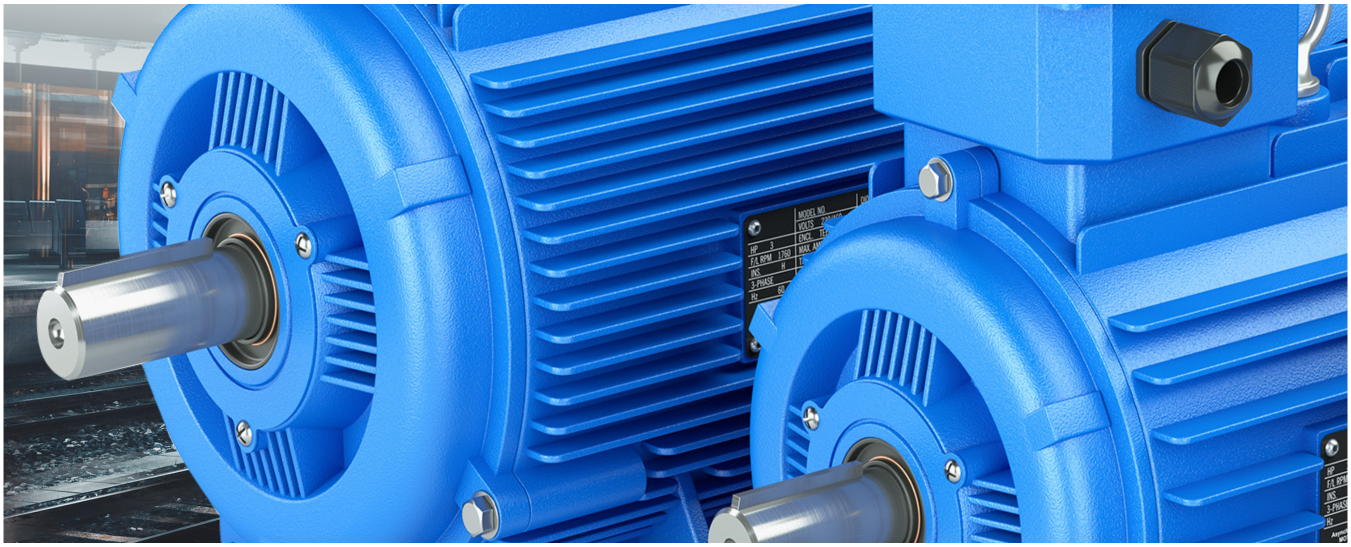

Considerations for Accelerometer Mounting on Motors

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Introduction

The objective of this paper is to present recommendations for accelerometer selection and mounting for condition monitoring and vibration analysis of motors. The recommendations are based on common faults experienced by DC and nonsynchronous AC motors. These common faults are detectable by employing vibration analysis and include both mechanical and electrical faults. Emphasis will be placed on the frequency range of the sensor and its mounting method in order to reliably detect these faults. As an example, consider impacting events which may be occurring at a periodic rate of a few hundred Hz (referred to as fault frequency), but the energy from each individual event may be carried away from the initiation site with frequencies in the low to high kilohertz range. Therefore the sensor used to detect events such as impacting, friction and fluting should be responsive over a broad frequency range from several hundred hertz to over 20 Kilohertz. For the classical mechanical faults such as balancing and alignment, a frequency band from about 0.2 times running speed to 50-60 times running speed is sufficient. Electrical faults require both the low and high frequency bands that mechanical faults require.

Following the background section, sections on selecting the appropriate accelerometer along with the effects of various mounting methods are presented. In general, there will be sensor performance tradeoffs with the less expensive sensors and mounting methods. Conclusions and recommendations are presented in the last section to address these benefits and tradeoffs.

Background

Motors can experience both mechanical and electrical faults, which introduce vibrations. These faults can be detected as long as the vibration sensors mounted have sufficient bandwidth and sensitivity. Mechanical faults accompanied by impacting, friction and fatiguing introduce vibration at frequencies greater than those of electrical faults, with the exception of fluting. Fluting introduces vibrations at about the same frequencies as friction. If the bandwidth of a sensor and its mounting method is sufficient to detect the mechanical faults, they will also detect the electrical faults. Typical mechanical and electrical faults[1] experienced on motors are listed below:

Typical mechanical faults experienced in motors:

1. Alignment
2. Bearing faults
3. Looseness
4. Friction
5. Resonance
6. Fluting for DC and variable frequency drive induction motors

Typical electrical faults experienced in induction and DC motors[1]:

1. Stator eccentricity, shorted laminations or loose iron
2. Eccentric rotor
3. Cracked or broken rotor bars
4. Loose or broken connectors
5. SCR problems for DC and variable frequency drive induction motors

The sensor bandwidth requirements for these faults are typically

a) 0.3 to 50 times running speed for the lower frequency band
b) 500 Hz to 20+ kHz for the higher frequency band

To illustrate the expected bandwidth associated with impacting, an experiment was set up involving flat large metal plate a few inches thick with three different size diameter balls. The balls are 0.5”, 1.0” and 1.5”D. The analysis bandwidth is 80 KHz. The spectral data results[2] are presented in Figure 1. The activity around 17 kHz in all three data sets is from a resonance in the setup. Ignoring the resonance activity, the small 0.5” D ball has its major activity in the 5-

35 kHz range. The primary energy for the 1.0” D ball is in the 2-15 kHz range. For the 1.5” D ball, the bandwidth where the major activity resides is in the 1-10 kHz range. The reduction of the center frequency with increasing mass of the impacting object is consistent with both experience and theory[2].

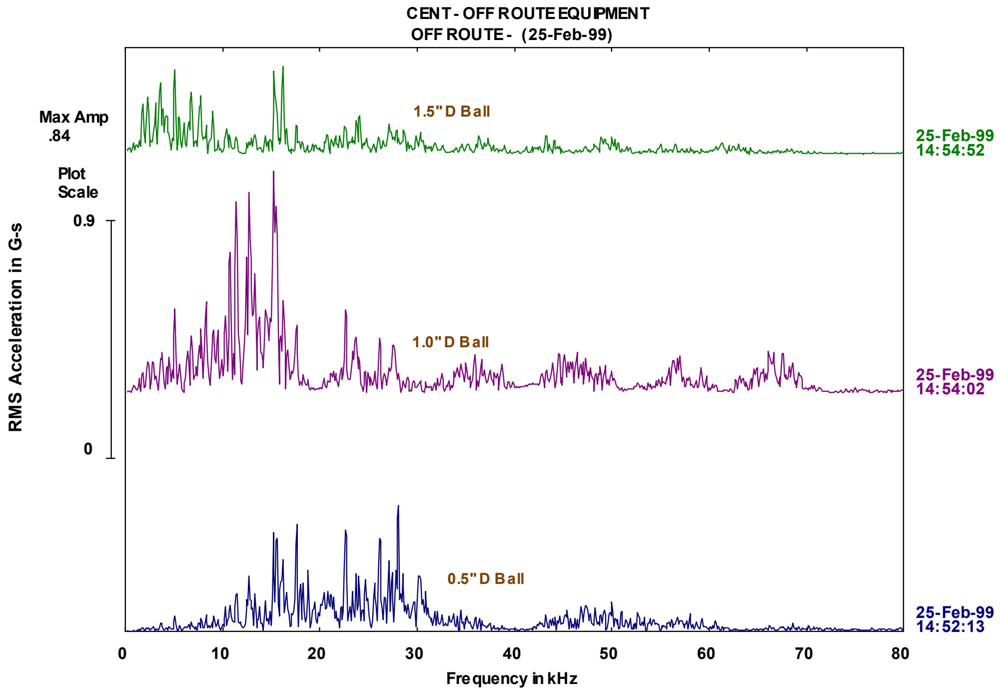

Figure 1
80 kHz bandwidth spectra data from 0.5”, 1.0” and 1.5” D ball impacting a large metal plate with sensor attached to the top of the plate

With friction, the energy is emitted primarily within a band with a center frequency dependent on the mass and speed of the object experiencing friction (similar to impacting). The difference between friction and impacting is that the center frequency of an object experiencing friction is greater than that same object experiencing impacting by 25-50%.

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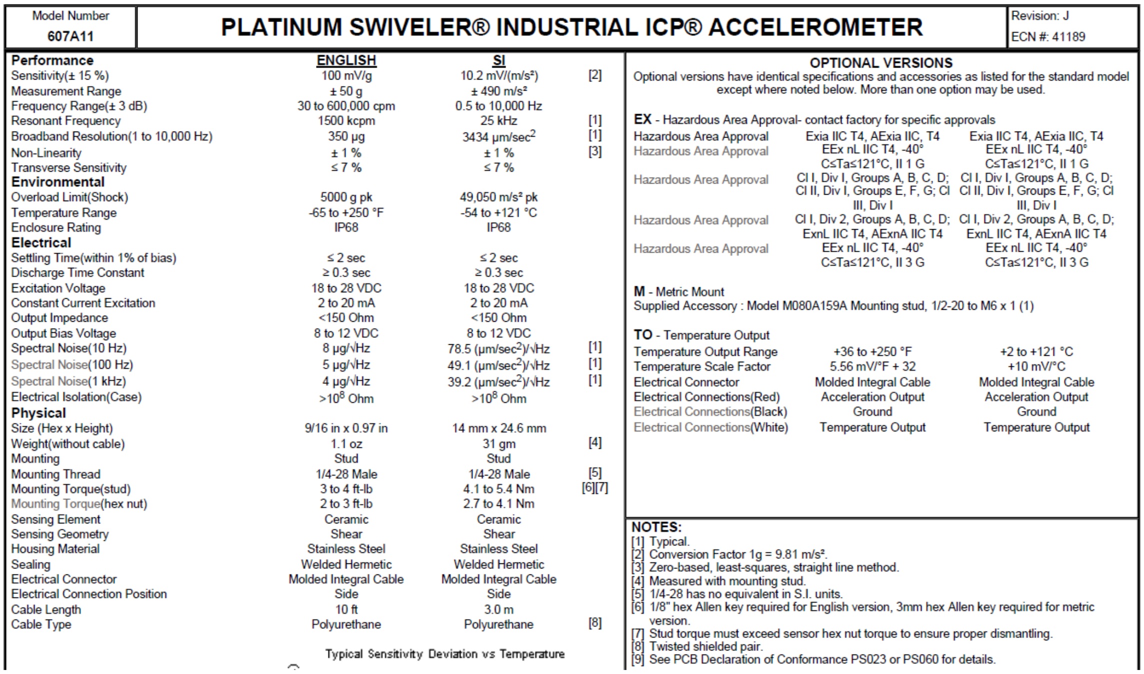
[1] Illustrated Vibration Diagnostic Chart, Technical Associates of Charlotte, NC
[2] James C Robinson, “High Frequency Vibration Analysis” Proceeding of Vibration Institute 2009 Annual Meeting.

Choosing the Appropriate Accelerometer and Mounting Method

ICP® powered accelerometers are most common for condition monitoring of industrial machinery. These typically have a sensitivity of 100 mV/g, a resonance frequency around 25-30 kHz, and a noise floor around 50-100 µg's/√Hz at 1 Hz. These are used in high volumes and are more economical than special purpose sensors such as high frequency or low frequency accelerometers. They generally are specified to have a flat frequency response within 3 dB from roughly 1Hz to 10 kHz when optimally stud mounted. The responses of the accelerometers above 10 kHz are generally not specified.

A typical specification sheet for an IMI Model 607A11 accelerometer is presented in Figure 2. This accelerometer is specified to be within ± 3 dB of 100 mV/g over a frequency range of 0.5 -10,000 Hz. There are no indicators as to how the sensor will respond to vibration frequencies exceeding 10 kHz, which most probably will be the case if impacting, friction or fluting is occurring. It is well known the accelerometer's response at the higher frequencies exceeding 10 kHz or so is dependent on the manner the accelerometer is attached to the surface.

To explore the effect of different attachment schemes, an accelerometer was selected to run frequency response curves from 100 to 50,000 Hz with various means of attaching the accelerometer to the surface. The frequency response curve for the accelerometer is presented in Figures 3. The mounting schemes include a stud mount with grease, a stud mount on a flat smooth surface, a rare earth flat magnet on a flat smooth mounting pad, a two pole magnet on a rough curved surface, and a two pole magnet on a smooth curved surface.



Model Number 607A11	**PLATINUM SWIVELER® INDUSTRIAL ICP® ACCELEROMETER**	Revision: J ECN #: 41189

Performance	**ENGLISH**	**SI**	
Sensitivity(± 15 %)	100 mV/g	10.2 mV/(m/s^2)	[2]
Measurement Range	± 50 g	± 490 m/s^2	
Frequency Range(± 3 dB)	30 to 600,000 cpm	0.5 to 10,000 Hz	
Resonant Frequency	1500 kcpm	25 kHz	[1]
Broadband Resolution(1 to 10,000 Hz)	350 µg	3434 µm/sec^2	[1]
Non-Linearity	± 1 %	± 1 %	[3]
Transverse Sensitivity	≤ 7 %	≤ 7 %	
Environmental			
Overload Limit(Shock)	5000 g pk	49,050 m/s^2 pk	
Temperature Range	-65 to +250 °F	-54 to +121 °C	
Enclosure Rating	IP68	IP68	
Electrical			
Settling Time(within 1% of bias)	≤ 2 sec	≤ 2 sec	
Discharge Time Constant	≥ 0.3 sec	≥ 0.3 sec	
Excitation Voltage	18 to 28 VDC	18 to 28 VDC	
Constant Current Excitation	2 to 20 mA	2 to 20 mA	
Output Impedance	<150 Ohm	<150 Ohm	
Output Bias Voltage	8 to 12 VDC	8 to 12 VDC	
Spectral Noise(10 Hz)	8 µg/√Hz	78.5 (µm/sec^2)/√Hz	[1]
Spectral Noise(100 Hz)	5 µg/√Hz	49.1 (µm/sec^2)/√Hz	[1]
Spectral Noise(1 kHz)	4 µg/√Hz	39.2 (µm/sec^2)/√Hz	[1]
Electrical Isolation(Case)	>10^8 Ohm	>10^8 Ohm	
Physical			
Size (Hex x Height)	9/16 in x 0.97 in	14 mm x 24.6 mm	
Weight(without cable)	1.1 oz	31 gm	[4]
Mounting	Stud	Stud	
Mounting Thread	1/4-28 Male	1/4-28 Male	[5]
Mounting Torque(stud)	3 to 4 ft-lb	4.1 to 5.4 Nm	[6][7]
Mounting Torque(hex nut)	2 to 3 ft-lb	2.7 to 4.1 Nm	
Sensing Element	Ceramic	Ceramic	
Sensing Geometry	Shear	Shear	
Housing Material	Stainless Steel	Stainless Steel	
Sealing	Welded Hermetic	Welded Hermetic	
Electrical Connector	Molded Integral Cable	Molded Integral Cable	
Electrical Connection Position	Side	Side	
Cable Length	10 ft	3.0 m	
Cable Type	Polyurethane	Polyurethane	[8]

Typical Sensitivity Deviation vs Temperature

OPTIONAL VERSIONS

Optional versions have identical specifications and accessories as listed for the standard model except where noted below. More than one option may be used.

EX - Hazardous Area Approval- contact factory for specific approvals

Hazardous Area Approval	Exia IIC T4, AExia IIC, T4	Exia IIC T4, AExia IIC, T4
Hazardous Area Approval	EEx nL IIC T4, -40° C≤Ta≤121°C, II 1 G	EEx nL IIC T4, -40° C≤Ta≤121°C, II 1 G
Hazardous Area Approval	Cl I, Div I, Groups A, B, C, D; Cl II, Div I, Groups E, F, G; Cl III, Div I	Cl I, Div I, Groups A, B, C, D; Cl II, Div I, Groups E, F, G; Cl III, Div I
Hazardous Area Approval	Cl I, Div 2, Groups A, B, C, D; ExnL IIC T4, AExnA IIC T4	Cl I, Div 2, Groups A, B, C, D; ExnL IIC T4, AExnA IIC T4
Hazardous Area Approval	EEx nL IIC T4, -40° C≤Ta≤121°C, II 3 G	EEx nL IIC T4, -40° C≤Ta≤121°C, II 3 G

M - Metric Mount

Supplied Accessory : Model M080A159A Mounting stud, 1/2-20 to M6 x 1 (1)

TO - Temperature Output

Temperature Output Range	+36 to +250 °F	+2 to +121 °C
Temperature Scale Factor	5.56 mV/°F + 32	+10 mV/°C
Electrical Connector	Molded Integral Cable	Molded Integral Cable
Electrical Connections(Red)	Acceleration Output	Acceleration Output
Electrical Connections(Black)	Ground	Ground
Electrical Connections(White)	Temperature Output	Temperature Output

NOTES:

[1] Typical.
[2] Conversion Factor 1g = 9.81 m/s^2.
[3] Zero-based, least-squares, straight line method.
[4] Measured with mounting stud.
[5] 1/4-28 has no equivalent in S.I. units.
[6] 1/8" hex Allen key required for English version, 3mm hex Allen key required for metric version.
[7] Stud torque must exceed sensor hex nut torque to ensure proper dismantling.
[8] Twisted shielded pair.
[9] See PCB Declaration of Conformance PS023 or PS060 for details.

Figure 2
Specification sheet for an IMI Model 607A11 Accelerometer

The objective in presenting these response curves is to illustrate how the frequency response differs with different mounting methods of the sensor. The variation of response begins to deviate for frequencies exceeding 2 kHz for the different attaching schemes. For the low frequency of 0.5 to 2 kHz, all attaching schemes demonstrated in Figures 3 and 4 are basically the same. For the frequency range of 10 to 20+ kHz, there are significant differences. In particular, the use of the two-pole magnet on a curved surface would miss many impacting, fluting and friction problems. In contrast, attaching the sensor using a flat magnet set on a smooth flat surface would catch those classes of problems. The optimum means of attaching the sensor would be using stud mount on a smooth flat surface.

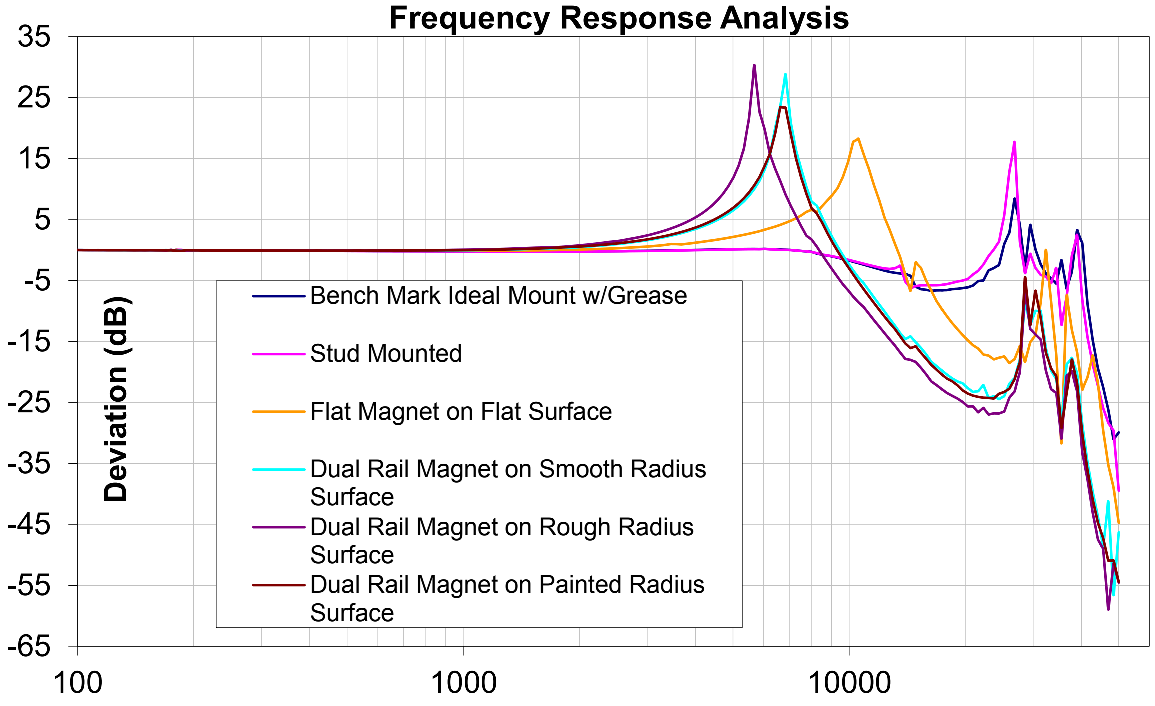


Figure 3
Frequency Response 100-50,000 Hz for several sensor mounting methods

From the data presented in Figures 3, it is concluded the stud mounted sensor provides useful data out to the 30- 40 kHz range. The flat magnet attached to a flat smooth pad provides acceptable data out to the 15 kHz range. The dual rail magnet on a curved surface provides detectability out to the 9 kHz range. The large resonant feature in the dual rail magnet on a curved surface in the 6 kHz range may be problematic for motors having rotor bar problems with a rotor bar pass frequency in the proximity of 3 kHz (it would make the second harmonic at 6 kHz artificially large). A large second harmonic of the rotor bar pass frequency contributes to the fault assessment of rotor bars[1].

In order to reliably catch faults generated by impacting, friction, fluting and rotor bars, the mounting scheme of a dual rail magnet on a curved surface is not acceptable. It will only provide accurate results for faults and vibrations less than 3 kHz. Attaching the sensor to a smooth surface via a flat magnet does provide an acceptable result, but the use of a sensor stud mounted to a dry clean smooth surface is the best. The sensor itself should have a resonance in the 25+ kHz range.

Conclusions

In motors, both mechanical and electrical faults can be captured and diagnosed using vibration analysis. The sensor used is generally an accelerometer with sufficient sensitivity and bandwidth to catch the defect signature. The commonly used accelerometer with sensitivity of 100 mV/g and a resonance frequency in the 25-30 kHz range is adequate. The accelerometer generally is a) attached to the surface using a 2-rail magnet set on a curved surface, or b) attached to a flat rare earth magnet placed on a smooth flat surface (mounting pad) or c) attached to the surface by stud mounting the sensor to a smooth flat surface (preferred method). In all three of the mounting methods, there must be a solid metallic transmission path from the outer race housing to the place where the sensor is mounted.

For the case of using a dual rail magnet on a curved surface, the response of the sensor/magnet was shown to be less than 10 kHz with a broad resonance in the 3-10 kHz range. Faults such as impacting, friction, fluting and at times rotor bar defects manifest themselves in or above this frequency range. Hence using only the dual rail magnet on a curved surface will exaggerate some common problems and will miss some very significant problems (such as friction, impacting and fluting).

Using a flat magnet to secure the sensor to a smooth surface, such as a mounting pad, extends the useable frequency approximately 15 kHz. This range is sufficient to capture most problems for industrial equipment. Stud mounting the sensor to the surface extends the useable frequency band to around 25 kHz. To extend the frequency band beyond 25 kHz, a different accelerometer with a higher resonant frequency would be required.

Recommendations

The best way to monitor using vibration analysis would be to stud mount an accelerometer in the axial, vertical and the horizontal directions on both ends of the motor. The initial expense and upkeep of this approach outweighs the benefits since there is a large population of motors in an industrial facility. The most economical scheme for monitoring would be to employ the 2-rail magnet attached to a curved surface. This method would miss many faults leading to impacting, friction and fluting. Additionally it can significantly distort certain faults due to the broad resonance introduced by the 2-rail magnet/accelerometer in the lower 2-9 kHz range. Therefore, the use of solely the 2-rail magnet on a curved surface is not recommended.

The recommendations for vibration data collection and analysis are:

1. One radial stud mounted accelerometer mounted on the outboard end of the motor
2. One radial stud mounted accelerometer mounted on the inboard end of the motor
3. Provide mounting pads (smooth flat surface with diameter sufficient to accommodate the flat magnet being used) at each of the strategic measurement points of radial at 90^o (inboard and outboard) relative to the permanently installed accelerometers and axially on both ends of the motor.

It is very important to maintain a solid metallic path from each measurement point to the structure supporting the load of the motor, which are generally the bearing outer races. Some pictures are presented in the Appendix showing how some users have installed mounting pads with a solid metallic path to the load zone(s).

For ideal measurements, permanently stud mounted accelerometers with a maximum frequency response of at least 10 kHz (3 dB). These provide excellent 24/7 monitoring of equipment when mounted in the positions suggest above, using a stud threaded into a flat and smooth surface. IMI Sensors offers the 603C01 and 602D01 accelerometers for this method.

IMI Sensors accelerometer models 603C01 and 602D01

Many predictive maintenance programs do not have the resources to permanently mount hundreds of accelerometer, and therefore they must use a route-based method. For this method it is recommended that the technician collecting data use a precision accelerometer with a high stability for consistent measurements. IMI offers model 622B01with a precision ceramic element and 628F01 with a quartz element for even better performance and stability across varying temperatures.

IMI Sensors accelerometer model 622B01 and various mounting pads

These precision accelerometers are most effective when used with a flat magnet with a high pull-strength to weight ratio and on a smooth flat surface. For best results, IMI recommends using an adhered or welded mounting pad at each measurement point, such as model 080A92. This provides an ideal mounting surface and ensures consistent sensor placement for effective trending. If a flat surface is not possible, IMI recommends a dual rail magnet with a high pull-strength to weight ratio, such as model 080A130.

Appendix

The primary purpose for this Appendix is to provide users some ideas of how other users have provided flat surfaces to a solid metallic path to the load zones on motors. The end bell on motors makes the task somewhat difficult. In Figure 5, the end user located flat spots at two locations (90 degrees apart) under the end bell. He then drilled holes in the end bell to a flat surface that could be used as the mounting pad or it could be used to attach a flat smooth mounting pad to. The picture in Figure 6 shows a case where a mounting pad was adhered to the flat spot under the end bell. Figure 7 shows a case where a larger bolt head (sufficient to accommodate the rare earth flat magnet) was welded onto an existing end bell boat.

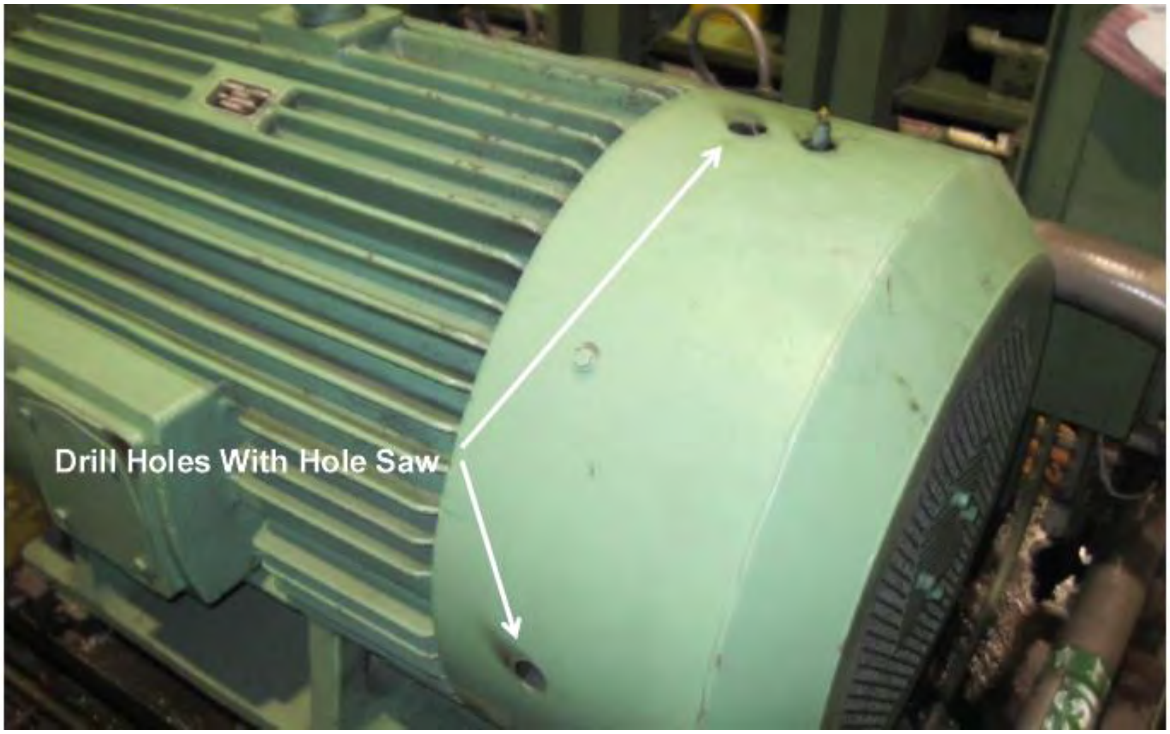


Figure 5
Drilled holes in end bell to spots where there are flat surfaces

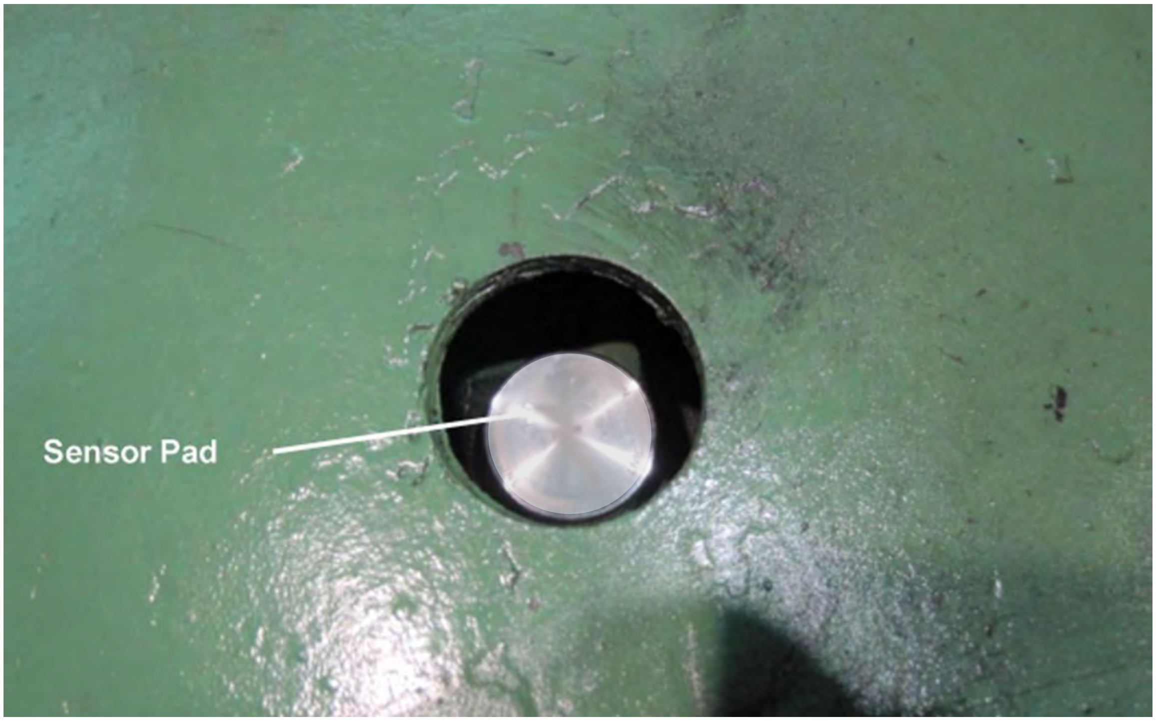


Figure 6
Mounting Pad attached to flat spot under the end bell

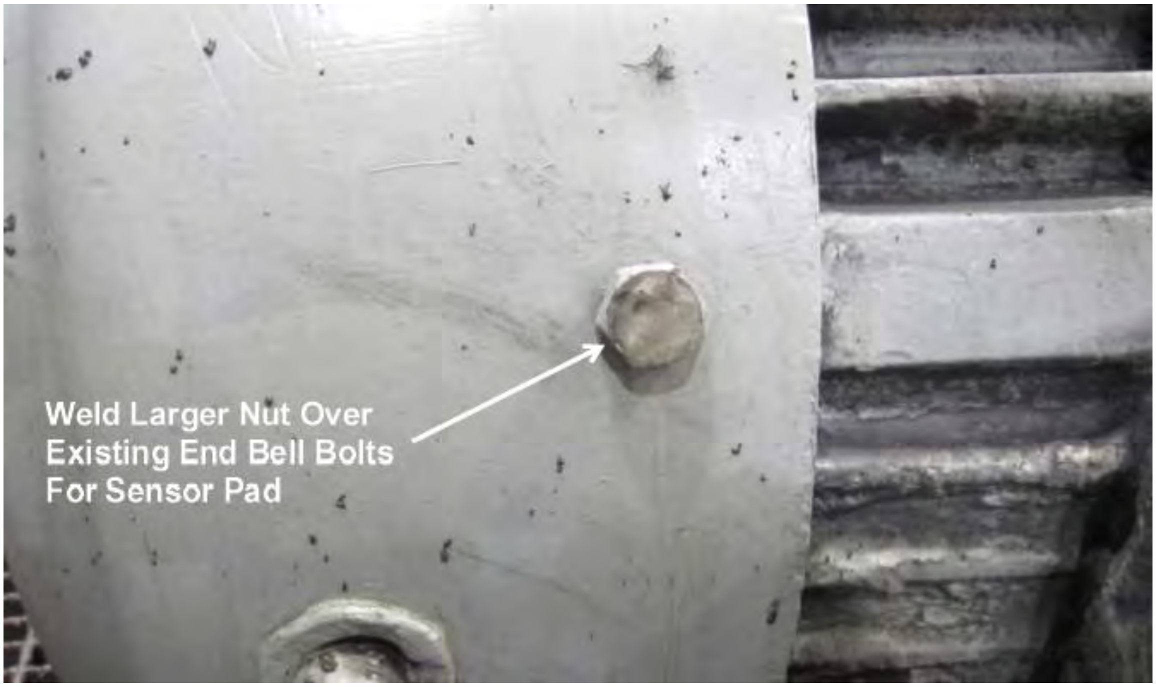


Figure 7
Larger nut head welded to existing smaller end bell

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