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CALIBRATION OF IEPE ACCELEROMETERS AT INMETRO

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Abstract: This paper discusses the calibration of IEPE accelerometers. The use of these low-impedance output transducers is growing fast worldwide and therefore the demand for their calibration is increasing proportionally. Since many secondary calibration laboratories are more experienced with calibrating high impedance charge output accelerometers, we frequently receive questioning about how to properly calibrate the IEPE models. Some experimental results are presented herein and the effects of some sources of error that can be present during a calibration process are discussed.

Keywords: Vibration, Calibration, Accelerometer, IEPE.

1. INTRODUCTION

Integrated Electronics Piezo Electric (IEPE) accelerometers are known by different proprietary names such as ICP®, Isotron®, Deltatron®, Piezotron® and others. These devices incorporate a built-in signal conditioning circuit to convert the high impedance signals generated by their piezoelectric sensing elements into a low impedance voltage output signal. In addition, other features such as gain and filtering can be also included.

A low-impedance output allows the use of twisted pairs or ordinary coaxial cables in place of the more expensive low-noise cables, which are used with charge output accelerometers, and also reduces problems with triboelectric effects.

The integrated electronics requires excitation power from a constant-current regulated, DC voltage source. This is usually provided through the same cable used for the transmission of the output signal. Under normal conditions, most accelerometers operate with a +24 Vdc excitation voltage and a constant current supply ranging between 2 mA and 4 mA.

Most IEPE power supply units incorporate a decoupling capacitor at its output stage to exclude the bias and provide an AC coupled output signal. Optional DC coupled models usually use a DC level shifter to eliminate the bias voltage.

2. CALIBRATION OF A POWER SUPPLY UNIT

For the electrical calibration of an IEPE power supply unit (PSU), a signal generator is used to simulate the AC voltage output signal of an IEPE accelerometer. It is necessary to have some device to decouple the generator output from the DC voltage furnished by the PSU under test. In addition, it is necessary to provide a similar electrical impedance to the PSU as when an IEPE accelerometer is connected to it. The basic setup normally used to calibrate PSUs is shown in Fig. 1.

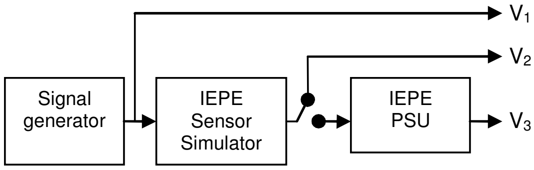

Figure 1 –Block diagram of the setup used to calibrate the SIM and the IEPE PSU

The complex sensitivity S_{SET} of the set comprehending a sensor simulator (SIM) and the PSU is determined from measurements of the ratio of the output and input voltages V_3 and V_1, respectively. The sensitivity S_{SIM} of the SIM is determined by the ratio of voltages V_2 and V_1. The magnitude and phase shift of the complex sensitivity S_{PSU} of the PSU can then be calculated by

$$\hat{S}_{PSU}(f) = \frac{\hat{S}_{SET}(f)}{\hat{S}_{SIM}(f)}, \tag{1}$$

$$\varphi_{PSU}(f) = \varphi_{SET}(f) - \varphi_{SIM}(f). \tag{2}$$

Depending on the instrumentation used to measure the voltage ratios V_2/V_1 and V_3/V_1, the phase response can be directly obtained or not. For better accuracy, an Agilent 3458A 8½-digits precision voltmeter was used to measure the voltages magnitudes. The phase response was measured with a dynamic signal analyzer (DSA) or a multichannel simultaneous sampling digital acquisition board (DAQ). In order to improve the reliability of the results obtained using these types of equipment, an additional precaution was taken. Two frequency response functions (FRF) were measured, differing by switching the channels cables connected to the input channels of the DSA. Taking the geometric mean of these measured FRFs, errors due to mismatch between the different measuring channels can then be significantly minimized.

The electronic scheme of a device built at INMETRO to be used as IEPE SIM is presented in Fig. 2. This circuit is mounted in a small shielded box (Pomona Electronics model 2391) and it includes a high-pass filter for decoupling of the

DC signal provided by the IEPE PSU and a parallel resistance to simulate the typical impedance loading of an accelerometer.

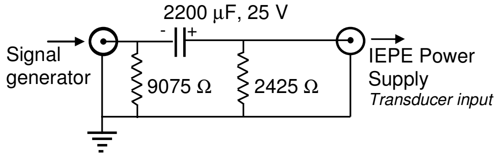

Figure 2 – Electronic circuit diagram of the IEPE SIM.

This IEPE SIM presents a broad frequency response, which allows its use in calibrations from 0.4 Hz up to 50 kHz. A frequency response function of the SIM measured in the frequency range 0.1 Hz to 20 kHz is shown in Fig.3. This figure demonstrates negligible influence of the simulator in calibrations of both magnitude and phase response above 10 Hz. At lower frequencies, its effect can be easily corrected using equations (1) and (2).

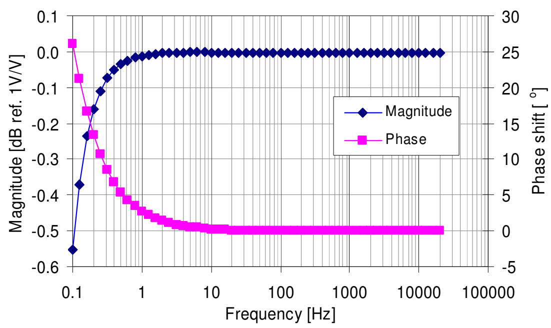

Figure 3 – Magnitude and phase response of the IEPE SIM.

Figure 4 presents calibration results of a PCB 482A10 PSU using the IEPE SIM presented in Fig. 2. The sensitivity magnitudes obtained for three different PSU gain settings (X1, X10 and X20) were normalized by the nominal gain to fit in the same Y-scale. This allows easy visualisation of the difference in the FRFs depending on the selected gain. It is clear that a flatter FRF is obtained for the smallest gain setting of this PSU. The larger deviations from the nominal sensitivities obtained for the two higher gain settings demonstrate the importance of calibrating this PSU for its use in accelerometer calibrations.

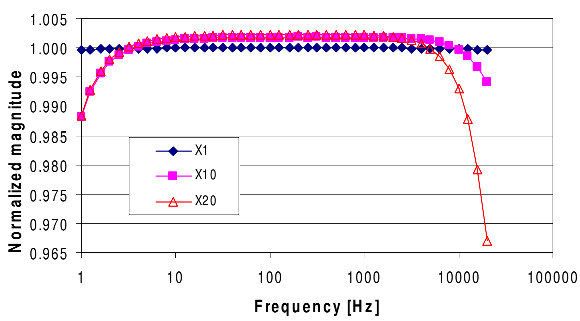

Figure 4 – Normalized magnitude of the sensitivity responses for the three gain settings of a PCB 482A10 PSU.

3. CALIBRATION OF AN ACCELERATION MEASURING CHAIN

The calibration of an IEPE acceleration measuring chain can be carried out by primary methods according to the international standard ISO 16063 part 11 [1] or by comparison methods according to part 21 [2].

An IEPE acceleration chain includes an IEPE accelerometer and an IEPE PSU. Once the voltage sensitivities of the chain S_{chain} and of the PSU S_{PSU} are obtained, the voltage sensitivity of the accelerometer S_{acc} can be calculated by

$$S_{\text{acc}} = \frac{S_{\text{chain}}}{S_{\text{PSU}}}. \qquad (3)$$

4. LOW-FREQUENCY STANDARDS

Calibration of IEPE accelerometers at low frequencies requires additional special precautions. Accelerometers specifically designed for use in low-frequencies require long settling times after mounting. It is important to monitor the DC bias until it is sufficiently stable, otherwise some DC drift can be observed during measurements.

PCB Piezotronics Inc. [3] recommends a procedure to calibrate the full frequency range of an accelerometer, excluding any effect caused by the decoupling capacitor included in PSUs. A “T” connector can be inserted between the accelerometer and the PSU sensor input to bypass it, obtaining a DC-coupled output signal from the accelerometer. By this way, the DC current supply is properly provided to the accelerometer, and the AC voltage output can be measured using the third arm of the T, instead of the output connector of the PSU.

If this procedure is used, then the measuring instrumentation needs to deal with the DC bias signal. There are different options available, as for instance, AC coupling the input of the measuring instrument, using a DC bias cancelling circuit or even setting DC coupled measuring systems to input ranges compatible with the maximum amplitude of the combined AC+DC signal. The problem here is that the DC component is usually around 7 to 9 V, which means that the input range of the measuring instrument needs to be at minimum 20 V to measure the full dynamic range of an accelerometer.

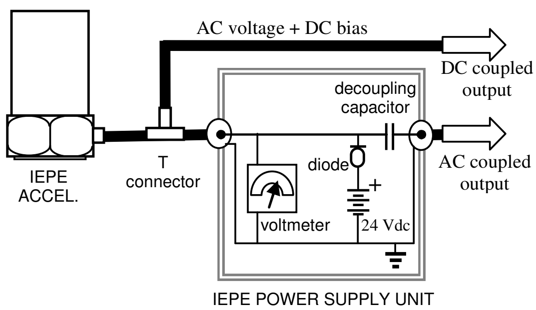

Figure 5 – DC-coupled connection of an IEPE accelerometer with a T connector to bypass the IEPE PSU.

5. GROUNDING CONSIDERATIONS

Electrical grounding can strongly affect the calibration results of IEPE accelerometers. Inadequate electrical insulation and multiple ground paths can affect the entire frequency response of the accelerometer.

Usually, laboratories can detect ground loop problems on high impedance charge output accelerometers by observing the presence of peaks in the sensitivity at the power line frequency (i.e. 50 Hz or 60 Hz, depending on the country) and integer multiples. In the case of IEPE accelerometers, ground loops might occur without being so easily detectable. The effect can appear as a smooth change in the entire FRF, which can lead to be neglected as a problem.

This problem has been evaluated at INMETRO using the scheme presented in Fig. 6, where several possibilities of ground connections could be tested during accelerometer calibrations using the comparison method. A back-to-back accelerometer, Endevco 2270 M15, was used as reference and a Dynamic Signal Analyzer, HP3562A, was used to measure FRFs in order to determine the voltage ratio between the two acceleration measuring chains. This reference accelerometer has an electrically insulated mounting base and the electrical connection between its outer case and the low-noise signal cable depends on the position of a grounding nut adjacent to its microdot connector.

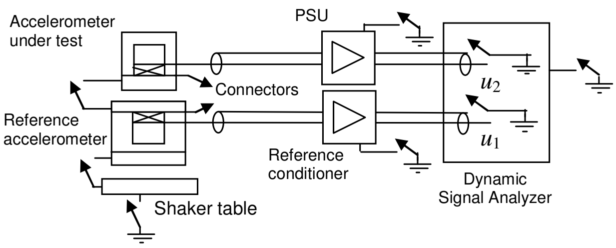

Figure 6 – Scheme of different grounding points that can be set in a comparison calibration of accelerometers.

Some results of the tests performed with an IEPE accelerometer B&K 4394-001 are shown in Fig. 7 to exemplify that an entirely floating system can provide a biased response (curve A) and a multiple grounding condition (curve C) can produce a deformed frequency response function. The correct response, obtained with a proper grounding configuration (curve B) is included as reference in this figure. It is important to highlight that these results were obtained using exactly the same mechanical mounting.

Ground loops can occur even when using the T-connection procedure discussed before. Usually it is not possible to properly eliminate a ground loop effect by solely configuring the input coupling as “float” at the readout instrument. This is the case with the Dynamic Signal Analyzer used in this study. A practice used at INMETRO is to break the electrical path by floating the earthing pin of AC power plugs used with line-powered laboratory grade IEPE PSUs.

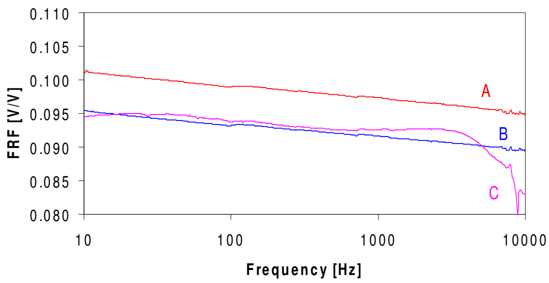

Figure 7 – FRFs obtained in comparison calibrations of an IEPE accelerometer: (A) ungrounded; (B) correctly grounded; (C) with a ground loop condition.

Battery-powered IEPE PSUs can be used to avoid this ground loop problem, but their circuit usually provides lower current levels (e.g. 2 mA) when compared to line-powered laboratory grade models in order to extend the battery lifetime. Depending on the technical requirements of a calibration, 4 mA or even a higher current level might be necessary to maintain the actual condition of use by the customer. Higher current levels (up to 20 mA) can be necessary, for instance, for driving long signal cables. Therefore, a calibration laboratory might need to use line-powered PSUs in several situations.

Figure 8 illustrates the problem of ground loop using the T-connection procedure. A relative difference between 0.5 % and -2.5 % was observed in comparison calibrations of an accelerometer B&K 4394-001 depending on the grounding configuration used. The reference measurement condition considered here was given by a PSU PCB 482A10 floated and a reference charge conditioner B&K 2650 grounded. The grounding nut of the reference accelerometer was grounded and the case of the IEPE accelerometer under test was also grounded. Both accelerometer cables and input channels of the DSA HP 3562A were grounded. The second measurement configuration differed from the first one by just grounding the AC power plug earthing pin of the PSU PCB 482A10, in order to simulate a ground loop condition. This figure shows that a broad frequency effect occurs when ground loops are present, with significant deformation of the entire FRF. It is clear that this kind of systematic error needs to be avoided by any calibration laboratory if small measurement uncertainties are desired.

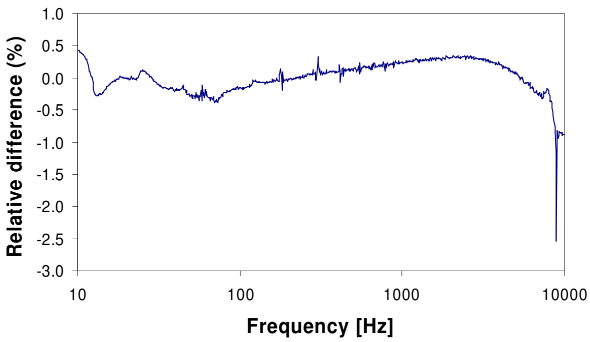

Figure 8 – Relative difference between FRFs obtained in comparison calibrations of an IEPE accelerometer: difference of a ground loop condition to a correctly grounded condition.

It is worth noting that the peak difference of -2.5 % that can be seen near 9 kHz in Fig. 8 is not caused by any change of mounting or resonance since the same mechanical mounting was used for both measurements. It is caused exclusively by the ground loop condition caused by grounding the PSU power cable.

A good practice to be applied is to check the electrical paths present in a specific mounting condition with an ohmmeter. Different accelerometer case materials, mounting methods (e.g. stud or adhesive) and the use of insulating adapters can require a change in the grounding configuration which is normally used. Accelerometers built with anodized aluminium cases can present inadequate insulation properties if their protection surface is severely scratched. Therefore, it is always good to check the actual electrical condition after the accelerometer mounting.

Primary interferometric calibrations are less sensitive to this kind of problem because a single measuring acceleration channel is measured. On the other hand, in comparison accelerometer calibrations, there is a higher risk of electrical coupling between the two measuring chains, due to mechanical connection between the two transducers. Therefore, IEPE transfer standard accelerometers calibrated by primary methods can be a very good way to verify the quality of the results obtained by comparison methods.

6. RESULTS IN INTERLABORATORY COMPARISON

Some IEPE accelerometers have already been chosen as circulating artefacts for interlaboratory comparisons at NMI level and this might occur more frequently in the future.

INMETRO/Brazil has participated in a bilateral supplementary comparison with NMISA/South Africa which was named AFRIMETS.AUV.V-S2. The artefact circulated for primary laser calibration in the frequency range 0.4 Hz to 50 Hz was an accelerometer measuring set, which included an IEPE standard accelerometer PCB 301M26 and a PSU PCB 482A21.

The results of voltage sensitivity magnitude reported by the participants [4] are shown in Fig. 9, which includes the expanded uncertainty of 0.3 % reported by both NMIs as Y-bars.

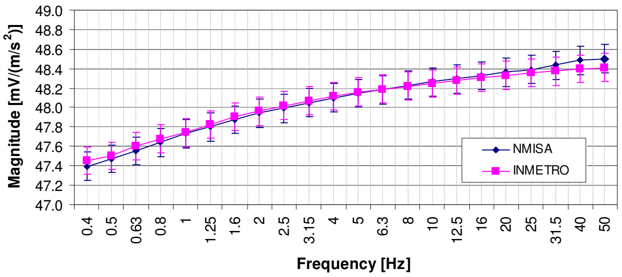

Figure 9 – Voltage sensitivity magnitude results and associated uncertainties reported by INMETRO and NMISA for the bilateral comparison AFRIMETS.AUV.V-S2

These results have demonstrated very good agreement between each other, as relative differences were smaller than 0.18 % in the entire frequency range of analysis.

Another supplementary comparison, AFRIMETS.AUV. V-S3, in which INMETRO is participating, is currently at stage Draft A and approaching conclusion. Its aim is to compare results of comparison calibrations of both high impedance charge output and IEPE type accelerometers in the frequency range 10 Hz to 10 kHz. The accelerometers circulated for this exercise were a charge output B&K 8305 and an IEPE PCB 301M15. The measurement uncertainties reported by INMETRO for the sensitivities of both accelerometers varied from 0.5 % to 1 %, depending on the frequency.

At secondary laboratories level, an interlaboratory comparison program was recently carried out within DAkkS accredited laboratories in Germany [5]. One conclusion of this project was that the calibration of IEPE amplifiers with the supply-current switched on seems to be still a challenge. As already discussed in this paper, the correct measurement of the sensitivity of PSUs is necessary to determine the sensitivity of IEPE accelerometers. Therefore, we can go further and consider that the calibration of both IEPE accelerometers and PSUs as independent units might be a challenge for many secondary accredited and non-accredited laboratories.

7. CONCLUSIONS

This paper presents some aspects related to the calibration of IEPE accelerometers. Since most NMIs and secondary laboratories are more used to calibrate charge output accelerometers, the authors believe it is important to disseminate more information about the calibration of IEPE type sensors.

At NMI and secondary calibration laboratories level, interlaboratory comparisons and measurement audits are likewise important to demonstrate measurement and calibration capabilities. Considering the broadband systematic effects caused on IEPE accelerometers by improper grounding as presented in this paper, we can conclude that calibration laboratories and technical assessors shall consider it properly.

In addition, if IEPE accelerometers are chosen as circulating artefacts for interlaboratory comparisons, it is important to include technical criteria or recommendations regarding grounding conditions in the measurement protocols.

The results obtained by INMETRO have shown that with the proper care, IEPE can be used to demonstrate metrological equivalence between different implementations at NMI level.

Additional research is still needed to improve the confidence in IEPE as reference standards. There is little or no information currently available regarding: long term stability, influence to environmental effects, influence of current supply, etc.

Therefore, it is important that manufacturers of IEPE accelerometers and NMIs increase the exchange of technical information to help the metrological community working with this kind of transducers in a proper and harmonized way.

8. REFERENCES

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