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Comparison of the signal characteristics measured by a MEMS and a Piezoelectric accelerometers

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Abstract**—*****This study is dedicated to verifying the performance of a MEMS accelerometer when used for machine condition monitoring based on vibration analysis. The performance of the MEMS accelerometer was compared to that of a piezoelectric sensor, traditionally used in this type of analysis. This goal was reached by measuring the RMS, Kurtosis and Crest levels of the signal obtained by the MEMS sensor against those obtained by the piezoelectric sensor under the same excitation parameters. Both the piezoelectric sensor and the MEMS circuit board were mounted on a special device attached to a shaker. The sensors were submitted to vibrations of 0.5g, 1g and 2g RMS on a frequency ranging from 1Hz up to 2500Hz on steps of 20Hz. The results show that the readings of the MEMS sensor present a maximum deviation of 6.6% when compared to the piezoelectric sensor. It was possible to conclude that a great portion of the deviation encountered was due to the dynamic characteristics of the mounting device and the fixation conditions of the MEMS sensor on this device*
Keywords**—*****Accelerometer, MEMS,Vibration,***

I. INTRODUCTION

In today´s economy, being competitive is the key to success. Industries that have an advantage are the ones that manage to produce more with fewer resources. As factories, face the challenge of getting smarter and more efficient, the need for process monitoring tools increase. One of the obstacles to efficiency is machine downtime. A great way to reduce this issue is the use of machine vibration monitoring systems. Up until very recently, the only suitable sensor to acquire condition monitoring grade vibration was the piezoelectric accelerometers. These sensors are great for the task, as they have a great frequency response and low noise. The drawback is that,these sensors are costly and require a reasonable amount of power to operate, which limit is the use of such sensors on battery-operated systems.

Starting of the past decade, the advancement of nanotechnologies enabled a new type of sensor that would tackle both problems at the same time, the cost and energy consumption. The MEMS accelerometer appeared as a promise of a low-cost, low power consumption, high manufacturing volume sensor, which could potentially be used for large-scale machine vibration monitoring. The question that needs to be answered is if these sensors deliver the required performance in terms of dynamic range and frequency response, two factors that are key to vibration anomalies detection, especially when dealing with bearings. Other researchers on this matter, have already done some work. Back in 2008, the first papers on this subject where published [1]. Albabar&Mekid compared the performance of three different MEMS sensors with piezoelectric and got good results, though some of the chosen models presented a higher level of noise than expected. In [2], the author concluded that the tested low-cost MEMS accelerometer presented compatible diagnose performance that of a high-end model.

This paper proposes a deeper look into the performance of the ADXL203 MEMS accelerometer and evaluate whether its amplitude and frequency responses are adequate for machine condition monitoring. To achieve this goal, three ADXL203 subjects are compared against a piezoelectric accelerometer. A software written in LabView controlled a shaker that swept the frequency span of this accelerometer while recording the results for further analysis.

II. MATERIALS AND METHODS

2.1 Sensor encapsulation

The tested MEMS sensor comes in a LCC encapsulation, thus, requires to be mounted on a PCB. As exposed PCBsare rather fragile to be mounted on a machine, a special stainless steel encapsulation was used to contain

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the circuitry and the connectors.Fig. 1 shows the internal structure of the steal body.

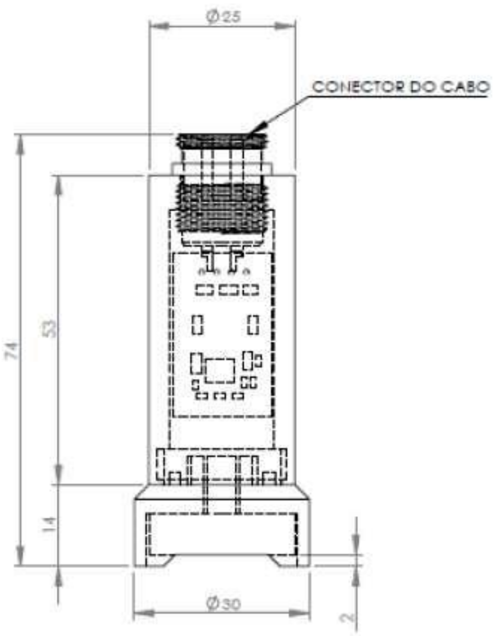

Fig. 1: Sensor encapsulation

Fig. 2: Sensor mounted on shaker

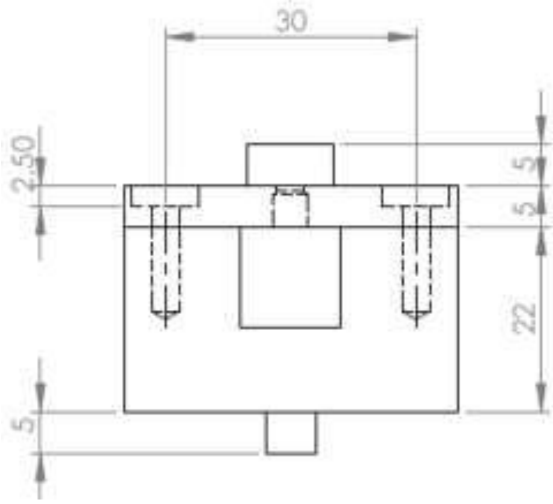

Fig. 3: Mounting device

To compare the response of the piezoelectric and the MEMS sensors, it is vital to excite them with the same source of vibration, in a controlled environment. It is desirable to capture it´s signals simultaneously, as it provides means for comparing the phase of the signals. In order to achieve these two requirements, a special mount was built (Fig. 3) and both sensors were connected to adata acquisition card that ensures simultaneous sampling between all the channels. The purpose of the mount is to provide a rigid base to hold the piezoelectric and the MEMS sensor and connect them to the shaker. Fig. 2shows the piezoelectric sensor and the MEMS sensor attached to the mount on the shaker. The piezoelectric reference sensor is mounted under the base while the subject MEMS accelerometer was mounted on top.

2.2 Control Software

A LabView software was written to provide control and data acquisition capabilities to the test stand. A NI9264 signal-generating card was used to control a BKSV 4808 shaker with a BKSV 2719 amplifier. A NI9234 24-bit ADC card was used to read the piezoelectric and the MEMS accelerometer using the same time base, which enables phase comparing.

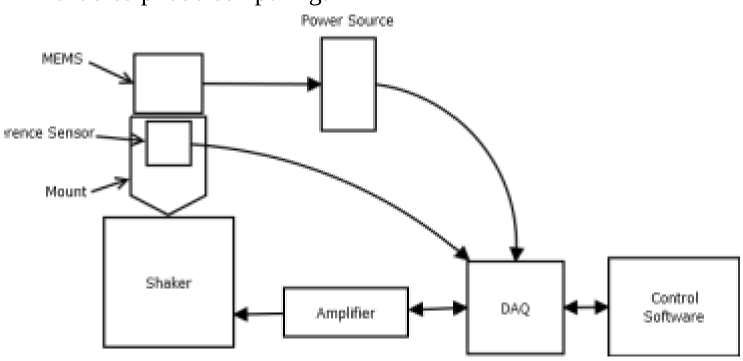

Fig. 4: Test stand schematics

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The software implements a PID control and uses the signal provided by the piezoelectric accelerometer as the feedback signal. The signal-generating card is controlled by the software to provide the input signal for the shaker´s amplifier, according to the response of the PID algorithm. The goal is to control the amplitude and frequency of the shaker so it can meet all the set points defined for the test. The test stand schematics is shown in Fig. 4

The controlled variable in the PID loop was the RMS level of the vibration. The piezoelectric sensor provided the reference signal. There was no need to control the frequency in a closed loop, once there was no relevant variance between the frequency being commanded to the shaker by the software and the measured frequency in the observed conditions. For the test, the used values for each one of the coefficients were P = 0.2, I = 0.01 and D = 0,005. This method is rather similar to that used in [1], though theauthors did not mention explicitly weather they used a PID loop to control the excitation. Fig. 5shows the control loop used.

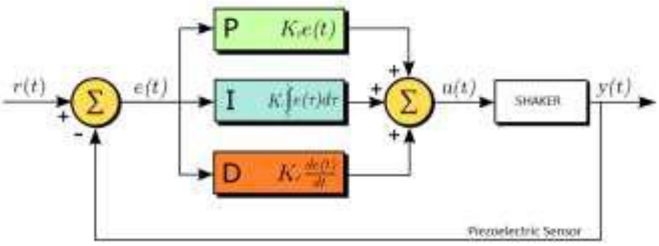

Fig. 5: Control loop

2.3.Test conditions

Three parameters were chosen to analyze the obtained data; the RMS value, Crest and Kurtosis form indexes.

The RMS or Root Mean Square, indicates the vibration energy in the signal. It is defined according to(1).

$$y_{rms} = \sqrt{\frac{1}{N}\sum_{n=0}^{N-1} {x_n}^2} \quad (1)$$

The Crest index is used to measure the amplitude of the highest peak in the signal in relation to the RMS value of the signal. If the Crest value is high, it means that the signal presents pronounced peaks, which indicates that the signal is not smooth. It is defined by (2).

$$C = \frac{P_l}{RMS} \quad (2)$$

The Kurtosis index translates in a numeric value, the "spikiness" of a signal. It represents a measure of the flattening of the density probability function near the average value [3] [4]. In other words, if the value of this index is higher than three, the signal is "spiky" and if it is lower than three, it means that the signal is flatter.

$$R_{ku} = \frac{1}{NR^4}\sum_{i=1}^{N} Y_i^4 \quad (1)$$

The form factors were chosen in order to identify any form distortions in the signal produced by the MEMS sensor in relation to the piezoelectric sensor, throughout the given frequency range. In the same way, the RMS value comparison was chosen in order to check both signals for

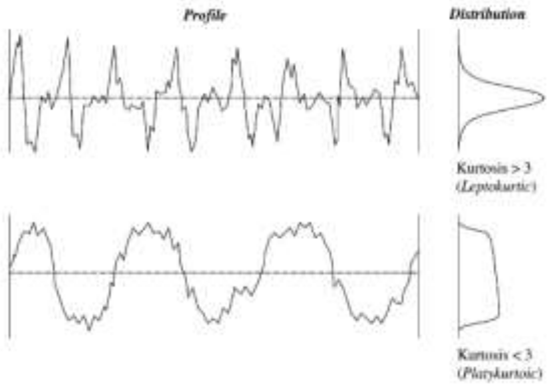

Fig. 6: Kurtosis characteristics

any difference in energy level through the frequency range. The intention was to verify if the MEMS sensor behaves in a similar way to the piezoelectric in deferent operation conditions.

III. RESULTS AND DISCUTION

3.1.Obtained data

To investigate the behavior of the sensors in different conditions of excitation, three prototypes were prepared. The frequency was increased in steps of 5Hz. Table 1 shows the test conditions

Table.1: Test conditions

Test Number	Prototype	Excitation amplitude (g RMS))	Excitation frequency (Hz)
1	660075	0,5gRMS	1 a 2500
2	660075	1,0g RMS	1 a 2500
3	660075	2,0gRMS	1 a 2500
4	660078	0,5gRMS	1 a 2500
5	660078	1,0g RMS	1 a 2500
6	660078	2,0gRMS	1 a 2500
7	660080	0,5gRMS	1 a 2500
8	660080	1,0g RMS	1 a 2500
9	660080	2,0gRMS	1 a 2500

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In the graphs below, the RMS level is maintained steady in the setpointsdescribed in Table 1, by the PID algorithm. Fig. 7*Fig. 1*presents the RMS levels measured by the reference transducer. It shows the three levels of excitation imposed on the MEMS sensors on each of the three passes.

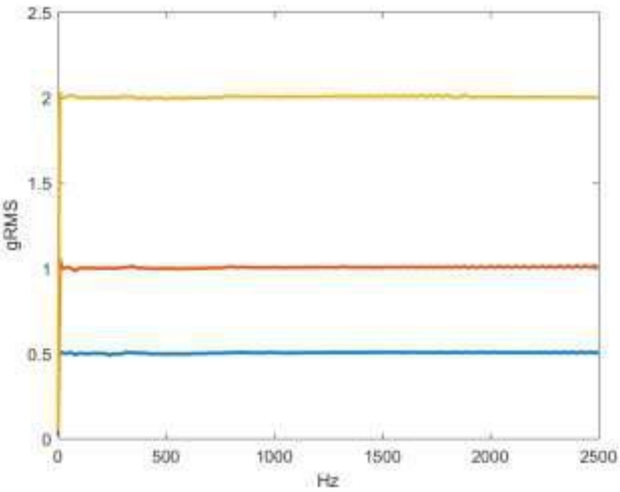

Fig. 7: Piezoelectric RMS level

Fig. 8shows the obtained results for the RMS value of the three tested sensors. Fig. 9and Fig. 10shows the obtained results for Crest and Kurtosis values measured along the frequency range. Each graph containsthe three tested prototypes on the three different amplitude setpoints.

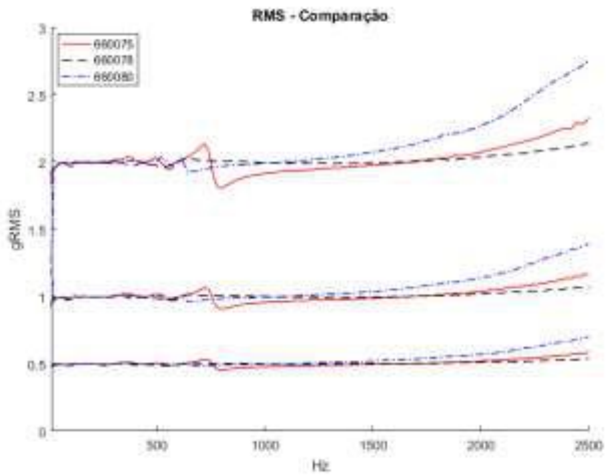

Fig. 8: MEMS RMS level

3.2.Data analysis

As seen on Fig. 7, the excitation levels were steady through the test. It means that the PID loop was effective on maintaining the reference signal constant, laying firm ground for the conclusions to be taken from the test. Fig. 8 shows that the three prototypes presented a constant measured level in almost the entire frequency span for all three excitation levels tested, except for the regions around 700Hz and above 2000Hz.

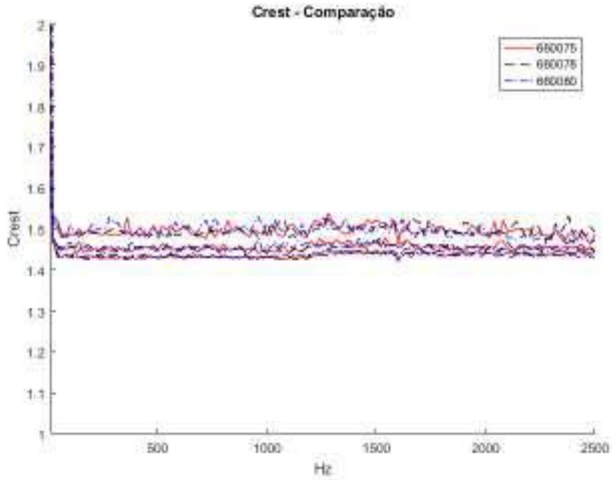

Fig. 9: Crest levels

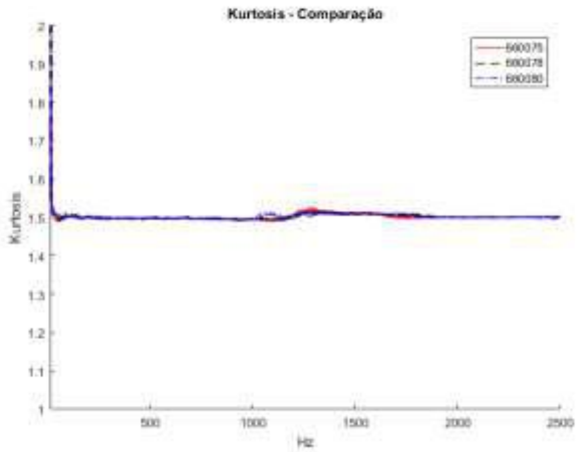

Fig. 10: Kurtosis levels

After finding these discontinuities in the measured signals during the post-processing procedure, the focus was on the mounting device used to secure both sensors on the shaker. Further observations suggested that the first ditch could be caused by the natural frequency of the device. The differences in the level of the signal could be explained by a not so firm mounting of the MEMS sensor on the mounting devices. As it can be seen on Fig. 2, a latter analysis proved that the MEMS sensor was not scrolled all the way, which could have caused the deviation observed,especially on frequencies above 2000Hz. Each of the three sensors showed a different deviation level, what suggests that they were fixed using different torque levels on the mounting scroll. An analysis on the mounting device revealed that the thread that held the MEMS sensor had an imperfection, whichkept the sensor from being scrolled all the way down.

The Crest graph on Fig. 9, shows that the three tested subjects have a very similar response in all the three test conditions along the entire frequency range. There is a

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total nine curves in this graph, with each different color representing a different test subject. The Crest value measured for the 0,5gRMS excitation is around 1.42. For the 1gRMS and 2gRMS this value is around 1.46 and 1.5 respectively. As the acceleration level increases, the peak level measured in relation to the RMS value if the signal also increases. However, it is not possible to conclude,by this data alone, that this rise in the peak level is due to a deviation in the measurement by the MEMS sensor or caused by the shaker itself.

Fig. 10shows the Kurtosis response for all the three test subjects in the three levels of excitation are very similar. The shape of the measured waveform is uniform along the tested amplitude and frequency range. There is a little distortion in the kurtosis level in the frequency around 1200Hz in all the tested subjects and all the conditions. This means that, in this frequency, the measured signal got a little more “spiky”. Again, it is not possible to determine, by this data alone, what might have caused this change. This is a matter for further investigation.

IV. CONCLUSION

This work showed that the MEMS sensor has traceable and consistent signal characteristics. The RMS levels, Crest and Kurtosis values of the sensors are consistent with whatcan be obtained by a piezoelectric sensor. The differences found in the measured signal among the three tested sensors, especially in the highest frequencies, showed the importance of ensuring the correct fixing conditions of the sensor on the device in which the vibration is measured. The shape and level of the acceleration signal obtained by the MEMS sensor is uniform along it´s frequency and amplitude span. Further studies, such as a modal analysis in the mounting device,have to be conducted in order to investigate the cause of the discontinuity in the RMS level graph in the frequency around 700Hz. The same affirmative is valid for the slight increase in the kurtosis index measured around the 1200Hz frequency.

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