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ISO 16063-11: UNCERTAINTIES IN PRIMARY VIBRATION CALIBRATION BY LASER INTERFEROMETRY. REFERENCE PLANES AND TRANSVERSE MOTION

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Abstract – Primary vibration calibration by laser interferometry using quadrature outputs has been used for the last 10-15 years. The ISO 16063-11 [1] was published in 1999 and this has increased the interest further.

With new compact laser interferometers the difficulties of optical alignment and adjustment has been practically eliminated and dedicated software has made the process automatic, permitting to gather much more data.

In most cases it is applied to reference transducers, either single-ended or meant for back-to-back calibration.

However the problem that the laser beam not always can be directed towards the point or surface to which it ideally should be directed, introduces errors that can be quite significant. At low frequencies this is often due to non-ideal exciter motions. At high frequencies it is often due to relative motion between points on apparently rigid mechanical structures or rocking or bending motion of the combined structures.

Some examples and solutions to these problems including uncertainty calculations will be presented.

Keywords: vibration, calibration, interferometry.

1. INTRODUCTION

The ISO 16063-11, Methods for the calibration of vibration and shock transducers — Part 11: Primary vibration calibration by laser interferometry, does not go into much detail when the quality of the motion is described. It states:

"Transverse, bending and rocking acceleration: Sufficiently small to prevent excessive effects on the calibration results. At large amplitudes, preferably in the low-frequency range from 1 Hz to 10 Hz, transverse motion of less than 1 % of the motion in the intended direction may be required; above 10 Hz to 1 kHz, a maximum of 10 % of the axial motion is permitted; above 1 kHz, a maximum of 20 % of the axial motion is tolerated."

About the calibration of back-to-back accelerometers it states:

"Typically, a 20 g mass is used. The laser light spot can be at either the top (outer surface) of the dummy mass or the top surface of the reference accelerometer.

If the motion is sensed at the top of the dummy mass, then the dummy mass should have an optically polished top surface, and the position of the laser-light spot should be close to the geometrical centre of this surface. In cases where the motion of the mass departs from that of a rigid body, the relative motion between the top (sensed) and bottom surfaces shall be taken into consideration. To simulate a mass of 20 g of typical transfer standard accelerometers, a dummy mass in the form of a hexagonal steel bar 12 mm in length and 16 mm in width over flats of hexagonal faces can be used. At a frequency of 5 kHz, for example, the relative motion introduces systematic errors of 0,26 % in amplitude measurements and 4,2° in phase shift measurements.

The standard states also uncertainties attainable as

"For the magnitude of sensitivity:

0,5 % of the measured value at reference conditions;

< 1 % of the measured value outside reference conditions."

The standard was mainly written to help national metrology institutes and similar laboratories to work in similar ways. These have since the publication claimed far better uncertainties (0.1 to 0.5% in the full frequency range).

In these cases the motion has normally been measured at the reference surface of the reference accelerometer, and a slotted mass has been used.

This means that the point(s) at which the motion is measured by the interferometer is positioned at a distance of some millimetres from the centre. This makes the transverse motion that is normally a rocking motion a major contributor to the uncertainty.

To avoid this, a dummy mass as described above, can be used and the motion measured at the centre. However this leaves the problem of estimating with high accuracy the motion at the interface between the dummy mass and the reference accelerometer.

2. TRANSVERSE MOTION OF EXCITERS

Manufacturers of exciters do sometimes give specifications for transverse motion, but the way these are obtained is rarely given and is probably mostly measured with small carefully symmetrical loads directly on the top of the moving element. Therefore an investigation of actual transverse motion was performed on 3 different exciters. One was a classical spring controlled model, the other two air-bearing exciters with specified low transverse motion. The results are shown in 18 figures.

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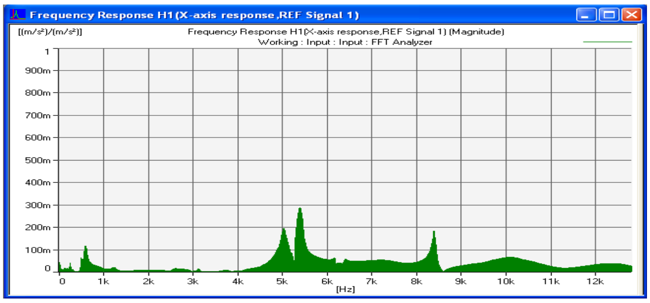

Figure 1. Exciter A, X-direction, 8305, 20gram.

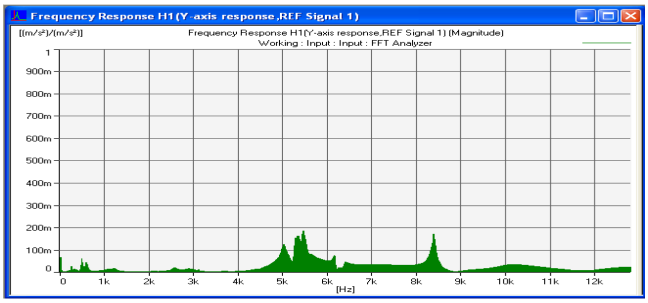

Figure 2. Exciter A, Y-direction, 8305, 20 gram.

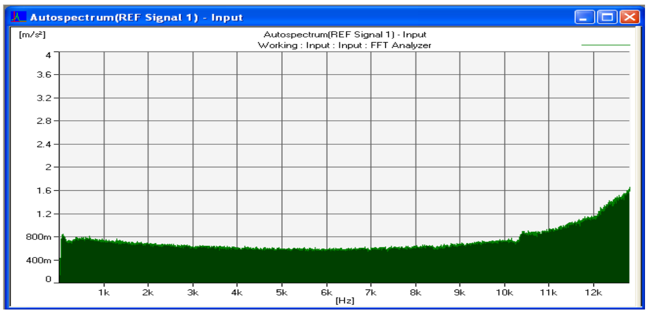

Figure 3. Exciter A, excitation spectrum

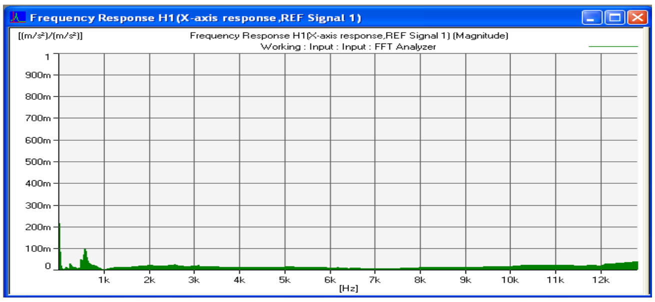

Figure 4. Exciter A, X-direction, 8305, 20gram. Mechanical Filter.

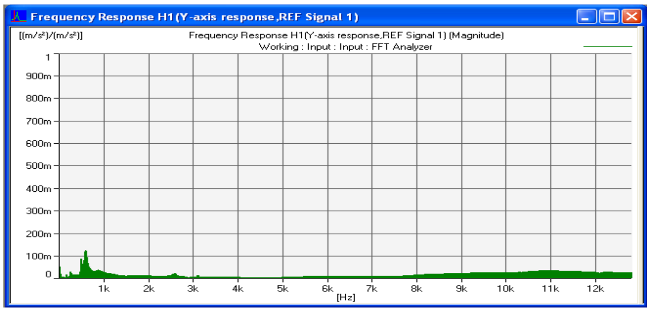

Figure 5. Exciter A, Y-direction, 8305, 20 gram. Mechanical filter.

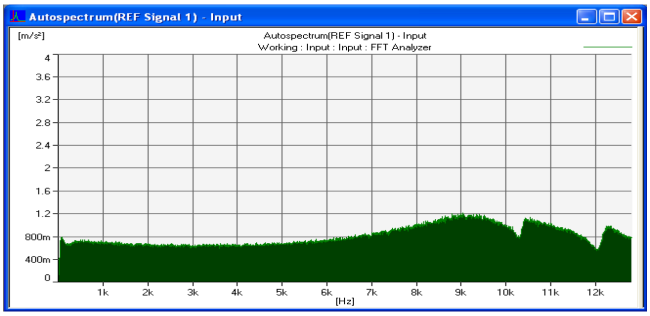

Figure 6. Exciter A, excitation spectrum. Mechanical filter.

The exciters A and B are air-bearing types; C is a classical spring type exciter. Measurements on A and B were made perpendicularly to the excitation direction in two different directions (X and Y 120 degrees apart) at the top end of a reference transducer Brüel & Kjaer Type 8305 with a 20 gram slotted load mass (PTB design) to be used for laser interferometry at the mounting surface of the accelerometer.
On exciter C the 8305 was loaded with a cubic 30 gram block with 4 identical accelerometers mounted on its surfaces to measure the transverse motion. The results from two accelerometers perpendicular to each other are given. The excitation was a random signal and the obtained spectrum as measured by the 8305 is shown as the third graph. The transverse motion is given relatively to the main direction; the maximum on the graphs corresponds to 100% transverse motion.
The three results are shown for each exciter. From figures 1-3, 7-9 and 17-19 it became clear that the specifications for transverse motion are not useful for estimating the motion and the uncertainties related to transverse motion when a back-to-back reference transducer is mounted directly on top of the exciter table. The combined structure of the exciter table and the reference transducer shows high transverse levels in the 4 to 9 kHz range, probably due to bending modes. A small asymmetrical load e.g. due to the connector can apparently create large rocking motions, typically with peaks of 30 to 60%.
A number of experiments were made to avoid this phenomenon.
The best solution was found to be a mechanical filter mounted between the exciter and the reference transducer. The filter should preferably be optimised to the specific type of reference transducer to give the best results. The principle of the mechanical filter is shown in Figure 10. It consists of two stainless steel parts connected by vulcanized rubber.
The results from using such a filter are shown in the right column, opposite the results without.
The resulting transverse motion is now reduced to less than 5% above 1 kHz for all the exciters.

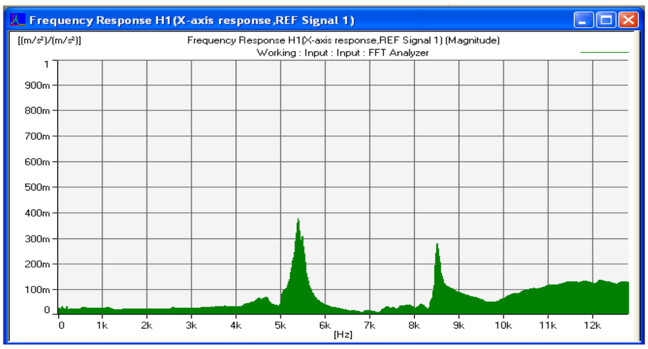

Figure 7. Exciter B, X-direction, 8305, 20gram.

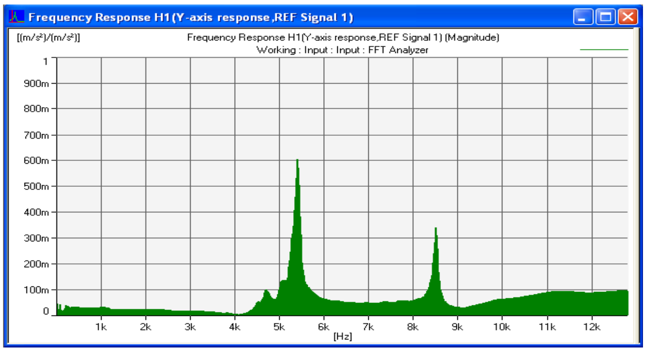

Figure 8. Exciter B, Y-direction, 8305, 20gram

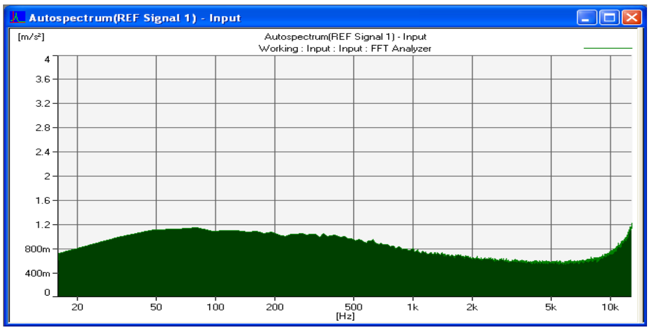

Figure 9. Exciter B, excitation spectrum

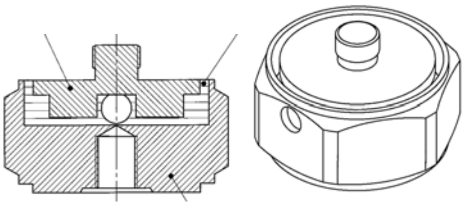

Figure 10. Mechanical filter

3. TRANSVERSE MOTION INFLUENCE ON CALIBRATION RESULTS.

To avoid/cancel out the influence of rocking motion the laser beam can be aligned with the centreline of the accelerometer (provided the rocking centre is also on that line) or two or more measurements can be made at points

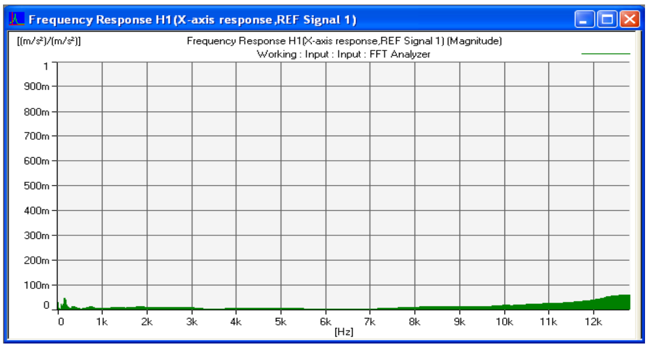

Figure 11. Exciter B, X-direction, 8305, 20gram. Mechanical filter.

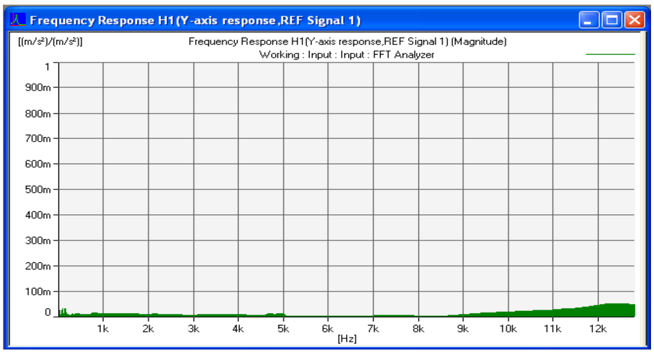

Figure 12. Exciter B, Y-direction, 8305, 20gram. Mechanical filter

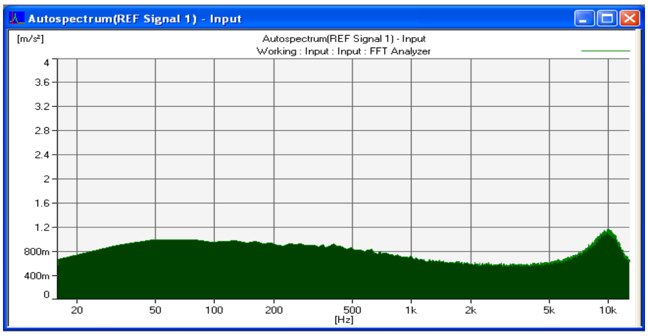

Figure 13. Exciter B, excitation spectrum. Mechanical filter

symmetrical about the centreline and the average value used. However the accuracy of the positioning of the points and the unknown centreline of the motion will always leave a certain influence from the rocking. To get a measure of the

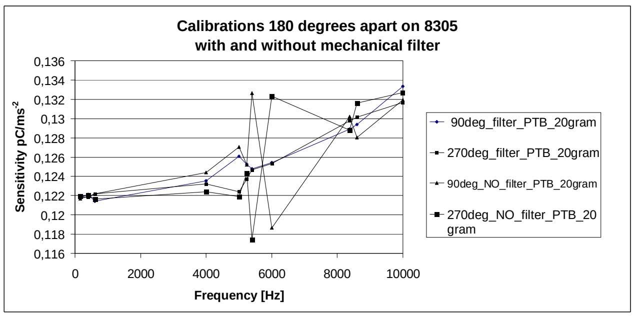

Figure 14. Measurement differences with and without mechanical filter (20 gram slotted mass).

importance of this, a series of measurements close to the critical frequencies were made. The results are shown in Figure 14. It can be seen that the difference between two diagonal points can be nearly +/-10% without filter whereas the difference is of the order of +/- 2% when the filter is used. That makes a big difference when the average has to be found. The influence can change the calculated uncertainties dramatically. If an off-centre position of 1 mm is used together with a distance to the rocking centre of 50 mm then changing the transverse motion from 5% to 25% will increase an estimated 2σ uncertainty of 0.4% to more than 0.8%.
To further prove the validity of the method an international comparison was made on a well-known reference transducer. Figure 15 shows the result of the comparison between a calibration performed at PTB, Germany and the calibration made at DPLA using mechanical filter and four points with the slotted mass shown in
Figure 16. The uncertainties from the PTB certificate (0.2, 0.3 and 0.4%) was used together with the presently stated DPLA uncertainties of 0.4 and 0.6% (above 5 kHz).

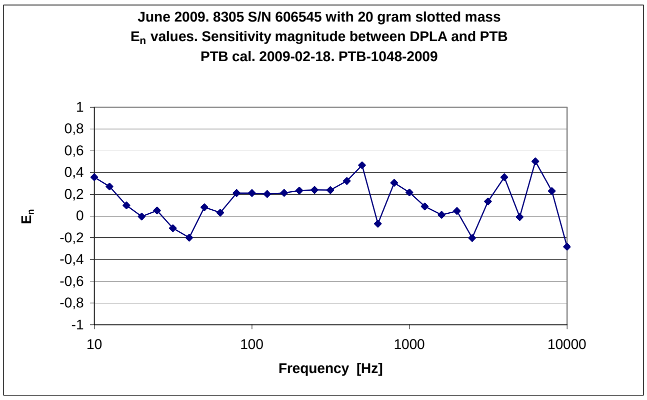

Figure 15. E_n values comparing a recently PTB calibrated 8305 with a calibration at DPLA using the mechanical filter

4. INFLUENCE OF LOAD MASS ON CALIBRATION RESULTS.

For the last twenty or more years a number of correction curves have been used for the back-to-back reference transducers. Recently some new, astonishing results were published by PTB [2].
At DPLA a number of measurements were undertaken to verify or question these new results. One of the first measurements was comparing the results on top of a 20 gram solid stainless mass as described in the standard [1] to the results obtained at the interface between the transducer and a slotted 20 gram mass. The difference is shown in Figure 20. This gives differences well beyond the value stated in the standard.
A number of measurements similar to the results reported in [2] are about to be finished, but seems to confirm the findings.

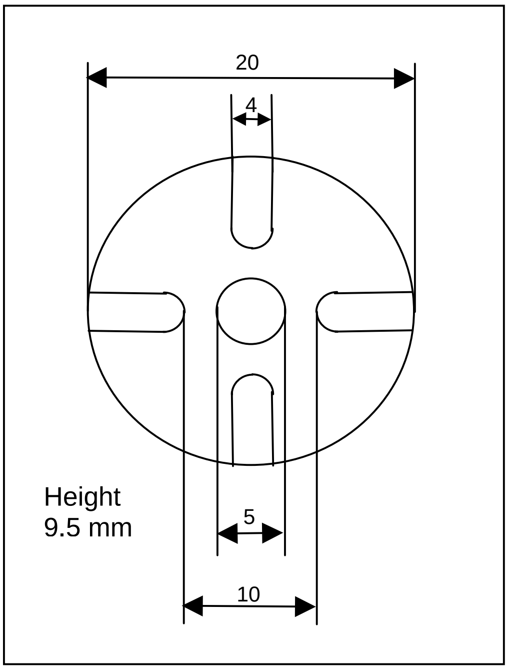

Figure 16. Stainless 20 gram slotted load-mass

5. CONCLUSIONS

The amount of transverse motion of different shakers has been investigated. The results show that even high quality shakers designed for calibration show very high levels of transverse motion at higher frequencies when back-to-back accelerometers with load masses are mounted on these shakers. This is detrimental to the laser-interferometric measurements used to give the best possible primary calibrations.
A solution to this problem has been devised in the form of mechanical filters breaking up the structure to remove the high frequency bending modes of the shaker plus accelerometer structure.

The use of slotted masses for calibration of back-to-back accelerometers has been taken up, and it has been shown that the difference between this and the often used mirror-masses is much larger than normally expected. This is the subject of further work and discussion.

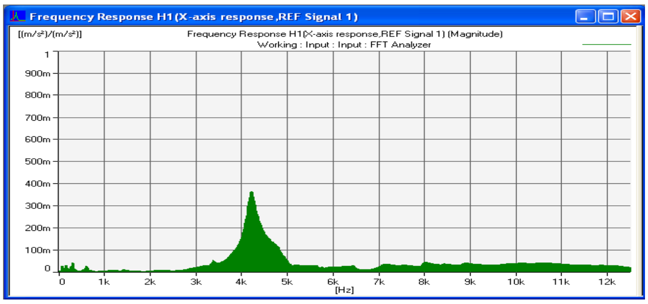

Figure 17. Exciter C, X-direction, 8305, 30gram.

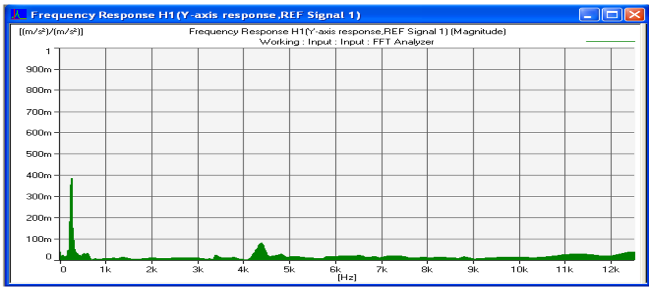

Figure 18. Exciter C, Y-direction, 8305, 30gram.

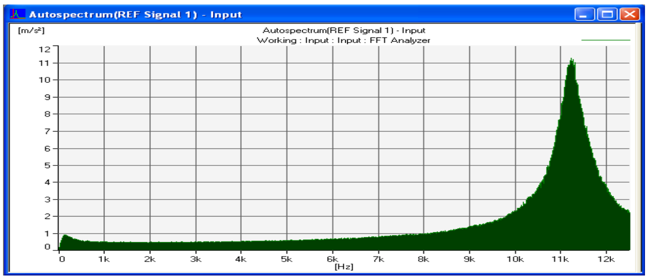

Figure 19. Exciter C, excitation spectrum.

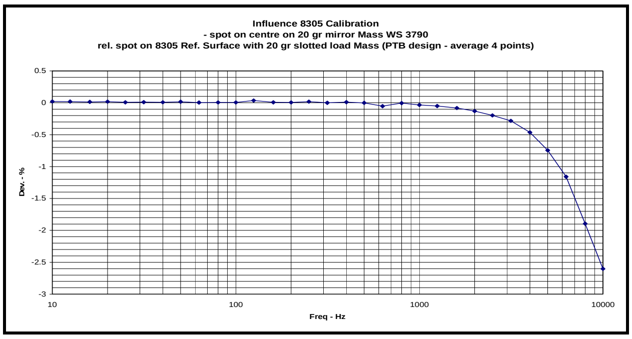

Figure 20. Difference between measurement on top of load mass and at the transducer surface

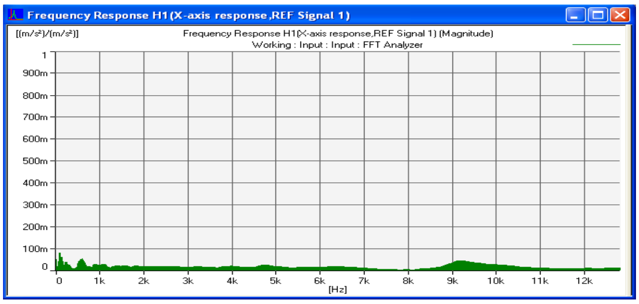

Figure 21. Exciter C, X-direction, 8305, 30gram. Mechanical filter.

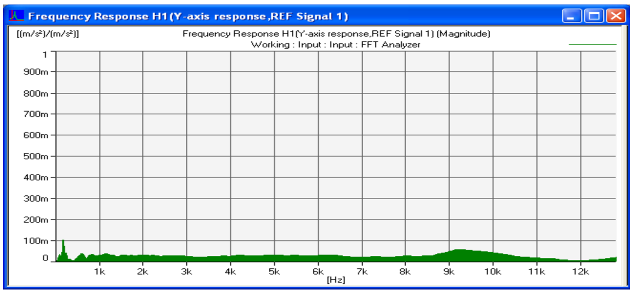

Figure 22. Exciter C, Y-direction, 8305, 30gram. Mechanical filter.

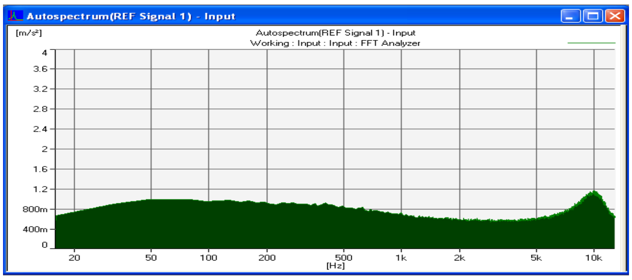

Figure 23. Exciter C, excitation spectrum. Mechanical filter.

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[1] ISO 16063-11, *Methods for the calibration of vibration and shock transducers — Part 11:Primary vibration calibration by laser interferometry*, 1999

[2] Angelika Täubner, Hans-Joachim Schlaak, Thomas Bruns, *Metrological and theoretical investigations of the influence of mass loads on the transmission coefficient of acceleration transducers of the back-to-back type*, Physikalisch-Technische Bundesanstalt, 38116 Braunschweig, Germany,