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UNCERTAINTY CONTRIBUTIONS IN SINUSOIDAL FORCE MEASUREMENT

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Abstract: This paper describes one of the uncertainty contributions which can be derived from sinusoidal force measurements. These measurements are based on the application of a scanning vibrometer and the use of triaxial accelerometers. The measuring of many acceleration points on the top mass of the transducer makes it possible to obtain acceleration distributions from which a standard deviation can be derived; the triaxial accelerometer allow the observance of certain effects, like rocking modes, or other problems related to specific excitation frequencies of the force transducer. Both measurements can be related to each other.

Keywords: Dynamic force, sinusoidal excitation, laser vibrometer, rocking motion, triaxial acceleration.

1. INTRODUCTION

Force measurement plays a major role in industrial processes, statically as well as dynamically. In the past a very versatile system of static force calibration was established, which last but not least can be recognized by the many high level force calibration laboratories and services around the globe. Nevertheless, most of the processes where force measurement is involved have a dynamic nature. So far only static calibrated force transducers also have been used in dynamic applications. The deviations in measurement associated with this may rise to the order of several percent and, especially in the vicinity of resonances, up to 10-100%. To close this gap, some developments were carried out in the past to provide dynamic force calibration. These developments have also triggered a project currently running in the European Metrology Research Programme (EMRP), the "Traceable Dynamic Measurement of Mechanical Quantities", which includes, apart from a work package on dynamic force, also work packages on dynamic pressure, dynamic torque, the electrical characterization of measuring amplifiers and mathematical and statistical methods and modelling [2]. The investigation of the uncertainty contributions in sinusoidal force measurement is crucial for providing a reliable dynamic calibration of force transducers. A sinusoidal calibration is usually performed with an electrodynamic shaker system. Thereby, the force transducer, mounted on this shaker, is equipped with a top mass, and the acceleration on the surface of this mass as well as the force transducer signal is measured during the sinusoidal movement. A more detailed description of the whole calibration process can be found in [2].

2. SCANNING MEASUREMENTS

A big advantage for the acceleration measurement is a scanning vibrometer which offers the opportunity to measure many points, e.g. on the whole surface of the mass block. By averaging the signals measured at these points, one can obtain realistic standard deviations, e.g. uncertainties. The dynamic behaviour during such a sinusoidal excitation depends on the kind of coupling of the top mass on the transducer as well as on the mounting of the transducer on the shaker table. In addition, of course, the internal mechanical structure of the transducer is of fundamental importance. One result of such a dynamic calibration is the dynamic sensitivity, which is the ratio between the force transducer signal and the measured dynamic force, which is the product of the acceleration of the top mass and its mass value. Due to the imperfect rigidity of the transducer, which depends on the internal structure, rocking modes may occur during at certain frequency. These rocking modes can be detected, for instance, from the uncertainty as a function of the frequency drawn for certain measuring channels. Figure 1 shows one example of such an

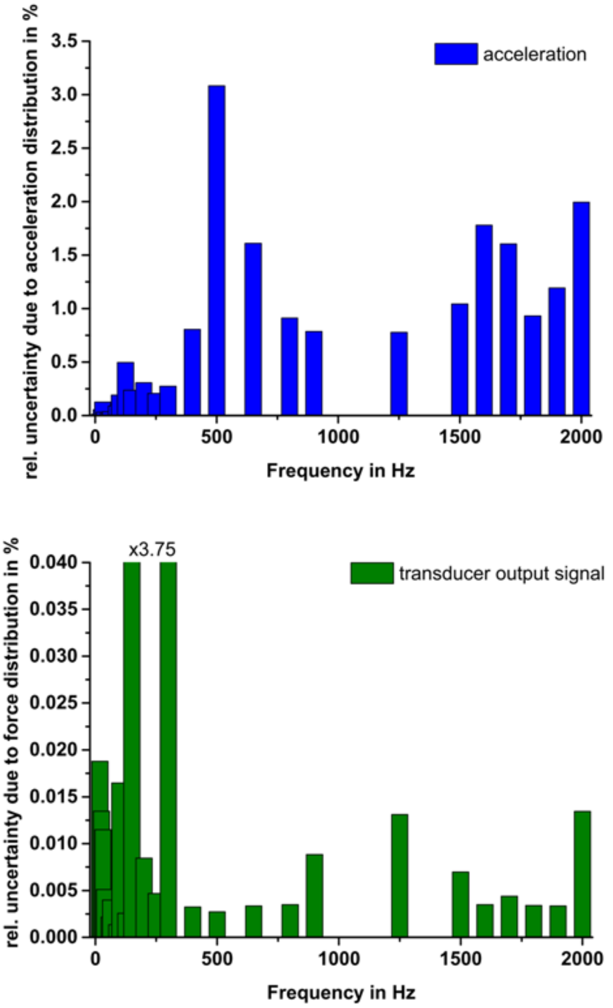

Figure 1. The figure shows the uncertainty of the measured acceleration on the top mass as well as of the force transducer signal. The uncertainty was obtained by averaging 62 acceleration measuring points and their 62 appropriate force signals at a certain frequency. It should be noted that, the uncertainty of the vibrometer contribute additional 0.2-0.3 % and the uncertainty of measurement of the force conditioning amplifier additional 0.1-0.2%. The two bars reaching 0.04% have to be multiplied by a factor of 3.75.

analysis. In this special case the uncertainty of the acceleration shows several frequencies where the uncertainty is significantly higher than elsewhere.
Surprisingly, this behaviour does not correspond to the synchronously measured transducer output signal. It seems that this special kind of force transducer is not so susceptible to interference from external influences. The origin of the relatively large uncertainties of the transducer output signal at 200 and 300 Hz is unknown; obviously this increase has nothing to do with possible rocking modes.
In practice, one could conclude from such a measurement of the uncertainty distribution that it is advisable to avoid the regions where the transducer perhaps shows some irregularities.
It should be noted that the uncertainty given above is not the whole uncertainty because the contributions influenced by the measuring equipment are not considered. They yield, depending on the frequency range, an additional 0.3-0.5%.
The scanning of the acceleration can be accompanied by triaxial acceleration measurements, where one can directly measure the transverse acceleration in certain directions. Combining the different methods may clarify the question of whether the increased uncertainty at certain frequencies can really be associated with rocking modes.

3. TRANSVERSE ACCELERATION

In order to investigate the possible rocking modes during the periodic excitation, the transverse acceleration was measured.
For this purpose a special arrangement of four triaxial accelerometers on top of a test mass was chosen.

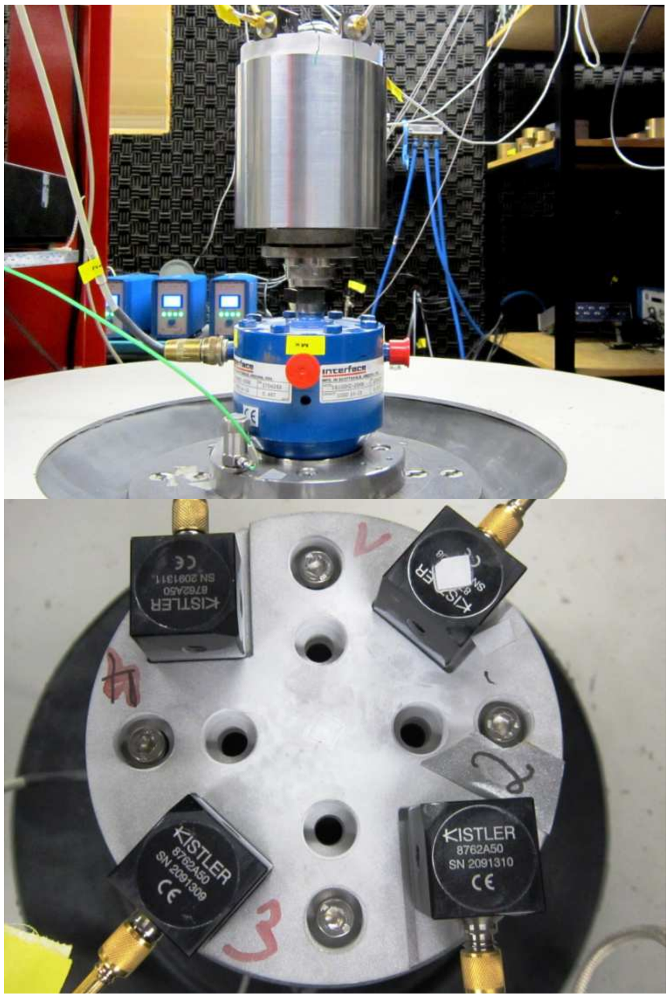

Figure 2. The upper picture shows the whole arrangement of the force transducer with the test mass, which was equipped with a special plate where four triaxial accelerometers mounted. The lower picture shows the plate with the four triaxial accelerometers.

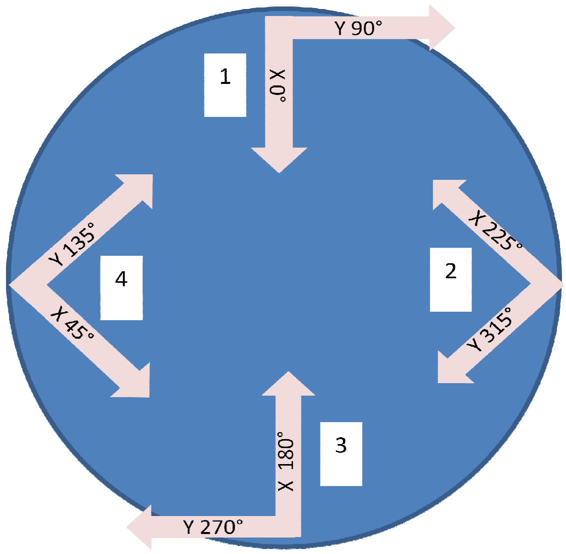

Figure 3. Schematic representation of the arrangement of the four triaxial accelerometers with their certain acceleration vectors in the transverse directions, x and y. In addition there are four accelerations perpendicular to the shown plane, in the z direction.

Figure 3 presents two pictures of the setup. The upper picture shows the force transducer equipped with an 8 kg test mass fixed with a mechanical adapter on the transducer. On top of the test mass the plate with the triaxial accelerometers can be seen. Besides the force transducer one can see one additional accelerometer mounted on the shaker table. The force transducer was an interface type with a nominal force range of 25 kN. Amplification of the force transducer output was realized with a DEWETRON conditioning amplifier.

The lower picture shows the arrangement of the triaxial accelerometers on the plate which is mounted on the test mass. For a better fitting of the accelerometers on the plate, a certain area of the plate was milled out. The sensors themselves were screwed in place from the reverse of the plate.

The accelerometers were arranged in such a way that the x and y components have an equidistant separation of 45 degrees. The sensors themselves were from Kistler, type 8762A50, which have shear sensor elements that feature extremely low thermal transient responses and have a high immunity to base strain and transverse acceleration. An advanced hybrid charge amplifier is incorporated with a wide frequency range from 0.5 Hz – 6 kHz. The acceleration range of the sensors is in a scale of ±50 g whereby the peak limit is by ±80 g and the

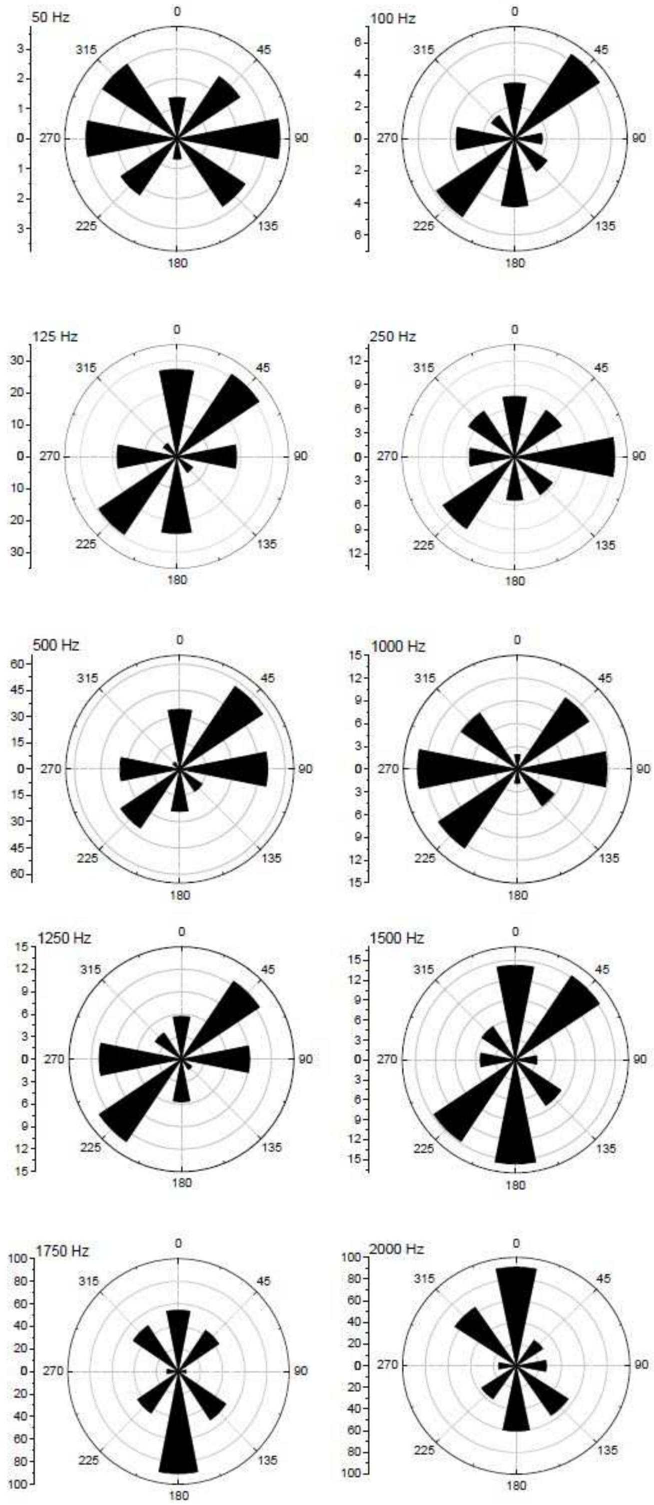

Figure 4. This figure shows the measured acceleration, observed in eight different directions at various frequencies, on top of the test mass. The scale on the left is the amplitude of the acceleration given as a percentage of the z-component of the acceleration. Note the widely-varying scales.

sensitivity is 100 mV/g, where g is the gravitational acceleretaion. The three outputs of each accelerometer were fed into the Kistler 5134B conditioning amplifier

which also provides the power supply for the integrated amplifier of the sensor.
Figure 4 shows the acceleration measurement values according to the eight transverse directions as a function of the excitation frequencies. The behavior can be quite well demonstrated in a kind of windmill plot. The length of the wings is proportional to the amplitude. The opening angle of the wings can be chosen arbitrarily, but is equal for all directions. On the scale on the left-hand side the amount of the acceleration amplitude in percent in relation to the z-amplitude is given. At first glance one can see that the transverse acceleration distribution changes with the frequency. If one observes at certain frequencies a rocking in the direction of 45°/225°, e.g. at 100 Hz and 1250 Hz, the picture changes at frequencies of, e.g. 1750 Hz and 2000 Hz, where the rocking occurs in the direction of 0°/180°. On the other hand, there are quite different amplitudes of the transverse acceleration as a function of frequency, which reach from a few percent at low frequencies up to 100% at high frequencies, related to the z-amplitude of the acceleration.

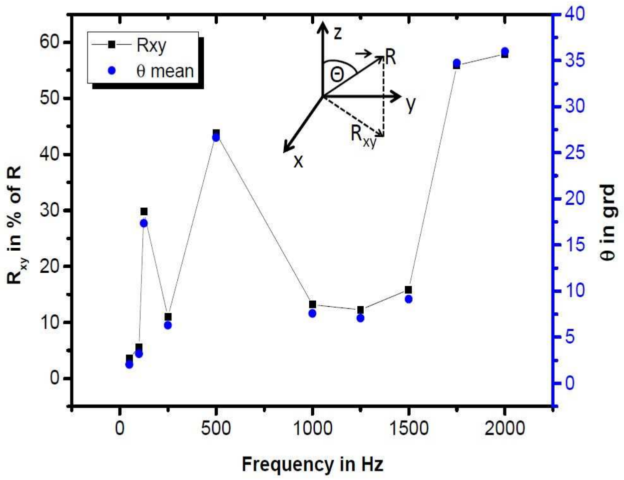

Figure 5. The amplitude of the transverse acceleration as well as the angle of inclination of the acceleration vector in respect to the vertical of the top mass surface (z-axis) as a function of the excitation frequency.

In Figure 5 the vector content of the transverse acceleration was calculated. According to the coordinate system, shown in Figure 5, the three vector components give one acceleration vector in space with a certain value, R and an angle of inclination, Θ, in respect to the normal of the force vector, which is perpendicular to the upper surface of the top mass (z-axis). The corresponding projection of this vector on the xy-plane as a percentage of R and the angle, Θ, is given in Figure 5 as a function of frequency. From the figure one can see that quite large rocking motions occur at certain frequencies. The question of what is the origin of such behavior arises. The origin of the large transverse amplitude at 500 Hz is probably connected with a cross resonance of the transducer. The main resonance of the setup is around 930 Hz. Experimentally, the uncertainties are large beyond the resonance frequency, which is also to be seen in this data, see e.g. Figure 1. If one compares both acceleration measurements, the scanning results according to Figure 1 and the transverse accelerations according to Figure 4 one can see a good correspondence at problematic frequencies, e.g. 500 Hz. In summary one can conclude that distinct higher uncertainties of the acceleration of the top mass can be related to rocking modes.

4. CONCLUSIONS

This paper describes some part of the uncertainty contributions which can be derived from sinusoidal force measurements. In contrast to single point acceleration measurements, the measurement of the whole acceleration distribution on the surface of the top mass makes it possible to observe effects, like rocking modes or other mechanical deficiencies. Surprisingly, the effects seen by the acceleration signal are often suppressed in the force signal.
It could be shown by transverse acceleration measurements that the measured uncertainty distribution of the acceleration on the top mass corresponds to the transverse motions at least below the resonance frequency of the setup.

Acknowledgement

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5. REFERENCES

[1] European Metrology Research Programme (EMRP), http://www.emrponline.eu

[2] C. Schlegel, G. Kieckenap, B. B. Glöckner, A. Buß, R. Kumme "Traceable periodic force calibration", Metrologia 2012, **49**, n° 3, 224-235.