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STATIC AND DYNAMIC MEASUREMENT OF FORCE TRANSDUCER'S DEFORMATION UNDER LOAD

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Abstract – At PTB, one designed and investigated measurement setups to determine the deformation of force transducers while applying a static or dynamic force. To measure the deformation, a differential vibrometer [1] is used which is integrated in the measurement setups. Using the deformation results one is able to calculate the transducers stiffness. An evaluation of the measurement uncertainty is presented as well as first experimental results.

Keywords: dynamic force, deformation

1. INTRODUCTION

Dynamic force measurement is getting more and more important [2, 3]. And in numerous dynamic applications, e.g. the calibration of fatigue testing machines, one not only needs to measure the force, but also the deformation path of the device to be measured. For this purpose we designed measurement setups which enable us to measure the deformation of force transducers under load. So while calibrating the device, in addition we get to know the device's stiffness.

2. MEASUREMENT SETUP

The setup for the static measurements, which is implemented into PTB's 20 kN-Force-Standard-Machine, is pictured in Fig. 1. The vibrometer setup consists of a ground plate and a frame which is screwed to the plate. The frame is made up of three beams which top sides are attached to a half circle to increase the setup's stiffness. Each of the two laser heads of the differential vibrometer is attached to the top side of one of the beams. The whole construction is designed in such a way that the laser beams are as centred as possible without touching the load frame, because this would lead to force shunts. One laser beam is reflected on the ground plate, where also the force transducer is positioned. The second laser beam is reflected on a plate which is attached to the load button and represents the top of the force transducer.

In the case of the dynamic setup (Fig. 2) the whole vibrometer setup is placed on a damping table to avoid vibrations caused by the 10 kN-Shaker-System [4]. The damping table can be adjusted in height, so the distance between the laser heads and the force transducer can be minimized according to requirements. The laser heads are placed on an arm which is attached to the damping table,

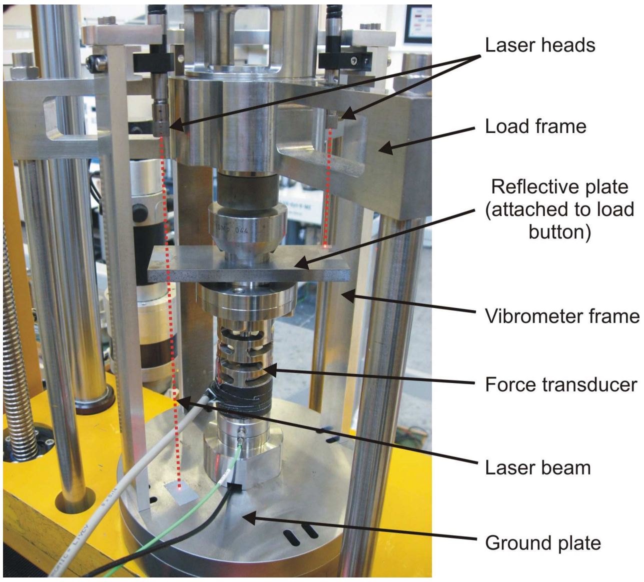

Fig. 1 Vibrometer setup for measuring the static deformation of force transducers at PTB's 20 kN-Force-Standard-Machine.

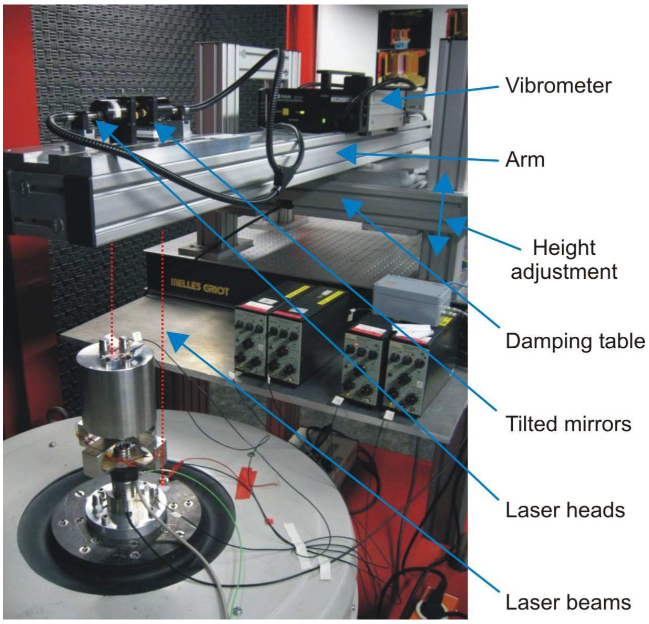

Fig. 2. Vibrometer setup for measuring the dynamic deformation of force transducers at PTB's 10 kN-Shaker-System.

directly above the force transducer. The laser beams can be adjusted using tilted mirrors. Like in the static case one laser beam is reflected on the ground plate, which represents the bottom of the force transducer. The second laser beam is reflected on top of the additional mass which is mounted on the top of the force transducer. Using only small forces up to 1 kN, the mass' deformation can be neglected.

3. FIRST MEASUREMENT RESULTS

First tests showed that for the static as well as for the dynamic setup, the vibrometer shows a noise signal of about 0.5 µm. These noise signals are caused by vibrations and air drafts which can not be eliminated.

To have the possibility to compare the experimental results, self designed force transducers were used for the deformation measurements. Knowing the transducer's geometry it is possible to calculate its stiffness by using the Finite-Element-Method (FEM).

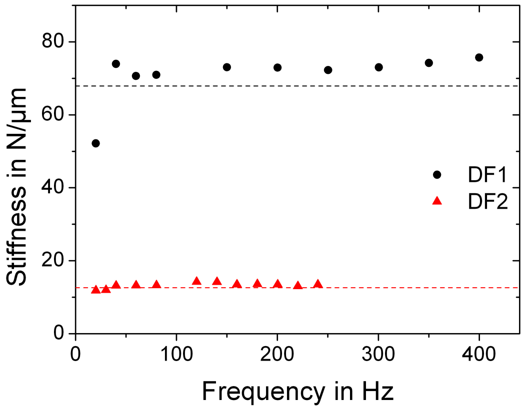

Fig. 3 Stiffness of the two deformation bodies DF1 and DF2 measured at different frequencies. The straight lines mark the values gained by using FEM.

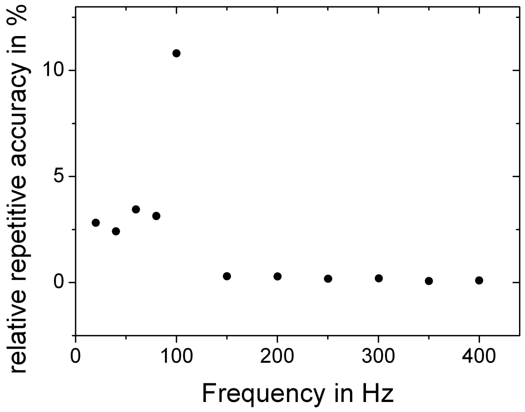

Fig. 4 Relative repetitive accuracy of the stiffness of DF1 gained from five deformation measurements at different frequencies.

For first measurements two deformation bodies DF1 and DF2 with calculated stiffnesses of 68 N/µm and 12.5 N/µm were used. As an experimental result using the static setup one obtained stiffnesses of 72 N/µm and 12.75 N/µm. Repetitive measurements approved these results with an uncertainty of 0.18 µm or a relative uncertainty of 0.95 %, respectively. One can see that caused by the repetitive measurements the uncertainty is much smaller than the vibrometers noise signal. The relative deviations between FEM analysis and the experimental results differ depending on the used deformation body. For DF1 the relative deviation is about 5.5 %, whereas for DF2 it is about 1.2 %.

The dynamic measurements were performed at frequencies from 20 Hz up to the frequency of the longitudinal resonance. Because the stiffness is correlated with the resonance frequency, DF1 was measured using higher frequencies (up to 550 Hz) than DF2 (up to 300 Hz). In Fig. 3 one can see the measured stiffnesses of both deformation bodies at different frequencies. The FEM results are also included into this figure for orientation. At frequencies higher than 100 Hz almost no frequency dependence is visible. At lower frequencies the results show larger differences. The largest deviations from the FEM results can be found at frequencies lower than 50 Hz. These higher deviations are mainly caused by secondary resonances which occur at both deformation bodies at low frequencies of about 30 Hz. Secondary resonances were also observed at 100 Hz. The resulting deviations in the stiffnesses at this frequency are that large, they are not shown in Fig. 3. This resonance behaviour is disturbing the measurement because the purely vertical movement of the setup consisting of deformation body and additional mass is overlayed with an overturning. This overturning results in a vibrometer signal which is not sinusoidal anymore. This effect is illustrated in Fig. 4, where one can see the relative repetitive accuracy of the stiffness of DF1 that was obtained performing five dynamic measurements at different frequencies. At higher frequencies the repetitive accuracy is smaller 0.3 %, whereas below 100 Hz it is about 3 %. And at 100 Hz it is rising to a value of more than 10 %. So it is obvious that using this measurement setup to identify a deformation body's stiffness one has to be clear about its resonance behaviour. The experimental results we gained at higher frequencies show relative differences from the FEM results of about 5 % for both deformation bodies.

4. UNCERTAINTY

In Fig. 5 a sketch is shown which illustrates the evaluation of the uncertainty of the vibrometer measurements caused by not exactly aligned laser heads. The laser beam is reflected at the measuring point and coupled back into the laser head. Because of the finite expansion of the laser optics it is possible to have a small variation from the angle of incidence when the laser beam still couples back into the optics. In this case the laser beam's distance from the measuring point is l_{laser}, whereas the shortest distance between the laser optics and the measuring point is l_{true}. The maximum difference l_{diff} between l_{laser} and l_{true} for a certain measuring point P can be written as

$$l^{P}_{diff} = \sqrt{(l^{P}_{true})^{2} + k_{P}^{2}} - l^{P}_{true} .$$

For the case sketched in Fig. 5 l_{diff} is about 5 µm. The resulting difference Δl during a load cycle with the maxima of the moving measuring points *P1* and *P2* can be calculated as followed

$$\Delta l = (l^{P1}_{laser} - l^{P1}_{true}) - (l^{P2}_{laser} - l^{P2}_{true}) = l^{P1}_{diff} - l^{P2}_{diff} .$$

This means that Δl depends on the shaker's travel (*P1-P2*). By increasing the travel, Δl is also growing. For a constant acceleration during a measurement the shaker's travel is the bigger, the lower the frequency is. Our measurements were performed with an acceleration of 100 m/s^2. This results in a shaker travel of about 1.3 cm at 20 Hz and a Δl of about 0.36 µm. At frequencies higher than 100 Hz the travel is below 0.5 mm and Δl is smaller than 0.015 µm. The calculated frequency dependence of the uncertainty caused by not exactly aligned laser heads is shown in Fig. 6. Larger accelerations would increase the uncertainty. The total uncertainty U of the transfer factor for the stiffness measurement also includes the uncertainties of the mass and acceleration measurement as well as correction factors of the used amplifiers. Using a k-factor of k=2 the total uncertainty results in U = 0.52 % for frequencies higher than 100 Hz.

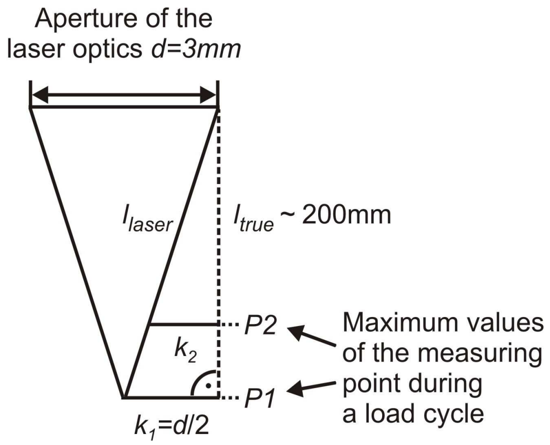

Fig. 5 Illustration of the evaluation of the uncertainty caused by not exactly aligned laser heads.

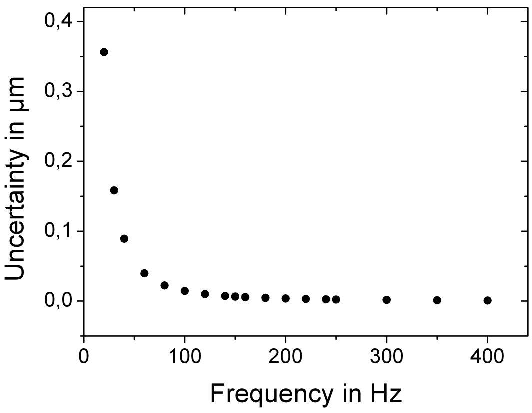

Fig. 6 Frequency dependence of the uncertainty caused by not exactly aligned laser heads.

5. CONCLUSIONS

The design of two new measurement setups was shown. These setups are combined with a differential vibrometer, to make it possible to measure the deformation of force transducers exposed to a static or dynamic force and calculate the transducers' stiffnesses. First investigations showed that it is important to know the transducers' resonance behaviour. Resonances can cause overturnings of the transducers movement which disturb the deformation measurement and lead to high uncertainties. Also the frequency dependence of the uncertainty caused by not exactly aligned laser heads was displayed. First deformation measurements showed a total relative uncertainty of less than 1 %.

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