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# A NEW FACILITY FOR CONTINUOUS AND DYNAMIC FORCE CALIBRATION WITH FORCES UP TO 100 KN

*Rolf Kumme* [1], *Bernd Glöckner* [1], *Christian Schlegel* [1]

[1] Physikalisch-Technische Bundesanstalt, Braunschweig, Germany, Rolf.Kumme@ptb.de

**Abstract** − A new dynamic force measuring facility is realized for continuous and dynamic calibration of force transducers by using the force comparison method. This method is based on the use of a selected reference force transducer with well known static, quasi-static and dynamic properties. The transducer under test can then be calibrated by a direct comparison with the reference standard.

**Keywords**: Dynamic force calibration, dynamic reference transducer

## 1. INTRODUCTION

In the many dynamic applications dynamic forces are measured up to 10 kN with frequencies up to 1000 Hz and up to 100 kN with frequencies up to 100 Hz. To cover these ranges PTB decided to extend the dynamic force range to larger forces and therefore a new facility was developed, which is be described in this paper.

## 2. MEASURING FACILITY

A new dynamic force measuring facility is realized and the difference of this new facility to a commercial material testing machine is, that the facility consists of different selected mechanical, hydraulic, electronic components and a new developed software to cover in future with high precision the force range from 0 N to 100 kN in tension, compression and tension/compression in the frequency range from 0 Hz up to 100 Hz. Fig. 1 shows the principle set-up of this facility.

In addition to the specified force and frequency range it was necessary to allow the mounting of a large number of different force transducer dimensions including the parts for force introduction. For the installation of force transducers a space of 500 mm x 1000 mm (width x height) is available, so that a large number of force transducers can be investigated including the use of large loading masses for direct traceability to mass multiplied by acceleration.

The use of an electrodynamic shaker system was not considered because of the high force range and the lower frequency range. On the other side PTB has already realized a dynamic force standard for dynamic forces up to 10 kN using the electrodynamic shaker system [1].

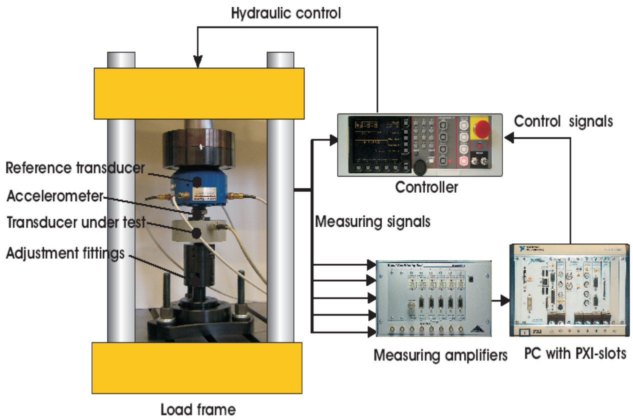


Fig. 1. Measuring facility with reference transducer for the dynamic calibration by the comparison method.

The used machine frame was modified in the following way to optimise the machine for the frequency range from 0 Hz to 100 Hz. The gravity centre of the machine was reduced with a PTB designed compact foundation, based on steel profile of 7 mm thickness. To increase the mass of the machine base and to reduce the machine vibration the steel profiles are filled with quartz sand which also improves the damping characteristic of the machine in addition to the machine damping below the machine base.
For dynamic measurements special designs have to be used to improve the stiffness and the alignment of the mounted force transducer under test. The calibration facility was therefore modified with special adjustment parts to reduce the alignment error in the machine by horizontal and angle alignment.

The basic working principle of a static and dynamic hydraulic material testing machine is similar, but in detail in respect to the frequency response a dynamic system has to be optimised. In static and in dynamic machines an oil flow with constant pressure is controlled by a servo valve to control the movement or the force of a double working hydraulic cylinder with equal cross section. Therefore forces can be realized in two directions. In addition a hydrostatic bearing is used in the cylinder to improve the axial force generation and to reduce friction. And the position of the piston is measured with an inductive displacement sensor.

With a control circuit we control the force generated by the piston cylinder system which is measured with the reference force transducer of the machine. But it is also possible to use the servo-hydraulic control system to control the displacement, or the oil pressure in the cylinder or other quantities, like the acceleration if we use acceleration transducers in the machine.

To enable a high dynamic performance a servo hydraulic system pressure of 280 bar was chosen and a hydraulic pump with a capacity of 80 l/min.

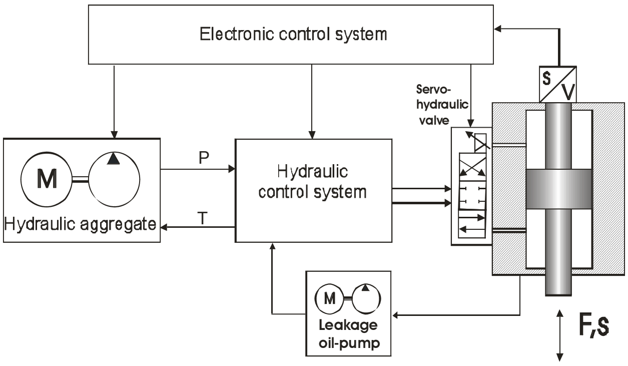


Fig. 2. Schematic principle of the hydraulic system

Fig. 2 shows the principle of the hydraulic part of the measuring facility. A hydraulic aggregate generates a constant system pressure. The hydraulic aggregate is connected by a pressure pipe with a hydraulic controlblock which distributes the oil to all hydraulic parts of the machine and also to other facilities which are under development. The servo-hydraulic valve is directly connected to the servoblock on the piston cylinder system. The leakage pump is necessary to return the leakage oil to the tank of the hydraulic aggregate. The electrical control of the control block and of the servo valve is realized by a controller, which is connected to a computer by a fast IEEE interface.

Forces on a force transducer can be generated by the hydraulic piston if the masses are coupled to the force transducer and if the piston is operated like a shaker or by generating forces within the coupled machine frame. Both operation modes are possible and are used.

a) Force generation by inertia forces
The principle force generation by inertia forces is directly traceable to the definition of force according the force definition mass multiplied by acceleration. The acceleration is limited by low frequencies by the maximum piston displacement and by larger frequencies by the oil volume and the frequency response of the hydraulic system. Fig. 3 shows a photo of the machine with a load mass of about 915 kg coupled to the force transducer to generate inertia forces. But only first measurements are carried out to verify that the machine can be used for calibrations with load masses. Further investigations have to be performed to compare the results with the results obtained on the electrodynamic shaker system described in [1].

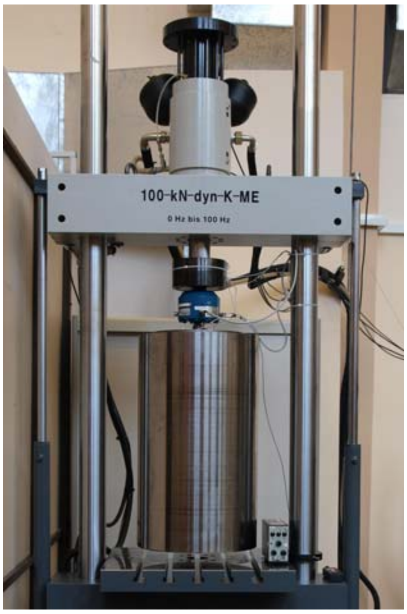


Fig. 3. Force generation with inertia forces

b) Force generation in a machine frame
The piston is working in a closed machine frame and the force transducer to be calibrated is mounted in series to the reference force transducer and the piston generates the dynamic force which is acting on both transducers (Fig.4).

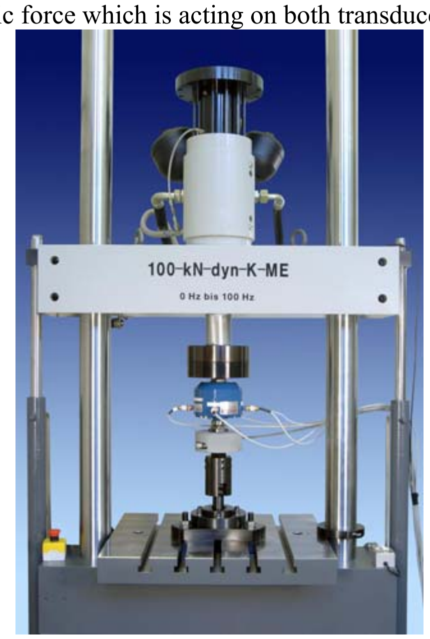


Fig. 4. Force generation in a machine frame used for comparison calibration

A 100 kN dynamic force machine was realized in PTB which uses the principle with a reference force transducer. This transducer was calibrated by static procedures in a deadweight machine and the dynamic properties can be determined with an absolute dynamic principle so that the dynamic force is traceable to mass and acceleration [3].
The reference force transducer consists of 4 separate strain gauge bridges. One bridge is used for the control of the machine force and one bridge is used as a reference signal for

the axial force. In addition two bending moment bridges are used to measure the optimal alignment of the transducer under test to the reference transducer in the machine frame. The reference channel is a high precise static and dynamic calibrated force transducer. Force generator, reference transducer and transducer under test are mounted in series and adjustment fittings are used for the connection and the alignment to the load frame of the machine. Alternative it is possible to couple a load mass to the reference transducer to determine the dynamic properties.

A multi-channel DC bridge amplifier is used for the strain gauge bridges and the signals are simultaneously digitised. For the numerical compensation of inertia forces the acceleration is measured between the coupling of the reference transducer and the transducer under test.

The servohydraulic system is controlled by a controller which generates different force signals (sinusoidal, rectangular, triangular or ramp) and which is controlled by a computer. The digitised signals are further evaluated by a PC (PXI-measuring system).

For periodical forces in the low frequency range of several Hz the transducer sensitivity can be taken into account by using the static determined interpolation equation [2]. In such a way it is possible to determine the linearity and hysteresis of the transducer under test by dynamic measurements. In the higher frequency range for periodical signals of all channels are analysed by Fast Fourier-Transformation (FFT). Therefore the nonlinearity and hysteresis analysis is limited to the low frequency range.

## 3. MEASUREMENTS

a) Continuous force calibration

Two in series connected force transducers (one reference force transducer and the transducer under test) were loaded with a tension force of -25 kN and with a constant force velocity increase of 5 kN/s the force was increased to a compression force of +25 kN (Fig. 5). The force indicated by the reference force transducer was calculated by the interpolation curve determined by the static calibration in the deadweight force standard machine. The signal of the transducer under test is measured in mV/V and the transducer can be calibrated by the comparison with the force indicated by the reference transducer. With this facility the force can be increased with velocities in the range from zero kN/s up to several hundred kN/s.

For a first verification of this comparison calibration method the transducer under test was also calibrated in a deadweight machine and the deviation to the continuous calibration method was evaluated. It was found that the ratio of the indicated force of the second transducer to the indicated force of the first transducer which is the reference transducer shows relative deviations of about 0.1 % compared to calibration of both transducers in the 100 kN deadweight force standard machine. This indicates that this comparison method can be used for continuous calibration of force transducers.

The comparison calibration principle is not limited to ramp functions. Also other time dependent force functions like sinusoidal, triangular, rectangular, random and others can be used. A further advantage is that the force can be applied only in the tension range or only in the compression range or over the whole range of compression and tension.

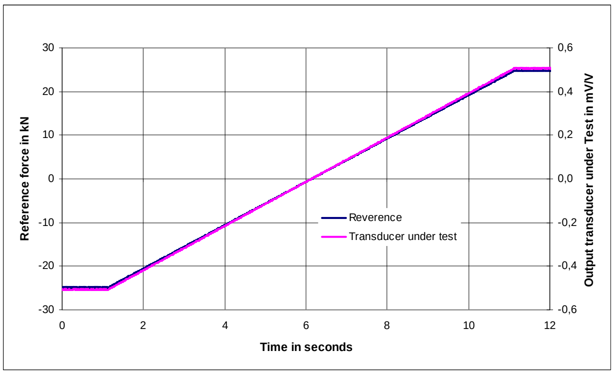


Fig. 5. Measurements with continuous forces

b) Measurements with sinusoidal forces

In the following sinusoidal forces are generated with different frequencies in the range from 0.125 Hz to 100 Hz at different frequency points and the force is acting on the two transducers mounted in series. To consider the inertia forces acting between the two transducers in addition to the force signals the acceleration was measured between the two transducers.

In contrast to a) the evaluation of the measurement results is based on the evaluation of the real and imaginary part of the measurement signals with FFT, so that the results contain amplitude and phase of all measurement channels. For the calculation the first harmonic was considered.

The coordinates of the force introduction point of the transducer to be calibrated are not fixed in the vertical axis. This is related to the deformation of the force transducers and the frame of the measurement facility and of all mechanical components like the force introduction components.

In the case of the sinusoidal force excitation the displacement $x$ of the force introduction point is related to the acceleration $\ddot{x}$ according equation (1) where ω is the angular frequency of the excitation force.

$$\ddot{x} = x \cdot \omega^2 \qquad (1)$$

The moving parasitical masses $m_{par}$, like the coupling elements and the moving parts of the force transducer spring generate an additional force $F_{zus}$

$$F_{zus} = \ddot{x} \cdot m_{par} \qquad (2)$$

This additional force is acting on the force transducer under test in addition to the applied force, which is measured by the reference transducer.

The acceleration and the mass of the coupling components can be easy determined by measurements but the parasitical mass related to the mass contribution from the force transducers can only be estimated or have to determined with more complex methods like described in [3]. Fig. 6 shows the arrangement of two acceleration transducers to measure the acceleration in the force introduction between the reference transducer and the transducer under test.

For these measurements a parasitical mass of about 3,5 kg was estimated which results at higher frequencies in higher uncertainty contributions.

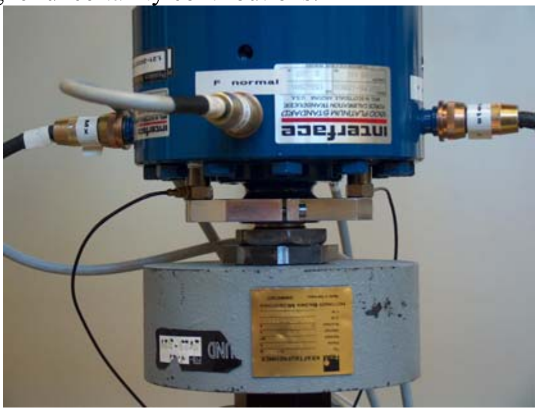

Fig. 6. Arrangement of the two force transducers and the acceleration transducers

Fig. 7 shows for example the influence of the inertia force of the parasitical mass and the result of the calculated compensation. It can be seen that the deviation can be reduced by the compensation method, but there are still deviations, which have to be further investigated.

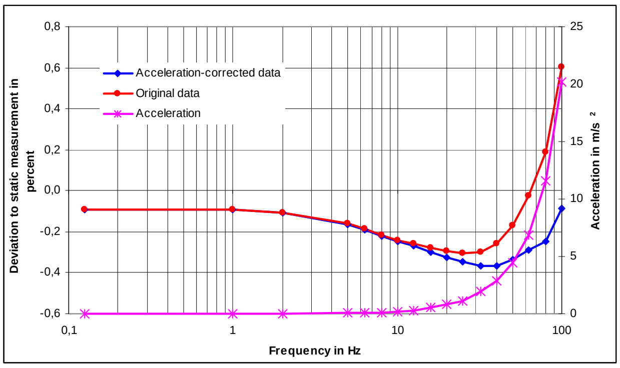


Fig. 7. Measurements with sinusoidal forces

The phase deviation between the output signal of the reference force transducer and the force transducer under test is in the investigated frequency range less ±0,2°.

## 4. CONCLUSIONS

A new facility for continuous and dynamic force calibration with forces up to 100 kN was developed for the frequency range from 0 Hz to 100 Hz. First measurements have shown deviations to the static sensitivity of the investigated transducers in the order less than 0.1% for continuous forces and for low frequencies up to 1 Hz. For higher frequencies up to 100 Hz the deviations increase up to 0.4 % if the inertia force is taken into account in a first approximation. Further investigations have to be carried out to evaluate these differences in more detail and to use the comparison method in the higher frequency range up to 100 Hz.

## 5. OUTLOOK

To further develop this facility to a national standard for continuous and dynamic forces up to 100 kN the uncertainty has to be evaluated in more detail. For the determination of the measurement uncertainty the long-term stability of the transducer by dynamic use, the operation in tension and compression range, the internal temperature change, the creep effect have to be take into account. In addition to the description of this new facility and the measurement results, the different effects, which have to be taken into account in the uncertainty budget have to be evaluated.

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