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# THE 250 KILONEWTON PRIMARY SHOCK FORCE CALIBRATION DEVICE AT PTB

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**Abstract** – A new facility for primary shock force calibrations up to 250 kN force amplitude is presented. Shock forces are generated by the impact of two airborne cylindrical mass bodies. Two laser-Doppler interferometers simultaneously measure the bodies' dynamic motions on their axes of motion. Traceability of force is realised by the determination of mass and acceleration.

**Keywords:** shock force calibration, impact, laser-Doppler interferometry.

## 1. INTRODUCTION

Along with the rising numbers of dynamic applications and the increased needs for measurement accuracy, e.g. for safety standards in the automotive industry [1, 2], precise measurements of shock forces or dynamic forces in general have now become an important issue. Unfortunately, written standards for dynamic calibrations are still lacking and traceability of force is still based on static calibrations which may give incorrect results for dynamic inputs.

In order to elaborate the scientific foundation for dynamic force calibrations, several devices have been developed at PTB in recent years. In the field of shock force calibration, a 20 kN impact force machine has been presented previously [3, 4, 5]. Based on the research and the experience obtained with this first device, a much larger device capable of the realisation of shock forces of up to 250 kN amplitude has been developed and finished which will provide calibration services for even large and heavy transducers in the near future.

The principle design of this new calibration device is depicted in Fig. 1. Two airborne mass bodies (M1, M2) and the force transducer (FT) to be calibrated are brought to a collinear collision. A hydraulic drive accelerates M1 to the velocity $v_0$ before impacting on the FT mounted on M2, which is initially at rest. Two laser-Doppler interferometers (LDI) simultaneously measure the dynamic motion of both bodies on their axes of motion. All velocity data is recorded with high sampling rate and analysed offline.

The applied primary calibration method provides traceability of force by the determination of mass and acceleration using the definition of force:

$$F(t) = m\,a(t)\,. \qquad (1)$$

Here, the time-varying acceleration data $a(t)$ is measured by means of interferometers and the mass values $m$ result from weighing or from construction data. Although equation (1) holds exactly for a rigid body only, this approach should usually give a good estimation for real bodies with elastic properties, as simulations have previously shown [3]. If this assumption fails, e.g. if the body's geometry and associated distribution of masses and elasticities result in an inhomogeneous acceleration distribution that cannot be neglected, the inertia force in (1) has to be expressed by the volume integration of all accelerated mass elements.

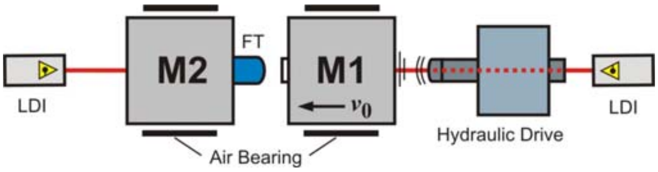


Fig. 1. Principle design

## 2. TECHNICAL REALISATION

Figure 2 presents a photograph of the developed 250 kN shock force calibration device. For the sake of clarity, its various components are explained in the design drawing in Fig. 3.

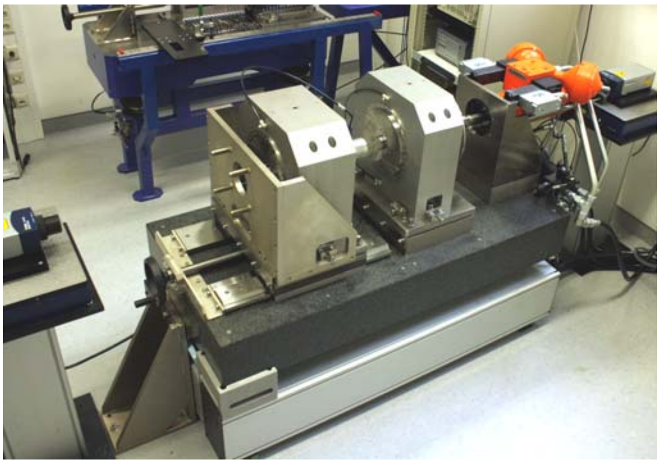

Fig. 2. Photograph of the 250 kN shock force calibration device.

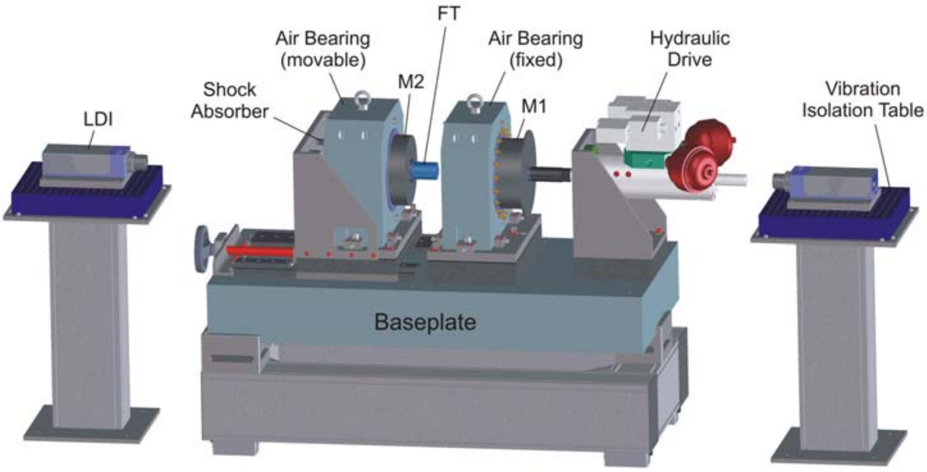


Fig. 3. Drawing of the 250 kN shock force calibration device.

Although basically similar to its smaller predecessor [4], the technical realisation of the 250 kN shock force calibration device differs in several aspects apart from just being a scaled-up version. The most important technical features of the new device are presented in the following:

1. The new facility uses two cylindrical impact bodies of approximately 100 kg each. Both cylinders are made of stainless steel and are guided by linear air bearings in order to minimise friction. In contrast to this new design, the smaller 20 kN calibration device uses air bearings with cube-shaped impact bodies of about 10 kg mass. The cylindrical form was chosen this time as it promises a less difficult fabrication and verification process of their highly accurate surface pairings, which becomes notably difficult for large and heavy bodies. As the rotational degree of freedom is not constrained, the mounting of the transducer is somewhat easier, because the routing of its cable is free.

2. The new device uses two split bearing seats in order to insert the heavy mass bodies by means of a crane. This uncomplicated procedure, which is shown in the photograph in Fig. 4, would also allow the replacement of the mass bodies, e.g. for investigations with lighter or heavier impact bodies made of other materials of differing density.

Fig. 4. Insertion of the mass body M1.

3. The airborne cylinders now totally cover their bearing seats as the required travel path has been greatly reduced. The air bearing seats contain two opposing rings made of sintered bronze which provide the air supply. In contrast to this new design, the air bearings of the former 20 kN device use a fishbone arrangement of numerous sinter pockets which are only partly covered by the airborne body. In comparison, the new design offers some advantages as its covered bearing surfaces are less sensitive to unwanted staining or contamination. Furthermore, taking operational costs into account, the expected air consumption should be significantly smaller.

4. A translation stage carries the air bearing of mass M2 and thus provides an adjustable mounting space. This adjustment of the axial impact position is required for the adaptation of the various transducer set-ups under test, considering their greatly differing dimensions. Furthermore, this axial translation is the prerequisite for the total bearing coverage described above.

5. The 250 kN shock force calibration device uses a computer-controlled hydraulic drive instead of a manually fired spring mechanism (20 kN machine). The stoke length of the piston ranges from 2 mm to 50 mm, its drive speed from 20 mm/s to 1.5 m/s. A position sensor supplies the information for the hydraulic drive control. The flow rate which determines the speed of the piston is regulated by proportional valves.

6. The interferometric measurement of the time-varying acceleration of the colliding mass bodies is performed by two LDIs mounted on a vibration isolation table each, in order to suppress influences from the environment. The interferometers simultaneously probe both bodies on their axes of motion. In order to have access to the front surface of the impacting mass body M1, the measuring laser beam is fed through a hole machined into the drive piston shaft. The on-axis measuring beam geometry of the new calibration device is insensitive to parasitic rotational components [5] which possibly show up in measurements with the 20 kN device, where the laser beam probes the surface under oblique incidence.

7. The front and back surfaces of both mass cylinders are equipped with changeable impact plates made of hardened steel, first of all, in order to provide the contact surface that impacts on the load button of the transducer under test (see Fig. 5), and secondly, to provide the mirror surface for the measuring laser beam of the LDI.

8. The pulse duration and spectral content of the generated shock pulse can be varied by replacing the hard metallic impact plate with a softer specimen or by inserting an appropriate pulse shaper.

## FIRST EXPERIMENTS

Some first tests have been carried out with the recently finished shock calibration device. The example given in Fig. 5 shows a heavy strain gage transducer of 225 kN load capacity and about 24 kg mass. The measurement presented in Fig. 6 displays a hard metallic impact of about 10 % peak amplitude and a pulse width of 1.2 ms.

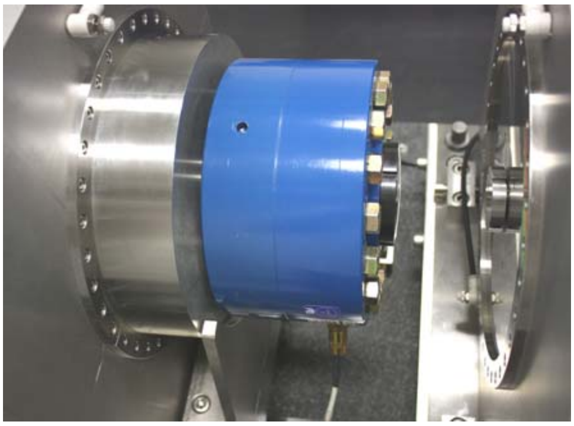

Fig. 5. Mounted force transducer.

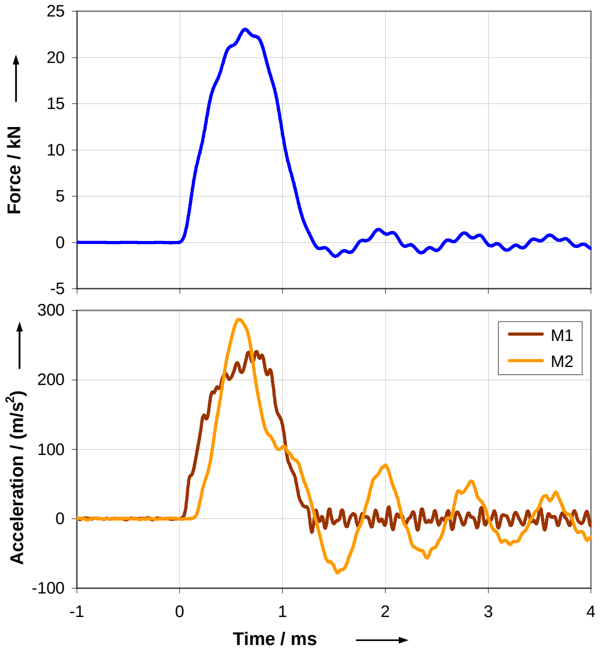


Fig. 6. Measured example of a hard impact shock pulse, force transducer signal (top), acceleration signals (bottom).

The upper diagram shows the force signal of the strain gage transducer, the lower diagram the corresponding acceleration signals derived from the LDI output. All signals have been passed through a second-order 5 kHz low-pass filter to suppress high frequent noise. The accelerated mass M1 impacted at a velocity of 0.17 m/s on the transducer's spherical load cap. This example clearly demonstrates that the force transducer, as well as the involved mass bodies – and their corresponding inertia forces – respond with some oscillations of differing spectral content which were excited during the impact. The low frequency component most likely corresponds to the vibration of the transducer's top mass or is due to the coupling to the mass cylinder M2, respectively. The high frequency components might be explained by modal forms of the involved structure.

It should be mentioned that the measurement signals of comparably soft shock pulses obtained by pulse shapers agree much better, as these oscillations are excited to a smaller extent.

## 4. CONCLUSIONS AND OUTLOOK

This contribution presents the new 250 kN primary shock force calibration device at PTB, explains its various technical features and gives a first measurement example. This research facility will be used for the establishment of validated shock force calibration methods (e.g. [6]) and will eventually provide calibration services for large capacity force transducers in the future.

## ACKNOWLEDGMENTS

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