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# MECHANICAL DESIGN OF A NEW DYNAMIC FORCE TRANSFER STANDARD

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**Abstract:**
This paper describes the development of a new modular dynamic transfer standard for measurement of force and acceleration in the field of dynamic force metrology. The force measurement concept depends on a strain gauge based shear-type force measuring instrument. The acceleration is measured using an installed reference standard accelerometer to the longitudinal axis of the force measuring instrument. The transfer standard is traceable to the primary dynamic force and acceleration standards at PTB.

**Keywords:** Dynamic force; Transfer standard; Force metrology

## 1. INTRODUCTION

The idea is to develop a transfer standard to provide the traceability for dynamic force measurement (e.g. fatigue testing machines). The recent experience in dynamic force metrology shows the need to provide a transfer standard in the range of about 20 kN. The stiffness of the sample that are used to test the dynamic properties of metallic materials are in the range between 1.5 to $5.5\times10^5$ N/mm.

## 2. DESCRIPTION OF THE WORK

There are many concepts to design a force transducer. The most stable principle for dynamic and static applications is strain gauge based force transducers [1]. The measuring of strain depends on the type of application of force. We can measure using simple cylinder, bending or shear beam. The reason why shear beam design was selected is that the stiffness of the sensor can be changed with fixation of its force capacity.

### 1. Design of the elastic element

If a simple beam with rectangular cross section loaded under force F, the position of all points on the beam surface will be changed due to straining. The strain along the longitudinal axis is called normal strain ε, and the strain in beam inclination is called the shear strain γ. The strain causes normal and shear stresses (σ & τ) inside the beam body. The shear stress can be calculated from

$$\tau = \frac{F}{2\cdot I}\left(\frac{h^2}{4} - y^2\right). \quad (1)$$

At the maximum shear stress plane with zero normal stress, the principal stress which is a pure normal stress can be measured on a 45° inclined plane to the neutral axis of the shear beam which is called the principal plane. At the principal plane, the principal strain is half of the maximum shear strain and the principal stress has the same value as the maximum shear strain. The applied force can then be estimated from

$$F = \frac{2\cdot\varepsilon_{1,2}\cdot E\cdot b\cdot h}{\frac{3}{2}2(1+\nu)}. \quad (2)$$

Principal strain measured by strain gauge

$$\varepsilon_{1,2} = \pm\frac{\frac{3}{2}\cdot F\cdot(1+\nu)}{E\cdot b\cdot h}. \quad (3)$$

Principal stress that used as an allowable stress in the design process is calculated from

$$\sigma_{1,2} = \pm\frac{\frac{3}{2}\cdot F}{b\cdot h}. \quad (4)$$

The stiffness equation used to optimize the dynamic properties of the force transducer is

$$K = \frac{E\cdot b\cdot h^3}{4\cdot l^3}. \quad (5)$$

While there is a dependence of the force capacity F on the third order of shear beam height h also there is a dependence of the stiffness on the third order of shear beam height which provides the ability to increase the stiffness with the same force capacity and vice versa. In the calibration of the fatigue testing machine [2], there is a need to control the stiffness of the reference force transducer for the same type of testing machine to simulate a certain type of testing specimens.

The mechanical design of the elastic element is performed in such a way so that the strain distribution over the area of the strain gauges is uniform without any peaks or strain gradients. There

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is no area on the elastic element with a higher strain than the strain gauge area. In addition, the fatigue life; which is a critical criterion in the design of dynamic force transducer for periodic forces; is consequently related to the strain level. Generally, the change in resistance of the strain gauge is related to the mean value of the strain under the area of the measurement grid, but the fatigue life is given by the maximum strain along this area [3-4].

## 2. Acceleration Measurement

A modular acceleration measuring system was then developed to provide the compensation of inertial errors, the inertial error is thus created only by the acceleration of the masses that are applied to the force sensing element which is called top mass. The error can be calculated by measurement of the top mass and the acceleration of this mass which is measured using the accelerometer. For calibration of the acceleration compensation system, the accelerometer can in principle be recalibrated using primary methods independent of the force transducer.

A system therefore built to compensate the inertial error. Three Kistler reference standard accelerometers type 8002K were mounted as follows; one accelerometer is mounted axially to the load string at the sensing element to measure the acceleration of the top mass of the force transducer. The other two accelerometers are mounted at the base plate of the force transducer to measure the acceleration of the base mass of the force transducer. The mounting of two axial displaced accelerometers enable the measurement of alignment error during dynamic force measurement. The cables are led out through drilled holes in the outer hub of the force transducer. The outputs of the three accelerometers were amplified using a Bruel & Kjaer Nexus charge amplifier which provides an analog voltage output that can be read by many controllers. This enables an online compensation of the force transducer output in the real application, if this is desired. Traceability of the acceleration measurement is achieved by calibration of the accelerometers against the PTB primary standard according to the calibration standard ISO 16063-11:1999, this calibration can be easily repeated as a result of the modular attachment of the accelerometers mounting. The three accelerometers were mounted using electrically isolated stud plates at the force transducer with 2 N·m tightening torque.

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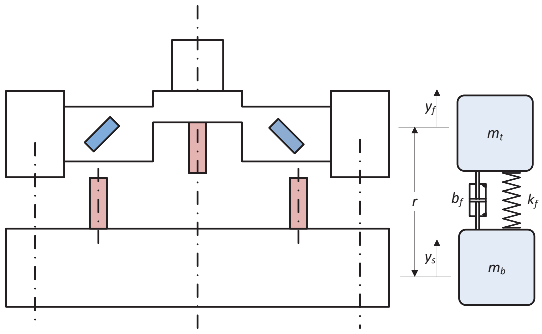


Figure1: Schematic of the force transducer with modular accelerometers to measure the acceleration of the top and base masses of the force transducer. The arrangement of the accelerometers enables the measurement of the alignment during dynamic measurements

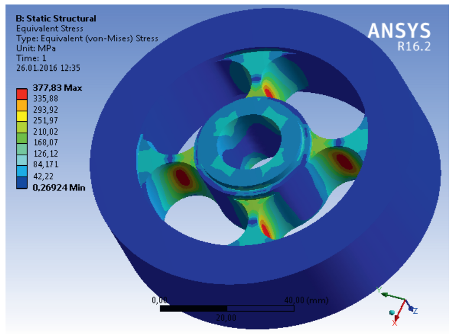


Figure2: Finite element analysis of the sensing element shows von-Mises stresses.

## 3. SUMMARY

A transfer standard for dynamic measurement of force and acceleration was developed and optimised to provide the traceability chain for dynamic force measurement for metrological services specially for dynamic calibration of material testing machines in the frequency range (from 0 Hz to 2000 Hz).

The dynamic characteristics were investigated to provide a model for the dynamic force measurement in applications with an estimation of the measurement uncertainty.

## 4. REFERENCES

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