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DETERMINATION OF MICRO- FORCES FROM 1 mN UP TO 10 N REALIZED WITH A FULL AUTOMATICALLY DEAD LOAD MACHINE DEVELOPED BY THE BEV

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Abstract: The Federal Office of Metrology and Surveying (BEV, Austria), developed in cooperation with the Vienna University of Technology an automatical Dead Load Machine to determine low force in the range from of 1μN up to 10 N,.

This Dead Load Machine allows 10 μN steps to determine low force by weights directly and has a resolution of 1 μN realised by a balance. Due to its special construction, the measuring range is continuous from 10 N tension to 10 N compression whereby it is possible to cover the complete range in 10 μN steps by loading weights. To realise force-steps of 1μN a ballance with a readability of 1 μg is coupled with a specially designed hydrostatic force transducer the suspension system of the weights.

Keywords: Micro- Forces; dead load machine; continuous measurement from tension to compression; hydrostatic force- transducer

1. INTRODUCTION

In cooperation with the Institute of Production Engineering of the Vienna University of Technology the Austrian national metrology institute, the Federal Office of Metrology and Surveying (BEV) has developed and realised an automatic Dead Load Machine to determine low force in the range up to 10 N. The realisation was finished in 2008. This project was supported by the Sartorius AG in Göttingen.

2. CONCEPT

The concept was to build up a Dead Load Machine which allows the determination of force in both direction without changing the position of the standard force transducer. It has to be possible to measure tension respectively compression in one step without opening the mounting of the standard force transducer. Furthermore it must have a resolution of 1 μN; for a set of 1mg up to 1 kg weights should be used.

The system should be designed in such a way as to exclude the possibility of jeopardizing the measurements

Fig. 1. Concept and Construction of the 10 N Dead Load Machine

3. CONSTRUCTION OF THE DEAD LOAD MACHINE

This Dead Load Machine allows 10 μN steps to determine low force by weights directly and has a resolution of 1 μN realised by a balance.

The whole system stands on a granite plate (balance table), while the balance itself is mounted on an additional very thick aluminium slab. In order to prevent disturbing environmental effects, the complete balance system, has a wind shield which is closed during measurement. In addition, the whole system is housed in a protective enclosure which is detached from the measurement unit. Both the control and power electronics were placed outside the enclosure in order to keep the effects of thermically induced currents to a minimum. The whole system is constructed mainly from non-magnetic and/or antistatic materials to prevent disturbances from magnetic fields.

Fig. 2. realisation of the 10 N Dead Load Machine (without covering); mechanism for the wire weights and for the disc weights in the middle; in the lower ground is the measurement cell for the standard force transducer, on the top the balance

Due to its special construction, the measuring range is continuous from 10 N tension to 10 N compression whereby the construction is like a beam balance with a counter weight on one side and the two parts of weights for the realisation of force on the other side. On this side there is also a so called "couple element" to the balance. A couple of counterweights on the beam compensate the weight of this "couple element" to the balance. One Part of the weights are especially designed wire weights from 1 mg to 500 mg, and the second part are disc weights from 1 g up to 500 g; the counter weights are two 500g disc weights.

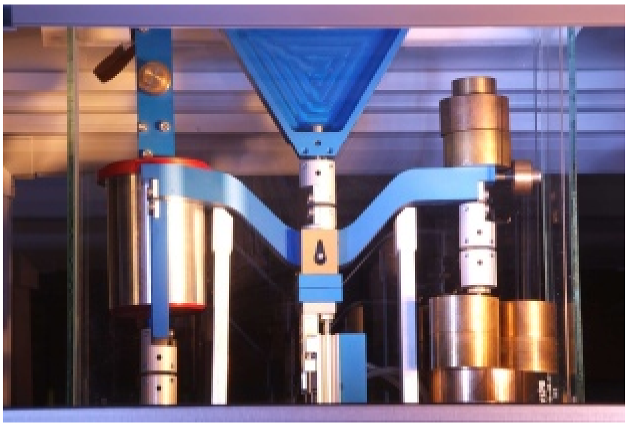

Fig. 3. Beam balance - Construction of the 10 N Dead Load Machine: on the left there is the "couple element" to the balance, and on the right there are different counter weights for compensation

With these weights it is possible to cover the complete force range in 10 µN steps by loading weights, which means in steps of 1mg weights. With a pneumatically controlled lift system it is possible to put separately every weight on the weight holder.

Fig. 4. Handling system for the weights: 1 g disc weight on the suspension system lifted by the aluminium disc and the white lifting mechanism with the contact control

While replacing the masses the suspension system is fixed by a mechanism to avoid a changing of the force to the transducer.

Fig. 5. Handling system for the weights of the 10 N Dead Load Machine

To realise force-steps of 1µN it was necessary to couple a monolithic weighing cell with a weighing range of 36g with the suspension system of the weights. Furthermore it is possible to determine the hysteresis in every point including the zero point.

The mass comparator which is used in the System is a modified Sartorius CCE36 mass comparator to 36 g maximum load which has a resolution of 1 µg. It was specially adapted by Sartorius for such a use. In addition the weighing pan for weights was completely redesigned.

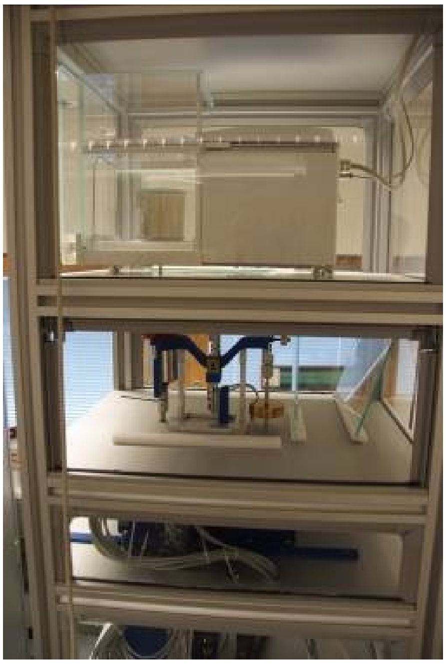

Fig. 6. Balance on the top of the Dead Load Machine with the “couple element” to the beam balance

Due to the measurement characteristics of the comparator (movement) and changing of the length caused by the temperature change, a “hydrostatic transducer” was developed connecting the suspension system to the balance and making the balance independent from the system. The “force” between the balance and the suspension system can be changed in a way, that in this “hydrostatic transducer” the buoyancy in a liquid of a floating body is changed. This floating body is a little double cylinder with a motor inside to change the volume of the cylinder. To avoid influence from the surface tension of the liquid the cylinder is completely immersed and fixed to the balance over a very thin rod. Due to the necessary transmitted force (up to approx. 0,4 N; 36g max. load of the balance) and a small size of the floating body a liquid with a very high density is used.

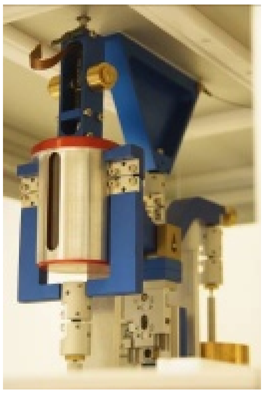

Fig. 7. the “hydrostatic transducer” for connecting the suspension system of the weights to the balance; the red vessel is for the liquid; the blue part above is the motor for reducing or increasing the volume of the cylinder inside the vessel

4. FUNCTIONALITY AND PROCEDURE OF THE DEAD LOAD MACHINE

The system is build up on the basis of a beam balance. Fixed with elastic bands there are two 500 g counterweights on one side and two groups of well known weights on the other side. The suspension system of these weights is fixed to the test forces transducer in the lower part and over the hydrostatic transducer to the balance on the top. Pneumatically controlled weight lifts handle all weights from 1mg up to 500g separately.

To avoid any thermal layering the system is encased in an isolated “water-cooled” covering.

Fig. 8. Temperature-housing of the dead load machine

The control programme should contain at least a standard programme for fully automatic calibration in accordance with the relevant operating instructions (e.g.: ISO 376). After introducing and mounting the force transducer into the measurement camber the system is closed and stabilized. After entering the maximum load of the force transducer into the computer the measurement procedure can be started. For a calibration there are two possibilities for the operator: on one side there is a standard program according to ISO 367 and on the other side there is the possibility to create a special program whereby every step of the up and down series of measurements (increasing or decreasing the value) can be selected. Every value in different arrangements of weights can be chosen.

To measure in the range from 1 µN to10 µN an automatic system changes the volume of the immersed floating body of the hydrostatic transducer. A volume change increases or decreases the buoyancy of this sinker and further the force between the balance and the suspension system. This changing and can be read on one hand on the balance and on the other hand on the force transducer to be measured. By increasing or decreasing the force with the hydrostatic transducer it is also possible to determine the hysteresis of a measuring point. With very careful and continuous up and down changing of the force it is possible to get informations about the stress behaviour in a point.

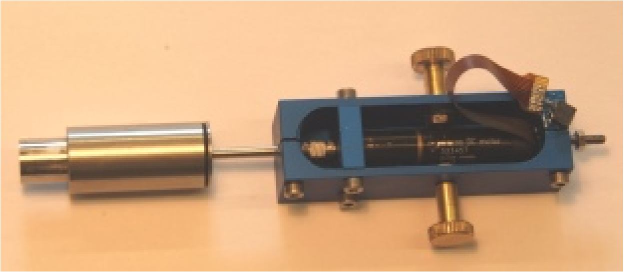

Fig. 9. The hydrostatic transducer: the changeable volume of the sinker with the motor

Also this system should have several suitable control and monitoring devices to prevent contact of magazine slots or weights to the suspension system in addition to other types of damage and errors. Due to minimal gaps between parts of the system with contact to the transducer and the rest of the device it is necessary to monitor any systematic error in measurement; without this control system it would not be possible to recognise a close contact or a wear point.

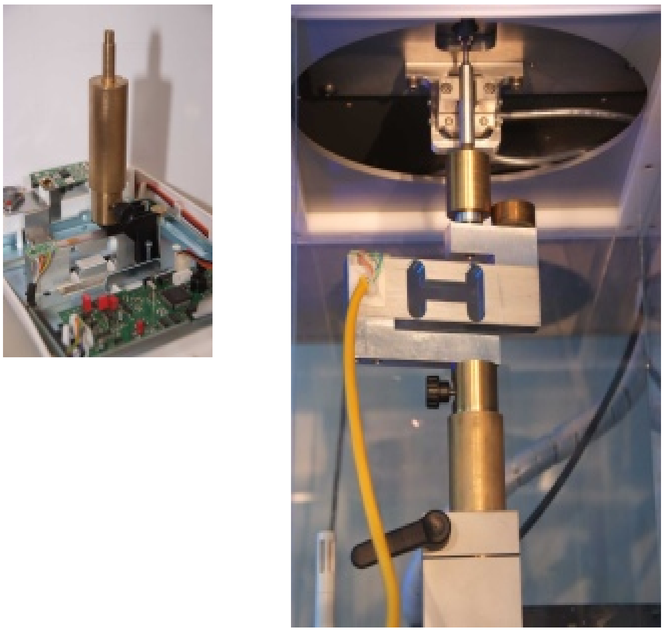

Fig. 10. The rebuilt 300 g balance as a standard force transducer connected to the suspension system of the balance. Above the force transducer there is a clamp to fix the suspension system

The mounting of the standard force transducer is constructed in a way that it is possible to measure tension respectively compression in one step without opening anything. So information can be given about the characteristic of the force transducer at zero, changing between tension and compression. By raising all weights and only one counter weight it is possible to start the measurement with 5 N compression and decrease the force in 10 µN steps by lifting different weights until 5 N tension is reached.

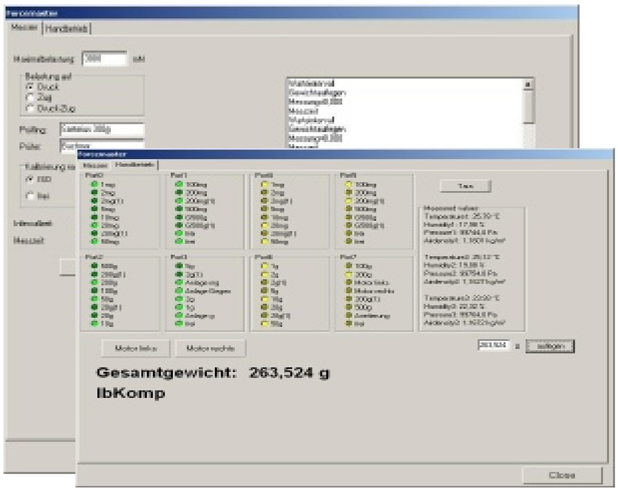

Fig. 11. desktop of the software; card rider “manual handling” shows an overview about the weights put on the suspension system. Also environment parameters with calculated air density for buoyancy correction from different chambers (weights and measurement) are indicated.

6. MEASUREMENT RESULTS FROM THE DEAD LOAD MACHINE

Starting in autumn 2008 a modified DMS applied – 300 g, balances cell was used as a force transducer to test the system. At the beginning of 2009 measurement series with this force transducer and already calibrated BEV force transducer (of higher capacity) have been carried out to validate the system. The first results achieved in the range down to 10 µN have been very good in terms of reproducibility and standard deviation.

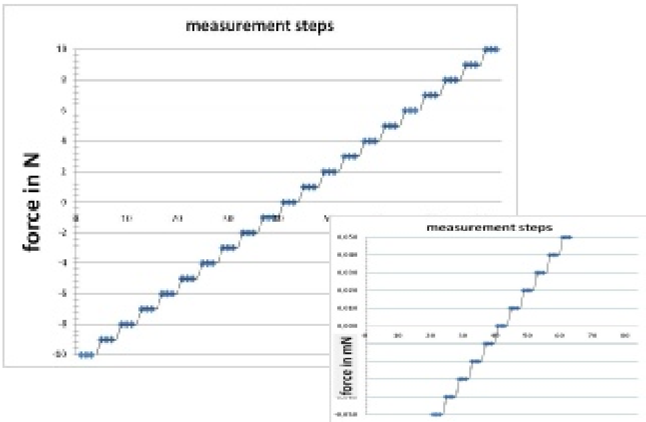

Fig. 12. series of measurements of the 10 N Dead Load Machine; only measured with weights in different steps.

Now the system is implemented at the BEV. One of the main problems at the moment is to find a fitting force transducer for the lower range. Starting in summer 2009, international comparative measurements will first take place on a bilateral basis. An international comparison between the BEV and the PTB (Germany) and in the future also with other metrological institutes, and others will be carried out; parts of the results will be published at end 2009.

The results and the documentation of the implementation at BEV will be finished in summer 2009.

7. CONCLUSION

With a very sophisticated construction it is possible to determine small force down to 1 μN fully automatically using masses beginning from 1mg. This Dead Load Machine will be used after implementation at the BEV on one hand for the realisation of small force and for scientific work and on the other hand for calibrations of force transducers up to 10 N.