

DETERMINATION OF FORCES FROM 10 N UP TO 250 kN USING TWO FULL AUTOMATICAL DEAD WEIGHT MACHINES DEVELOPED BY THE BEV

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Abstract – The Austrian national metrology institute, the Federal Office of Metrology and Surveying (BEV) developed and realised in 2008 an automatic dead weight machine to determine small forces in the range of 1 μ N – 10 N with a special construction that allows to measure continuously from 10 N tensions to 10 N compressions. It makes possible to cover the complete range without changing the mounting of the force transducer under calibration.

After the successful establishment of this equipment, the BEV started in 2010 together with the Institute of Production Engineering (IFT) of the Vienna University of Technology to realise another dead weight force machine in the range of 5 N – 2 kN based on the same technique. This machine also allows to measure continuously in 10 N steps over the whole range from tension to compression without changing the mounting of the force transducer.

To cover the higher range of force in addition to the previously described ones, a dead weight standard machine based on the conventional technique (separated measurements for tension and for compression) in the range of 50 N - 250 kN was built. This machine is also capable using a hydraulic amplification to cover the range of 1MN and 5MN.

All dead weight machines allow controlling each and every weight separately. They have special designed beam balance constructions to compensate the weight of the suspension system. Due to the precise determination of the position of the balance beams using laser, the systems are able to compensate the deformation of the force transducer under stress. The usage of this compensation is drastically improving the reproducibility of the systems.

A further advantage of these machines is that their constructions enable the periodic recalibration of the weights without changing the adjustment of the dead weight machine.

All the systems were finished at the end of the year 2011. According the schedule first internal and then bilateral

international comparisons will be carried out from summer of 2012 to validate the performance of the machines.

Keywords: Dead weight force standard machine, periodic calibration, force- transducer, laser based positioning system

1. INTRODUCTION

In order to meet the requirements for a state-of-the-art metrology institute and in an endeavour to realise an automatic force laboratory, the Federal Office of Metrology and Surveying (BEV), the national metrology institute of Austria has started 2010 in coordination with the realisation of a new laboratory building for the BEV also a force project. This project was a further cooperation with the Institute of Production Engineering (IFT) of the Vienna University of Technology, as a very competent partner and with experiences from other common projects in the frame of automation in mass, density and small forces [1],[2],[3],[4],[5],[6],[7]. The goal for the BEV and the IFT had been, to developed and to realised under limited conditions automatic dead weight standard machines to determine force in the range of 5 N – 250 kN, with an accuracy as high as possible.

2. CONCEPT

The concept was to construct dead weight machines up to 250 kN. This decision depends on the historical fact that the BEV has high accurate force transducers up to this nominal value, which were also used in the frame of the physical technical testing services of the BEV. Due to the financial opportunities and the limited place a decision was made to realise this force range in two sub-ranges. The first one should be from 5 N up to 2 kN with a resolution of 5 N. The second one should be overlapping with the first one and operating in the range of 50 N – 250 kN with a resolution of 50 N over the whole range.

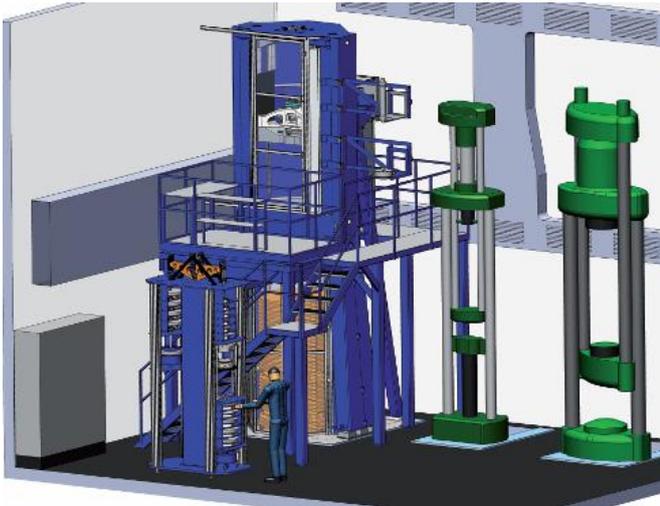


Fig. 1: Overview of the Concept: the 2 kN (in the foreground) and 250 kN dead weight standard machines with the linked hydraulic one.

The smaller dead weight machine up to 2 kN had to allow the determination of force in both directions without changing the position of the force transducer under test. It makes possible to measure tension and compression in one step without opening the mounting of the standard force transducer based on the principal of the dead weight machine for small forces [1]. Furthermore it had to have a resolution of 5 N over the whole range using a set of weights from 0,5 N up to 500 N.



Fig. 2: Steel frame of the 250 kN dead weight standard machine; to increase the stability of the welding construction it is filled out with concrete.

The construction of the bigger dead weight machine up to 250 kN is to determine the force in a conventional manner. That means the measurement position for tension is

above the working bridge of the suspension system and the measurement position for the compression below; to change the stress it is necessary to change the position of the force transducer in the working frame)

One of the primary goal was, that all weights should be placed in the frame in a way, that it is possible to removed them for mass recalibration without any changing or additional adjustment of the construction.

3. WORKING PRINCIPLE OF THE 2 kN MACHINE

Due to the special construction of the smaller system, the measuring range is continuous from 2 kN tension to 2 kN

compression. The construction is a beam balance with the necessary counter weight on one side and with two separate stacks of weights for the realisation of the force on the other side. One of these stacks consists of especially designed ring weights from 0,5 N to 50 N, while the other contains disc weights from 100 N up to 500 N. The counter weights are four discs with approx. 50 kg.

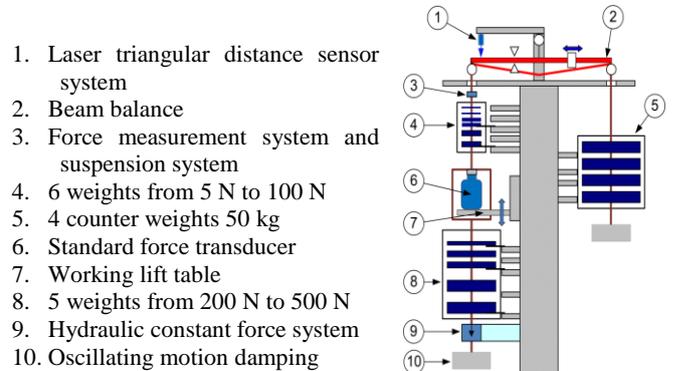


Fig. 3: Concept of the 2 kN dead weight machine

Using the above described weights, it is possible to cover the complete force range in 5 N steps by loading of 0,5 N weights. The hydraulic controlled lifting system puts separately each and every weight on the weight holder. During the process of placing the masses, the suspension system is fixed avoiding the force change on the transducer and keeping the force constant. Using simultaneously the weights and the counter weights it is possible to measure

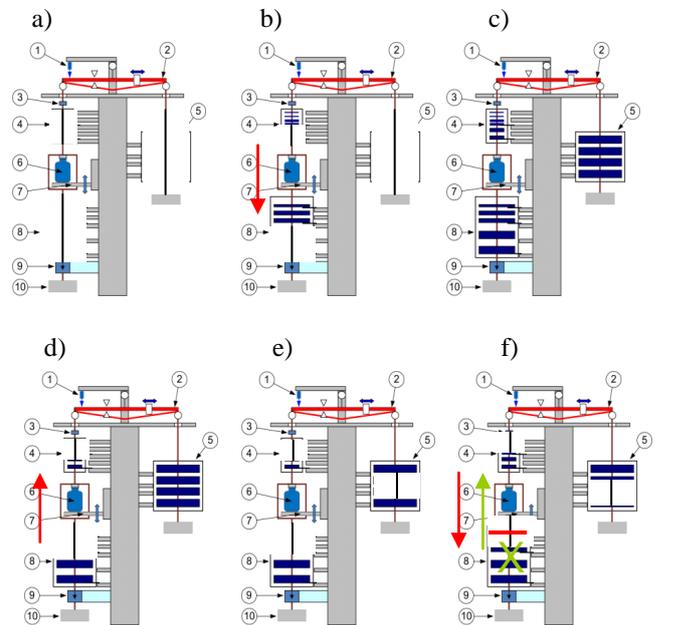


Fig. 4: Working principle of the 2 kN dead weight machine: The force transducer is fixed on the liftable table and has contact to the suspension system; the balance is adjusted;
a) no weights are placed on the suspension system; the force on the force transducer is zero
b) weights are placed on the working side of the suspension system → compression
c) all weights (2000 N left and 2000 N right) are placed on the suspension system; the force on the force transducer is zero

- d) weights, removed from the working side of the suspension system → tension
- e) weights (1000 N left and 1000 N right) are placed on the suspension system; the force to the force transducer is zero
- f) weights (up to 1000 N) are placed on the working side of the suspension system → compression and weights (up to 1000 N) replaced → tension

For example: starting with weights 1500 N on the working side and 1000 N on the counter side gives 500 N compression to the force transducer. Reducing the weights on the working side step by step decreases the force to the force transducer to the situation where the force is zero that means 1000 N on both sides. Continuing reducing the weights on the working side would “decreases” the force; in fact it gives a tension to the force transducer e.g. to 500 N on the working side and still 1000 N on the counter side gives 500 N tension to the force transducer. So it is possible to realise force from max. 1000 N compression to zero and continue up to max 1000 N tension and back without changing the mounting of the transducer. It serves for



instance for the determination of the hysteresis of the force transducer including the zero point.

Fig. 5: Realisation of the 2 kN dead weight machine (without cover); Suspension system for the weights; in the middle is the measurement chamber for the force transducers with the mounting system and the axis to lift the table and to compensate the deformation of the force transducer

4. CONSTRUCTION OF THE DEAD WEIGHT MACHINE

According to the concept the realisation of the system has two independent stages. The first force standard machine generates force in compression and tension from 5 N up to 2 kN using 5 N steps in one working chamber. The second machine generates force in compression and tension in two working chambers from 50 N up to 250 kN . The construction of both machines is based on the principle of a beam balance. The build in counter weights compensate the loading frame and the suspension system of the weights. All steps are realised directly by dead-weights, which are



independently attached to the loading frame by special coupling elements.

Fig. 6: Construction of the 250 kN Dead Weight Machine

The whole system stands on a steel frame placed in a concrete block. In order to reduce the disturbing environmental effects, the complete balance, the weights and the measuring chambers are surrounded by wind shields and housings, which are closed during the measurements. Furthermore, the whole system is housed in a protective

enclosure, which is separated from the measuring units. Both the control and power electronics are placed outside the enclosure in order to reduce the influence of the heat produced by the current. Most of the parts of the system are made of non-magnetic (stainless steel) and/or antistatic materials to prevent unwanted influence from the magnetic fields.

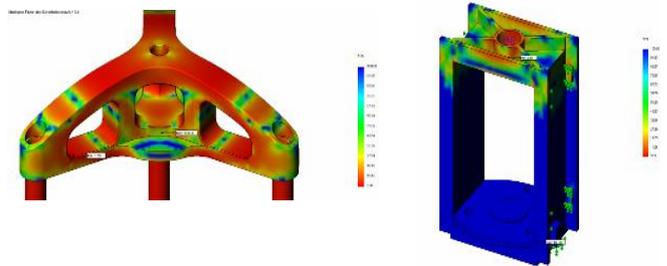


Fig. 7: Calculation and computer simulation of load spreading and deformation under maximum stress of two parts of the 250 kN dead weight machine (Working bridge of the suspension system on the left side; working frame on the right side)



Fig. 8: Realisation of the systems: 2 kN (left) and 250 kN dead weight machines with the linked 1 MN hydraulic machine. On the 250 kN dead weight machine there is a liftable working platform for the operator

The bigger system for larger forces with a measuring range of 50 N – 250 kN has also a construction base on a beam balance with counter weights on one side and two stacks of weights for the realisation of force on the other side. The mass of counter weights is about 1200 kg and compensate the weight of the suspension system.

One of the stacks consists of especially designed ring weights ranging from 5 kg to 100 kg, while the second are disc weights from 200 kg up to 500 kg and a set of 500 kg disc weights (overall 10 tons) are in diameter more than 1,2 m. The 50 kg disc counter weights consist an adjustable block.

Fig. 9: Part of the weight holder system: hydraulic cylinders for releasing or fixing each of the disc weights



To cover the higher force ranges this system was completed with a hydraulic amplification. Up to a load of 100 kN there are connected over a hydraulic pressure transmitter and in addition with a pressure booster two hydraulic Force Machines; one 1 MN and the other 5 MN.. These two machines originate from the previous force equipment, were demounted in the old laboratory and completely rebuilt. To reduce the reachable uncertainty in measurement the transformation ratio were changed from 1:50 and 1:250 to 1:10 and 1:50.

Fig. 10: Hydraulic system to lift the weights (down) and hydraulic cylinder for keeping the force constant (top). in the middle is the hydraulic pressure transmitter (blue) to the hydraulic force machines



All weights are placed in a sort of a drawer; due to this construction it is easy to build in the weights, and also enables an easy removal for the recalibration of them. It provides on one side a highly efficient way for periodic recalibration of the masses without destroying the adjustment or the metrological history of the force machines, and on the other side to establish the traceability of the force direct to mass.

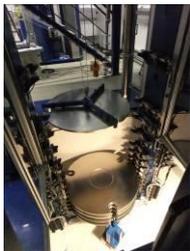


Fig. 11 and 12: 5000 N weights were brought in and the suspension system were linked. The suspension system can be removed by opening 3 glamps and 3 screws. On the floor of the basement one of three hydraulic brakes to minimalise the movement of weight stack during the measurement can be seen.

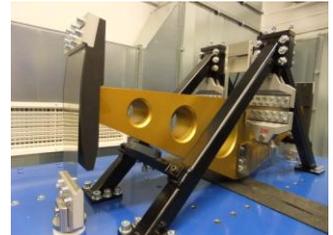
5. FUNCTIONALITY AND USAGE OF THE DEAD WEIGHT MACHINE

Both systems are built on the basis of a beam balance. There are counterweights fixed with elastic bands on one side and groups of well-known weights on the other side. The loading frame and the suspension system of these weights are fixed to the force transducer under test. Hydraulic controlled weight lifts handle all weights separately. Due to the single handling systems it is possible to carry out measurements in free chooseable steps and with every combination of weights.

The compensation of the mass of the suspension system with counter weights enables to reduce the minimal load of the dead weight machine. At the same time it gives an influence of not determinable forces. Every beam balance shows a reset force if it is not in equilibration. In fact every force transducer is measuring its deformation under stress, but connected with a "beam balance" it shows this reset

force. The solution for avoiding this influence was the implementation of a laser system for the determination of the position of the balance beam completed with a system to compensate the deformation of the force transducer under stress. This compensation in both Standard machines drastically increases the reproducibility of the systems. Present tests have been shown, that the stability of the balance beam position at the end of the beam and furthermore the stability of the loading frame is better than 1mm in a distance of more than 1200mm. These tests have been carried out with different force transducers and deformations up to 2 mm by max load.

Fig. 13: Beam balance - Construction of the 2 kN dead weight machine: on the left there is the elastic bend to the suspension system and on the right there are different counter weights for the compensation. In the middle (top) there is the reflector of the Laser system.



To avoid any thermal layering in the systems and to protect the weights against any fouling the systems are divided in different sections.

The complete system is controlled by a Programmable Logic Controller (PLC); for operating there is use a commercial Notebook via W-LAN.

After mounting the force transducer there are different procedures and measurement routines available; on one side there is a full automatic measurement routines according to the ISO standards, and on the other side a single step mode or a free choose able program can be used. So it is possible to carry out standard calibration and calibration in agreement with the requests of the customers as well as carrying out special studies and research.

Fig. 14: 250 kN: elastic bends to the counter weight for the compensation of suspension system weight. On the top of the counterweight there are chambers for the weight adjustment. In the middle (top) there is the reflector of the Laser system for the positioning system.



6. MEASUREMENT RESULTS OF THE DEAD WEIGHT MACHINE

Starting summer of 2012 there will be carried out several comparisons with different standard force transducers at the BEV to validate the performance of the systems.

Starting in October 2012, bilateral international comparison measurements will take with the PTB (Germany).

The results of the validation and these comparisons will be finished in the end 2012.

The first results are intended to be published in the frame of IMEKO conference, TC3.

Fig. 15: the linked 1 MN hydraulic machine on the left side and the 5 MN hydraulic machine on the right



7. CONCLUSIONS

With the sophisticated construction of the dead weight machines it is possible to determine fully automatically the force down to 5 N using masses direct linked to the mass standards. These dead weight standard machines will be used after the implementation period at the BEV. It serves for the realisation of force, for scientific purposes and for calibrations of force transducers up to 5 MN.

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