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PRACTICAL OPERATION OF A 3 TONS SCALE TESTING ROBOT

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Abstract: The automatic deadweight machine at the Weighing Instruments Laboratory of the PTB was designed for testing weighing instruments with a maximal load of up to 3t under varying climatic conditions. The paper reports on the practical operation of the machine for performing legally mandatory weighing tests according to OIML recommendations R76. In particular, critical interference resulting from the wide temperature range of -10°C to +40°C have to be identified and controlled.
Keywords: Deadweight machine, climatic testing, automatic testing

1 BACKGROUND

The idea for an automatic deadweight machine was conceived in the mid 1990s. At that time, it became apparent that the facilities at the PTB for type testing of weighing instruments with maximum capacities of up to 3 tons were inadequate. After the planing stage, which included a feasibility study, the automatic deadweight machine was first operational in the fall of 1997. The PTB already reported [1] at an earlier IMEKO Conference about this early stage. Being a prototype, it is not surprising that a multitude of unforeseen problems necessitated minor modifications in the design of both the hardware and software. For this reason, regular testing of weighing instruments could commence not until two years later. This paper will report on the first practical operations of the automatic deadweight machine.

2 THE TEST FACILITY

The machine is designed for testing nonautomatic weighing instruments with maximal capacities in the range from 50kg to 3000kg. The instruments mainly targeted are platform scales and fork lifts scales. The test facility comprises the deadweights, the machine for grabbing, lifting and stacking the weights, the control unit based on a PLC (programmable logic controller) and a MMI (man- machine interface) running on a PC, and a climatic chamber.

From early on, the two main objectives were that (a) the design of the deadweights allow for maximal flexibility with respect to load values, and that (b) the machine can automatically conduct weighing tests without an operator having to intervene during a loading cycle.

The first objective responses to the requirements which legal metrology [2] puts on the selection of up to 10 load steps during a loading cycle for testing weighing instruments, in particular for instruments with partial or multiple weighing ranges.

The high strain put on the operator by handling heavy weights under adverse ambient conditions (temperatures between -10°C and 40°C, relative humidity of up to 85%) gave reason to the second objective. A loading cycle can take up to 1 hour. With the automatic deadweight machine, the operator does not need to spend this time inside the climatic chamber, but can view the progress of the loading cycle from outside or remotely.

The main design-limitation for the automatic deadweight machine was the requirement that it fit into an existing walk-in climatic chamber with an inner volume of $W \times D \times H$ = 5m×3m×2.8m.

2.1 The Deadweights

There are two mass stacks of stainless steel divided into pieces of

$$5\times5\text{ kg} + 5\times10\text{ kg} + 12\times20\text{ kg} + 6\times50\text{kg} = 615\text{ kg} \quad (1)$$

and

$$6\times50\text{ kg} + 5\times100\text{ kg} + 6\times200\text{ kg} + 2\times500\text{ kg} = 3000\text{ kg} \quad (2)$$

The relative uncertainty is in both cases U_{rel}=5x10^{-6}. This implies an uncertainty for the mass of 15 g for the 3 t stack, and of 3g for the 615 kg stack.

For each stack, weights varying in value differ only by their height. Each weight is equipped with four recessed pockets. The top surface of each weight has two cone-tipped guide posts protruding which exactly fit in to the guide holes in the bottom of each weight and assures for a vertically aligned stack.

The weights in each stack can be placed in any desired order, and any number of weights can be taken from the stack. This is **the** unique feature of the mass stacks, allowing for maximal flexibility with respect to different EUTs. However, the weights from the two stacks cannot be combined. The assembly of the designed stack will take about 30 minutes.

2.2 The Machine

The machines most vital parts are it's two sets of four pneumatic fingers. In each set, the fingers are all arranged in one horizontal plane. The PLC controls the motions grab/release and up/down of each pair independently. The vertical position of the fingers is sensed by a laser-optical device, the status and the grab/release motion by a proximity sensor. The latter guarantees a correct and complete dislodging of the fingers from the weights.

Figure 1. Two pneumatic fingers engaged in the pockets of the deadweights.

Figure 2. The automatic deadweight machine is positioned over a fork lift scale.

The PLC is served by an MMI with graphical user interface to allow the following modes of operation:

Manually: Fine grain control over all functions of the PLC.

Semi-automatically: Put on, or lift of, one weight from EUT.

Automatically: This is the normal mode. It runs the complete weighing cycle by putting on each weight in turn, and by unloading the EUT through reversion.

Once the machine is manually brought into operating position, the PLC does not have control over the horizontal positioning of the machine and the weights.

3 APPLICABILITY AND LIMITATION

The deadweight machine was designed to perform the temperature and damp heat tests required by [2]. The temperature tests consist of a set of loading cycles at the default temperatures 20, 40, -10, 5 and 20 degree Celsius, see also Figure 3. For the damp heat test, the EUT is exposed to a temperature of 40°C and a relative humidity of 85% for 48 hours. Loading cycles have to be conducted at the beginning and at the end of this period.

Other tests, such as testing the tare operation and repeatability, are also possible. However, testing of eccentricity and tilting is only possible if the limiting values below are not exceeded during the test.

Limitations:

a) The machine cannot adjust for any excessive horizontal motion or tilting of the EUT and/or the deadweights. Excessive displacement or tilting will prevent the fingers to grab the weights securely. The limiting value for tilting is 1/100, the limiting value for horizontal displacement through a complete cycle is about 1cm, but only 0.4 cm during the loading of an individual weight. These values are independent of direction.

b) The limiting height of load receptor combined with mass stack is 160 cm. This may be as little as 40 cm for the load receptor, as the fully assembled 3 tons stack measures 120 cm.

c) The lifting and lowering of the weights by the machine is fairly slow. This assures a smooth operation without impact pulses when putting a weight on the EOT. On the other hand, the weighing cycle for the fully assembled 3 tons stack takes about 40 minutes to complete.

Initially, the strains put on the machine at -10°C were underestimated. The resulting problems were, however, solved by insulating and heating the electrical engines, and by upgrading the 8 pneumatic cylinders of the fingers.

3 THE DEW PROBLEM

The formation of dew on the mass stacks, a common phenomena during the heating phase in a climatic chamber, was also a big problem for the automatic deadweight machine. It was compounded by the facts that the laser optic for sensing the finger positions is fooled easily by water drops, and that condensed water would penetrate and settle between the gaps of the tightly stacked weights.

Dew effects primarily the weights, as the ratio of heat capacities for the weights and the EUT is increasing with the mass of the weights, and is in the range of 10 to 20 for weighing instruments with a maximum load of 3 tons.

3.1 Counter measures

The following measures have been tested with the facility:

Active measures by heating the weights

a) through convection with radiator or heat blower. Even if directed at the weights, the environment and the EUT heat up much faster than the weights, having a counterproductive result (see *slow heating* below).

b) through conduction with electrical heating elements. The heating elements must, due to the relative small heat conductivity of steel, be applied at several points over the surface of the weights. Or the elements are permanently placed between the stacks. Because of the intricate application procedure, and the generated offset in mass, these solutions are not feasible.

Passive measures by

c) slowing the heating phase such that the temperature of the weights never drop below the dew point temperature. This implies heating periods of several days and demands a high degree of control (temperature/humidity adjustment and stability) over the climatic chamber.

d) removing the weights from the chamber at low temperatures. Evicting and reinstallation of the weights is time consuming, and will therefore upset the temperature and humidity balance in the chamber.

e) keeping the weights insulated at low temperatures.

Strategy (e) was adopted. A box made of 3cm thick hard shell foam available at home improvement stores was build to contain the weights. Figure 3 shows the temperatures of the 3t mass stack through a temperature cycle required by [2] for the naked and the insulated stack. In the latter case, the stack was insulated after the 40°C loading, and the insulation was removed for the -10°C loading and after the 5°C loading.

Note that in the insulated case, the temperature of the mass stack stays well above the dew temperature. In the uninsulated case, the temperature of the stack falls below the dew point at chamber temperatures raising above 5°C. The application and removal of the box can be accomplished within a minute.

For the damp-heat test at 40°C and 85% relative humidity, the dew point is at 37°C. To prevent dewing in this case, the only solution is to dry-heat the chamber at 40°C for about 35 hours, which is the time needed for the 3t stack to reach 37°C, starting at room temperature.

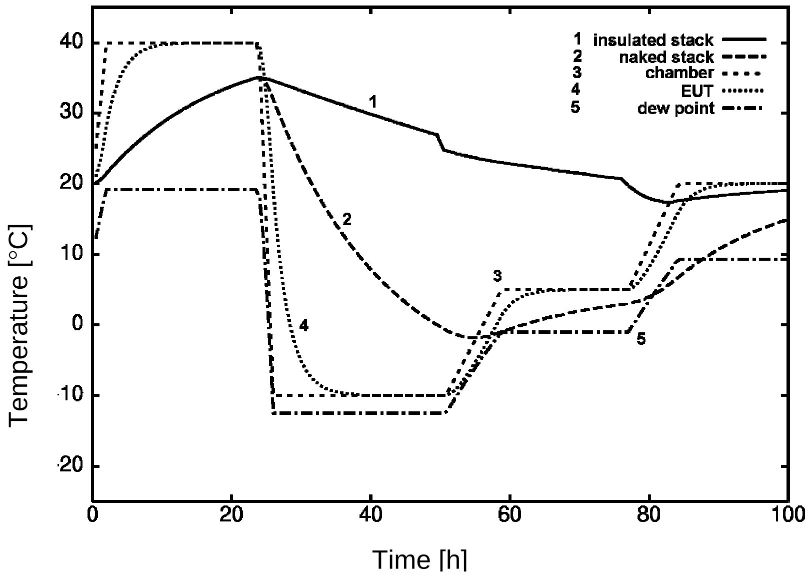

Figure 3. Temperatures of naked versus insulated 3t mass stack through one temperature cycle.

3.2 Drag force resulting from convective air movement

The temperature difference between the mass stack and the ambient air $DT=T_S-T_¥$ of up to 40 K is considerable, and the drag force exerted to the mass stack and the weighing instrument by the free convective air movement has to be estimated. The change of the apparent mass as a function of mass m and DT can be computed according the empirical equation [3]

$$Dm = k_v\,(m|DT|)^{3/4} + k_h\, m|DT|. \tag{3}$$

The coefficients k_v and k_h depend on the geometry of the mass and the arrangement of the mass on the weighing instrument. For a variety of geometric shapes, it was determined in a series of experiments that the coefficients average k_v = $215\times10^{-9}kg^{1/4}K^{-3/4}$ and k_h $=78\times10^{-9}K^{-1}$. This implies a correction of Dm=11 g for m=3000 kg and Dm=3 g for m=615 kg which coincides in order with the mass uncertainties of the dead weights. The combined error of both drag and mass uncertainty of the stacks is required by [2] to be less than 1/3 of the maximal permissible error of the EUT. A weighing instrument of Class III with the maximal (by [2]) possible number of scale intervals of 10.000 (1000 to 3000 is common), has a maximal permissible error **mpe** of $1.5\times10^{-4}\times3000$ kg=450 g for m=3000 kg, and $1.5\times10^{-4}\times600$ kg=90 g for m=600 kg. The drag force is therefore small enough to be neglected.

4 EXAMPLE

One of the EUTs tested in the automatic deadweight machine was a fork lift equipped with a weighing instrument, see Figure 2. A fork lift can be considered a critical EUT for the test facility because it yields much more under load than a comparable platform scale. In addition, a fork lift scale tends to tilt, and because it is wheel mounted, easily shifts its position.

The maximal load of the fork lift is 1500 kg, spanning 3 partial weighing ranges with scale interval 100 g for range 0 kg–300 kg, 200 g for 300 kg–600 kg, and 500 g for 600 kg–1500 kg. According to the recommendations in [2], the load values should be close to the points were the mpe changes in Figure 4. Because this cannot be accomplished with the fully assembled stack in (2), the already mentioned flexibility of the stacks could be used to reassemble the stack into

$$(50+50+100+100+100+200+200+200+500)\text{ kg}=1500\text{ kg} \tag{4}$$

partitions.

The maximal permissible error and the measured error curve for loading and unloading as a function of the load is shown in Figure 4. The observed error curve has shape typical for weighing instrument testing. Note that there are no glitches in the error curve, but that the safety margin at lower loads (below 200 kg) is small. This emphasizes the need to load the EUT at the recommended mpe-changes, and therefore the need for flexible mass stacks with a high number of partitions at small mass values.

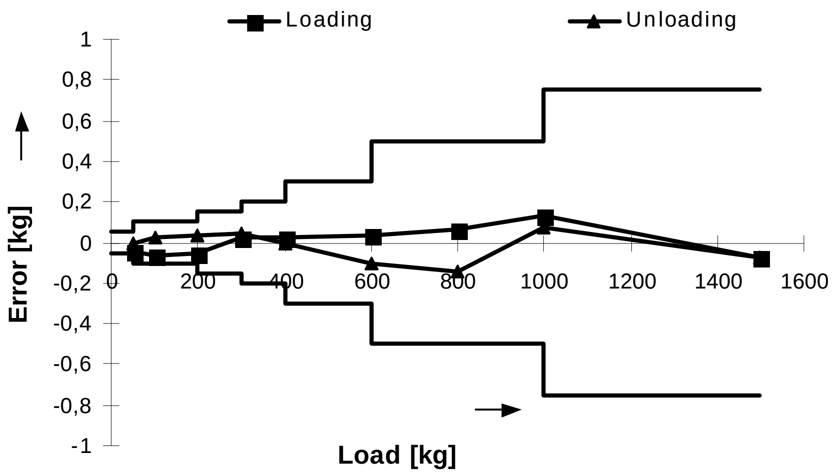

Figure 4. Maximal permissible error mpe and measured error curve of the EUT.

The critical characteristics of the EUT mentioned at the beginning of this section did not pose a limitation to the automatic deadweight machine. However, extra effort had to be put into assuring that that EUT could not move.

In none of the testings performed by the automatic deadweight machine on both platform and fork lift scales, one could observe the influence of a systematic error originating from the machine or the dead weights.

5 CONCLUSION

The automatic deadweight machine is fully operational within the temperature and design limits. It offers a high degree of comfort to the operator, and it allows the legal metrological demands to be met, especially for EUTs with multiple or partial weighing ranges. All problems that surfaced during the testing phase of the machine were successfully solved. In particular, the dew problem was mastered in a simple and cost efficient, yet very effective, way.

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