

## **Add-on of the 2-MN force standard machine for testing load cells**

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### Abstract

This paper presents a new temperature chamber in combination with the 2-MN-deadweight force standard machine (FSM) which allows testing and certification of load cells with nominal loads up to 2 MN (200 t) by the Physikalisch-Technische Bundesanstalt (PTB). This facility is unique in Europe; for the first time it offers manufacturers and customers the possibility to certify load cells with very high nominal loads as used in the heavy industry for instance.

In spite of a small installation space for the temperature chamber which is limited by the construction of the FSM the temperature chamber permits measurements in a temperature range from -20°C to +55°C combined with small spatial and temporal temperature gradients of < 0.2 K per 100 mm and per hour. Thus it fulfils entirely the requirements for testing load cells as defined in the OIML-Recommendation R60 [1].

Keywords: Temperature Chamber; Load Cell; OIML R60

### 1. Introduction

With an annual export of 780 million Euros which is 50% market share in Germany and 26% worldwide [2] the industry of measuring instruments represents one of the most important industrial sectors in Germany. Nowadays, the weighing technology reaches from “micro weighing instruments” with a maximal load of only 5 g and a digital resolution of 0.001 mg to huge crane weighers as used in the heavy industry with maximal loads of 500 t and typical resolutions of 200 kg. Numerous applications of weighing instruments, whether for commercial transactions with goods or for the determination of mass for the billing of fees, are subject to verification in conformity with national or European legislation. The legally prescribed precondition for the national or European verification is the certification of weighing instruments for which the PTB department “Mass” is responsible in Germany. Since it is not always useful or feasible to test the whole weighing instrument, it is possible to test individual modules.

The most important module is the load cell as the core of any modern electromechanical weighing instrument. In a load cell, the weight force applied usually causes an electrically evaluable variation of resistance in so-called strain gauges. Further measuring principles, such as the electromagnetic force compensation, are limited to applications in special-accuracy and high-accuracy weighing instruments.

The metrological tests for the certification of load cells must take climatic influence factors into account which are described in the international accepted OIML-Recommendation R60. The most important assessment criteria laid down in the OIML-Recommendation R60 are reproducibility, linearity and hysteresis as well as creeping and zero returning of load cells at temperatures of  $-10\text{ }^{\circ}\text{C}$ ,  $20\text{ }^{\circ}\text{C}$  and  $40\text{ }^{\circ}\text{C}$ . The equipment available at PTB so far allows the testing of load cells with nominal loads of a few grams up to 100 t. But in order to meet the legal requirements also for the certification of load cells with very high nominal loads, it is necessary to extend the existing test range. By providing the 2-MN-FSM, which was put into operation in 2004, subsequently with an adapted temperature chamber, PTB keeps pace with ongoing developments in the field of weighing technology. In this way, the testing of load cells with nominal loads up to 200 t, which had been required for a long time by the industry, becomes possible. Until now, such facilities have not been available in Europe.

A photomontage of the 2-MN-FSM with the fitted temperature chamber as well as the cooling unit installed on the crosshead is shown in figure 1.

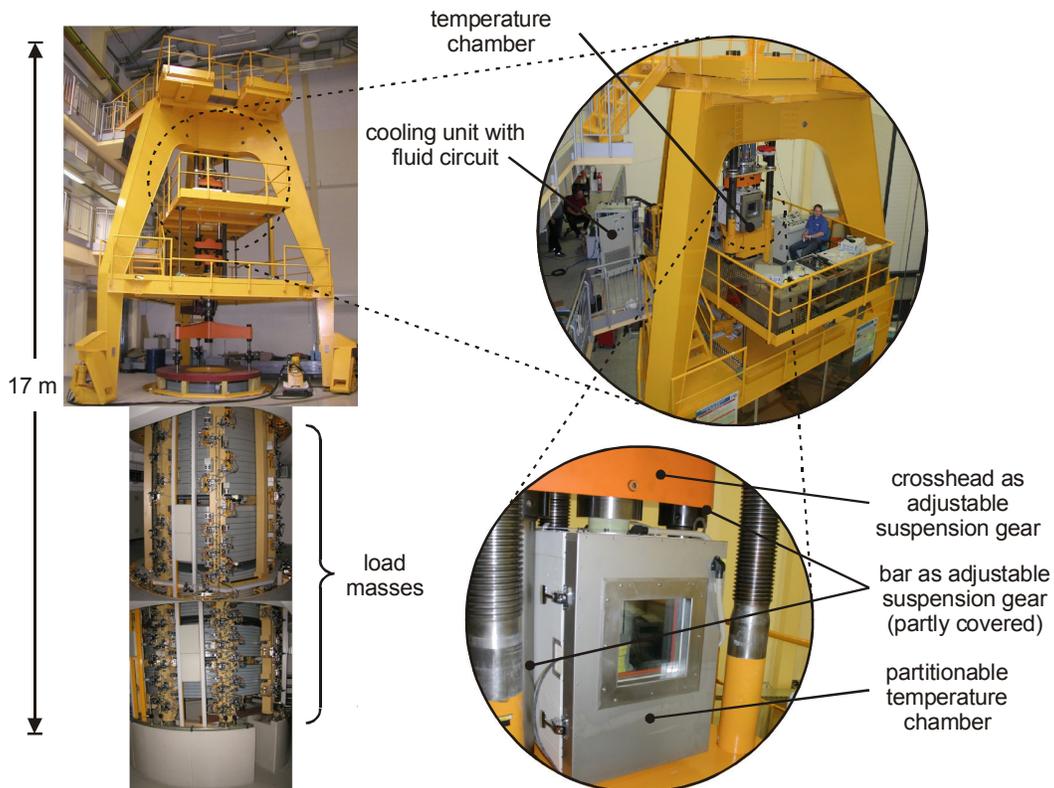


Figure 1: Photomontage of the 2-MN-FSM with the fitted temperature chamber as well as the cooling unit installed on a crosshead.

## 2. Metrological requirements

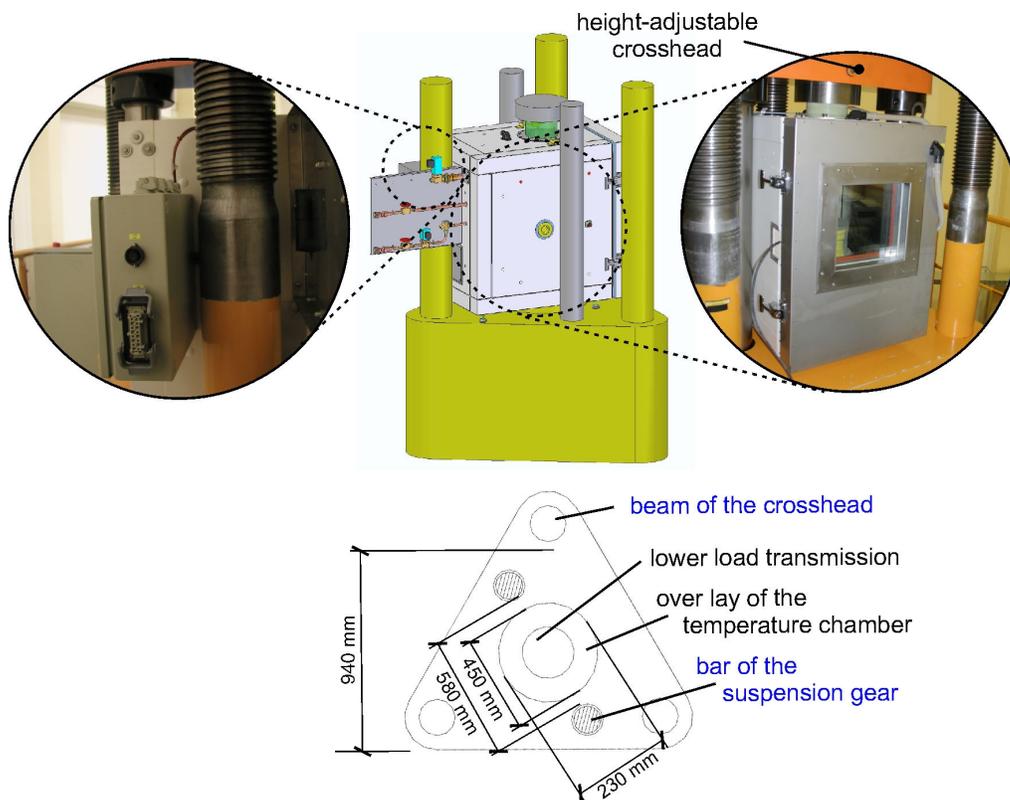
The metrological specifications of the temperature chamber result from the requirements given in the OIML Recommendation R60 for load cells [1]. The spatial temperature gradients should not exceed  $0.2\text{ K}$  per  $100\text{ mm}$  in the mounting area of the load cell and the temporal temperature gradients should

not exceed 0.2 K per hour. For testing load cells the maximum deviation of the actual temperature should not exceed 0.3 K of the nominal temperature.

Unlike the OIML Recommendation R60 which provides a temperature range from  $-10^{\circ}\text{C}$  up to  $+40^{\circ}\text{C}$  the new temperature chamber allows an expanded temperature range from  $-20^{\circ}\text{C}$  to  $+55^{\circ}\text{C}$ . Thus the new temperature chamber also copes with prospective international recommendations and requirements essential to support the technical progress. To prevent condensation while testing load cells with different temperatures, drying of air circulation is essential for the temperature chamber.

### 3. Constructive specifications

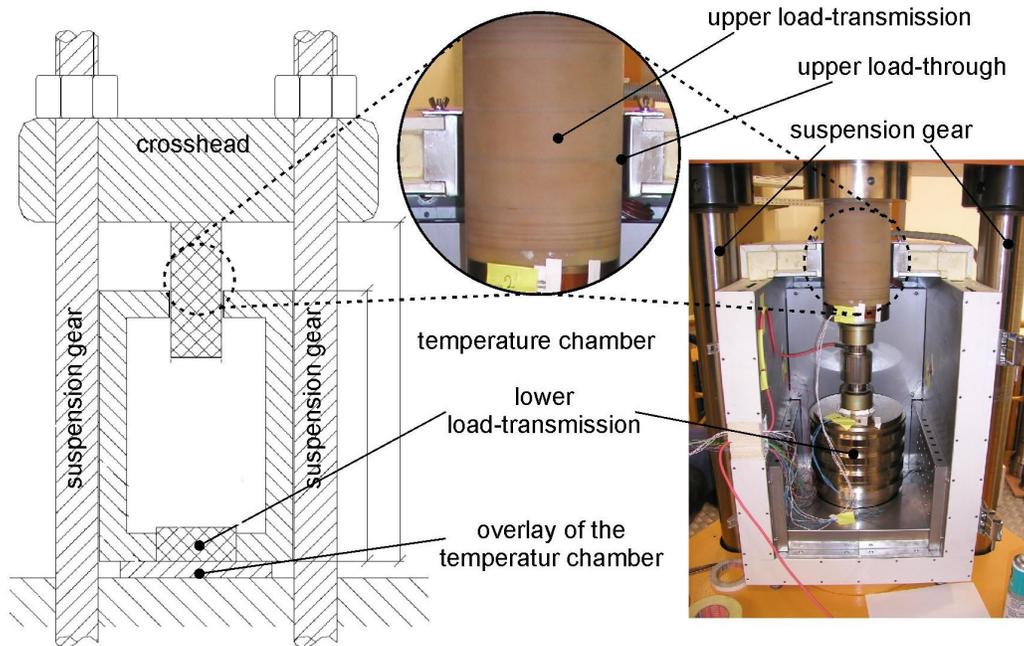
The maximum dimensions of the temperature chamber are 570 mm width by 1000 mm depth by 800 mm height. The width is limited by the two bars of the adjustable suspension gear of the FSM and the depth by a beam of the height-adjustable crosshead. The height of the chamber is limited by the maximum traverse path of the height-adjustable crosshead of the FSM. A photomontage and a schematic drawing of the installation space provided by the 2-MN-FSM and the fitted temperature chamber are shown in figure 2.



**Figure 2:** Photomontage and a schematic drawing of the installation area provided by the 2-MN-FSM and the fitted temperature chamber

The dimensions of typical load cells with high nominal loads fix the minimum inside dimensions of the temperature chamber of 350 mm width by 400 mm depth by 600 mm height. The front view of the installation area pro-

vided by the 2-MN-FSM in a schematic drawing and an interior view of the temperature chamber with a mounted load cell and additional temperature sensors are depicted in figure 3.



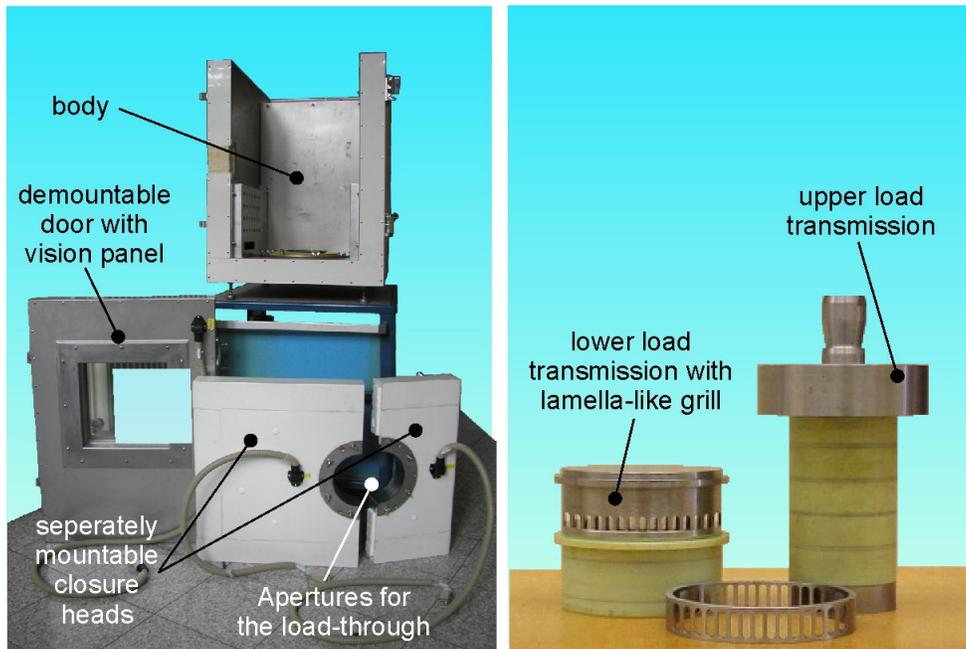
**Figure 3:** Front view of the installation area provided by the 2-MN-FSM in a schematic drawing and an interior view of the temperature chamber with a mounted load cell and additional temperature sensors

The fitting of the temperature chamber restrains the traverse path of the height-adjustable crosshead of the FSM and thus the adjustment of the 2-MN-FSM to test load cells with different height. Consequently additional levelling pieces (see figure 3) are necessary to still allow tests of load cells with different heights.

An upper load transmission, extended into the temperature chamber through a load-through, carries out the force introduction into the load cell. To prevent a force shunt on the load-through the gap between upper load transmission and temperature chamber should be sufficiently large. On the other hand a gap as small as possible reduces the air circulation between the temperature chamber and its environment and therefore leads to higher temperature stability inside the chamber. An optimal solution is a gap bathed by air which is large enough to prevent a force shunt and small enough to reduce air circulation. Furthermore a gap bathed by air prevents glaciations of the gap and force shunts caused thereby when operating the chamber below the freezing point. In practice the gap is a few millimeters wide and adjustable to the respective locations by movable blinds as shown in figure 5.

The 2-MN-FSM is primarily used to calibrate force measuring devices without consideration of climatic influence factors. For these calibrations the temperature chamber is needless and even distracting. Consequently an easy mounting and demounting of the temperature chamber into and out of the FSM without additional fit-up aids must be ensured. This is realised by means of a

modular design of the chamber as shown in figure 4. The chamber is made of a body, a demountable door with vision panel and two separately mountable closure heads with apertures for the load-through of the upper load transmission.



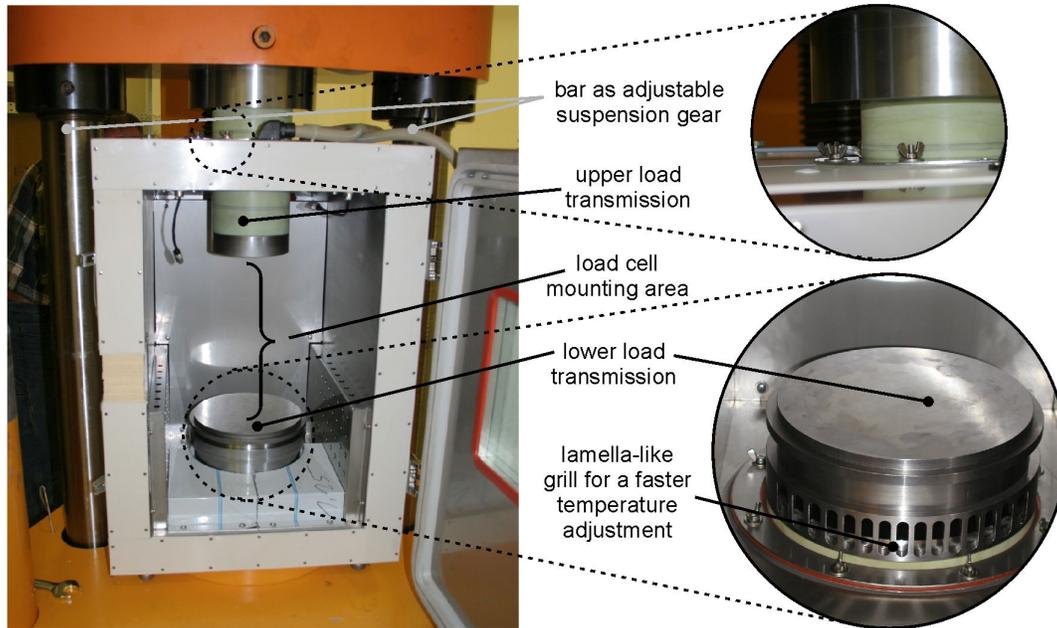
**Figure 4:** Modular design of the temperature chamber (left side hand) and the upper and lower load transmission respectively the lamella-like grill for faster temperature adjustment (right side hand).

Aggravating marginal conditions for compliance with the metrological specifications of the temperature chamber are the parts of the FSM protruding into the inside of the chamber for the load transmission onto the load cell. These load transmissions (see figure 4, right side hand) cover the major part of the temperature chamber area. In order to reduce the heat conduction, they are not entirely made of steel but partly of special pressure-resistant plastics as thermal barriers.

Due to a increased mass of these load transmissions compared with the original ones of the FSM, particularly of the upper load transmission which directly acts on the load cell, a correction of the mass about  $23.9 \text{ kg} \pm 0.1 \text{ kg}$  has to be considered.

Complementarily, the lower loading piece is provided with a lamella-like grill through which temperate air is introduced by means of air conduction shields. This allows not only a faster temperature adjustment but also the required spatial temperature gradients of  $< 0.2 \text{ K}$  per  $100 \text{ mm}$  in the mounting area of the load cell.

The inside view of the temperature chamber with the upper and lower load transmissions partly made of special pressure-resistant plastics is shown in figure 5.



**Figure 5:** Inside view of the temperature chamber with the upper and lower load transmissions partly made of pressure-resistant plastics

#### 4. Conceptual design of the cooling unit

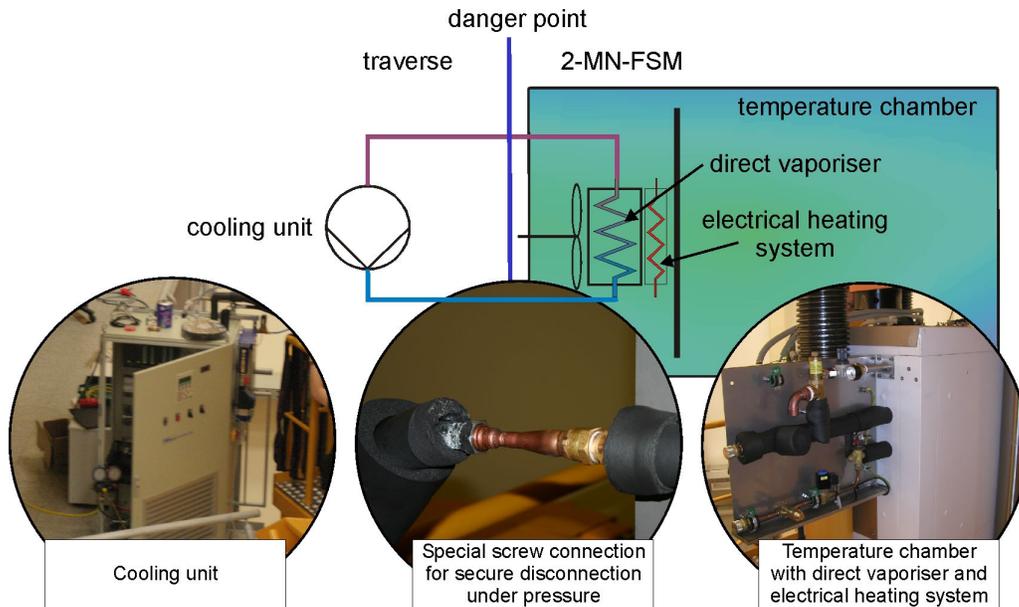
A very important design criterion is the absolute protection of the FSM against fluid leakages. This is of vital importance since the deadweights of the FSM are made of steel. Corrosion of the deadweights due to leakages in the fluid circuit of the chamber can lead to weight force changes with disastrous consequences on the uncertainty of measurement. For this reason, the temperature adjustment of the chamber is carried out by air circulation in combination with a direct vaporiser and an electrical heating system inside of the temperature chamber.

The liquid leading cooling unit consisting of the compressor and the condenser and is situated at a safe distance of the 2-MN-FSM on a crosshead as shown in figure 1. The cooling agent of the cooling circuit absorbs thermal heat at the direct vaporiser inside the chamber. The condenser of the cooling unit dispends this heat at the ambient air. The compressor performs the required mechanical work. A pressure relief valve controls the cooling circuit.

The connexion between the cooling unit and the vaporiser is realised by flexible tubes for cooling agent and special screw connexions so that a disconnection under pressure is possible and simultaneously a complementary protection against leakages of cooling agent is ensured. Furthermore the fluid of the cooling circuit immediately becomes gaseous under ambient conditions which makes contact with the deadweights impossible.

Normally a cooling unit has only one power level. A desired temperature is realised by chopping the cooling unit. However, this method of course leads to intolerable variations in temperature. Smaller variations in temperature are achieved by a constant-working cooling unit and an electrical heating system

inside the temperature chamber, which directly heats the air to the specified temperature. The sensor for temperature control is mounted within the supply air channel of the chamber. A schematic drawing of the conceptual design of the temperature chamber is shown in figure 6.



**Figure 6:** Schematic drawing of the conceptual design of the temperature chamber

Apart from safety-related aspects the advantage of this design is a significant smaller temperature variation and a short response time of the electrical heating system and thus a realisation of a continuous temperature control.

## 6. Metrological investigations

The objective of the investigations is to determine the spatial and temporal temperature gradients of the temperature chamber. Therefore the temperature profile during the temperature change from +20°C to +50°C, from +50°C to -20°C and from -20°C back to +20°C had been recorded in different locations within the temperature chamber as shown in figure 3, e.g. on the outside walls and on the upper and lower load transmission inside the chamber. The objective of the investigations is to determine the spatial and temporal temperature gradients of the temperature chamber.

To make statements about spatial temperature gradients the measured temperatures on the upper and lower load introduction are evaluated. Temperature differences between the load introductions directly lead to spatial temperature gradients within the load cell and may have a strong influence on its measuring result.

The measured temperature differences are smaller than 0.3 K if sufficiently long periods of temperature change for both -20°C as well as for +50°C are respected. Therewith also for load cells with small installation weights of 150 mm including elements for load introduction the spatial temperature gradients within

the installation area of the load cell are smaller than 0.2 K per 100 mm and thus they fulfil the necessary requirements.

With regards to the occurring temporal temperature gradients two effects have to be taken into account. The first effect concerns to temporal temperature gradients which are observed due to control deviations of the cooling unit. These control deviations are observed in time intervals of a few minutes and are in the order of 0.1 K independent of the reference temperature. But temperature deviations in this order of magnitude have no influence on the measurement signal of the load cell at all because there are grand but not exactly specified heat capacities of the load cell, the elements for load introduction and load transmission control.

The second and much more critical effect is the heat conduction due to the upper and lower load transmission elements protruding into the inside of the chamber. This heat conduction leads to a continuous temperature drift and thus to temporal temperature gradients, which may have influence on the measurement results of the load cells to be tested. Figure 7 shows the temperature on the upper and lower load transmission as a function of the measuring time after a skipping of the nominal temperature from +50°C to -20°C. This temperature step is the maximum possible temperature change.

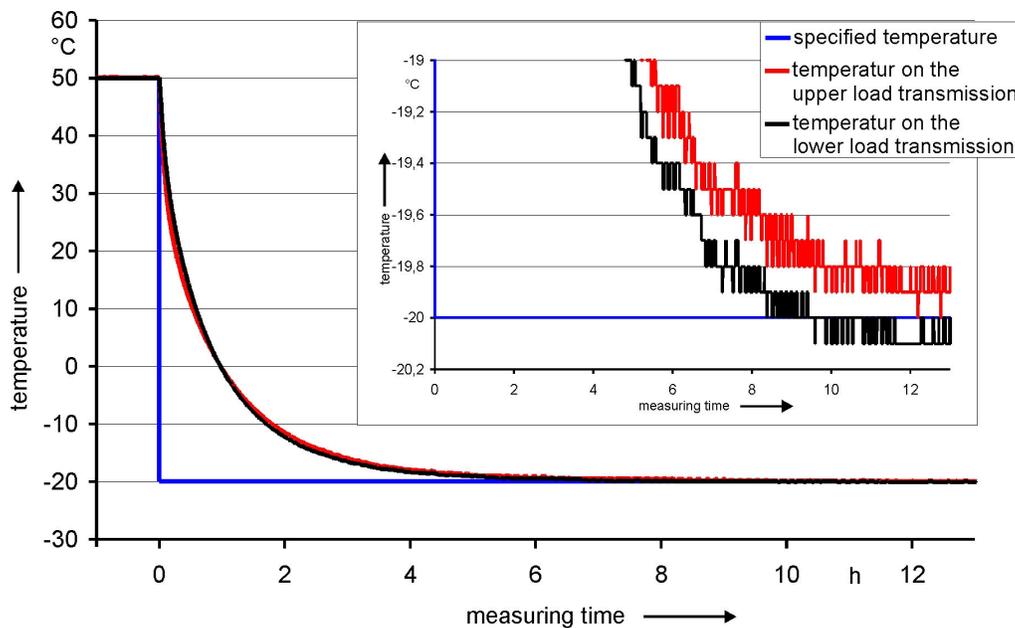


Figure 7: Temperature on the upper and lower load transmission as a function of the measuring time after skipping of the nominal temperature from +50°C to -20°C

The investigations point out that even 7 hours after the change of the nominal temperature the observed temperature gradient of 0.35 K / hour is far beyond the specifications required. Only after 10 hours with a temporal temperature gradient of 0.05 K per hour sufficient temperature equilibrium is achieved within the temperature chamber.

Another important criterion particularly during a temperature change from  $-20^{\circ}\text{C}$  up to  $+50^{\circ}\text{C}$  is the requirement of no permanent condensation within the temperature chamber and on the load cell tested. Indeed the temperature chamber has a dryer for compressed air. But due to huge heat capacities – simply the mass of the upper and lower load introduction and of the additional levelling pieces is approximately 200 kg stainless steel – demanded a sufficient slow change in temperature to avoid condensation.

Figure 8 shows the nominal value and the actual value of the temperature as well as the humidity within the temperature chamber as a function of the measuring time  $t$  during an increase of temperature from  $-20^{\circ}\text{C}$  up to  $+20^{\circ}\text{C}$  with an increasing rate of 4.5 K per hour. This is the maximum increasing rate without condensation within the temperature chamber and detected experimentally.

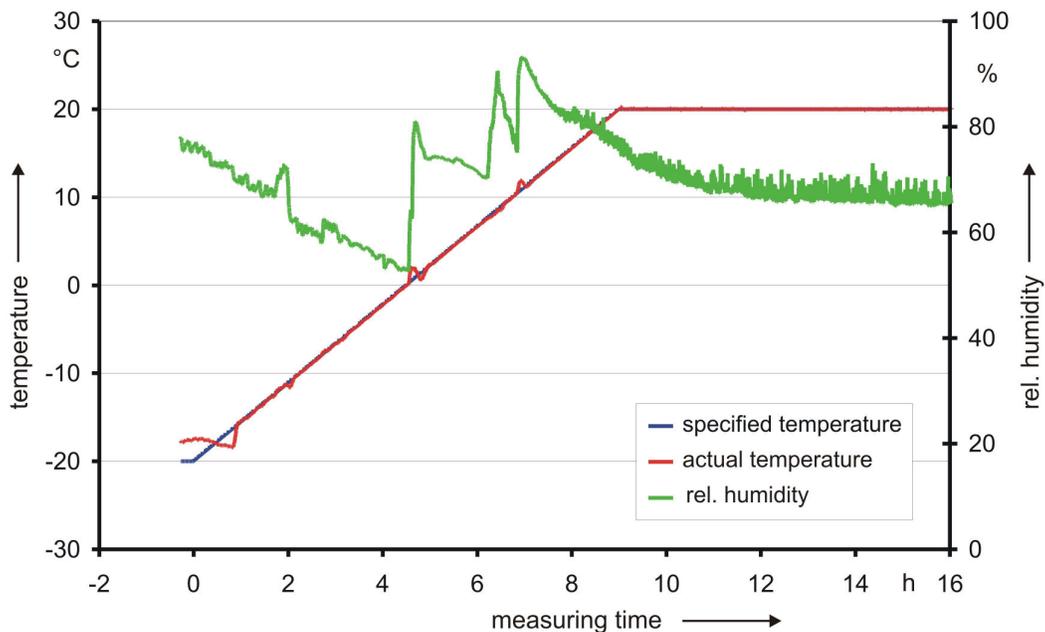


Figure 8: The nominal value and the actual value of the temperature as well as the humidity within the temperature chamber as a function of the measuring time  $t$  during an increase of temperature from  $-20^{\circ}\text{C}$  up to  $+20^{\circ}\text{C}$  with a increasing rate of 4,5 K per hour

The investigations point out with an increasing rate of 4.5 K per hour that the humidity within the temperature chamber increases the value of 90% only temporary and there is no permanent condensation within the temperature chamber.

The temporal temperature gradient measured in this case is inside the additional levelling pieces and thus afflicted with a high time constant is decreased after approximately 12 hours on a value smaller than 0.05 K per hour. Consequently with the defined increasing rate a temperature change from  $-20^{\circ}\text{C}$  up to  $+20^{\circ}\text{C}$  is possible within an acceptable time.

## 7. Conclusion and outlook

A new temperature chamber in combination with the 2-MN-deadweight force standard machine (FSM) allows testing and certification of load cells with nominal loads up to 2 MN (200 t) by PTB. This facility is unique in Europe; for the first time it offers manufacturers and customers the possibility to certify load cells with very high nominal loads as used in the heavy industry for instance.

The construction of the temperature chamber considers both safety-related and design-engineering aspects specified by the 2-MN-FSM as well as high metrological requirements defined in the OIML-Recommendation R60 for testing load cells. For instance 12 hours after a temperature change the temporal temperature gradients decrease on a value smaller than 0.05 K per hour and thus completely fulfil the requirements. The spatial temperature gradients within the installation area of the load cell are smaller than 0.2 K per 100 mm. With an expanded temperature range from -20°C up to +55°C the temperature chamber also fulfil future requirements.

## 8. ACKNOWLEDGMENTS

- [1] International Recommendation OIML R60 – Metrological regulation for load cells, Edition 2000
- [2] Informationen zum Eichwesen, Ausgabe 1/2007: Zeitschrift der Gewerkschaft Mess- und Eichwesen BTE, S. 4

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