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RECOMMENDATION FOR THE REVISION OF TEST PROCEDURES FOR LOAD CELLS IN LEGAL METROLOGY

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Abstract – Load cells (LC) used in weighing instruments under legal control can be tested separately as a module according to the OIML recommendation R60 (R60). R60 prescribes the principle metrological static characteristics and static evaluation procedures for LCs used in weighing instruments for legal metrology. Since the 1st revision of R60 published in 2000 further developments of LCs lead to new experience and requirements.

This paper presents abnormalities of LCs observed on single test patterns like the influence of the force introduction, eccentricity effects, effects of excitation voltage variations, drying effects of the strain gauge sealing but also effects of temperature gradients that may strongly affect the metrological characteristic of LCs.

The effects have to be discussed and taken into account for a planned 2nd revision of R60 if needed.

Keywords: load cell, test procedure, legal metrology

1. INTRODUCTION

The application of weighing instruments for purposes of trade using mechanical balances is certainly older than 4000 years. Today generally electromechanical weighing instruments are used. The heart of an electromechanical weighing instrument is the module load cell (LC). It transforms the force of a weight as a quantity of mass into an electrically measurable quantity. Beside the electromechanical force compensation for high precision measurements most LCs use strain gauges as sensor concept for force measurement.

Today more than 85% of the weighing instruments are of modular design. This concept means that not the whole weighing instrument has to be tested completely. It is sufficient to test defined parts – so called modules – separately and to proof the compatibility of the modules within the weighing instrument [1, 5]. The most important part of a weighing instrument is the module LC which is tested and certified according to OIML recommendation R60 (R60) for LCs [2].

R60 prescribes the principle metrological static characteristics and static evaluation procedures for LCs used in weighing instruments for legal metrology. The first edition of R60 was published in 1991 and considered repeatability, linearity, hysteresis, zero point stability and creep effects of the LC as well as temperature and barometric effects. However, it appears that not all effects relevant for weighing instruments had been considered adequately. The first revision of 2000 takes humidity effects and aging effects under environmental conditions are taken into account. Furthermore the increasing application of digital LCs requires the consideration of additional effects like electromagnetic susceptibility, electrostatic discharge, power voltage variations or warm-up times.

Since the first revision nine years had passed a period of technical progress of LCs and collecting new experience with R60 as well as the modular concept. The experience point out even the first revision has not considered all relevant effects adequate.

This paper presents abnormalities of LCs, such as influence of the force introduction, eccentricity effects, effects of excitation voltage variations, drying effects of the strain gauge sealing. Also effects of temperature gradients may strongly affect the metrological characteristic of LCs, yet are taken into account within the current issue of the R60.

It is the aim of this paper to give an overview concerning noticeable problems, not to discuss them in detail. So the effects are observed on various test patterns for certification with different designs and nominal loads. The results should be discussed within the scope of a coming revision of R60. Continuative investigations and measurements should be carried out in the future if needful.

2. DIFFERENCE BETWEEN FORCE TRANSDUCER CALIBRATION AND LOAD CELL TESTING

This chapter discusses the question if the comprehensive experience achieved with force sensor calibration can be used for testing and certifying LCs. In principle force transducers and LCs are identical in construction and design and they use the same measurement technique. They vary in the field of application and the metrological boundary conditions which have to be taken into account.

But in contrast to calibration standards of force transducers such as ISO 376 [3] R60 utilizes the principle of considering several LC-errors being combined. So it is not considered to specify individual errors for given characteristics such as non-linearity, hysteresis, etc. for a tested pattern, but rather to consider a maximum permissible error (*mpe*) as a function of the applied load (mass) for a group or family of LCs.

Commonly the tests are carried out on LCs with smallest capacities and within the group of the best metrological characteristics. The next larger capacity been tested is between 5 and 10 times that of the nearest smaller capacity. This means that within a LC-group not every specified LC has to be tested.

To avoid certifications based on measurement results of potential "golden samples" the test results are not the only basis for the specification given in a test certificate. The manufacturer data sheet has to be considered as well. Individual error limits indicated on the data sheet are not allowed to be wider than error limits of the R60. This points out that a test certificate should contain no better data than those specified by the manufacturer himself [4].

3. TEST PROCEDURES ACCORDING THE RECOMMENDATION OIML R60

R60 specifies the static metrological characteristics and static evaluation procedures for LCs measuring of a mass and considers their reproducibility, linearity, hysteresis and creep effects, as well as the zero point return usually at 20°C, 40°C and -10°C. It approves of so-called accuracy tests with increasing and decreasing discrete load steps. The test sequence for each test temperature is shown in Figure 1.

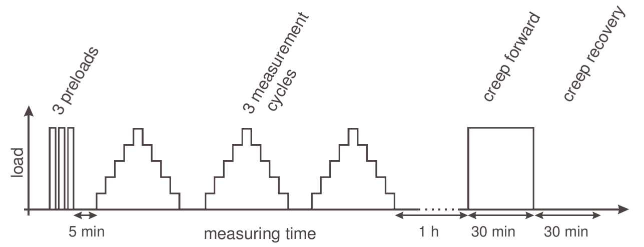

Figure 1: Recommended test sequence for each temperature according to R60

The measurement values are taken at time intervals between 10 seconds and 60 seconds after the initiation of loading or unloading. The time intervals depend on the load change. One hour after the accuracy test creep forward and creep recovery are measured for 30 minutes.

3.1 Classification of load cells

LCs are classified in four accuracy classes, A to D, for use in special-, high-, medium- or ordinary-accuracy weighing instruments. The requirements of an accuracy class are fulfilled if the error of measurement lies within a maximum permissible error (*mpe*) which depends on the maximum load m and the maximum number of LC verification intervals $n_{\max}$. Table 1 shows the accuracy classes and the corresponding *mpe* with a verification interval

$$v = \frac{m}{n_{\max}} . \quad (1)$$

The apportionment factor p_{LC} in table 1 assigns a portion of the whole error granted to a weighing instrument to the LC alone. This factor is an important quantity to realize the modular concept and to prove the compatibility of the modules within a weighing instrument.

Table 1: Accuracy classes and corresponding maximum permissible errors (*mpe*) according to R60. The apportionment factor is typically $p_{\mathrm{LC}} = 0.7$ for LCs.

mpe	$p_{\mathrm{LC}} \times 0.5v$	$p_{\mathrm{LC}} \times 1.0v$	$p_{\mathrm{LC}} \times 1.5v$
class A	$0 \leq m \leq 50000v$	$50000v \leq m \leq 200000v$	$200000v < m$
class B	$0 \leq m \leq 5000v$	$5000v \leq m \leq 20000v$	$20000v < m \leq 100000v$
class C	$0 \leq m \leq 500v$	$500v \leq m \leq 2000v$	$2000v < m \leq 10000v$
class D	$0 \leq m \leq 50v$	$50v \leq m \leq 200v$	$200v < m \leq 1000v$

4. REQUIREMENTS ON LOAD CELLS ACCORING OIML RECOMMENDATION R60

The most important evaluation criteria and requirements on LCs according to R60 are based on the repeatability, the LC error, temperature effects on minimum dead load output (MDLO), time depending effects like creep and dead load output return (DR) as well as humidity effects and are presented in this chapter. Not considered, but important as well, are barometric effects and the requirements on LCs equipped with electronics.

4.1 Repeatability

By means of three measurement cycles with increasing and decreasing loads for class C and D respectively five measurement cycles for class A and B, respectively, the repeatability error is separately determined for each temperature separately. The criteria for repeatability is fulfilled if the maximum difference between identical load steps is not greater than the absolute value of the *mpe* for that load as defined in table 1.

4.2 Load cell error

Figure 2 shows the *mpe* for class C3 with $n_{\max} = 3000$ verification intervals and the LC-error, expressed in verification intervals v as the function of the load, for a LC with a nominal load of 200 kg and under temperature conditions of 21.0°C, 40.6°C, -10.1°C and again at 21.0°C.

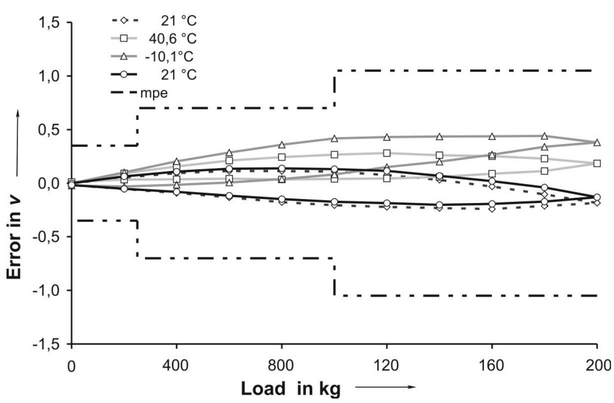

Figure 2: The *mpe* for class C3 with $n_{\max} = 3000$ verification intervals and the LC-error, expressed in verification intervals v as the function of the load, for a LC with a nominal load of 200 kg under -10.1°C, 21.0°C and 40.6°C conditions.

According to R60 the LC-error utilizes the principle that several LC-errors such as non-linearity, hysteresis and zero point return e.g. are considered together in one measured curve which is zero point adjusted and derived form separate testa at each temperature. The LC-error is defined as the difference between the output signal of a LC under load and a straight line drawn between the minimum load output and the LC-output at a load of 75% of the measuring range taken on increasing the load at 20°C. The "indication unit" of the LC-error is the verification interval *v*.

4.3 Temperature effect on minimum dead load output

This criterion describes the temperature effect on the minimum dead load output (MDLO) of a LC. The minimum dead load E_{min} is the smallest value of a mass or a preload which must be applied to a LC without its output signal exceeding the *mpe*. For most of the LCs $E_{min} = 0 \cdot E_{max}$ is essential to maintain the *mpe*. Admittedly a few LCs demand a defined E_{min} in the region of a few percent of E_{max}.

The criterion is fulfilled if MDLO of a LC over a defined temperature range does not vary by an amount greater than p_{LC} times the minimum dead load verification interval v_{min} for any change of ambient temperature of 2°C for LCs of class A or 5°C for LCs of class B, C or D.

In thus connection v_{min} is the smallest verification interval into which the LC measuring range can be divided and thus the smallest difference of mass which can be measured by the LC. The criteria of the LC is given by the ratio

$$Y = \frac{E_{max}}{v_{min}} . \quad (2)$$

Figure 3 shows the change of MDLO due to temperature effects expressed as the change of the verification interval *v* for a class C3-LC with a nominal load of 10 kg as a function of the ambient temperature between -10°C and +40°C. The smallest verification interval v_{min} of the LC is given by a ratio $Y = 20000$. In accordance with the LC-error the "indication unit" of the temperature effect on MDLO is the verification interval *v*.

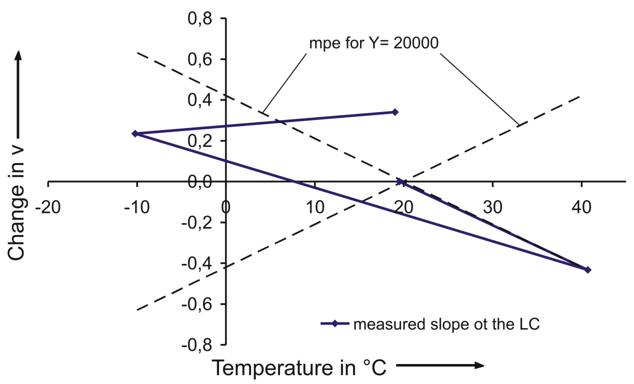

Figure 3: Temperature effect on minimum dead load output (MDLO) in verification intervals *v* for a class C3-LC with Y = 20000 as a function of the ambient temperature between -10°C and +40°C.

The criterion for the temperature effect on MDLO is fulfilled if each slope between the minimum dead load outputs measured at different temperatures is smaller than the maximum allowed slope for a defined ratio Y.

4.4 Time depending effects

A typical time depending effect is creep defined as change of the LC-output with time while under constant load and constant environmental condition. According to R60 creep is measured at a constant load between 90% and 100% of E_{max}. The criterion is fulfilled if the change of difference between the initial output of the LC - normally measured with E_{min} directly after load change - and the LC-output under load obtained during the next 30 minutes does not exceed 0.7 times the absolute value of the *mpe* for the applied load.

A second criterion which has to be maintained is given by the difference between the output obtained 20 minutes and 30 minutes after loading which shall not exceed 0.15 times the absolute value of the *mpe*.

The third and most discerning criterion is the dead load output return (DR). It is the difference between the initial minimum dead load output and the output after returning to E_{min} subsequent to 30 minute creep measurement. Depending on the load change the measurement value is taken at time intervals between 10 seconds and 60 seconds after the unloading, while DR shall not exceed half the value of a LC verification interval defined by a ratio Z:

$$DR \le \frac{E_{max}}{2 \cdot Z} \quad (3)$$

A LC used for single range weighing instruments has to fulfil the criteria $Z = n_{max}$. If a LC shall be used in a multi interval instrument, the higher criteria $Z > n_{max}$ must be kept.

Figure 4 exemplarily shows the error limits for creep and DR as well as measured creep effects and DR for a LC of class C3 and Z = 5000 under 40.6°C temperature condition and expressed as change of the verification interval *v* as the function of time.

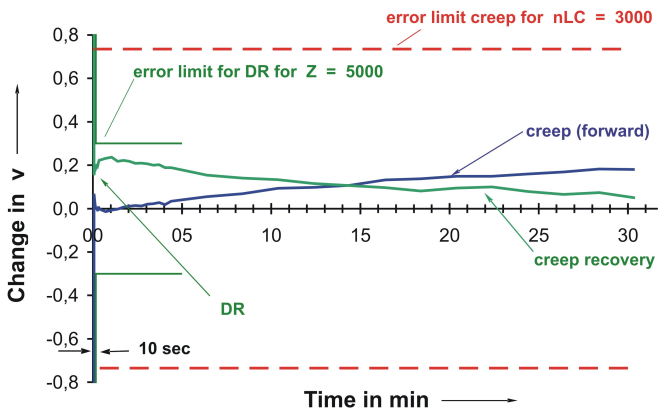

Figure 4: Error limits for creep and DR as well as creep effects and DR for a LC of a class C3 and Z = 5000 under a temperature condition of 40.6°C expressed as change of the verification intervals *v* and as the function of time

In this example the error limit for creep and DR are very well kept. In principle this LC could also be used in a multi interval weighing instrument with the higher requirement $Z \geq n_{max}$.

4.5 Humidity effects

Humidity effects designate LC-errors due to different temperature and humidity conditions. R60 describes different procedures for determining humidity effects. The most severe procedure for determining humidity effects is the cyclic damp heat test. This test consists of exposure to 12 temperature cycles of 24-hour duration each and thus considers the long term stability of the LC. The relative humidity is between 80% and 95% and the temperature is varied from 25°C to 40°C, in accordance with the specified cycle. The criteria of R60 is fulfilled if the humidity effect on MDLO measured before and after the damp heat test does not exceed 0.04 times n_{max}. As a second criterion the span between the maximum dead load output and MDLO before and after the damp heat test cell shall be smaller than the verification interval *v*.

5. UNCONSIDERED ABNORMALITIES

The 1st revision of the R60 had been released in the year 2000. Since this time further experience has been collected and LCs have been developed further on. Subsequently, typical abnormalities of LCs unconsidered by R60 but observed within the last years are presented and discussed.

5.1 Influence of force introduction

For the construction and development finite element method tools are used to simulate and optimise the metrology behaviour of LCs. But it is not understood of course that these LCs optimised for special applications also keep the requirements of general clause for LC as described within the modular approach of weighing instruments and in more detail specified with general requirements defined in WELMEC 2.4 e.g. [5].

As an example increasingly smaller designs of LCs result in the circumstance that the limiting criterion of St. Vernant is not necessarily complied with. This criterion signifies that there is no influence on the measurement result if the distance between force introduction and strain gauge application is sufficiently large [6]. If this criterion is not fulfilled, e.g. for LCs with small dimensions, the force introduction, but also the clamping torque and settling effects may effect the LC output. As discussed in [7] for double bending beam and shear beam LC the diameter of a ball joint or ball supported force introduction strongly influence the gradient of the characteristic line of a LC.

Another effect is observed on single point LCs as shown in a schematic drawing in figure 5.

Because these LCs have no degree of freedom for horizontal displacement or inclination the influence of thermal stress due to different expansion coefficients of the LC-material and force introduction may directly affect the output signal and MDLO, respectively, if the criterion of St. Vernant is not fulfilled.

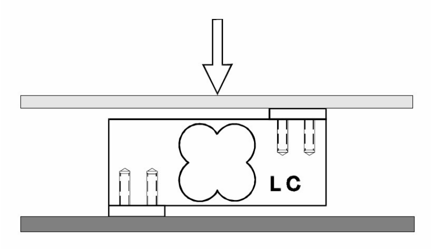

Figure 5: Schematic drawing of a single point LC with a platform as load receptor and the force introduction

The effect of thermal stress on MDLO is shown in figure 3 and figure 6. While figure 3 shows the temperature effect on MDLO for a LC and force introduction both made of stainless steel, figure 6 shows the behaviour in case an aluminium force introduction is used for the same LC.

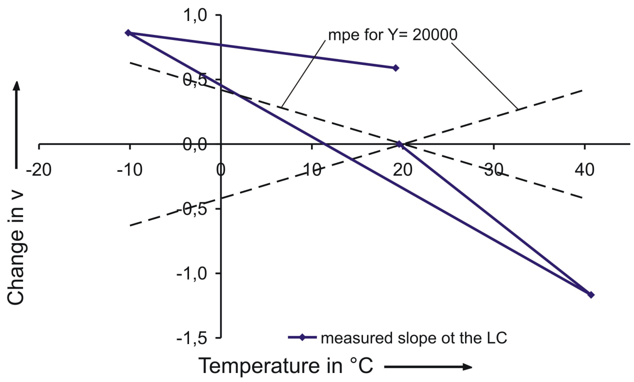

Figure 6: Temperature effect on MDLO expressed in verification intervals *v* for the LC of figure 3 with a force introduction made of aluminium as a function of the ambient temperature between -10°C and +40°C and a maximum slope for Y = 20000.

While the LC fulfils a ratio of Y = 20000 if stainless steel is used (see figure 3) an aluminium force introduction fails to fulfil the requirements (see figure 6) and only fulfils the requirements of a more than four times reduced ratio of Y = 4500.

The investigations point out that even if the requirements for a general adoption of a force introduction according to [5] are fulfilled, the geometry of the force introduction and the materials used for it may strongly influence the output signal and thus the metrological characteristic of a LC. These effects cannot be neglected. However, sufficient concrete descriptions of the load introduction and definitions of useful materials are not required in R60 up to now and should be discussed for the coming revision.

5.2 Eccentricity effects

It is essential that a weighing instrument meets the *mpe* also for different positions of a load on a load receptor. Adequate eccentricity tests are described in OIML-Recommendation R76 for non-automatic weighing instruments [8]. Admittedly corresponding tests are not mandatory to be carried out if the modular approach and the general requirements for LC according to [5] are applied. Also in R60 adequate tests are not envisaged.

But eccentricity effects may strongly influence the output signal, particularly in case of single point LCs as documented in figure 7. The diagram shows the *mpe* for class C3 and the LC-error expressed in verification intervals *v* as the function of the load for a LC with a nominal load of 8 kg and under 20°C temperature conditions. The load is applied on different positions of the load receptor.

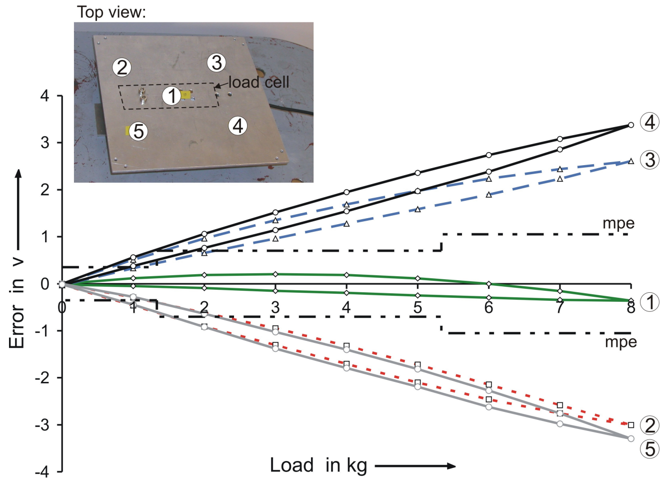

Figure 7: The *mpe* for class C3 and the LC-error expressed in verification intervals *v* as a function of the load for a LC with a nominal load of 8 kg and under 20°C temperature conditions. The load is applied on different positions of the load receptor.

The results point out that depending on the position where the load is applied the *mpe* for the LC is significantly exceeded.

For this reason PTB carries out additional eccentricity tests according to [8] additionally if single point LCs are tested according to R60. But these tests are not mandatory and for this reason they are unconsidered criteria for certifying LC according the current issue of the R60.

5.3 Effects of excitation voltage variations

Beside smaller LC dimensions and new designs advanced developments on the field of indicator devices must be taken into account. While R60 usually allows tests with a fixed excitation voltage of e.g. 5 V or 10 V current indicators provide a much wider excitation voltage range from 0.5 V up to 30 V, a fact that is not taken into account in the current issue of R60.

As shown in figure 8 the excitation voltage affects the gradient of the characteristic line of a LC. The diagram shows the *mpe* for class C3 and the LC-error expressed in verification intervals *v* as a function of the load for a LC under 20°C conditions and different excitation voltages in a range between 2 V and 15 V.

Based on the characteristic line measured for 5 V the *mpe* is clearly exceeded, particularly for excitation voltages of 10 V or higher. Furthermore the results point out linearity and hysterese are not affected by varying the excitation voltage. Consequently the gradient of the characteristic line can be ignored if the excitation voltage for the LC is constant and the weighing instrument where the LC is built in has an adjustment device, which is normally ensured for weighing instruments used in legal metrology.

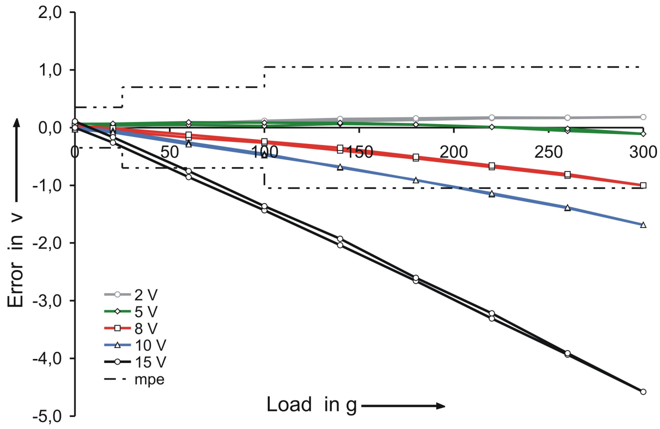

Figure 8: The *mpe* for class C3 with n_{max} = 3000 verification intervals and the LC-error expressed in verification intervals *v* as the function of the load for a LC under 20°C temperature condition and for different excitation voltages between 2 V and 15 V.

Whether a varying excitation voltage affects the temperature behaviour of the output signal is subject of current investigations at PTB. As well effects of AC- or DC-excitation voltages, carrier frequency effects but also effects of signal shaping (sine-signal, triangle-square-pulse) on the output signal of a LC are unknown up to now. This points out further future studies are essential for more experience.

Not negligible is the effect of the excitation voltage on the drift behaviour of a LC as shown in figure 4 and figure 9. While figure 4 shows the creep behaviour and DR for a LC with an excitation voltage of 5 V, figure 9 shows the results of the same LC under 10 V conditions.

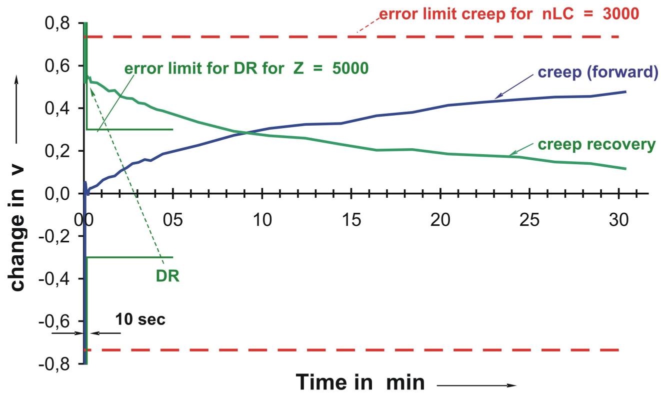

Figure 9: Error limits for creep and DR as well as creep effects and DR for the LC of figure 4 under 40°C temperature condition with an excitation voltage of 10 V instead of 5 V expressed as change of the verification intervals *v* and as the function of time

In this case DR failed the requirements for Z =5000. It is expected that with even higher excitation voltages the error of DR continues to increase. Temperature effects due to the excitation voltages in the area of the strain gauge application are a possible reason for this behaviour and make assume that the excitation voltage affects the drift behaviour essentially as well under -10°C or +40°C temperature conditions.

The previous results advise to test LC with varying excitation voltages to certify LC in a wide excitation voltage range. Up to now corresponding tests are not provided by R60 and have to be discussed for a coming revision of the recommendation.

5.4 Drying effects of silicon compound for sealing

Drying effects of silicon compound for sealing the strain gauge application of LC also strongly affect the LC-output as shown in figure 10. The diagram shows the *mpe* for creep and DR as well as creep effects and DR for a class C3-LC with Z= 6000 under 20°C temperature conditions. The first creep measurement has been carried out directly after the delivery of the LC. The repeated creep measurement has been carried out directly after the accuracy test at 20°C, 40°C, -10°C and again under 20°C temperature conditions.

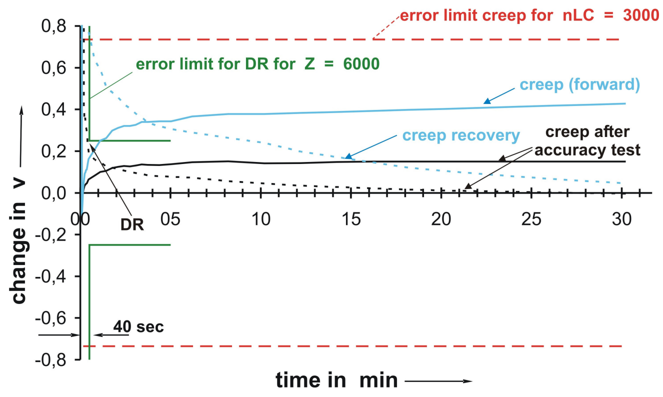

Figure 10: Error limits for creep and DR as well as creep effects and DR for a LC under 20°C conditions before and after the accuracy test expressed as change of the verification intervals *v* and as the function of time

As results the LC failed Z = 6000 directly after delivery while at the repeated measurement it fulfils the requirements.

Additional creep measurements during the storage of the LC under 40°C conditions point out drying effects of the silicon compound for sealing are liable for the measurement behaviour.

Every LC with silicon compound can show similar effects in principle. Within the revision of R60 it has to be discussed if a modified test procedure can consider this behaviour or if it is necessary to shift the LC into a defined state by applying damp heat cycles previously. In the latter case the procedure would be similar to the three preloads at the beginning of an accuracy test for shifting the LC into a defined mechanical state (see figure 1).

5.5 Effects of temperature gradients

The influence of temperature gradients on the output signal of LCs is completely unconsidered up to now. Correspondingly the current issue of R60 has no concrete specifications about spatial or temporal temperature gradients. Simply a temperature stability of 2°C within a test cycle according figure 1 is specified and has to be fulfilled. Reliable results concerning time gradient effects are not available up to now.

However, it is likely that temperature gradients are not negligible as inconsistent measurement results of tests carried out in different climate chambers and under different periods for changing temperature and thus different temperature gradients suggest.

Due to economic interests manufacturers of LC prefer short periods for changing temperature accepting temperature gradients. Notified bodies like PTB try to realize temperature gradients as small as possible and thus realize long tempering times up to 24 hours generally.

Figure 11 shows the strong influence of temperature gradients. The diagram shows both the ambient temperature between 39°C and 40°C and MDLO of a LC expressed as change of the verification intervals *v* under a relative humidity of 30 % and 85 % as a function of time.

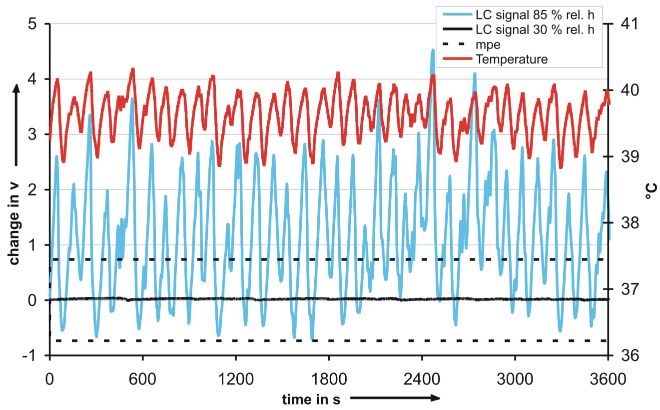

Figure 11: Ambient temperature between 39°C and 40°C and MDLO of a LC expressed as change of the verification intervals *v* under a relative humidity of 30 % and 85 % as a function of time.

Under 40°C temperature conditions and a relative humidity of 85 % the investigations document a strong correlation between a temperature variation of 1°C and MDLO. With a change in the order of ±2*v* the *mpe* of the LC is failed by far. Under similar temperature fluctuations in the same range of 1°C but under reduced relative humidity conditions of 30% MDLO passed the requirements clearly.

Since temperature fluctuations in a range of 1°C are common environmental conditions of a weighing instrument e.g. used on a farmer’s market a LC showing the characteristics of figure 11 is not qualified for legal metrology. On the other hand it is questionable if this characteristic is detectable under optimised laboratory conditions with temperature und humidity fluctuations as small as possible.

The reason for the LC behaviour in figure 11 is completely unknown up to now. However, repeated measurements confirm the results. Currently long term measurements are carried out on the LC to get more experience and to investigate drying effects and the influence of accuracy tests under different temperature conditions.

The results carried out with this LC indicate that it may be more suggestive to test LC under environmental conditions which are more practical e.g. by using temperature gradients due to defined temperature fluctuations in a fixed time.

6. CONCLUSIONS

This paper presents experience with the current issue of R60 within the last years. It shows as well that there are abnormalities of LCs which may strongly affect the LC-output and thus their metrological characteristics but have not been taken into account. In particular the influence of force introduction, eccentricity effects, effects of excitation voltage variations, drying effects of the strain gauge sealing, but also effects of temperature gradients are presented and discussed. All these effects are not considered in the current issue of R60 but should be discussed and considered in a coming 2nd revision of R60 if needed.

It is the aim of this paper to give an overview concerning noticeable problems, not to discuss them in detail. So the effects are observed on various test patterns for certification with different designs and nominal loads. Continuative investigations and measurements should be carried out in the future if needful and the results be considered within the scope of a coming revision of R60 which had been decided on the last CIML meeting dated 27-31 of October 2008 in Sydney.

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