The calibration system of force measurement devices - conceptions and principles

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ABSTRACT

Developed, put into practice and used the universal automatic system MABA-2000 for calibration of force measurement devices in accordance to ISO 376-1999, ISO 7500-1999 and manufacturer requirements.

The system includes a set of load cells from 1 kN to 5 MN, amplifier DMP-40 (HBM), computer and accessories.

Mathematically proved the possibility of calibration in points, which vary from series to series, proved, and confirmed the application of calculation of formulas accuracy deviation and repeatability in accordance to ISO 7500-1999. This approach increases the productivity and simplifies the calibration process.

Software MABA-2000 permits to communicate the measurement line “load cell-amplifier-computer” and to perform calibration process on mode ON-LINE: input of the measurement data, indications of the deviations in real time, calculations of the uncertainties, calculations of the calibration results and output of certificate.

For calibration by method of Dead Weight a computer automatically selects a set of standard weights as a function of the True Force and value of gravity acceleration.

The strict and precise method of the measurement results’ rounding optimizes the value of uncertainty.

Calculation of interpolation polynoms of $1^{st}, 2^{nd}, 3^{rd}$ degree is done automatically too, and does not require additional resources or time.

The software MABA-2000 includes also the subroutine for the measurement load rate and calculates uncertainty in accordance to customer requirements.

Keywords: force measurement devices, calibration process, software, uncertainty.

1. CALIBRATION PROCEDURES IN QCC HAZOREA

Three basic directions definition the work of our laboratory (see figure 1):

1. Calibration by Customer or Manufacturer specification (as a rule of a thumb these are push-pull force measurement devices)
2. Calibration in accordance to [1]
3. Calibration in accordance to [2]

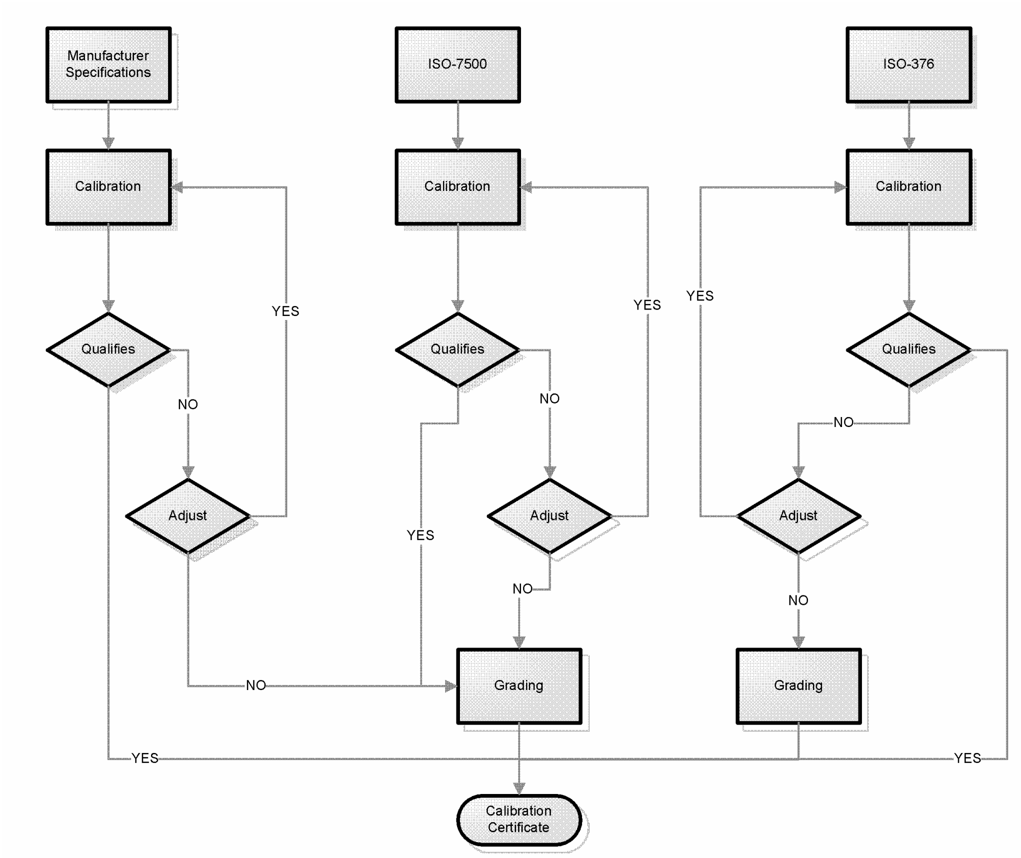


Figure 1: Flow chart of force calibration procedure in QCC Hazorea

Note for Manufacturer specification: when calibration results are not in the permissible limits, estimation of state of the device will be in order to criterion of [1] – using the standard's “down-grading” (step in the direction of customer).

2. WRITING OF MEASUREMENT RESULTS

Two parameters define the "on-line" method measurement results:

1. Number of digits after the decimal point N_S :

$$N_S = 0 \text{, when } r \geq 1; \; N_S = -\,\textit{round down}\,(\log r), \qquad (1)$$

where r -is the resolution of the Unit Under Test (UUT).

2. Rounded mean value of force $\overline{F}_{rd}$ as a function of resolution r

$$\overline{F}_{rd} = round\left(\frac{\overline{F}}{r}\right) \cdot r\ , \qquad (2)$$

where $\overline{F}$ - is the mean value of reading ("True Force" method) or applied force ("Indicated Force" method).

3. DATA PROCESSING BY METHOD INDICATED FORCE

The calibration of force measurement devices by "Indicated Force" method is performed in accordance to the next scheme:

1. Force is applied to the Load Cell and to the UUT's measurement device. The amplifier DMP-40 (manufactured by HBM) uses calibration table of the current Load Cell (kN - mV/V) to convert the electrical signal ***S*** from the Load Cell to software as measured force ***F***. The software compares ***F*** and reading ***R*** and calculates deviation $\delta = R\text{-}F;$

2. In some cases, mainly in order to minimize the measurement's uncertainty [3], the computer reads the measured electrical signal ***S*** (mV/V). The measured force value is given by interpolation polynom *F=f(S)* and calculates deviation $\delta = R\text{-}f(S);$

3. When we measure with another amplifier (without internal memory) an interpolation polynom is the only possible way.

4. CALCULATION METHOD OF THE DEVIATIONS (RELATIVE ACCURACY AND REPEATABILITY ERRORS)

The requirement of "slowly increasing force and <u>reading in the same value</u> for three series of measurement" sometimes can not be achieved, because not all of the load mechanisms (hydraulic, mechanical or electrical) ensure the required load rate. Our theoretical research and application of it shows that those limits can be wider than they are.

For the ***j***-th series of measurements (as a rule, number of series *n* is 3, see [1]), when R_0 is a nominal value of reading :

$$F_j = R_0 - \frac{R_0 - F_j}{R_0} \cdot R_0 \qquad (3)$$

Let us mark

$$\Delta_j = \frac{R_0 - F_j}{R_0} \qquad (4)$$

Formulas (3) and (4) transformed to the next equation:

$$F_j = R_0 - \Delta_j \cdot R_0 = R_0 \left(1 - \Delta_j\right) \qquad (5)$$

Using definition made in [1], - paragraph 4 - the arithmetic mean of several measurements for the same discrete force is:

$$\overline{F} = \frac{\sum_{j=1}^{n} F_j}{n} = \frac{1}{n}\sum_{j=1}^{n} R_0\left(1-\Delta_j\right) = R_0 - R_0 \cdot \overline{\Delta} = R_0\left(1-\overline{\Delta}\right), \qquad (6)$$

where $\overline{\Delta}$ is a mean value of deviations from formula (4).

Relative accuracy error $\boldsymbol{q}$ of the force measuring system of the testing machine [1], paragraph 6.5.1:

$$q = \frac{R_0 - \overline{F}}{\overline{F}} = \frac{R_0 - R_0\left(1-\overline{\Delta}\right)}{R_0\left(1-\overline{\Delta}\right)} = \frac{\overline{\Delta}}{1-\overline{\Delta}} \qquad (7)$$

When for the same discrete value of reading R_0 in $\boldsymbol{j}$ –series of measurement a nominal values R_j are different, then:

$$G_j = R_j - \frac{R_j - G_j}{R_j} \cdot R_j, \qquad (8)$$

where G_j - is the value of applied force for reading

$R_j \neq R_0$.

Similar to formula (4) we have

$$\Delta_j = \frac{R_j - G_j}{R_j} \qquad (9)$$

Combination of formulas (8) and (9):

$$G_j = R_j - \Delta_j \cdot R_j = R_j\left(1-\Delta_j\right) \qquad (10)$$

Because the approximation of relative deviation Δ is a linear function, then

$$R_j = \frac{G_j \cdot R_0}{F_J} \qquad (11)$$

The equations (10) and (11) give us:

$$G_j = \frac{G_j \cdot R_0}{F_J}(1-\overline{\Delta}) \Rightarrow F_j = R_0\left(1-\Delta_j\right) \qquad (12)$$

Therefore, this equation is identical equivalent to equation (5) and we have a very important conclusion that to calculation of relative accuracy error $\boldsymbol{q}$ in calibration discrete value of force R_0 is not necessarily to compare the applied force F_j to constant (from series to series) value of reading R_0.

Then the definition of relative repeatability error ***b*** according to [1], paragraph 6.5.2 will transform to the next equation:

$$b = \frac{F_{max} - F_{min}}{\bar{F}} = \frac{R_0 \cdot \Delta_{max} - R_0 \cdot \Delta_{min}}{R_0\left(1 - \bar{\Delta}\right)} = \frac{\Delta_{max} - \Delta_{min}}{\bar{\Delta}} \tag{13}$$

All of the cited above reasons and mathematical evidences was build on the assumption of linearity approximation of the deviation Δ. However, for the more precise evidence we must expect the non-linearity deviation's function. For this case we can expand this function to Taylor series:

$$F_j = F_{j0} + \Delta \cdot F_{j1} + \Delta^2 \cdot F_{J2} + ... + \Delta^k \cdot F_{jk} \tag{14}$$

The limitation criterion of a number of the Taylor series is the next equation:

$$\Delta^k \le U_{Fj}, \tag{15}$$

where U_{Fj} uncertainty of measurement F_j

From our practice maybe to limit on the second member (*k*=2) of the series Taylor.

5. CALIBRATION OF TESTING MACHINES WITH READING DEVICES IN NOT FORCE UNITS

For measurement devices with non-force units reading scale - units of pressure, linear deformation, current, voltage. The calibration results are presented as a dependence force of reading $F = f(R)$ and dependence reading of force $R = f(F)$,

where *F*-is an applied force (for example, kN);
R-is a scale reading (for example, psi).

In our calibration certificate we present the data in the following forms:

1. analytical;
2. table;
3. graph.

Analytical dependence – a 1st, 2nd or 3rd degree polynom, this function permits us to calculate the theoretical force value in the calibration point R_j and the relative interpolation error:

$$f_C = \frac{F_A - F_{Tj}}{F_{Tj}}, \tag{16}$$

where F_{Tj} - theoretical force value in the point R_j using $F = f(R)$;
F_A - the applied (measured) force.

In the calibration table we present the next accuracy parameters:

Relative interpolation error
Relative repeatability error
Relative resolution
Uncertainty of the measurement

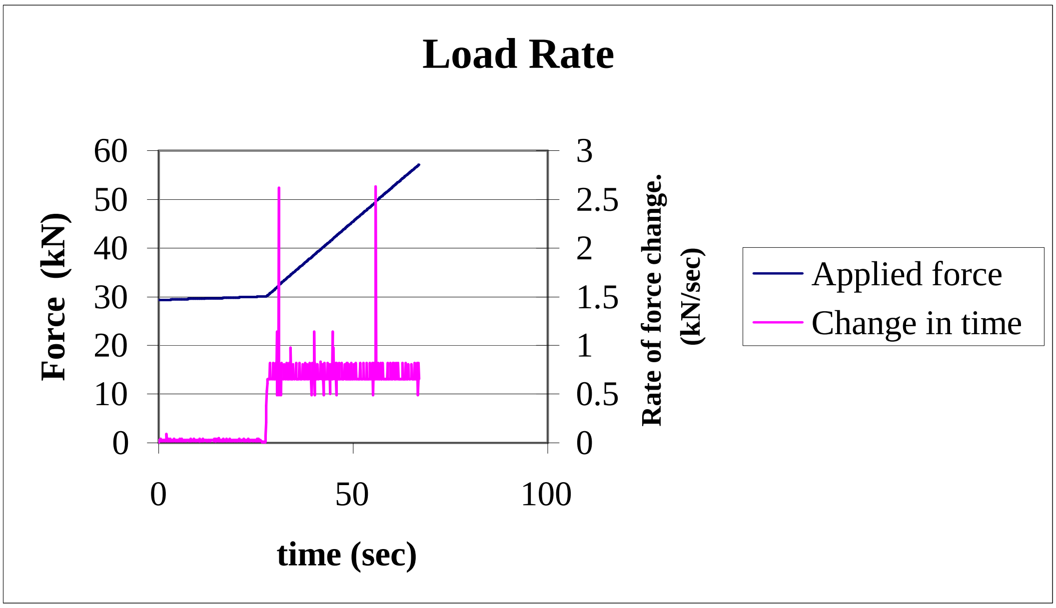
On the basis of those parameters we can define the accuracy grade of UUT. The table in this form with the note **"In order to use ISO 7500 the UUT's measurements have been converted to force readings using the interpolation formula"** widens paragraph 6.2.4 of [1]-"The resolution, *r***,** shall be expressed in units of force"**.**

6. CALCULATION OF UNCERTAINTY

We perform the measurement uncertainty calculation for all of the calibration points, using recommendations from [4] and other documents and research works, for example [5]. We plan to research more details and conceptions of force measurement uncertainty in the future.

7. CALIBRATION OF LOAD RATE

In some cases (particularly presses for concrete products) it becomes very important to maintain real time constant value of Load Rate. One of part our measurement system is the option "Calibration Load Rate", that permits by usage Load Cell, Amplifier and Computer to measure and to print calibration results (figure 2)



Results for: 34-54 seconds	
Load Rate	0.68kN/s
Uncertainty	0.09kN/s

Figure 1: Calibration Load Rate

8. SHORT TIPS

1. For the calibration of force machines which destroy the product (tension of textile or steel products, compression of concrete products) and work in "Peak Hold" mode only, we have the option "Peak Hold". This option permits the operator to synchronize work of the UUT and Standard Instrument (SI), and to perform the calibration on high level from uncertainty point of view.

2. The option "Expected Deviation" is very comfortable mean for indicating measurement process in real time. The operator has important measurement information (relative accuracy error) about calibration process in each measurement point.

3. MABA-2000 calculates sets (combinations) of weights for calibration by Dead Weight method using the resolution like the indicated- see (1) and (2).

9. CONCLUSIONS

1. We have proved the possibility to use an "on line" method for writing the measurement results, using a mathematically proven model.

2. Calculation method of the relative accuracy and repeatability errors can be wider than the ISO 7500 standard definitions.

3. ISO-7500 can be extended for non-force units scaled devices.

4. By the system of calibration force measurement devices MABA-2000 it is possible to calibrate Load Rate of force.

5. The system MABA-2000 includes some comfortable means (mode "Peak Hold", mode "Expected Deviation", etc.)

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