Uncertainty evaluation in the self-alignment test of the upper plate of a press

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Abstract. This paper describes a method to evaluate uncertainty of the self-alignment test of the upper plate of a press according to EN 12390-4:2000. The method, the algorithms and the sources of uncertainty are described.

1. Introduction

The testing machinery used to carry out tests on hardened cement are required to comply with a standard specifying their own calibration. In terms of the calibration associated with the measuring force system, the main difference between the two most used standards is the existence of three classes in standard EN 12390-4:2000 instead of four classes in standard ISO 7500-1:2004, with the elimination of class 0,5.

Despite great emphasis in the application of force in both standards, standard EN 12390-4:2000 sets three compulsory tests in order to guarantee that the force applied on the specimen acts uniaxially.

2. Testing equipment

Annex A of standard EN 12390-4:2000 specifies that the execution of the test should be implemented with the use of a cylinder made of chromium-nickel steel. Its dimensions include a diameter of 100 ± 1 mm and a height of 200 ± 1 mm. It must be instrumented with four complete Wheatstone bridges and with thermal compensation. The placement of the four bridges must be at half the height of the cylinder and at opposite sides. This transducer should be used together with an amplifier display unit, promoting a balanced output signal in a position without any force applied.

The standard specifies a maximum admissible error for the set transducer/display unit of 0.1 % or 5x10⁻⁶ mV/V. The calibration of this transducer should be carried out with traceability to national or international standards every two years (at most).

It is usual the certificates for these transducers to be conclusive, stating that the set transducer/display unit is able to perform tests according to a particular standard.
3. Test according to EN 12390-4:2000

In order to qualify a press used in the hardened cement test, it is required to perform three tests to quantify the self-alignment of its upper plate, the alignment of the components of the press and the restrictions to the movement of the upper plate.

3.1. Self-alignment of the upper plate

The self-alignment of the upper plate is evaluated by the application of a force between 200 kN and 220 kN. The values of the four bridge positions are registered simultaneously when the plate is tilted to point A and then to point C, in the axis BD, and to point B followed by point D, in the axis AC.

The extension ratios are determined according to expression (1) for each strain gauge and for each position

\[ r_n = \frac{e_n - e_m}{e_m} \]  

(1)

The self-alignment is determined in relation to the strain gauge bridge by the difference between the highest value of \( r_n \) and the lowest value of \( r_n \) on the four positions of the upper plate, using expression (2)

\[ \Delta r_n = r_n_{\text{máximo}} - r_n_{\text{mínimo}} \]  

(2)

With this procedure, to evaluate the self-alignment of the upper plate four force applications are required, one for each upper plate tilting, in all four directions (A, B, C e D), and for each force application four values are registered with respect to the four strain gauge bridges of the force transducer (1,2,3 and 4).
3.2. Uncertainty evaluation

The main sources of uncertainty associated with this test, arise from the four bridges force transducer. This transducer is classified by the manufacturer as being class 1, according to standard ISO 376:2011.

During the four repetitions of force application, it is difficult to stabilize the cement test machine in exactly the same value of force, thus the source of uncertainty considered was reproducibility instead of repeatability.

As the reading is in electrical signal and not directly in units of force, the interpolation error was not considered.

Table 1: Sources of uncertainty considered

| Source of uncertainty               | Type and Distribution | Value   | Origin                              |
|-------------------------------------|-----------------------|---------|-------------------------------------|
| Maximum error                       | B-R                   | 0.10 %  | EN 12390-4:2000                     |
| Reproducibility                     | B-R                   | 0.20 %  | ISO 376:2011 – class 1              |
| Zero                                | B-R                   | 0.05 %  | ISO 376:2011 – class 1              |
| Creep                               | B-R                   | 0.10 %  | ISO 376:2011 – class 1              |
| Uncertainty of calibration          | B-N                   | 0.05 %  | ISO 376:2011 – class 1              |
| Temperature effect during test      | B-R                   | 0.10 %  | technical documentation (Δt ≤ 10 K) |

It is expected that temperature variations occur during the test, and they might affect each amplifier in different ways. Therefore it was considered the maximum variation in electrical signal for a 10 K variation, as given by the manufacturer.

Table 2: Self-alignment of upper plate test results

| Force / kN | e1    | e2    | e3    | e4    |
|------------|-------|-------|-------|-------|
| 200        | 0.12644 | 0.18912 | 0.17060 | 0.14917 |
| 200        | 0.11857 | 0.20090 | 0.17499 | 0.14845 |
| 200        | 0.11976 | 0.19239 | 0.17356 | 0.14855 |
| 200        | 0.12084 | 0.19011 | 0.16387 | 0.14103 |

A full measurement was done and the results are given on table 2. The transducer was centred on the lower plate of the press using a digital calliper and its estimate to be centred at ± 0.05 mm.

The extension ratios and associated uncertainty are shown in Table 3. The uncertainty was calculated using the law of propagation of uncertainty according to GUM 2008 [1].

Table 3: Values of extension ratios and uncertainty

| Δr₁  | Δr₂  | Δr₃  | Δr₄  |
|------|------|------|------|
| 0.058 | 0.059 | 0.030 | 0.023 |

| uΔr₁ | uΔr₂ | uΔr₃ | uΔr₄ |
|------|------|------|------|
| ± 0.0048 | ± 0.0065 | ± 0.0068 | ± 0.0054 |
To perform a validation of results a Monte-Carlo simulation was carried out, for a number of trials of $10^6$. The number of trial was select according to JCGM 101:2008 to deliver a 95 % coverage interval for the output quantity such that this length is correct to one or two significant decimal digits\(^2\).

The extension ratios and associated uncertainty, considering the output distribution as Gaussian ($k=2$), are shown in Table 3.

**Table 4:** Values of extension ratios and uncertainty using Monte-Carlo simulation

| $\Delta r_1$ | $\Delta r_2$ | $\Delta r_3$ | $\Delta r_4$ |
|--------------|--------------|--------------|--------------|
| 0.058        | 0.059        | 0.030        | 0.023        |

| $U\Delta r_1$ | $U\Delta r_2$ | $U\Delta r_3$ | $U\Delta r_4$ |
|---------------|---------------|---------------|---------------|
| $\pm 0.0049$  | $\pm 0.0067$  | $\pm 0.0062$  | $\pm 0.0053$  |

Using the procedure described by point 8 of JCGM 101:2008 it’s possible to validate the uncertainty results obtained early. It was considered only one significant digit on the uncertainty so the $\delta$ is equal to 0,0005.

On table 5 are listed the values of $y_{low}$ and $y_{high}$ obtained by the Monte-Carlo simulation and the limits $d_{low}$ and $d_{high}$ used to assess the validity. These absolute values must be not larger than $\delta$ calculated earlier.

**Table 5:** Values $y_{low}$, $y_{high}$, $d_{low}$, $d_{high}$

| $y_{low}$    | $\Delta r_1$ | $\Delta r_2$ | $\Delta r_3$ | $\Delta r_4$ |
|--------------|--------------|--------------|--------------|--------------|
| 0.0536       | 0.0527       | 0.0238       | 0.0183       |

| $y_{high}$   | $\Delta r_1$ | $\Delta r_2$ | $\Delta r_3$ | $\Delta r_4$ |
|--------------|--------------|--------------|--------------|--------------|
| 0.0631       | 0.0657       | 0.0365       | 0.0287       |

| $|d_{low}|$    | $|d_{high}|$ |
|--------------|--------------|
| 0.00001      | 0.00005      |
| 0.00001      | 0.00005      |

**4. Conclusions**

An estimate of the measurement uncertainty using the law of propagation of uncertainty was performed for the self-alignment of the upper plate of a press in accordance with standard EN 12390-4:2000.

It was used also a Monte-Carlo simulation. The uncertainties obtained for both methods were similar. To validate the results it was used the procedure described by point 8 of JCGM 101:2008. The uncertainty must be rounded to one significant digit in order to validate the procedure.

The values of uncertainty obtained are of a magnitude several dozens of times lower than the maximum admissible value of that standard (0.10).

However, only the effects attributable to the force transducer were taken into account.

The correct positioning of the transducer on the bottom plate is of vital importance. Those effects were not analysed in this paper, however it is strongly suggested to include a source of uncertainty to account for them.
References
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