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# Accuracy assessment of an industrial actuator

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## Abstract

A commercial linear actuator equipped with a 0.1 µm resolution encoder was used as a contact displacement sensor with adjustable force. The accuracy of the position reading of the actuator was evaluated from experimental data taking into account the uncertainty contributions. The tests consisted of length measurements of grade 0 steel gauge blocks. Measurements with different values of contact force were performed to assess its influence. A statistical analysis of the experimental data was performed to support the accuracy assessment. Systematic effects were identified and corrected. An expanded uncertainty ($k$=2) lower than 1 µm was estimated.

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*Keywords:* Actuator; Accuracy; Uncertainty.

## 1. Introduction

Dimensional measurements using contact sensors are affected by the measuring force applied by the measuring equipment. The systematic effect of the elastic deformation is compensated when the geometry of the contact and the material properties are known [1]. The uncertainties of the compensation may compromise the overall accuracy of the measurement especially when elastic deformations are high and the materials properties are not well defined, i.e. when measuring polymer parts. In this context, a measuring system with an adjustable measuring force is useful for defining the systematic effect of the contact force during the measurement.

The contact displacement sensor selected is a commercial linear actuator equipped with an encoder for a feedback control of the position. The system has been tested using reference artifacts and the uncertainty has been assessed using a statistical method compliant to the "*Guide to the expression of Uncertainty in Measurement" (GUM)* [2]. The main contributions to the uncertainty were identified using the *Procedure for Uncertainty Management (PUMa method)* described by ISO 14253-2 [3]. These statistical tools have already been effectively employed in uncertainty estimations of measuring equipment [4-5].

## 2. Measuring process

### 2.1. Measuring system

- Actuator: the linear actuator is produced by SMAC Corporation (US). The main characteristics are listed in Table 1.

Table 1. Actuator features.

| | |
|---|---|
| Dimensions / mm | 70×55×25 |
| Stroke / mm | 10 |
| Voltage supply / V | 24 |
| Maximum current / A | 1.6 |
| Encoder resolution / µm | 0.1 |
| Nominal force / N | 3 |

The actuator is provided with a linear encoder, with a glass measuring scale, to feed a closed loop control. Thus it can move controlling the force, the position, the speed or the acceleration of the stem. A built in instruction package

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allows to use it as contact displacement sensor (the stem moves slowly and stops as soon as the contact with an object is detected).
- Gauge blocks: grade 0 steel gauge blocks (ISO 3650 [6]) are used as reference object to be measured. The blocks are wrung together to cover 8 mm stroke with steps of 1 mm. The coefficient of thermal expansion (CTE) of the blocks is 11.5 ppm/°C, as reported in the calibration certificate.
- Metrology frame: the main frame consists of a main plate and supports made in invar, with a CTE equal to 1.6 ppm/°C. The actuator is fixed on the plate by means of two clamps. The gauge block is placed on a flat surface and the correct position on the plane is ensured by a three points contact.

### 2.2. Definition of the measuring task

The aim of the work is the determination of the metrological characteristics of the measuring system (described in detail in Section 2.1). Random and systematic effects are investigated under different conditions (measuring force and position of the actuator stem). The use of statistical tools allows for the separation of random and systematic contributions of the measurement errors.

The output signal of the system consists of the encoder counts. It can be transformed into length units applying a multiplicative factor to be defined from the measurements.

The contact force applied during the measurement is controlled by measuring the current consumption of the actuator. This force has been varied from 0 N to 3 N. The standard uncertainty of the force measurements is estimated to be 0.015 N, from a preliminary investigation using a calibrated load cell.

The experiments are performed in a metrology laboratory with a controlled ambient temperature. Even if the temperature on the measuring system is not directly measured, a reasonable temperature range may be defined basing on previous measurements.

The measurand is defined as the encoder output (i.e. the position of the actuator stem measured by the internal encoder) when the tip of the stem is in contact with the reference object.

The measuring setup is represented in a simplified form in Fig. 1.

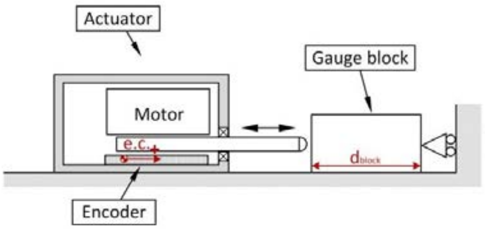

Fig. 1. The measuring setup (e.c. = encoder counts, $d_{block}$ = dimension of gauge block).

From the particular orientation of the reference system, the smaller is the gauge block under measurement the bigger the output of the encoder. When performing the data analysis, the raw data values are rescaled as follows:
- The values are transformed from encoder counts into millimeters (1 e.c. = $10^{-4}$ mm).
- The values are shifted of a constant value to make the output relative to the bigger gauge block to coincide to zero. Consequently, all the values are nominally positive and represent a relative variation of the encoder output.

### 2.3. Experimental procedure

The calibration procedure consists in measuring the length of gauge blocks of 9 different dimensions (from 20 mm to 12 mm, with a step of 1 mm) with 8 different contact forces (nominally 0.17 N, 0.33 N, 0.50 N, 0.66 N, 0.83 N, 1.00 N, 2.00 N, 3.00 N).

The test is performed in the following way:
1. The gauge block is positioned.
2. The actuator is programmed to measure the gauge block with each of the different force level.
3. The gauge block is repositioned and step 2 is repeated. Step 3 is repeated 3 times.
4. The gauge block is replaced with another one of different dimension and steps 2 and 3 are repeated.
5. The whole procedure is repeated another time for a total of 6 repeated measurements for each combination of gauge block and measuring force.

## 3. Definition of the mathematical model

The mathematical model for the measured length $D$ may be expressed by three additive terms, i.e.:

$$D = D_{scale} - \Delta L_{force} - \Delta L_{gauge} \tag{1}$$

where $D_{scale}$ is the component of the measured length taking into account the thermal expansion of the glass measuring scale, $\Delta L_{force}$ is the deformation due to the contact force and $\Delta L_{gauge}$ is the thermal expansion of the measured gauge blocks.

The first term of the mathematical model ($D_{Scale}$) may be expressed as follows:

$$D_{scale} = (r - r_0) \cdot \alpha \cdot \left[1 + CTE_{scale} \cdot (T - 20)\right] \tag{2}$$

where $r$ is the raw encoder output, $r_0$ is the reference for zeroing the encoder output, $\alpha$ is the transformation factor (from encoder counts to millimeters), $CTE_{scale}$ is the thermal expansion coefficient of the glass measuring scale and $T$ is the temperature of the whole system. Considering now directly the lengths of the blocks, equation (2) becomes:

$$D_{scale} = (L_{20} - L_{block}) \cdot \left[1 + CTE_{scale} \cdot (T - 20)\right] \tag{3}$$

where $L_{20}$ is the length of the 20 mm gauge block used to zeroing and $L_{block}$ is the length of the measured block. Since