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# ASSURING THE TRACEABILITY OF ELECTRONIC LEVELS FOR CALIBRATION OF GRANITE SURFACE PLATES

***A. Gusel, B. Acko and A. Sostar***
Laboratory for Production Measurement, Faculty of Mechanical Engineering
University of Maribor, 2000 Maribor, Slovenia

*Abstract: Surface plates are used in the industry and measurement laboratories for performing measurements of length, angles and deviations of form and position of measured subjects, for checking and control of measurement bars and rulers. Our aim is to perform a calibration of the surface plate without involving either interferometric system or autocollimator, which would be too expensive, therefore using only electronic levels. And even when the appropriate device for calibration is chosen, the decision between many different types of algorithms has to be made. On top of all, traceability of measurement must be also assured. Research work in this field, represented in this article, is focused mainly on assuring the calibration traceability of results when performing measurements of flatness with electronic levels. Traceability is assured with accurate sine bar SL001, developed in our laboratory especially for purposes of very precise calibrations.*
*Keywords: flatness measurement, surface plates, traceability assurance*

## 1 INTRODUCTION

Surface plates are used in the industry and measurement laboratories for performing measurements of length, angles and deviations of form and position of measured subjects, for checking and control of measurement bars and rulers. Surface of the measurement plate therefore represents a basic, reference plane, mostly all of form and/or position measurements are depended on. Surface plates are classified into different quality classes upon exactness of flatness (00, 0, 1, 2, 3). When calibrating a surface plate, measurement grid is drawn with the lead pencil onto the surface of the plate, and the measurement itself is executed according to the grid. Two types of measurement grids are commonly used: Union Jack and rectangular grid. Calibrated quantity is flatness of the upper surface of the plate.

Calibration of the surface plate can be performed with various devices:

- Laser interferometers,
- Electronic levels and
- Autocollimators.

Most commonly used devices for flatness measurements are electronic levels. Advantages of electronic levels over other measuring devices are: they are inexpensive, simply to use and the measurement can be quickly and easily performed. It is also the only measurement method which allows the measurement device to be moved.

When performing a flatness measurement, attention must be paid to:

- Temperature of environment, measuring devices and surface plate,
- Dimension of the surface plate,
- Environment conditions (humidity, air pressure, draft…),
- Dust, dirt and
- Human impact.

## 2 CALIBRATION PROCEDURE

Measuring surface is cleaned using special liquid for stone surface (granite or ceramic plates) and a soft paper towel. Base of electronic level must also be cleaned to remove retarded dirt. Thermal stabilization of a surface plate is not foreseen, because the calibration itself is performed at the current conditions in the laboratory. When exposed to greater temperature differences (between room temperature and level temperature – at transportation), electronic levels must be thermally stabilized for 2 hours to prevent temperature drift between electronic level and surface plate that could also affect measurement. Measuring surfaces are checked to see if there are any scratches or other damages that could impede calibration. Demands that have to be fulfilled when drawing the grid:

- The map should be drawn on a sheet of paper with highlights located on the surface plate itself with soft lead pencil that does not scratch surface.
- Markings should not be put directly on the grid lines, since the levels must be free to slide on the surface along these lines.
- The length of each line should be an even-integer multiple of the length of the foot-spacer or level base (only when using Union Jack grid; when using rectangular grid, odd-integer multiples are allowed).

Characteristic data is entered into the program. Electronic level is carefully positioned along the steel ruler on first line of the grid. Deviations of first grid line are measured and recorded by the computer. Procedure is repeated until all lines are measured. Measurement evaluation is performed by algorithm, included in manufacturers software.

## 3 ASSURANCE OF TRACEABILITY WHEN PERFORMING MEASUREMENT OF FLATNESS ON SURFACE PLATES

When calibrating a surface plate (performing a measurement of flatness), measuring device, used in the measurement, is electronic level. In order to assure the traceability of the results, electronic levels must be calibrated. Measurement equipment used for the calibration is:

- Sine bar SL 001, calibrated in LTM using CMM ZEISS UMC 850; sine bar was constructed and produced in Laboratory for Production Measurement, for purposes of exact calibrations of electronic levels with extreme accuracy. Normally, such bars are around 300 mm long; this one is 500 mm in length. The exact length L between the support balls of the sine bar SL 001 is calibrated on CMM ZEISS UMC 850, with uncertainty of U = 4 μm.
- Gauge blocks KOBA and CARL ZEISS (both class K),
- Temperature measurement system ZEISS TEMP 10.

### 3.1 Measured characteristics of electronic levels

Following characteristics of electronic levels are measured/checked:

- Cross (side) stability (DIN 877): Allowed deviation of the inclination of the main level meter at side inclination of 10° is one scale increment or 20 μm/m (greater of both values is taken).
- Allowed drift of electronic level meters (DIN 2276): Drift in one hour should not be greater than 0,05% of the measuring range.
- Measurement of deviation of zero indication,
- Setting of zero (absolute) indication on level meters that can measure relative angles,
- Measurement of deviation of zero indication of the horizontal and vertical surface,
- Measurement of the scale deviation,

Inclination adjustment on sine bar:

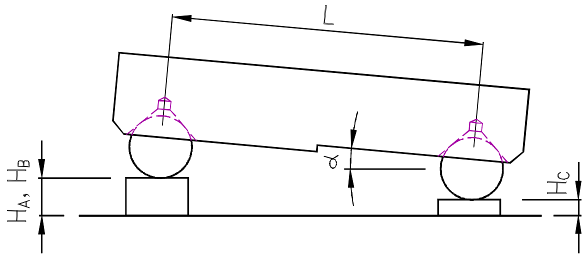


**Figure 1.** Sine bar SL001, used for calibration of electronic levels

Angle of the sine bar is calculated with the formula:

$$a = \arcsin \frac{H_C \text{ -1- } (\frac{H_A + H_B}{2})}{L} \tag{1}$$

$\alpha$ – angle of the sine bar in degrees
$L$ – distance between the support balls in [mm]
$H_A$ – length of the gauge block in the support »A« in [mm]
$H_B$ – length of the gauge block in the support »B« v [mm]
$H_C$ – length of the gauge block in the support »C« v [mm]

Possible inclination steps:

- 0,002 mm/m (0,41") within range of ±0,02 mm/m (±4,13")
- 0,020 mm/m (4,13") within range of ±1,0 mm/m (±206,3")
- 0,200 mm/m (41,3") within range of ±2,0 mm/m (±412,5")

## 3.2 Measurement uncertainty analysis

Mathematical model of the measurement is described with the following equation:

$$ä_{á} = á_i + (L_K - L_{K0})/L_L - ä_Z/L_L - ä_{KR}/L_L \quad (2)$$

$ä_{á}$ angle deviation (calibrated value),
$á_i$ indication of the level meter,
$L_{K0}$ basic (starting) gauge block length,
$L_K$ actual gauge block length,
$L_L$ length of the sinus lineal,
$ä_Z$ deviation caused by wringing gauge blocks on the granite plate,
$ä_{KR}$ deviation caused by roundness deviations of the supporting balls.

### 3.2.1 Estimation of standard uncertainties of the input values and combined standard uncertainty

a) Uncertainty of level meter indication:

- The greatest deviation of indication on (electronic) level meter with digital indication and resolution 1 µm/m is ±0,5 µm/m; standard uncertainty at supposed rectangular distribution is u = 0,29 ìm/m.
- The greatest deviation of indication on (electronic) level meter with analogous indication (scale with pointer) and resolution 1 µm/m is ±0,2 µm/m; standard uncertainty at supposed rectangular distribution is u = 0,12 ìm/m.
- The greatest deviation of indication on (liquid) level meter with analogous indication (scale on the glass tube) and resolution 20 µm/m is ±10 µm/m; standard uncertainty at supposed rectangular distribution is u = 5,78 ìm/m.

b) Uncertainty of adjusted angle (inclination) caused by length deviations of the sinus lineal and the gauge block:

- The greatest possible deviation of the length difference between two gauge blocks (starting and actual gauge block) is ±0,1 µm (uncertainty of calibration of each gauge block is 0,05 µm, temperature deviation is negligible).
- The greatest possible deviation of the length of the lineal is ±7 µm (uncertainty of calibration of the distance between the supporting balls on CMM is 4 µm, and the greatest possible deviation caused by temperature deviation, which is in the limits ±1°C, is about ±5,5 µm).
- The greatest possible angle span caused by above length deviations is ±0,40 µm/m at the smallest measured angle and ±0,46 µm/m at the greatest measured angle; standard uncertainty at supposed rectangular distribution is u = 0,20 µm/m res. u = 0,23 µm/m.

c) Uncertainty caused by wringing gauge blocks on the granite plate:

- The following experiment was made: gauge block 1,000 mm was wrung on the granite plate several times and the distance between the plate and the top surface of the gauge block was measured each time (using inductive probe). The deviation between two extreme measured values was 0,2 µm. This deviation can cause the angle span (in actual measurement of level meter) of ±0,4 µm/m; standard uncertainty at supposed rectangular distribution is u = 0,23 µm/m.

d) Uncertainty caused by roundness deviation of the supporting balls:

- The roundness deviation on the contact segment of the ball is according to the producer data equal to 0,1 µm. This can cause the greatest angle span of ±0,4 µm/m; standard uncertainty at supposed rectangular distribution is u = 0,23 µm/m.

**Table 1.** Standard uncertainties of the input value estimations on the lower limit of the measurement range

| Value X$_i$ | Estimated value [ìm/m] | Standard uncertainty [ìm/m] | Distribution | Sensitivity coefficient | Uncertainty contribution [ìm/m] | | |
|---|---|---|---|---|---|---|---|
| á$_{id}$ | 2,0 | 0,29 | rectang. | 1 | 0,29 | | |
| á$_{ik}$ | 2,0 | 0,12 | rectang. | 1 | | 0,12 | |
| á$_{im}$ | 2,0 | 5,78 | rectang. | 1 | | | 5,78 |
| (L$_K$-L$_{K0}$)/L$_L$ | 2,0 | 0,20 | normal | 1 | 0,20 | | |
| ä$_Z$/L$_L$ | 0 | 0,23 | rectang. | 1 | 0,23 | | |
| ä$_{KR}$/L$_L$ | 0 | 0,23 | rectang. | 1 | 0,23 | | |
| | | | | Total: | 0,56 | 0,42 | 8,18 |

á$_{id}$ angle indication on electronic level meter with digital indication,
á$_{ik}$ angle indication on electronic level meter with analogous indication (pointer),
á$_{im}$ angle indication on liquid level meter,

**Table 2.** Standard uncertainties of the input value estimations on the upper limit of the measurement range

| Value X$_i$ | Estimated value [ìm/m] | Standard uncertainty [ìm/m] | Distribution | Sensitivity coefficient | Uncertainty contribution [ìm/m] | | |
|---|---|---|---|---|---|---|---|
| á$_{id}$ | 2000 | 0,29 | rectang. | 1 | 0,29 | | |
| á$_{ik}$ | 2000 | 0,12 | rectang. | 1 | | 0,12 | |
| á$_{im}$ | 200 | 5,78 | rectang. | 1 | | | 5,78 |
| (L$_{K1}$-L$_{K0}$)/L$_L$ | 2000 | 0,23 | normal | 1 | 0,23 | | |
| ä$_Z$/L$_L$ | 0 | 0,23 | rectang. | 1 | 0,23 | | |
| ä$_{KR}$/L$_L$ | 0 | 0,23 | rectang. | 1 | 0,23 | | |
| | | | | Total: | 0,57 | 0,43 | 5,18 |

According to EAL coverage factor k=2 is used for the calculation of the expanded uncertainty. It was found out that the uncertainty is almost equal over the entire measurement range. The greatest uncertainty was taken for all cases and rounded up.

The expanded uncertainty for electronic level meters (resolution 1 μm/m) is:
U = 1,3 μm/m – for electronic level meters with digital indication and
U = 1,0 μm/m – for electronic level meters with analogous indication.

### 3.2.2 Uncertainty of measurement of zero indication deviation

Uncertainty was evaluated by experiment. Zero indication measurement was repeated 20 times. Statistical evaluation made no sense, since the deviation between two extreme results was 1 digit (electronic level meter with resolution 1 μm/m was used).

Expanded standard uncertainty was therefore evaluated to be:
U = 1 μm/m.

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**AUTHORS:** A. GUSEL, B. ACKO and A. SOSTAR,Laboratory for Production measurement, Faculty of Mechanical Engineering, University of Maribor, Smetanova 17, 2000 Maribor, Slovenia, Phone ++386 62 220 7579, Fax ++386 62 220 7990, E-mail: andrej.gusel@uni-mb.si