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Declination angle gage for tilt measurement sensors

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Abstract

There are many examples of devices which need information about tilt angle. Legged mobile robots need tilt information for locomotion stabilization. Coaxial two wheeled mobile devices and snake like robots need tilt information for vertical stabilization. Safety systems for monitoring of dangerous tilt angle are sometime needed. The calibration and testing process is very important before using of the tilt sensors. This paper deals with declination angle gage for testing of these tilt sensors. Declination angle gage allows setting any reference angle for testing of tilt sensor. Calibration and testing process explores the validity and uncertainty of measurement through the tested tilt sensor.

Keywords: declination, tilt measurement, uncertainty, gage

Nomenclature

DAG	declination angle gage (abbreviation)
H_1	dimension between the left setting roller centre and upper surface (mm)
H_2	dimension between the right setting roller centre and upper surface (mm)
L_{SP}	pitch of setting rollers axis (mm)
L_{ZMR}	dimension of linear gage block (mm)
R_1	radius of left setting roller (mm)
R_2	radius of right setting roller (mm)
$u_{B\alpha SP}$	standard uncertainty (type B) of declination angle gage DAG (rad, deg °)
t_{Hx}	pulse width (ms)
$Z_{MAX\alpha SP}$	maximum inaccuracy of declination angle gage DAG (rad, deg °)
$Z_{MAX\alpha SPmm}$	maximum parallelism deviation of declination angle gage DAG verified with angle gage block (mm)

Greek symbols

α_{SP}	angle of declination angle gage DAG (rad, deg °)
α_{SPMAX}	maximum angle of declination angle gage DAG (rad, deg °)
α_{SPMIN}	minimum angle of declination angle gage DAG (rad, deg °)
α_{SP1}	angle between the join of setting rollers centres and horizontal plane of DAG (rad, deg °)
α_{SP2}	angle between the ideal upper surface and real declined upper surface of DAG (rad, deg °)
α_{SP1MAX}	maximum angle between the join of setting rollers centres and horizontal plane of DAG (rad, deg °)

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α_{SP1MIN}	minimum angle between the join of setting rollers centres and horizontal plane of DAG (rad, deg °)
α_{SP2MAX}	maximum angle between the ideal upper surface and real declined upper surface of DAG (rad, deg °)
α_{SP2MAX}	minimum angle between the ideal upper surface and real declined upper surface of DAG (rad, deg °)
δ_{R1}	geometric deviations of left setting roller (mm)
δ_{R2}	geometric deviations of right setting roller (mm)
δ_{H1}	geometric deviations of dimension H_1 (mm)
δ_{H2}	geometric deviations of dimension H_2 (mm)
δ_{LSP}	geometric deviations of dimension L_{SP} (mm)

1. Introduction

Problem of locomotion stabilization of mobile robots and vehicles are very often solved through the accelerometers or any other tilt sensors [1-6]. Verification of these sensors can be realized with an angle reference etalon – "declination angle gage - DAG" with suitable uncertainty of measurement. Declination angle gage can be realized with sine bar with gage block [7, 8]. Tilt angle depends on dimension value of gage block. Sine bar (fig. 1) consist of upper surface and two setting rollers. Pitch length of setting rollers is calibrated and known (e.g. 200 mm). Sine bar is placed on granite surface plate adjusted with water level. Tilt sensor is placed on upper surface of sine bar. One of the setting rollers is lifted with linear gage block. Tilt angle depends on linear gage block dimension and pitch of setting rollers.

Tilt sensor with pulse width modulation output signal has been tested on this declination angle gage stand (fig. 1).

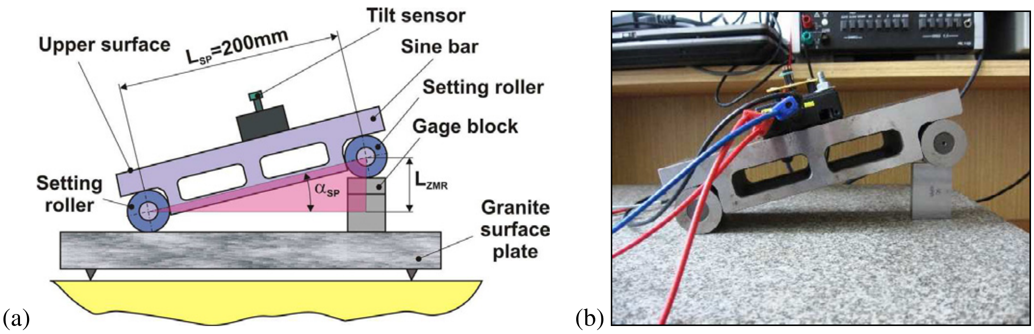


Fig. 1. Arrangenement of testing stand with sine bar and linear gage block for setting of selected tilt angle value.

2. Testing setup and measurement

Selected angle of sine bar is adjusted with suitable dimension of linear gage block. Our tested tilt sensor reacts through the pulse width of output signal. Steady state output value of pulse width can be measured with various methods (fig. 2). Measurement stand (fig. 3) includes:

- Basic Atom microcontroller with LCD display (for visualization of measured value).
- Digital storage oscilloscope for measuring of pulse width of sensor output signal.

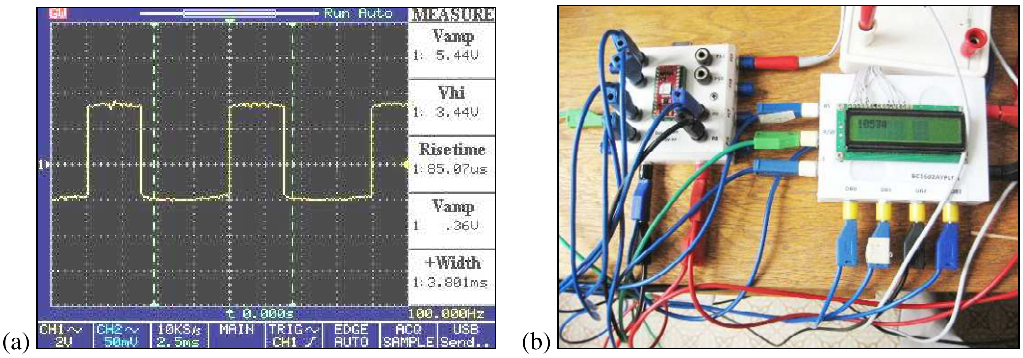


Fig. 2. Measurement of pulse with of sensor output signal.

Minimum count of measurement is 10 for obtaining of standard uncertainty of type A (measurement with same conditions) [9]. More samples (e.g. 100 measurements with same measurement conditions) are useful for histogram evaluation and identification of probability distribution law. Measured data can be used in math statistical test for normality or other statistical test for probability of data distribution law. It is possible to choose coverage factor after identification of probability distribution law. Coverage factor enables to compute the standard uncertainty and extended uncertainty of measurement.

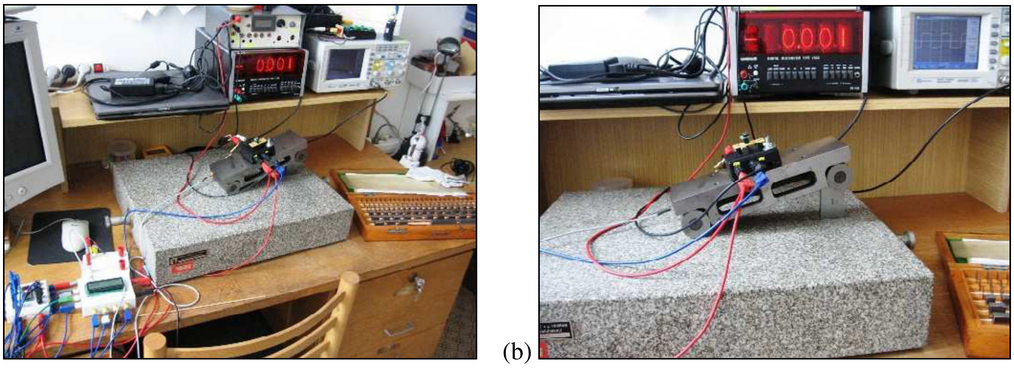
(a) (b)


Fig. 3. Measurement experimental setup for tilt sensor testing.

Mean values of measured data for both methods (Basic Atom microcontroller and digital storage oscilloscope) are shown on fig. 4. Every mean values is calculated from 10 measurements. These dependencies are fitted with polynomial functions. Data measured with microcontroller has better regression coefficient, than data measured with oscilloscope.

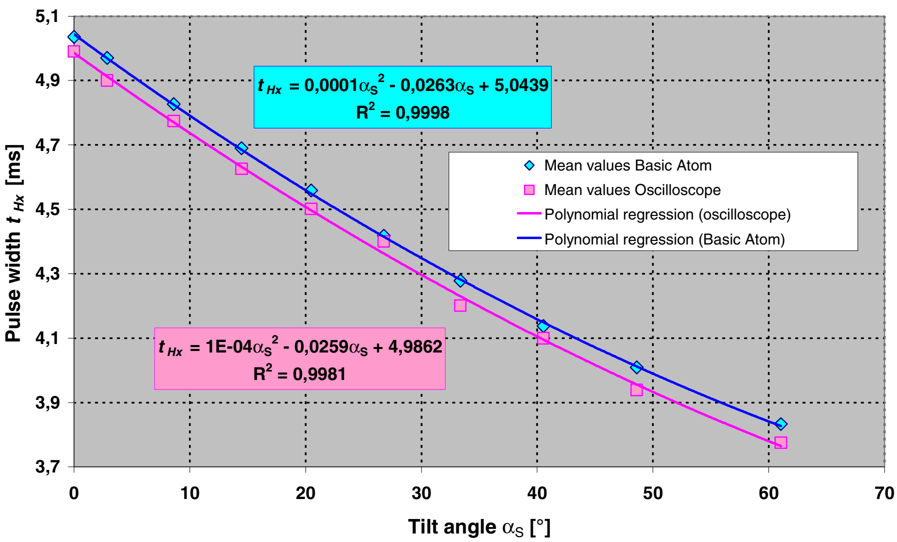


Fig. 4. Mean values of measured data and polynomial regression for both methods.

3. Maximum inaccuracy of declination angle gage

Maximum inaccuracy of DAG (fig. 5) is defined as interval, where real angle of DAG lies (with respecting of geometric deviations of all DAG parts). Math model of DAG is defined as:

$$\sin \alpha_{SP} = \frac{L_{ZMR}}{L_{SP}} \quad (1)$$

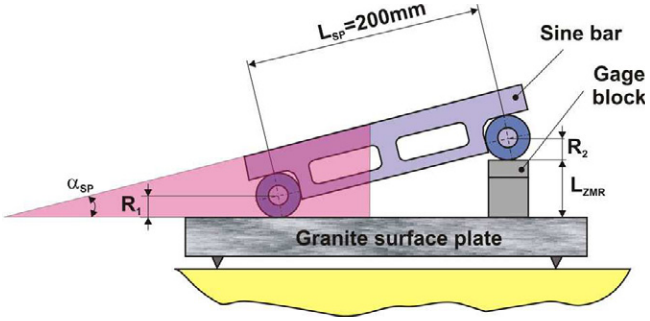


Fig. 5. Model of declination angle gage DAG.

Previous model is insufficient for analysis of its maximum inaccuracy from the viewpoint of geometric deviations of sine bar and linear gage block. Influence of sine bar inaccuracy can be evaluated in two phase:

- Change or inaccuracy of tilt angle caused with geometric deviations of setting rollers.
- Change or inaccuracy of tilt caused with geometric deviations of upper surface.

In accordance with these phases, it is possible to decompose model of declination angle gage into two partial models (fig. 6, fig. 7):

- model of angle between the join of setting rollers centres and horizontal plane α_{SP1},
- model of angle between the ideal upper surface and real declined upper surface (caused with geometric deviations) α_{SP2}.

$$\alpha_{SP} = \alpha_{SP1} + \alpha_{SP2} \tag{2}$$

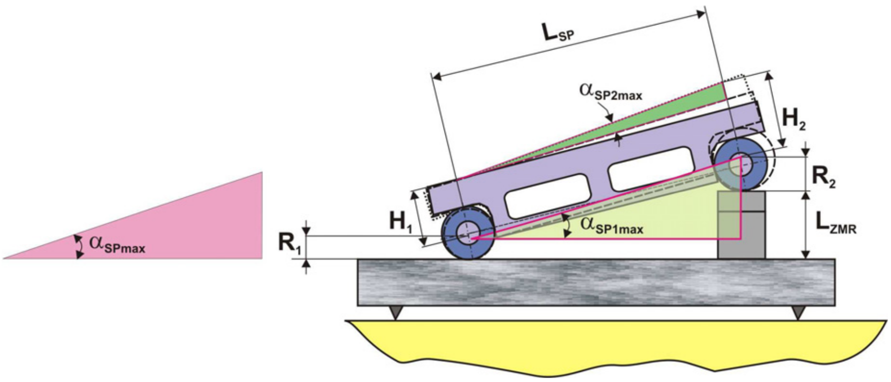


Fig. 6. Model of maximum angle of declination angle gage DAG α_{SPmax}.

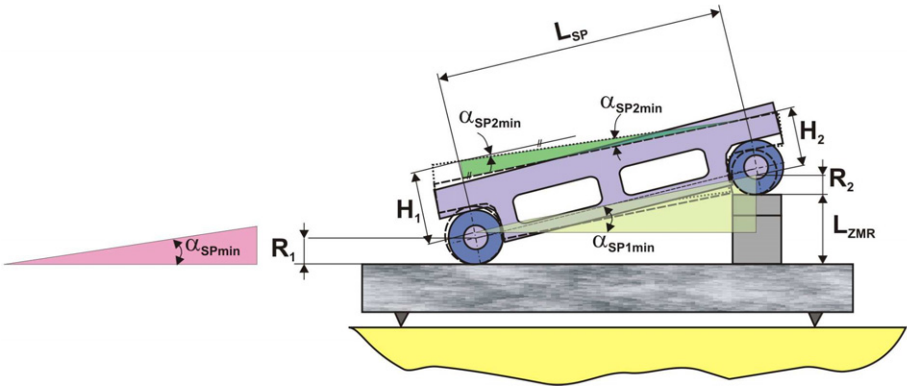


Fig. 7. Model of minimum angle of declination angle gage DAG α_{SPmin}.

Let's assume the producer deviations of all DAG parts declared by producer. Maximum DAG inaccuracy is possible to explain as difference between the maximum and minimum possible value of DAG adjusted tilt angle α_{SP}.

$$Z_{\max \alpha SP} = \alpha_{SP\max} - \alpha_{SP\min} \tag{3}$$

Maximum DAG angle α_{SPmax} is possible to obtain as sum of maximum values of angles α_{SP1max} a α_{SP2max}. Minimum DAG angle α_{SPmin} is possible to obtain as sum of angles α_{SP1min} and α_{SP2min}. Mentioned angles are defined as:

$$\alpha_{SP1\max,\min} = \arcsin \frac{L_{ZMR} + R_2 - R_1}{L_{SP}} \tag{4}$$

$$\alpha_{SP2\max,\min} = \arctan \frac{H_2 - H_1}{L_{SP}} \tag{5}$$

Producer of sine bar and gage block defines the maximum deviations of every dimension. Previous equations covert to equations with respecting of these deviations:

$$\alpha_{SP1\max,\min} = \arcsin \frac{(L_{ZMR} + \delta_{ZMR}) + (R_2 + \delta_{R2}) - (R_1 + \delta_{R1})}{L_{SP} + \delta_{LSP}} \tag{6}$$

$$\alpha_{SP2\max,\min} = \arctan \frac{(H_2 + \delta_{H2}) - (H_1 + \delta_{H1})}{L_{SP} + \delta_{LSP}} \tag{7}$$

Calculation of maximum and minimum angles (6) and (7) needs the analysis of deviations influence. All deviations of sine bar are constant for every angle but linear gage block deviation is different for every adjusted angle. Consequently, it is possible to draw graph of maximum inaccuracy of DAG for every case of linear gage block (fig. 8). Values on fig. 8 are sown in angle minutes of degree. Maximum value of DAG inaccuracy is 0.55° (i.e. 0.01rad). It is important to say, that it is maximum inaccuracy of DAG angle, which is coming from assumption of maximum possible deviations of every part of DAG. So it assumes worst case of every deviation. Generally in practise, situation is not so bed. Probability that this worst case occurs is only very small. Experimental way is one of the possible how to identify the maximum inaccuracy.

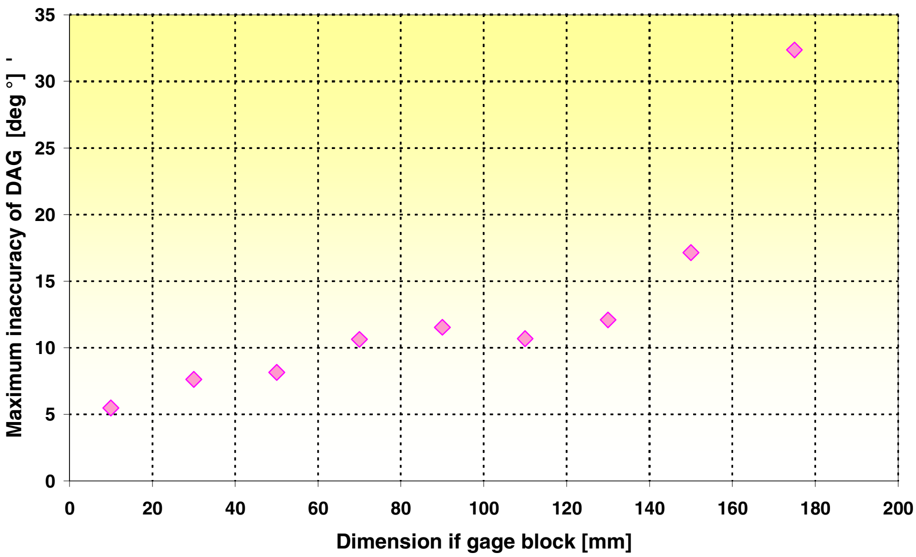


Fig. 8. Worst case of maximum inaccuracy of DAG angle for every case of linear gage block (theoretically computed value).

4. Experimental identification of maximum inaccuracy and uncertainty (typ B) of DAG angle for tilt measurement

Experimental verification of maximum inaccuracy of DAG angle is possible to realize with set of angle gage blocks (fig. 9). For selected angle gage block it is necessary to calculate (with equation 1) dimension of linear gage block for sine bar. After that DAG can be completed with angle gage block. It is necessary to measure deviation of parallelism between the upper side of angle gage and surface of granite table (fig. 10).

(a) (b)

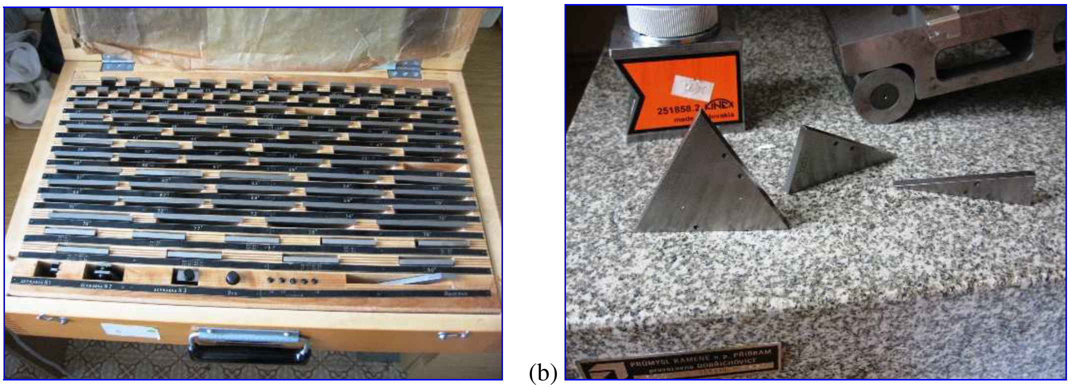


Fig. 9. Set of angle gages GOST 2875-62N U205.

This experimental identification needs to select:

- suitable nominal value of angle gage block,
- and dimension of linear gage block which corresponds to nominal value of DAG angle (computed from equation 1).

After completing of this arrangement (fig. 10), upper side of angle gage block should be parallel with granite surface. Parallelism deviation can be checked with dial indicator with holder. Dial indicator moves on upper surface of angle gage block. Ideal state is if deviation is zero displayed on dial indicator.

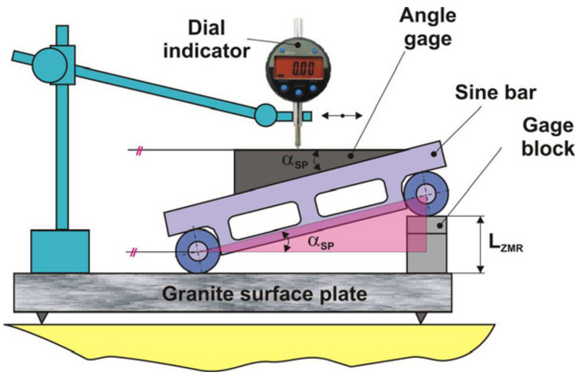


Fig. 10. Arrangement of experimental identification of maximum inaccuracy of DAG angle.

The selected angle gage block requires the accuracy possible linear gage block. The problem is limited possibilities to assemble any dimension. Standard set of linear gages enables to assemble arbitrary linear gage block with dimension resolution 0.005mm. Consequently, it is important to select nominal angle which enables to assemble linear gage block and angle gage block as accurately as possible. Error caused with rounding could deteriorate process of experimental identification of maximum inaccuracy.

Two combination of gage block have good minimum rounding error:

- angle gage block: 30° → linear gage block: 100.000mm
- angle gage block: 60° → linear gage block: 173.2051mm, (rounded: 173.205mm)

Experimental identification of maximum inaccuracy can be realized as it is shown on fig. 11. Our measured deviations are shown on fig. 12 for both combination of linear gage block and angle gage block.

(a) (b)

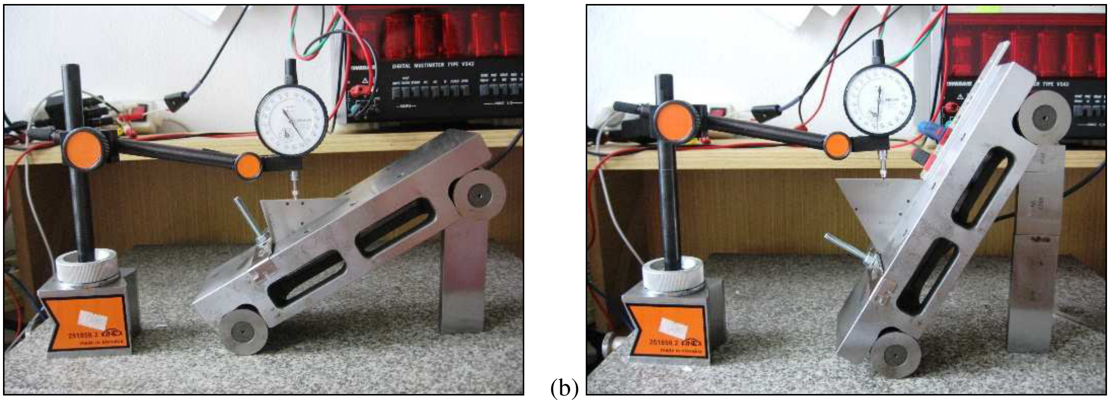


Fig. 11. Experimental identification of maximum inaccuracy of DAG angle.

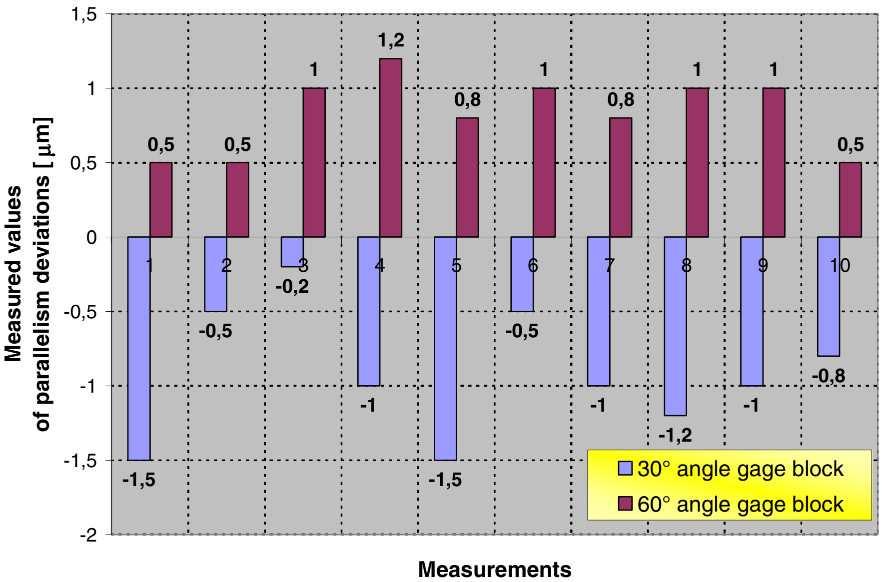


Fig. 12. Measured values of parallelism deviation in process of experimental identification of maximum inaccuracy of DAG angle.

Maximum parallelism deviation has value:

$$Z_{\max \alpha SPmm} = \pm 1{,}5 \mu m \tag{8}$$

This deviation can be converted to maximum inaccuracy of DAG angle.

$$Z_{\max \alpha SP} = \pm 2{,}13 \cdot 10^{-5} rad = \pm 0{,}0012204 44 \deg = \pm 5'' \tag{9}$$

5. Conclusion

Maximum inaccuracy obtained in experimental identification has much better value than theoretically value computed from worst case. It is necessary to note that experimentally obtained value includes inaccuracy of sine bar, inaccuracy of linear gage block and also inaccuracy of angle gage block with dial indicator placed in holder. It means that, worst case value has minimum probability.

Gaussian normal distribution can be assumed in determining of standard uncertainty type B. Coverage factor has value 2 for probability 0.95. Maximum standard uncertainty of type B on explored range of DAG has value:

$$u_{B\,\alpha\mathrm{SP}} = 1{,}07 \cdot 10^{-5}\, rad \pm 0{,}0006° = \pm 3'' \tag{10}$$

This uncertainty of “declination angle gage – DAG” is suitable for conventional accelerometers and tilt sensors [6].

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