543. Measurement of Angular Displacement by Means of Laser Scanner

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Abstract. The paper deals with the investigation of laser scanning instrument‘s possibility to be used for determination of the angular position or displacement of the object. Laser scanners are used widely in geodesy, structural and machine engineering areas. Such application gives new opportunities for measurement of an angle position of object in such places and positions, where usually used angle measuring instruments are not available or not possible to use. In this paper the determination of angular position of rotary device by means of plate freely placed on the rotating part and the laser scanning instrument is presented together with some experimental results of such layout application.
Keywords: angle, displacement, determination, laser scanner.

1. Introduction

Metrological calibration or testing of angle measuring instruments is quite important task ever since angle measurements were started to implement. These tasks are still of an extreme importance today since lots of angle measurement devices are implemented in many branches of industry, such as machine engineering, construction works, geodesy etc. Generally, there are several groups of plane angle measurement methods which could be implemented for the task in concern [1]:

- Solid angular gauge method:
  - polygons (multiangular prisms);
  - angle gauges, etc.
- Trigonometric method (angle determination by means of linear measurements);
- Goniometric method (plane angle determination by means of a circular scale):
  full circle (limb, circular scales, etc.);
  non-full circle (sector scales).

Usually, the calibration of angle measuring instrument is performed by means of the comparison of the instrument under testing against the reference one. Several technical decisions for the angle determination can be implemented in order to create a reference measure. The most significant means used for this purpose are [1]:

- Polygon/autocollimator;
- Moore’s Precision Index table;
- Circular scale/microscope(s);
- Angular encoders.
- Ring laser (laser gyro);
- Interferometric angle generator.

In case of the implementation of the mentioned devices for the angle comparison there is a need to use an expensive and complicated device for the creating of reference measure, also the precise alignment (centring and levelling) of the reference measure is needed [1]. Additionally, in some cases (as in case of use of polygon/autocollimator) only a limited number of angular positions could be tested or as it is typical using Moore's Precision Index or the circular scale, the entire process of calibration can hardly be automated. Some of methods, as the calibration devices using interferometer angle generator can not be implemented at industrial conditions.

In case of the calibration or testing of the low accuracy angle measuring instruments (turn tables in mechanical industry, construction site geodetic instruments etc.) some robust, uncomplicated (in terms of adjusting) and less sensible for the environmental conditions system is needed [2].

Here in this paper we describe a simple limited accuracy angle measuring instruments calibration method based on the laser scanning capabilities of geodetic instruments.

2. Principle of the Proposed Angle Testing/Calibration Method

The proposed principle of calibration of angle measuring instruments relies on the 3D point coordinates determination by the geodetic laser scanning equipment. A general principle of action of simplest instrument which can be implemented for the task (tacheometer with laser scanning possibilities) is shown in Fig 1.

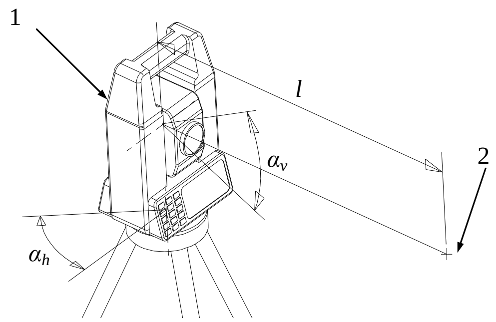


Fig. 1. Point position (coordinates) determination principle by measuring geodetic instrument: *1* – geodetic instrument (tacheometer), *2* – point which coordinates had to be determined

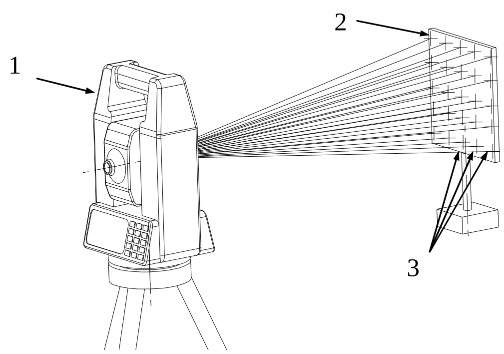


Fig. 2. Mesuring of point cloud of plate surface: *1* – geodetic angle instrument (tacheometer), *2* – measuring plate, *3* – determined points

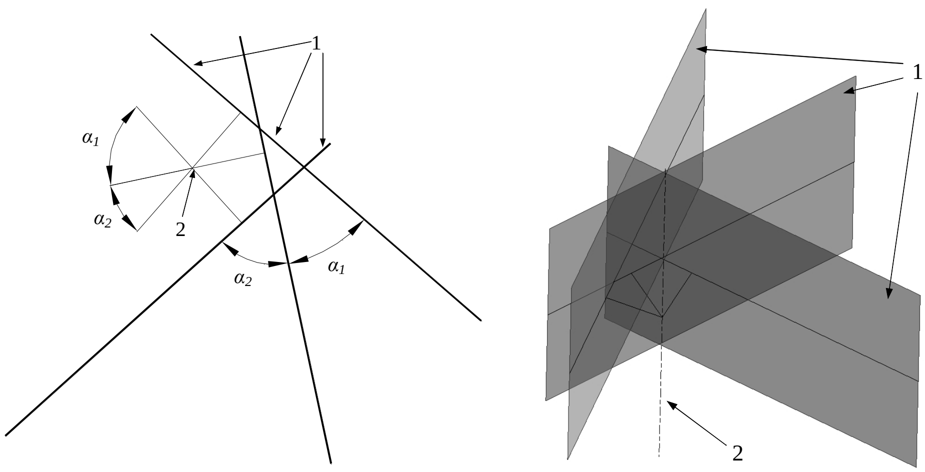
Geodetic instrument (tacheometer) measuring horizontal α_h, and vertical α_v angles of direction and comprising distance (l) from the instrument (1) to the measured point (2) by the built in laser distance-meter is shown in Fig. 1 [3]. It acquires the 3D coordinates of measured point position. Scanning tacheometer while determining points coordinates using same principle, has an option of automated measurement of certain area with the certain pitch, therefore a point cloud of desired object surface can be obtained.

Principle of performance of terrestrial laser scanner is very similar; only the mentioned laser scanner can acquire point cloud at significant higher speed with higher density, though with lower accuracy of the point determination.

Having the possibility of scanning the required surface it is possible to obtain the point cloud from its surface (Fig 2).

Therefore as can be seen form Fig 2, by means of scanning geodetic instrument (1) the surface points (3) of the plate (2) at certain pitch can be determined. Having the point cloud of plate surface, the data can be transferred to some kind of CAD software where the best fit (average) plane can be attached to the point cloud. That way the plate surface position can be reverse-engineered inside the CAD software.

In case the measured plate was rotated to a certain angle after the measurement was completed, using the principle described above the surface plane of the plate can be determined again (at the new position). Having the plate's surface at several angular positions the spatial angle between the planes can be determined; therefore the rotation angle of the plate also can be obtained (Fig. 3).



a) b)

Fig. 3. Drawing of the angle measurement layout:
a) 3D view, b) angle measurement, *1* – planes, *2* – axis of rotation

As can be seen from Fig 3, a, there will always be a single rotation axis of the determined planes, being the same as the rotation axis of calibrated rotary device. Since there will always be the same rotation axis, the spatial angle between the planes will be the angle of rotation of the calibrated device (Fig 3, b). Rotation angle (α) of the tested instrument is calibrated by comparing it with the reference one created in the computer program used for this application. So, the measurements can be considered as reference-free (with the virtual reference created inside PC).

Therefore, there is no difference how the plate (the point cloud of which should be obtained) is positioned; the only limitation is stability of the plate on the tested instrument and its visibility for scanning instrument. Consequently, there is no need in precise positioning neither calibration plate nor the scanning instrument (since the spatial angle is calculated between two obtained planes), which makes the preparation for the calibration considerably easier and simpler.

The large number of point cloud of the plate will decrease the general error of the drawn 3D plate. The larger number of points will be obtained, the higher accuracy of measurements will be reached by creating an average best fit plane in CAD software.

An example of application of such testing/calibration arrangement is shown in Fig. 4.

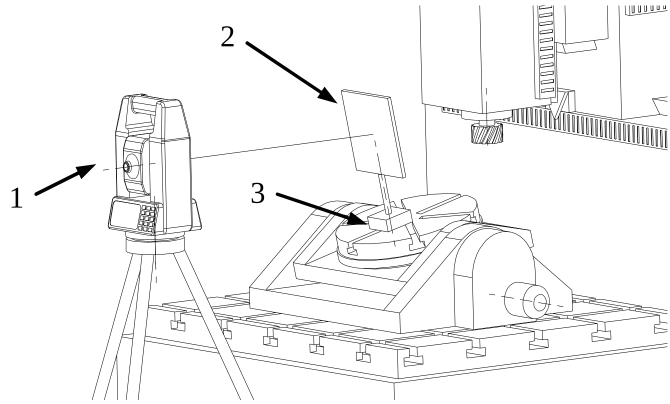


Fig. 4. Example of testing/calibration of rotary table of industrial milling machine: *1* – scanning instrument, *2* – milling machine, *3* – turn table (4^{th} and 5^{th} coordinate)

In case shown in Fig. 4 angular positioning control of the turn table (4^{th} and 5^{th} coordinates) of five-coordinate milling centre is presented. The calibration plate (3) (simple plane plate) is firmly (for example by magnetic holder) placed on the turn table of the milling machine (2) at any position. The geodetic scanning instrument (1) is positioned next to the turn table (so that the plate is visible by the scanning instrument). The point cloud of the plate surface is obtained at the initial angular position of rotary table (and the calibration plate) to be tested. After the rotary table was rotated to a certain (calibration) angular position the point cloud of the plate can be obtained at that position. At the end of measurement process there should be a number of point clouds of the plate at different angular positions of the calibrated instrument (and the plane) obtained. Having the point clouds the plane best fit surfaces can be drawn through those point clouds in CAD program, after that the angle between the plates can be determined, this angle being considered as the reference one. That way both the 4^{th} and the 5^{th} coordinate of rotation of the table can be tested using the mentioned instruments in industrial conditions (workshop).

Similar angular position calibrations can be performed on many kinds of machines as, for example, spindles of turning machines (in case the turning was interpolated), turning tables of different CNC machines, etc. Measurements can be performed with extremely short time needed for fixing the arrangement. The measurements can be performed at practically any environment (only avoiding direct sunlight, heat radiation and other sources of optical distortions of the surrounding air), with further processing of the images performed by computer software at any suitable facility or even at the calibration facility. The entire computer results processing can also be quite easily automated.

Obviously the calibration with single calibration plate can not be performed at the entire range of angular measurements (360°) of calibrated instrument since the plate will not be visible by the scanning instrument. To perform the full circle calibration the plate or the scanning instrument should be repositioned or there should be some special shape of the calibration plate (there can be used a three or four angle polygon object instead of the plate) or several plates at special intervals used. The plate can also be positioned on any part of the calibrated instrument where the suitable attachment points are available. Obviously there is also no limitations in size of the plate and its distance to the axis of rotation (the larger the plate or its distance to the axis of rotation the larger linear movement, detected by the scanning instrument, of the plate and its points will be obtained) therefore the higher accuracy can be achieved with the only limitation in visibility of the plates by scanning instrument.

Calibration measurement can also be performed at quite long (up to 10 m) distance from the scanning instrument to the object to be tested, though the distance influences the accuracy of measurement so it should normally be reduced at short range as possible [4].

Accuracy of Testing

Practically the special measurement arrangement was composed for experimental testing according to the suggested calibration method (Fig. 5).

The calibration plate (3, Fig. 5) was placed on a precise turn table (2) produced by *Wild Heerbrugg* company (its angular accuracy is equal to 0.3″) [5]. A scanning Trimble 5503 tacheometer (having the stated standard deviation of linear measurements of ±3 mm) was placed next to the plate at a distance of approximately 2 m.

Fig. 5. Measurement equipment arrangement for testing of suggested calibration method: *1* – scanning instrument (tacheometer), *2* – turn table, *3* – calibration plate

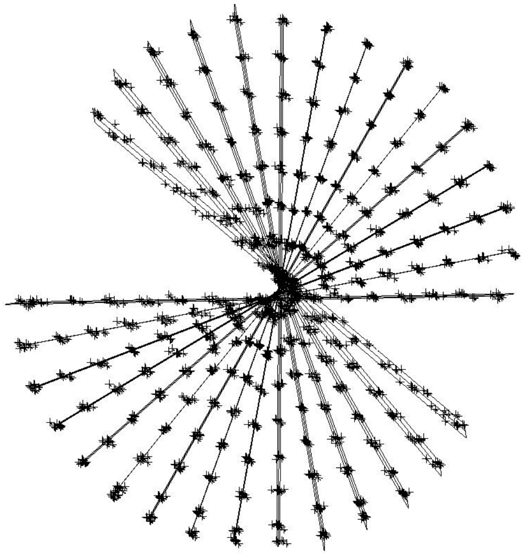


Fig. 6. Point clouds of angular positions (first set the accuracy of measurements) with the best fit planes fixed

During the tests 144 plate surface points were measured at each angular position of the rotary table. Large number of points measured was used to decrease the random errors of the coordinates determination of a single point, by obtaining the number of points and calculating the average best fit plane. Entire measurement process for at a single angular position of rotary disc (obtaining of 144 points) took about 20 min, such long time of measurement was due to the nature of the scanning instrument implemented – tacheometer is not normally intended for surface laser scanning applications (laser scanning being only a secondary feature).

Turn table (with the calibration plate attached) was turned with a step of 10° starting and ending at the positions where the plate surface was no longer visible by the tacheometer. After that the measurements were repeated with rotary table moving backwards at the pitch of 15°.

After obtaining the point clouds (for each step) the best fit plane for each measurement step was created using Imageware software. Angles between the plates were later calculated by the Unigraphics CAD software (Fig. 6).The results of tests of angular position generated by the turn table, precisely determined by its encoder and considered as reference compared to the results obtained from the planes drawn through the measured surfaces (deviations of angular position determine) are shown in Fig. 7.

As can be seen according to the results of experiment the maximal deviation of angular position determination by means of the suggested method does not exceed ±7.88´ (test 2, angular position 0°). Standard deviation evaluate of the tests performed is 4.0´ (with the standard deviation of the rotary table positioning neglected due to its small value).

As can be seen, the accuracy of experimental angle determination is not too high, nonetheless it could be quite sufficient for the less accurate angle positioning instruments (such as industrial turn tables etc.). Therefore the method without further improvements could be implemented in practice (though for the calibration of less accurate instruments).

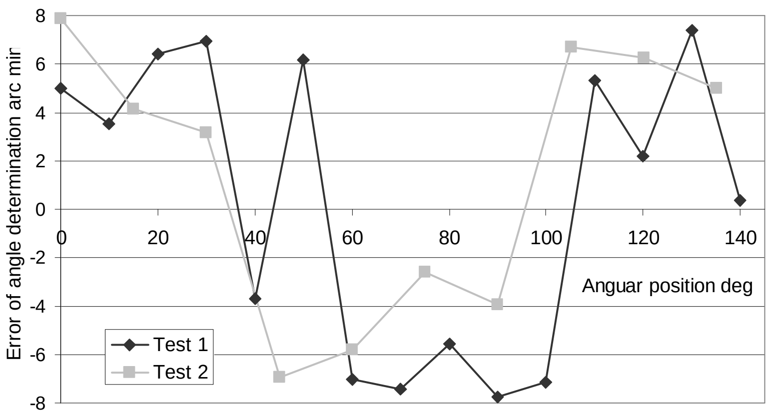


Fig. 7. Deviations of angular position determination

Possible Sources of Errors and Means for Higher Accuracy Achievement

Since the described experiment was only the initial trial to adopt the described method of calibration of angle measuring devices, there are plenty possible sources of errors with possibilities of the accuracy increase. Among the many possible the main sources of errors in case of that particular experiment could be named [4]:

- Errors of tacheometer angle measurements – horizontal and vertical angles (or limited resolution of measurements);
- Errors of distance measurements by distance-meter of the instrument (or limited resolution of measurements);
- Errors of distance-meter calibration (systematic errors of measurement);
- Optical distortions of the air;
- Errors caused by the limited reflection of calibration plate.It can be stated, that the greatest part of errors causing the low accuracy of measurement during performed practical tests could be caused by the limited accuracy of scanning tacheometer that was available for an experiment. Therefore, implementing the instrument of higher accuracy (having the stated accuracy of 1 mm or even higher) could increase the accuracy of angle determination.

Another important source of possible errors is the systematic errors of scanning instrument laser distance-meter. Such systematic errors normally are eliminated by calibration of the distance-meters and introducing the cyclic correction of the measurements (depending on the distance to the measured object). Unfortunately such short distance calibration can not be performed at available facilities and generally is not considered to be necessary since normally tacheometer measures points at much larger distances (therefore the distance-meters are calibrated to achieve higher accuracy at larger distances).

Optical distortion of the surrounding air is obviously present in case of any optical measurements, thus any fluctuations of surrounding air, direct sunlight, any heat sources can influence accuracy of measurements and should be avoided.

Reflective properties of the calibration plate can also influence laser based measurements; both colour and surface facture of plate is important (for example mat black colour gives large errors of measurement or the measurement are not possible at all). Therefore the surface and colour of calibration plate surface should be correctly chosen considering the properties of laser used.

Conclusions

A new method of angle measurements allowing rapid arrangement of testing equipment and fast calibration process at the instruments work environment was suggested and described in the paper.

The experiment of implementation of the mentioned calibration method shows accuracy of the measurements not exceeding ±7.88´ (standard deviation 4.0´), which allows implementation of the method "as is" for the calibration of less accurate angle measuring instruments or equipment.

Some improvements could be made to the mentioned method allowing increasing the accuracy of measurements considerably.

Further tests should be performed both in the field of accuracy increasing of measurements and practical implementation of the method, especially in the work environment of the plant of manufacture.

Acknowledgments

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