337. Mechatronic Structure of Modern Test Bench for Precise Angle Calibration

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Abstract. Many optoelectronic measuring instruments, vibro-scanning devices and deflection systems have angular sensors or circular scales as a reference measure for angle determination. Most of angle measuring devices must be tested or calibrated with a relevant precision therefore a special test rig for these purposes is needed. At current technical level the precision of measurements of vibro-displacement, amplitudes or frequency of vibrations implies not only precise manufacturing and assembly but also a necessity to incorporate modern computer technologies enabling automation of the measuring process. All these components of modern technologies can be accomplished by using mechatronic constituents. This paper presents a brief review of the angle testing/calibration equipment with the integrated mechatronic devices.

Keywords: test rig, photoelectrical encoder, multiangular prism, autocollimator, scale, microscope.

Introduction

Nowadays the capabilities of angle measuring devices used in modern industry are of highest accuracy – its discretion is as low as 0.1″, the range of angle measurement extends from 0° to 360° and scanning angle for vibro-measurement and laser scanning devices reaches the values of several degrees of arc. Some of the most precise instruments for the flat angle determination are the geodetic instruments – theodolites and tacheometers. Special test bench is created at VGTU Institute of Geodesy for calibration of these instruments and can easily be used for measurement of angle transducers, circular scales, rotary or precise angle scanners, instruments and devices. Here we present the analysis of angle measuring possibilities the test bench together with the description of its mechatronic, electro-optical and mechanical components.

1. Basic structure of the test bench

Operation of the test bench for the calibration of geodetic instruments is based on the comparation principle [1, 2]. The readings from the tested device (tacheometer, theodolite) are to be compared to the readings from the reference measure (horizontal angle etalon in this case). Basic structure of the circular scales dividing machine was used for this purpose. Equipment was modified by installing the automated computer control, rotary encoder for angular position determination of the rotary table of the machine, the adjustable fixture for geodetic instrument placement, etc. The tribrach of the instrument under testing (tacheometer, theodolite) (14, Fig. 1) is attached to the rotary table (4) of the machine. During the calibration process the rotary table of the machine together with the tribrach attached to it is being rotated to a certain preselected angle position by means of a step motor with the worm-gear (8) controlled by a PC (1) via the control unit (7). Angle of rotation is determined with the photoelectrical rotary encoder (6). The final angular position of the housing of the geodetic instrument is measured by pointing autocollimator (10) at the mirror (12) attached to the housing of the instrument. Tested instrument operates conversely to the way it should work during the normal geodetic measurements when the tribrach of the measuring device is stable and the device itself is being turned to the desired direction. After rotating the rotary table, the readings from the geodetic instrument are taken and compared to the readings from the angle standard used in the test bench. Obtained difference in angle readings enables determination of the errors of the tested device.

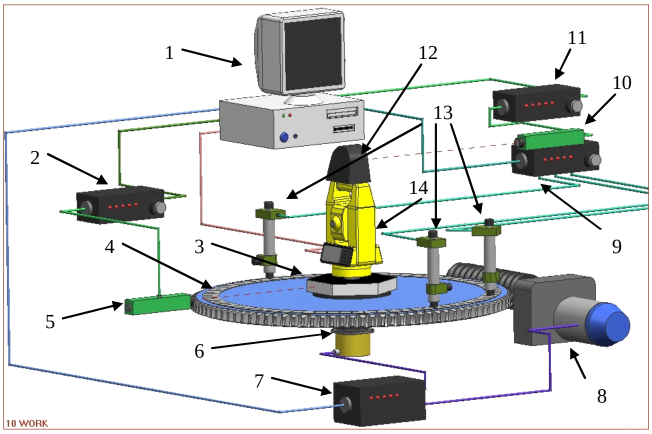

Fig. 1. A basic structure of the test rig: 1 – PC, 2, 11 – autocollimator control unit, 3 – multiangular prism (polygon), 4 – rotary table, 5 – autocollimator, 6 – photoelectric rotary encoder, 7 – rotation control unit, 8 – step motor drive, 9 – microscope control unit, 10 – autocollimator, 12 – reflecting mirror, 13 – photoelectric microscopes, 14 – geodetic instrument

Flat angle calibration test bench is designed with the possibility for angle calibration using several angle measurement facilities, such as multiangle prism (3) - autocollimator (5), rotary encoder (6), circular scale (made on the surface of the disc 4) - photoelectric microscope(s) (13). They can be arbitrarily selected based on their accuracy parameters and accuracy of the instrument to be calibrated. Output of these measurement instruments is transmitted into the PC.

Special electronic control unit is installed for the rotation of the rotary table (7, Fig. 1). It must receive signals from the rotary encoder (6), transfer the impulses to the step motor (8) rotating the worm-wheel until the angular value from the encoder will be equal to the preselected one in the computer. The device itself incorporates three modules: signal from the encoder receiving module, comparing module (with input link to the computer) and the module for generating impulses (sending impulses to the step motor control unit). The receiving module of the control unit receives the electronic impulses sent by the angle encoder, interpolates and translates them into the angular values. Those values are transmitted to the comparing module. The comparing module of the control unit is connected to the PC via the RS323 plug and sends the angular values to the PC. The real angle value is compared continuously until it reaches the value determined by the computer. The signals from the impulse generating module are fed to the step motor control unit *БУШ-1УХЛ4*, where the signals are amplified and sent to the windings of the step motor *ШД5Д1*.

Angle measurements using the circular scale as an angle standard has its advantages. Firstly, due to the large number of angle values that could be taken as reference angles. The same circular scale with the photoelectric microscopes placed at the diametrically opposite sides of the scale forms the standard angle of 180° [3, 4]. The scale is moved by *i* angular steps and values of measurement are registered ($i = 0, 1, 2, \dots, (2n-1)$, $2n$ – number of strokes in the scale). The third microscope is positioned on the optical axis of one of the strokes of the scale, determining the pitch of measurement - φ_t. Its readings are designated as c_i and Δ is a position error of the third microscope. A general expression for the errors is given by [3]:

$$\begin{cases} \delta\varphi_i = \frac{1}{2}\left[\delta\varphi_n + \delta\varphi_0 - c_{n+i} + c_i - \sum_{j=n}^{n+i-1}(c_j + c_{n+j}) + 2i\Delta\right], \\ \delta\varphi_{n+i} = c_{n+i} - c_i + \delta\varphi_i. \end{cases} \quad (1)$$

The function for error determination consists of a large number of equations. This also poses problem since the software that is generally applied is not quite suitable for the task. By measuring the scale at every 1°, the equation system from 360 members will be created and by measuring the scale at every 1/3 degree it will yield 1080, and so on. The raster scale having 21600 strokes will require the same number of equations to be solved for the error determination [4-6]. *Mathematica* software has been chosen for the calculations for its capabilities to seamlessly expand linear equation systems up to hundreds of thousands of unknown values of the circular scale errors [5].

2. Supplementary angle measuring instruments

The units drive and information-measuring system described earlier are used for the reference angle determination and the rotary table positioning into the preselected angular zone.

Supplementary measuring instruments (multiangular prism - autocollimator and microscopes) are used for receiving the signal from the measurement object. The general diagram of the measuring process is illustrated in Fig. 2.

Reading instruments M1 and M2 are pointed at the reference measure and the object to be measured. The data processing performed in the PC permits to evaluate the concomitant and non-concomitant errors; estimates of standard deviation *S*, systematic $\hat{x}$ and random ε errors (uncertainty) and the general expression of the result is presented including a graphical form of distribution of errors.

Achieved results allow assessing the accuracy of the calibrated instrument and performing relevant actions for error correction. General-purpose photoelectrical instruments (autocollimator, microscope) were modernized by fitting them with the additional CCD cameras. The new CCD cells are mounted instead of the old photoelectric sensor without the essential changes in the construction.

Modernized autocollimator consists (Fig. 3) of the basic structure (1) with the additional box and CCD matrix (7), which output is linked to the computer via the USB connection. The light from the diode (5) passes through the optical plates (2, 3) and is sent to the objective (4) and multiangular prism (8). The other part of light is directed to the eyepiece (6).

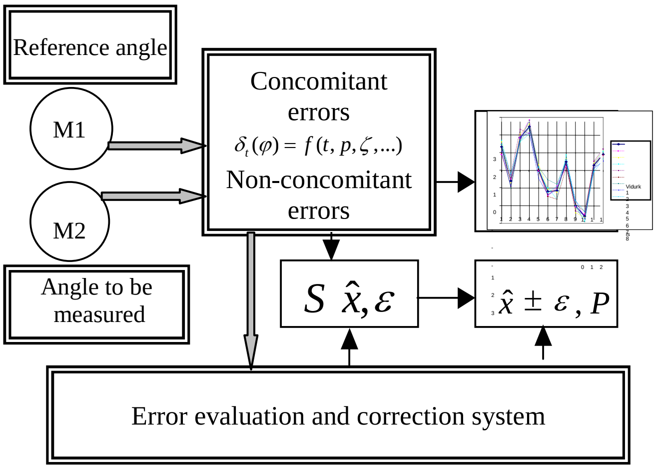

Fig. 2. The block – diagram of the measuring process

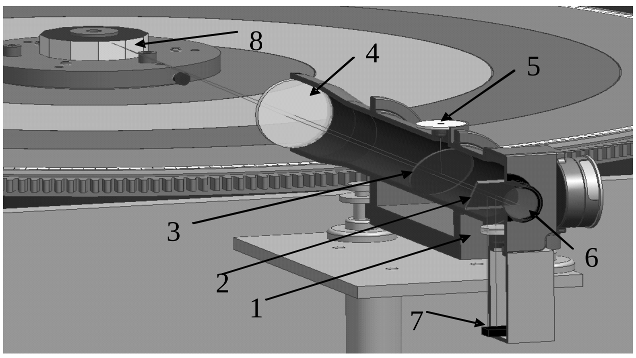

Fig. 3. The cut - section view of modernized autocollimator: 1 – housing, 2, 3 – light reflecting/transmitting plates, 4 – objective, 5 – the light source, 6 – eyepiece, 7 – additional box with CCD matrix, 8 – polygon

The position of the stroke from the autocollimator and the reflected stroke are shown in Fig. 4 on the program window of the PC. The distance between these strokes indicates an error of the angular position of the rotary table with the object to be calibrated fixed on the table. The CCD image processing is performed by the custom-built computer program *"Autokolimatorius 2.0"*.

The modernization performed on the photoelectric microscope was identical to the one performed on the autocollimator. The signal processing is also identical since the program window is essentially the same.

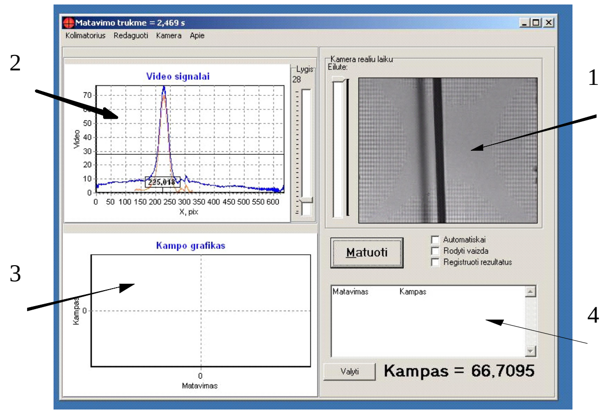

Fig. 4. *"Autokolimatorius 2.0"* program window: 1 – view of original and reflected strokes of autocollimator, 2 – signal from the CCD cells, 3 – results graph, 4 – numerical table of the results

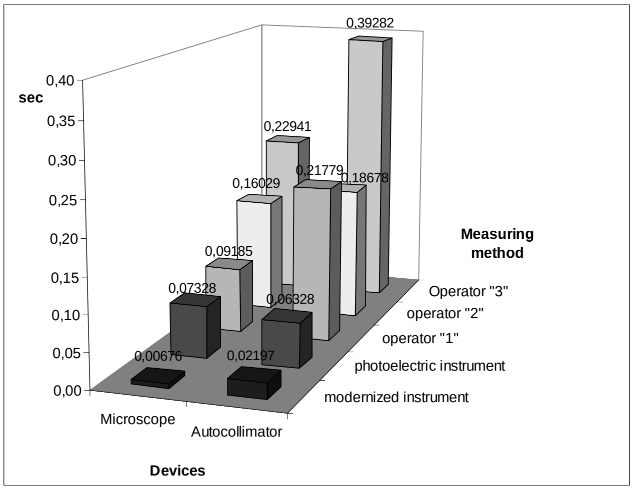

Fig. 5. Uncertainties of measurements depending on the measurement type and instrument

Conclusions

Developed flat angle calibration test bench provides a capability of measuring geodetic instruments, angle positioning systems, laser scanning as well as rotary and vibro-scanning devices with high accuracy and low uncertainty. The instruments used (rotary encoder, autocollimator, microscopes, circular scale) enable a wide range of angle measurements to be performed. The measurement process is automated thereby ensuring higher accuracy and efficiency of measurements in comparison to the usual calibration processes performed by operators.

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