Procedure Title: 30° And 45° Angle Blocks By Circle Closure (14011)
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1.0 Scope

The purpose of this procedure is to give detailed instruction on measuring the 30 and 45 degree angle blocks using an autocollimator, index table and the circle closure technique. The procedure gives instructions for setting up the equipment, preparing the blocks for test, making the measurements, entering the data into the computer, analyzing the data, and preparing a calibration report. It assumes the angle blocks are from the standard set of 16 blocks (1, 3, 5, 20 and 30 arc seconds; 1, 3, 5, 20 and 30 arc minutes; and 1, 3, 5, 15, 30 and 45 degrees). It also assumes the blocks are the standard size, with gauging faces that are approximately 25 mm by 50 mm on the short side. Hypotenuse faces are 60 mm and 70 mm respectively.

2. Definitions

Cross talk – the vertical angle read due to improper rotational alignment of the autocollimator when the instrument is set to read a horizontal angle, or the horizontal angle read when the autocollimator is set to read the vertical angle.

3.0 References

Reeve, C.P., The Calibration of Angle Blocks by Intercomparison, NBSIR 80-1967, NIST, 1980.

Reeve, C.P. The Calibration of Indexing Tables by Subdivision, NBS Internal Report 75-750, 1975.

Hume, K.J. Metrology with Autocollimators, Hilger and Watts, Ltd, London, 1965, Chapters 6 and 7.

T. D. Doiron and J. R. Stoup, "Uncertainty and Dimensional Calibrations," Journal of Research of the National Institute of Standards and Technology, Volume 102, pp.647-676, 1997.

4.0 Equipment List and Environment

Davidson D-800 autocollimators with 0.01 second resolution
Kepco 0-20 Power supplies
Data acquisition system to add or subtract the output voltages from the autocollimators and display results
Moore 2160 and AA Gage Ultradex 513 indexing tables
Rust Inhibiting Grease
Interferometer for measuring flatness

Air puffer, gloves, alcohol, lint-free towels, alignment mask

The angle of angle blocks do not change with temperature, and thus laboratory environment (19 °C to 21 °C) is adequate.

5.0 General

NIST measures customer angle blocks by comparing the test blocks to an NIST master block of the same size using an autocollimator as the comparator. An alternative method for measuring the larger-angle angle blocks is to place them on the indexing table and perform a circle closure measurement. The measurement can be made with one autocollimator. Circle closure is simply the fact that all errors of an indexing table sum to zero, since you begin and end in the same place. Typically the error curve follows a sine wave. The 30 or 45 degree angle of the particular block can be compared to all of the 30 or 45 degree intervals of the indexing tables. This method is generally faster than the comparison method, since only one autocollimator is involved. The limitation of this method is that the smaller the angle block, the more measurements needed to complete the circle. Practically speaking, a 30 degree angle block gets measured 12 times per side, and takes roughly 30 minutes per side to complete.

As is the case with most sizes of blocks, the limitation in accuracy is the block geometry, not the method of measurement. Blocks with large flatness errors between faces (high peak to valley value, or non-symmetry of the shape of the surface) tend to give different readings when measured in different orientations. They also tend to give different readings in the same orientation if the autocollimator is changed. A necessary part of any calibration is to check the flatness of the faces. The flatness should be checked if the blocks have not been previously measured for flatness. Although the Zygo phase stepping interferometer is the first choice and most often used for NIST calibrations, equipment such as the Acme viewer, or an optical flat and a monochromatic light source are suitable for this measurement. This procedure assumes that the reader is proficient in the use of these devices. The results should be recorded for use in determining the uncertainty budget. It is a reasonable assumption, from history of NIST master artifacts, that unless there is obvious damage to the block (corrosion, dings, or missing areas) the gauging faces will retain their flatness value and surface topography for extended periods of time. This allows for an initial flatness determination to be used for the uncertainty analysis in subsequent periodic calibrations of the same block(s).

6.0 Setup

Prior to use the autocollimator needs to be checked for scale magnification and linearity. A cross talk check and general function check can also be performed, although once adjusted properly it should not be necessary to perform these prior to each use. Since the autocollimators do not get moved around often, a cross talk check and general function check would only need to be performed if suspicious results indicated a problem. It is more likely that knobs can be bumped on the controller or power supply, thereby making the linearity and magnification checks necessary prior to any work involving the autocollimator. These types of checks are described here.

General function check

In an initial setup the stops on the autocollimators should be adjusted so the barrel rotates 90 degrees (± a few seconds) when rotated between the stops. The stops must be set so there is no cross talk in the autocollimator. Each autocollimator should also be checked to see if the readings on a flat mirror are the same for each quadrant of the beam. This is done by placing a mask over the end of the barrel which allows light in only one quadrant, and then rotating the fixture and observing the readings. The readings should not change by more than 0.10 second.

Cross talk check

To check for cross talk, place a mirror (or angle block) in the center of a rotary table (capable of continuous motion). The autocollimator is aligned with the mirror/block. Set the autocollimator to read vertical angle change. Rotate the mirror/block through the entire measurement range of the autocollimator and watch for changes in the output. There should be no significant change in the vertical reading of the autocollimator from the horizontal mirror motion. Adjust the stop and repeat until a desired level is obtained, typically less than 1 arc-second. The test is then performed with the autocollimator set to read horizontal angle change while moving in a vertical direction. A tilt table can be used to accomplish the vertical motion. Adjust the remaining stop and repeat until a desired level is obtained.

Scale magnification and linearity

Each autocollimator should be checked to assure that a 12-second change of the autocollimator produces a 12 volt change in the electronics panel display. The scale linearity should be checked at the same time. Set the display by moving the switch on the electronics panel to the appropriate position “A” or “B” depending on the autocollimator being tested. Switch the autocollimator to manual mode on the controller. Rotate the knob on the autocollimator counterclockwise (CCW) until it stops rotating. From this starting point, rotate the knob clockwise (CW) until its’ zero position aligns with the mark on the side of the autocollimator. Do not rotate CW beyond the mark and backtrack CCW to obtain the reading as this introduces backlash into the number. Record the reading in the logbook stored in the lab. Continue taking readings in 1 arc-second steps CW until all 12 arc-seconds of the autocollimator range have been obtained. Make sure that the voltage difference between each 1-second interval does not deviate from any other interval by more than 0.03 seconds. If the 0-12 second scale difference does not read a difference of 12 volts, the voltage control knob on the power supply should be adjusted until the reading is correct.

6.1 Block Preparation

If the blocks have been coated in heavy grease, which is unusual, they should be cleaned in the Varsol tank. Clean each block individually so they cannot bump together and damage the gauging surfaces. After cleaning in Varsol, or for most blocks shipped with a coating of light oil, clean each block individually with ethyl alcohol to remove any dirt or oil on the surfaces. The cleaning should consist of a first cleaning using a clean cloth and alcohol and a second where the alcohol film left behind is wiped from the block using a lint-free tissue. Do not leave a coating of alcohol on the blocks, especially the steel blocks, as alcohol absorbs some water from the air

during storage and use, and the water can produce rust on the steel blocks. Place the blocks for each set to be calibrated in wooden trays near the measuring equipment. Keep the blocks covered when not in use to avoid gathering dust on the surfaces. Contact the customer if any damage is noticed on any of the angle blocks. Keep in mind that if a block's gauging face is damaged, it will change it's value from the calibration history.

6.2 Equipment Used

The calibration is made using one autocollimator and two indexing tables. A model D-800 Davidson autocollimator, or equivalent, is aligned so that is nearly centered with the top indexing table. A fixturing plate is bolted to the top of the indexing table. The plate is used to wring down the angle block. Stone to remove any burrs and alcohol clean the plate. Apply a light coat of Rust Inhabiting Grease (RIG) to the entire plate and wipe clean. Just a light coat should be left on the plate, only visible if light hits it at the correct angle. It should be a slightly different color and not perceivable if viewed straight on.

Set each indexing table to its' zero position. With the block in the top-up position, wring the block to the plate so that the short side of the block faces the autocollimator. The short side is the gauging face that is not the hypotenuse. It is crucial that the block is centered with the center of the plate. The aluminum masks with holes punched in them – three at one end and two at the other – can be used to ensure the block is centered in the field of view. Once centered, rotate the top table until the hypotenuse gauging face is toward the autocollimator. Check for center with the aluminum mask. If both faces are centered, the measurement can almost begin. Check the vertical alignment of the autocollimators by adjusting the front screw so the split image is in the center of the field of view.

7. Measurement

Two sets of measurements are taken for each size angle block. The blocks are measured in both the top-up and bottom-up orientations as shown in the figure below. The blocks are measured using the data sheet designed for circle closure. The Excel file "30°, 45°, summary sheet.xls" can be used for the data sheets and the calculations.

Figure 1. Angle block measurement orientations.

Place the hood around the autocollimator barrel and enclose the angle block. Secure with masking tape around the barrel. Place the perforated sheet above the hood and measurements

can begin. A series of data (as seen on the data sheet) consists of 3 readings, a first reading on the short side, a reading on the hypotenuse, and a repeat reading of the short side.

Switch the controller to norm and watch the readout for approximately 15 seconds, or until the display isn't noisy. Observe the display for approximately another 15 seconds. Record the average reading during that time span. Rotate the index tables according to the data sheet and wait for approximately 15 seconds for the reading to stabilize. Observe and then record the average reading during another approximately 15second time span. Rotate the index tables following the data sheet and repeat the initial reading. This repeated position assures that the system has not changed, that gradients are small and that the data is good. The first and last reading in any one series should agree to better than 0.10 arc-second. Repeat the series if this condition is not satisfied.

Once any one series is completed, a break can be taken if necessary. Switch the controller to man if a break is needed. Do not break during a measurement series.

Rotate the indexing tables according to the data sheet until all data has been collected in that block orientation. Switch the controller to man and remove the perforated sheet and hood from the autocollimator. Remove the angle block and re-wring it in the remaining position at the center of the plate. Check each face for center by using the aluminum mask and observing through the autocollimator eyepiece. Continue taking data until all measurements in all series have been recorded. Switch controller to man and prepare for another block, if necessary. Repeat until all blocks in the set have been measured.

8.0 Data Analysis and Report

The computer with the Excel file "30°, 45°, summary sheet.xls" does the data analysis. Calculate the average of the two positions. Check the values against history. If values are off from history by greater than ±0.25 arc-seconds the block should be re-measured. If this happens twice an examination of the basic set-up should be made. If the problem cannot be found the Group Leader should be consulted. A sample report is appended to this procedure. Record the values into the customer history spreadsheet, each customer will have their own unique sheet.

9.0 Uncertainty

The uncertainty of the measurements will be calculated for each block set. The uncertainty will be a fixed number based on pooled historical data. It is likely that the uncertainty will be different for each block, but should be between 0.20 arc-second and 0.50 arc-second. The flatness component is determined by entering the Zygo flatness data into the Excel spreadsheet "Flatness U.B. component.xls" which determines the angle change due to the flatness of the faces. A rectangular distribution is calculated from the range of peak to valley (pv) readings across (horizontally) the block faces. The Zygo output allows for pv determination through any desired slice(s) of the block face. Blocks with flatness problems so large that the uncertainty exceeds 0.75 arc seconds should not be measured. A sample uncertainty budget is appended to this procedure.

10.0 Data Sheets

Sample data sheets are appended to this procedure.