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CALIBRATION AND VERIFICATION OF HORIZONTAL CIRCLES OF ELECTRONIC THEODOLITES

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ABSTRACT

The paper presents the verification and calibration of horizontal circles of electronic land surveying instruments – theodolites and tachymeters, sometimes known as integrated measuring instruments (IMI). The basic definitions are interpreted and illustrated - verification and calibration as basic metrological activities. The process for the verification of the quality of horizontal circles as opposed to the accuracy of angular measurements is based on the standard STN ISO 8322. The calibration as a specific measurement art using the standards of optical traverses was realised on EZB 3 equipment, which is part of the primary standard for horizontal angles at the Slovak Metrological Institute (SMI). The standard EZB 3 equipment, which was adapted and used for this purpose, enables the calibration of optical traverses with a combined standard uncertainty of $m = 0.06''$ and the step 5° calibration (a multiple of 5°) with an uncertainty of $m = 0.1''$. On the TZB 3 adapted for the calibration of the theodolites, the horizontal circles of more optical and electronic theodolites (tachymeters) were calibrated.

The paper presents the results of the Topcon GTS 6A and Leica TC 800 instruments. The processing of the measurement of the calibration was realised by regression and analysis using Excel 2002 software, first as a linear and later as a non-linear analysis with a graphical output.

KEY WORDS

- calibration,
- primary standard of planar angle,
- optical traverse,
- horizontal circle of theodolite,
- autocollimator

INTRODUCTION

Modern technologies used in present-day measuring practice demand the application of qualitative measuring techniques. A measuring technique has to fulfil the criteria of accuracy guaranteed by the producer and also defined by the verifying certificate. The requirement of a high quality of geodetic activities is directly connected with the requirement for using calibrated and eventually verified geodetic instruments.

CALIBRATION AND VERIFICATION - BASIC METROLOGICAL ACTIVITY

Calibration is defined as "a complex of operations, which by defined constraints, determines the relations among values indicated by a standard or measuring system or by values represented by a certified measure or reference material and the corresponding values of the quantities, which are realized by the standards" [1], [6].



Verification is a complex of activities with the aim of finding out and confirming that the standard corresponds to the specified requirements. The result of the verification is a statement as to whether the given standard fulfils the requirements or not [1], [6].

Calibration is a basic metrology activity; it is a specific kind of measurement using standards. Without the use of calibrated standards, it is not possible to provide quality in the production or even the credibility of the measured results [6]. With the current development of progressive measuring technologies and integrated measuring instruments (IMI) in surveying, it is necessary to devote enhanced and sustained attention to the verification and calibration of geodetic instruments as an inseparable part of measurement.

VERIFICATION AND CALIBRATION OF HORIZONTAL CIRCLES OF GEODETIC INSTRUMENTS

Verification of the quality of the divided circles of geodetic instruments is not as frequent as verification of scales by other measures, e.g., linear. There are several reasons for this: the high degree of accuracy from their production (the application of line masks on the glass circles by optical theodolites and eventually by the creation of incremental line or code circles) – their range is $2'' - 8''$; the high costs for determining the periodical error of a circle, the necessity of expensive testing equipment and the possibility of decreasing the effect of error in the dividing of a circle by a suitable measuring technology for horizontal directions [2].

IMI divided circles are no longer produced on divided instruments, but are produced by an optic-electronic copy from a so-called maternity circle, which also has periodical errors. The amount and running of systematic and random errors can be mathematically presented by the Fourier series. The results of testing have shown that the errors from dividing a code circle (maximal amplitudes) are an important factor of accuracy for electronic instruments and can also be higher and less stable than by optical theodolites [5].

Currently, the most often used process for verification of the quality of horizontal circles and eventually the accuracy of angle measurements is a process according to STN ISO 8322, which assumes measurement in two faces, four ranks and two series. The measurements have to be realized over two days.

Each series of measurements consists of four temporarily separated groups of measurements of directions. After finishing the measurement in the first rank, a 90-minute pause follows. The reading on the horizontal circle is moved about 50^{gon} or 45°

degrees after each rank. Part of the measurement is the registration of actual meteorological conditions (temperature, atmospheric pressure and moisture). Through the automated registration of the measured values, it is possible to automate the whole processing using a computer.

The accuracy of the angle measurements and eventually the measurement of directions is characterized by the mean error m_a according to this norm. This error arises from the cooperation of the whole error range – the elementary errors of the instrument, the person and the environment during the measuring process.

The process realized according to the above-mentioned advice enables the determination out and confirmation that the standard corresponds to the specified requirements – it enables its verification.

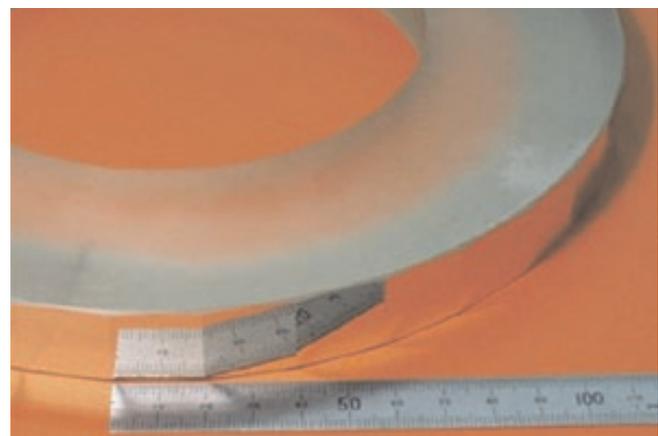


Fig. 1 Optical traverse

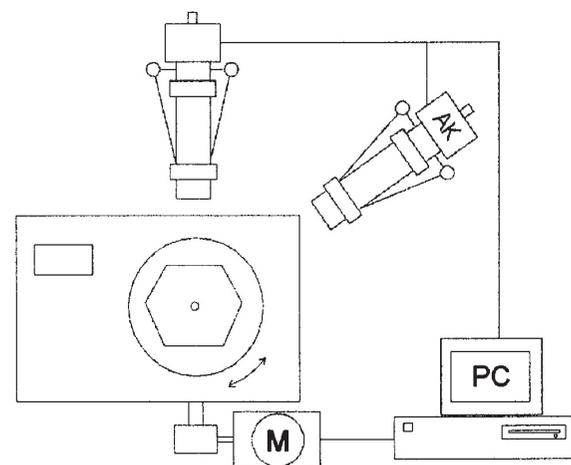


Fig. 2 EZB-3 standard equipment for the calibration of traverses

EQUIPMENT FOR AUTOMATED CALIBRATION OF OPTIC TRAVERSES AND HORIZONTAL CIRCLES OF GEODETIC INSTRUMENTS

Optical traverses are one of the parts of the primary standard of a planar angle. It is a (mostly) ordinary n-edged prism, whose functional surfaces are planar and treated into the mirror's reflection. Vertical lines to the functional surfaces create a schema of directions. The optical traverses (Fig.1) are produced with the functional surfaces of a number between 6 and 72; this means with nominal angles among the functional surfaces from 60 degrees up to 5 degrees. Optical traverses for metrological purposes are produced by only a few firms in the world because their technical production is very difficult [4].

Two methods are used for calibrating optical traverses, namely, the method of two autocollimators and the method of dividing a table (circular equipment with a circled scale) with an autocollimator. The equipment for working on both the mentioned principles is a part of the primary planar angle standard at the Slovak Institute of Metrology (SIM), which, in 1998, was acclaimed for the national standard of the planar angle of the Slovak Republic. The primary standard enables the calibration of optical traverses with a combined standard deviation of corrections of $m=0.06''$ [4].

The EZB-3 standard equipment for the automated calibration of traverses is created by Zeiss Jena and is a turning dividing table with a servo-drive, on which a calibrated optical traverse is situated, along with a couple of photo-electronic autocollimators (Fig.2). These elements are situated on a basic cast iron disc with an anti-vibration arrangement.

Both autocollimators in a basic position are aimed at the neighbouring functional surfaces of the traverse. During the step-by-step turning of the traverse, the autocollimators measure the deviations of the position of the vertical lines to the functional surfaces of the traverse in regard to the optical axis of the autocollimators.



Fig. 3 Calibration of Topcon GTS 6B instrument on the EZB – 3

In order to calibrate the theodolites, the EZB-3 equipment for traverse calibration was supplemented with a 72-edged optical traverse situated instead of a calibrated traverse. One of the autocollimators, which also serves as a part of the servo-driving of the turning of the dividing table, was aimed at the optical traverse. The calibrated instrument was centrally situated on the optical traverse, which had a mirror fixated on the alidade. The centring accuracy of the instrument is given by the value of 0.1 mm (fixation with a screw). The second autocollimator was situated on the basic board in such a way that its optical axis was at the height of the telescopic axis of the theodolite (Fig. 3).

Before any measurement it is necessary to fulfill the adjustment conditions described in detail in [4]. After adjustment of the measuring formation, the autocollimator of the traverse is aimed at the required functional surface of the traverse by turning the circular part of the table with the traverse and theodolite. Then with the help of the reverse turning of the theodolite alidade, it is aimed at a subsidiary telescope mirror. The data from both autocollimators are read as is the value of the dividing circle of the theodolite with a given number of repetitions. The circular part of the table is turned to the next required functional surface of the traverse, and the whole process is repeated. The turning of the circular part of the table about the required angle concerns a slight turning for the aiming of the traverse autocollimator, and the reading of the data from both autocollimators is automated.

For these purposes the measured program of the traverse calibration was repaired as follows: one calibration step consists of scanning data from both autocollimators and their transfer to a PC of the measured system and of the following turning of the traverse with the theodolite about the required angle (a multiple of 5 degrees) with a deviation of $0.1''$.

The correction from dividing the theodolite circle is given by the following function

$$k_i = f(A_j, k_j^p, B_i, a_j, b_i) \quad (1)$$

where: k_i is the correction of dividing the theodolite circle at the "i" point of the dividing circle,

A_j – reference angle of the traverse for surface "j",

k_j^p – correction of functional surface "j" of the traverse,

B_i – value of dividing the theodolite circle at the "i" point of the dividing circle,

a_j – reading of the autocollimator scale on the functional surface "j" of the traverse,

b_i – reading of the autocollimator scale at the "i" point of the dividing circle of the calibrated theodolite.

Provided that during the pointing the dividing circle of the calibrated theodolite and the autocollimator scales are oriented as follows: the



GRAPHIC PRESENTATION OF MEASURED DATA
Topcon GTS-6A serial number: BF0101

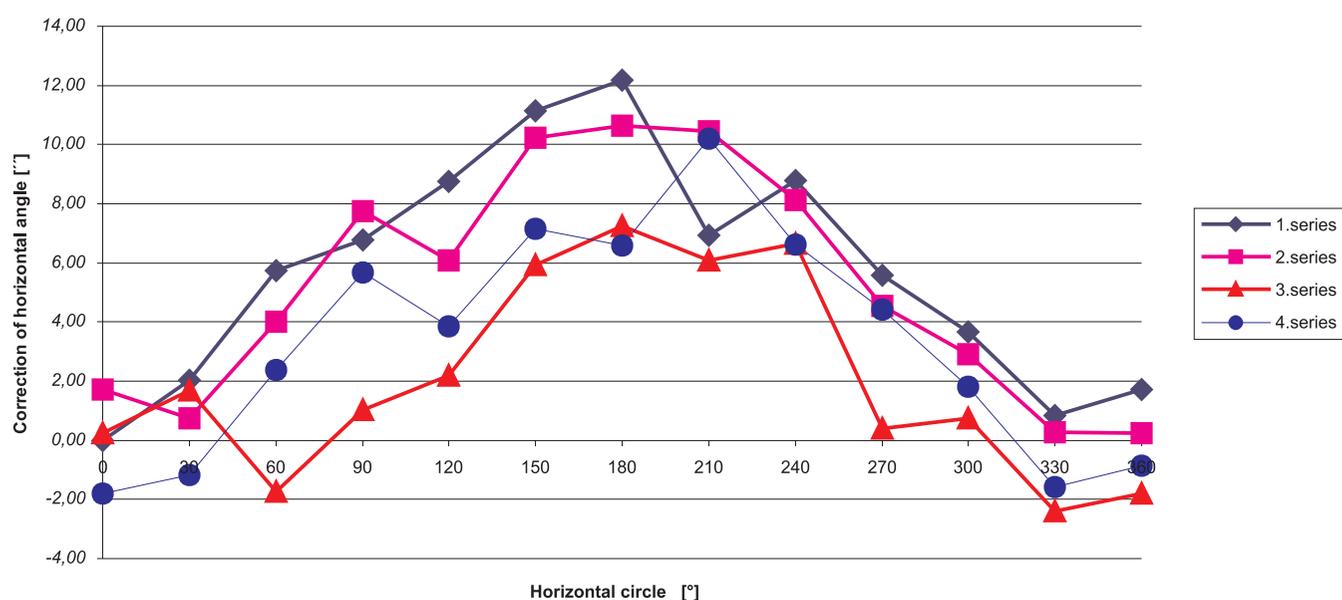


Fig. 4 Graphic presentation of corrections of the horizontal circle of the Topcon GTS-6A

reading value of the theodolite increases at the first traverse function surface and reading value of the autocollimators decreases, then the correction of the dividing circle of the theodolite is as follows:

$$k_j = \frac{360}{N} (j-1) + k_j^p - B_i - a_j - b_i, \quad (2)$$

where: N is the number of functional surfaces of the traverse.

Corrections determined in this way are important for theodolites with an unchanging position of the dividing circle. Knowing these corrections then enables the realization of the optimisation of the measuring process using the theodolite. With theodolites, which have a the possibility of changing the position of the origin of the dividing circle, the behaviour of the corrections provides a concept about the behaviour of the errors of the reading system of the horizontal circle without any possibilities for their correction.

According to the given formula (2), partial elements such as the standard uncertainty of the traverse correction, the standard uncertainty of reading a divided theodolite circle, the standard

uncertainty of reading the autocollimator on the functional surface of the traverse, the standard uncertainty of reading the autocollimator on the mirror of the theodolite, the effect of the parameters of the functional surface of the traverse on the autocollimator reading, and the effect of the parameters of the functional surface of the theodolite mirror on the autocollimator reading have an effect on the uncertainty of the corrections [4]. The effect of the partial uncertainties of the calibration equipment is important only for the values of reading any uncertainty on the dividing theodolite circle under a value of 0.5" [4].

CALIBRATION OF HORIZONTAL CIRCLES OF GEODETIC INSTRUMENTS ON EZB-3 EQUIPMENT

Horizontal circles of several optical and electronic instruments were calibrated on EZB-3 adapted standard equipment for the calibration of theodolites (to illustrate, there are selected results of the calibration of Topcon GTS-6A and Leica TC 800 instruments from 2004, Figs. 4 and 5).

GRAPHIC PRESENTATION OF MEASURED DATA
Leica TC 800 serial number: 407910

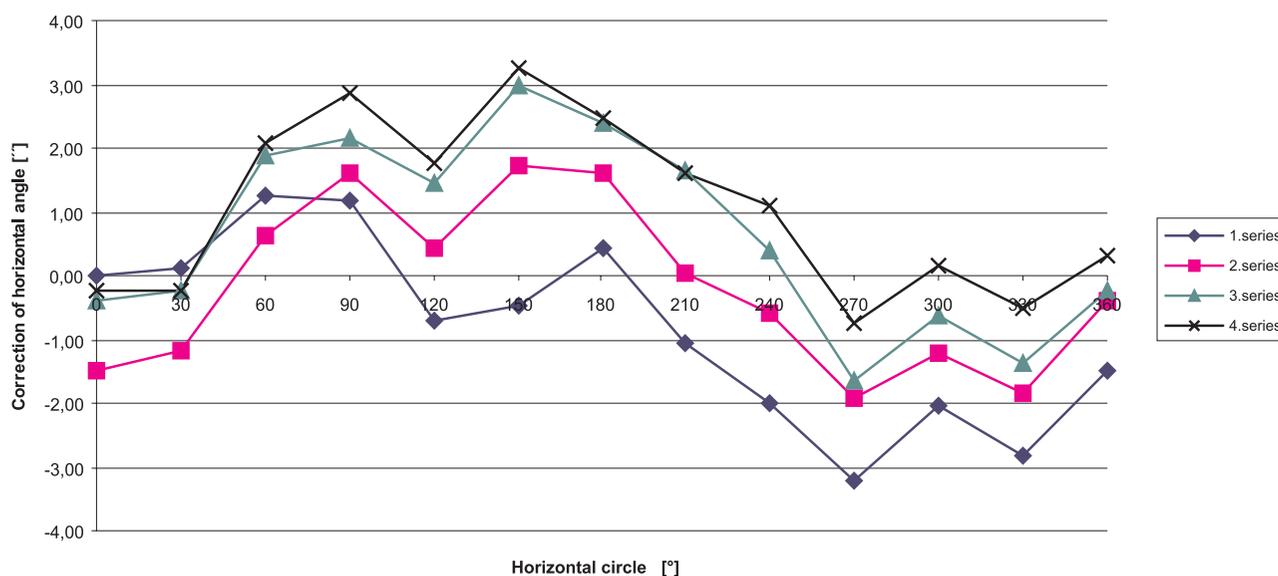


Fig. 5 Graphic presentation of corrections of the horizontal circle of the Leica TC 800

GRAPHIC PRESENTATION OF CORRECTIONS OF HORIZONTAL ANGLE
Topcon GTS-6A serial number BF0101 after non-linear regression of the fifth stage

$$y = 4E-11x^5 - 2E-08x^4 + 2E-06x^3 + 0.0002x^2 + 0.0272x - 0.0167$$

$$R^2 = 0.974$$

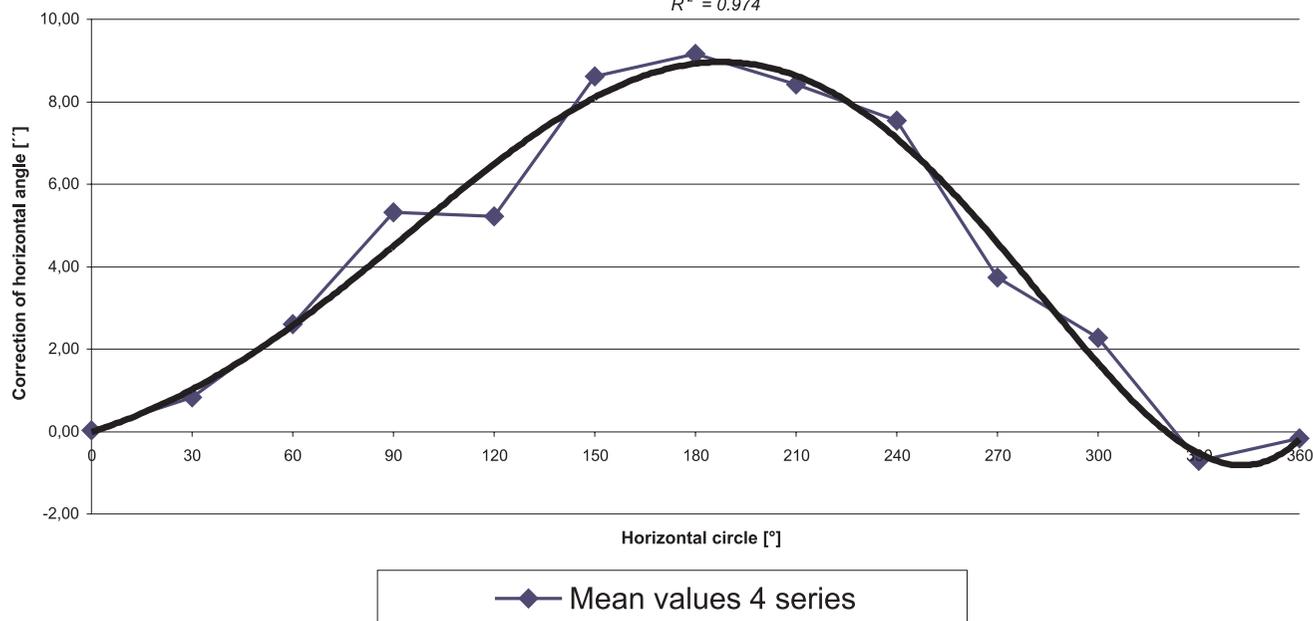


Fig. 6 Regression polynomial for Topcon GTS-6A



Tab. 1

Topcon GTS-6A		
Type and regression order		Regression coefficient R ²
Linear	1.	0.0039
	2.	0.8652
Non-linear	3.	0.8653
	4.	0.9652
	5.	0.9740
	6.	0.9740
Leica TC 800		
Type and regression order		Regression coefficient R ²
Linear	1.	0.2412
	2.	0.4993
Non-linear	3.	0.7853
	4.	0.8448
	5.	0.8454
	6.	0.8458

PROCESSING AND GRAPHIC PRESENTATION OF CALIBRATION RESULTS

From the valuation of the calibration results, we also determined the regression curve, which also represents the calibration curve (function) for the individual instruments in this case. The testing of the outlying values was realized with the help of the McKay test on an $\alpha = 1\%$ significance level [2], [7]. This means that with a probability of 99% and a risk of 1%, we can say that there are no outlying values in the determined group of the correction values for the horizontal angle. The regression analysis was realized using Excel 2002, first as linear and then as non-linear up to the sixth order. The most suitable order of regression was selected on the basis of the R² regression coefficient. The values of the regression coefficients are presented in Tab.1, and the running of the regression polynomials are presented on Figs. 6 and 7.

Tab. 2

Type of instrument	Polynomial order	Standard deviation [“]
Topcon GTS-6A	5	0.87
	6	0.82
Leica TC 800	4	0.74
	5	0.73

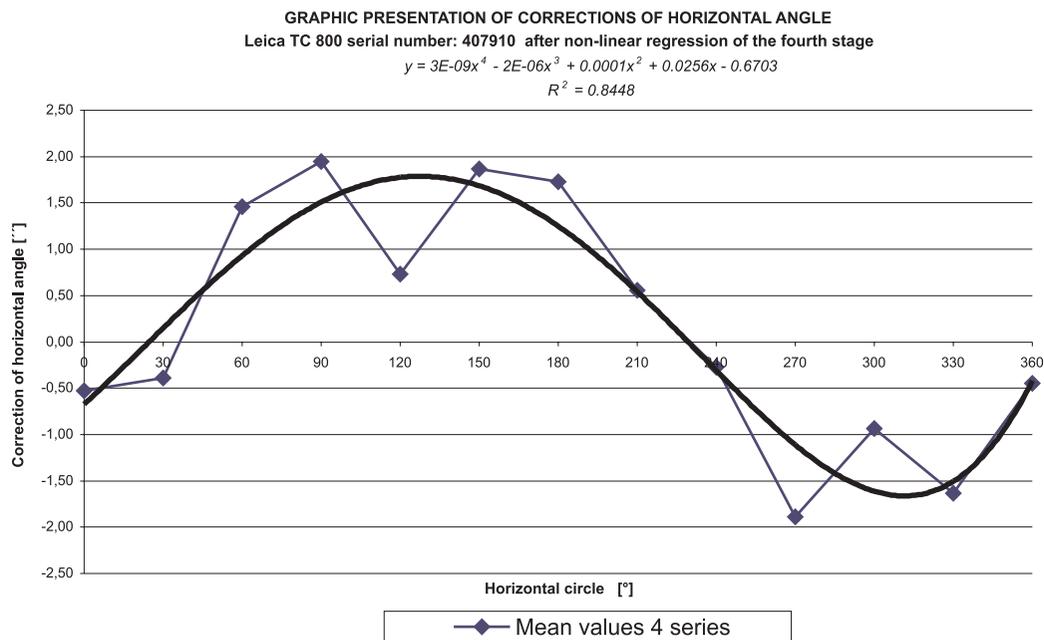


Fig. 7 Regression polynomial for Leica TC 800

The standard deviation in the determination was estimated according to the following formula [3]:

$$\hat{\sigma} = \sqrt{\frac{|v^T \cdot v|}{n - (a + 1)}} \quad (3)$$

where: v are corrections of the measured values on the regression curve,

n – number of node points,

a – order of approximation.

CONCLUSION

The optical or electronic theodolite (in connection with a range finder such as IMI) introduces a basic angle and linear instrument

in geodesy – a working measure with an irreplaceable place in measuring practice, which has to be calibrated and verified.

The calibration described process provides:

- direct continuity on the primary standard of the planar angle,
- calibration of the horizontal circle of whole theodolites,
- the minimal calibration step is 5° or its integral multiple,
- the calibration (regression) polynomial for the horizontal circles of geodetic instruments is a basic calibration result and introduces the possibility of supplying dividing errors of the horizontal circle of a geodetic instrument (Figs. 6 and 7).

The results presented, which were achieved through calibration of the selected instruments, confirm their necessity and point at the complexity of the whole calibration process.

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