Journal of Geodesy, Cartography and Cadastre

Considerations on possibilities of quality control for geodetic instruments by metrological procedures applicable in the field

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Received: April 2015 / Accepted: September 2015 / Published: June 2016

Abstract

Quality control of geodetic instruments is one of the main objectives of geodetic metrology. Ideally, this control can be achieved in a metrology laboratory where most procedures can be applied in a unified manner. In the absence of such a metrology laboratory, quality control is a complex and difficult task, especially due to the lack of integration of the metrological measurement procedures. In this article, the authors present some considerations on possible solutions to such difficult problems.

Keywords

Geodetic metrology, electronic total stations, EDM (Electro-Optical Distance Measurements), quality control of instruments, geodetic calibration, geodetic testing, geodetic standards.

1. Introduction

According to DEX (The Explanatory Dictionary of the Romanian language) the metrology is: "Part of physics that deals with precise measurements, with the establishment of measurement units and measurements processes, etc. ; All the activities (legal and administrative) related to measurements, on standards, devices and measuring instruments and their oversight from economic standpoint" [1].

It is well known that geodesy includes a series of procedures which are based on physical and mathematical principles and methods. The geodetic instruments are complex electronic devices often being modular and to realize the quality control of these instruments returns to geodetic engineers who know the principles and how these tools work.

In terms of metrology, the geodetic engineer has the following responsibilities:

a) The quality control of geodetic instruments
b) The optimal exploitation of geodetic instruments.

Both of these issues appear to be similar, but the differences between them are more substantial. Quality control of geodetic instruments (a) involves checking how the instruments respects tolerances provided by the manufacturers. Optimal exploitation of geodetic instruments (b) involves first finding the potential of the instruments (on each module) and then dealing with the procedures and methods that can achieve this potential. The optimal exploitation of geodetic instruments is often a neglected process wrongly considering that, once the instrument is controlled/checked and tolerances provided by manufacturers are respected, the metrology process ends here.

Unfortunately, things are not so simple. The two metrological directions are not independent but are correlated. The principles are the same in both metrological directions, some methods are the same and some different but similar. From this point of view it is difficult to draw a clear line between the two directions.

At first sight / approach, the quality control of the instruments seems to be a simpler task, more affordable than optimal exploitation, but this is not true. Both aspects of the calibration process have common fundamental principles and common application methods.

The quality control of geodetic instruments has two distinct phases:

1. The quality control process realized on the instrument purchase. It is an important stage and each engineer is responsible for checking how the instrument accuracy indicators are in tolerances - implicitly or explicitly provided by the manufacturer. The engineer must know the full meaning of specific terms, to know how to discern the technical data given in the technical manuals and to know the accuracy and precision

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indicators interpretation of the instruments - listed by manufacturers. Once this information of the instrument is filtered, the engineer must be also familiar with its operating principles, its degree of complexity, how many module the instrument has and not least, to identify the metrological procedures and measurement methods that fit that instrument. In this respect, it is worth noting that some manufacturers make changes (from their point of view they are improvements) in the calibration processes, either in the software component or in the hardware component, and in some cases these changes are not at all documented [2].

2. Quality control performed periodically. This phase (executed repeatedly and periodically) is practically a metrological monitoring process. This phase is distinct from the monitoring conducted in the initial phase. In the initial phase are established specific values for the calibration constants, some of them taking the role of metrological references in the next stages. An example of this is the regular monitoring of the degree of wear of the quartz oscillator - that generate the carrier wave and then the fundamental frequency and implicitly the unit of distance in EDM devices (integrated -or not - in electronic total stations). In the first phase is established the scale constant (in fact establishing the degree of deviation of the fundamental frequency from the nominal value). In the next steps of monitoring, the scale constant is determined successively and periodically - the changes from the reference value reflecting directly deviations of the fundamental frequency from the initial frequency and hence from the nominal frequency..

In essence, the two phases of quality control (initial verification and regular monitoring) consist of the same metrological procedures and methods, following the same principles and also the same metrological arrangements.

2. Problematic

The two phases of quality control of instruments described in the previous section can be performed ideally in a geodetic metrology laboratory. A geodetic metrology laboratory is a laboratory specially built around the principles of classic metrology and geodetic metrology and can reproduce specific arrangements necessary for geodetic instruments calibration. Not every metrological laboratory is a geodetic laboratory - therefore it is not enough that it can provide horizontal or vertical references. A geodetic metrology lab is built so that it can resolve in an integrated way a complete series of metrological tests, suitable to as many geodetic instruments as possible.

The modern geodesy works with a diverse set of tools: theodolites classical and electronic theodolites, electronic total stations (modular instruments), specialized EDM instruments, distomats, classical and electronic levels, GNSS receivers, laser scanning systems, etc. If on these considerations is adding the fact that these tools are continuously improved we have a picture regarding the complexity of the quality control process for these tools.

The positive side is that a metrology geodetic lab well designed, well-implemented and well equipped, ensures, for most metrological tests (covering at least the basic modules), the following:

a) An integrated (and unitary) testing/calibration process. Most test and measurement procedures can be integrated in the same place, with minimal movement of the instrument that is checked.

b) Economy of resources involved. As a corollary to this unitary metrological approach - is that the measurement procedures can be achieved with a small number of operators (often a qualified person alone is enough), the costs being minimal.

c) Stable and controlled environment. A significant advantage of metrology laboratory is that it ensures stability in the environment of the testing process. Thus, a homogeneous medium (same atmospheric parameters at any point in the laboratory), a humidity control, lack of vibrations, no dust, etc. provide an optimal context when the measurement procedures are performed. This ensures also stability in the achieved results thus ensuring the metrology principle of reproducibility [3].

d) Accuracy. The most important aspect (linked to all others) is the criterion of precision and accuracy. A metrology laboratory provides simply superior accuracy in the diagnosis and calibration of geodetic instruments. Depending on its basic operating principle, a metrology laboratory allows similar or even superior accuracy of the interferometer. In a metrology laboratory is always respected a fundamental principle of metrology: the calibration reference must have at least an order of magnitude higher as precision and accuracy in relation to the size that is verified.

e) Minimum time. A complete calibration procedure is done in a minimal time, thus is obtained the maximum efficiency. Thus, by simulation the optical visa at infinity is instantly covered the entire measuring range of the instrument that is diagnosed. For example, the pointing errors (that participate both in measurements of distances but also in the angular measurements) are minimized in the metrology lab compared with those performed in the field [4]. Highlighting the energetic parallaxes of the beams emitted by an electronic total station with respect to the optical line of sight is made not only extremely accurate in a metrology laboratory but it is effectuated fir the entire measuring range of the instrument.

f) Unitary assembly. A metrology laboratory can (by its optical and mechanical arrangements) to solve problems that cannot be solved in the field (in some cases only partially). Some examples: testing and calibration of an instrument across its entire working range , checking the degree of perpendicularity between retro-reflective prism facets ("corner cube" prisms), monitoring of calibration constants for different work areas of the main axis of rotation of a theodolite / total electronic station (similar effect with the "precession" and "nutation" from astronomy) [5, 6] , the degree of flatness of a surface, the degree of parallelism and perpendicularity of the two or more surfaces, etc.

In contrast to the above mentioned, the field procedures suffer some obvious limitations:

a) Difficulties in ensuring a stable environment for testing / calibration. The presence of vibrations generated either by wind or natural phenomena (expansion / contraction caused by temperature variations) or artificial (passing trucks, subway, etc.) can affect the test / calibration to the point that is unusable. In addition, the residual errors in the detection of changes in air temperature degrades the accuracy of determining the calibration constants.

b) The compliance with the measurement principles can be slow and sometimes incomplete. For example, the calibration of an instrument is indicated to be in the entire work range of that instrument for the measured quantity. In the field procedures, this is extremely difficult and sometimes impossible, the operator is forced to resort to interpolations and extrapolations that generate additional errors in the calibration process.

c) Resources involved. Due to the lack of a unitary and integrated context for calibration, field procedures require the presence of additional operators. An optimal communication between them is necessary (walkie-talkie type systems). The metrological arrangements that respect the metrological principles are often implemented on the ground by several tripods with the associated adapters. They are heavy, difficult to handle and requires additional time in changing their location.

d) Failure to conduct complete measurement procedures or complete calibration procedures. The field procedures cannot check - for example - prism retro reflectors (degree of squareness of its facets) or cannot generate the verification reference planes for rotating levels. Certain procedures cannot be successfully implemented completely (only partially) in the field - such as checking of energetic parallax of the *EDM* line relative to the optical line of sight to some electronic total stations (the *EDM* beam passing through a horizontal slot, probably for constructive reasons). The angular deviation of *EDM* line from the line of sight can be determined in these cases only partially: through the horizontal component. For the electronic total stations that do not have this limitation, the field procedures determines the angular deviation of the *EDM* lines in both directions (horizontal and vertical), the calibration being completely from this point of view.

It is worth mentioning that there are situations (rare indeed) when field procedures allow calibrations that cannot be achieved without the help of a metrology laboratory (or it cannot be made at all).

In this regard, the scale constant for *EDM* devices cannot be determined easily in metrology laboratory. Discrimination of such a constant can be applied only on long alignments (over 500m or even 1Km). These are difficult to implement in metrology laboratories. There are solutions to this kind of problem, in that the *EDM* beam is deflected on various routes using mirrors that generate optical paths of several hundred meters. These solutions, however, are expensive and require additional space in the metrology lab.

Another disadvantage of a metrology laboratory (and an advantage of field procedures) is that it (metrology lab) is not always available. Field procedures, with all its disadvantages, are available to every operator. Even if the optimum exploitation of the geodetic instruments can be achieved only in favorable conditions, the quality control can be easily solved, being reachable for everyone who is well acquainted with the field procedures.

3. Field procedures – viable solutions in the absence of a metrology laboratory

Developing a complete standard for on-field verification of the geodetic instruments is a difficult task [7]. The difficulty lies in the complexity of surveying instruments and their quick evolution. It is estimated that the electronics domain progresses at a stunning rate: the performances double every 6 months. This progress in electronics is reflected visibly into geodetic instruments. Thus new facilities are implemented in electronic total stations, *GNSS* receivers and laser scanning systems.

Fortunately, many of these facilities are modular, allowing a modular metrology treatment for geodetic instruments. An electronic total station can be analyzed independently from a metrological perspective for each of its modules:

a) The angular module. This module is the electronic theodolite incorporated in the electronic total station. The module can be treated as a normal classic or electronic theodolite, for which all the metrological procedures are valid. Unfortunately, the electronic evolution of the geodetic instruments comes with several challenges. It is worth mentioning the fact that some electronic total stations [2] have implemented in their calibration software procedures a new way of computing the calibration constants – the incremental mode. This computing method comes with its advantages but the negative side is given by the lack of adequate documentation for this approach. In the technical book of this instrument this incremented computing method is not even mentioned [2].

b) The *EDM* module. The distance measuring device that is incorporated on each electronic total station can be treated as a separate module. Thus, a specialized *EDM* instrument (not measuring angles) or an electronic total station can be treated similarly in terms of metrology. It's worth mentioning that in the case of electronic total stations with reflectorless facilities, the *EDM* lines (infrared and reflectorless) are distinct and so these should be treated separately from a metrological point of view. Moreover, the whole *EDM* system includes the whole instrument-reflector assembly and so it must be entirely analyzed from a metrological perspective (including the reflection system, whether it is given by the optical prism or reflective surfaces).
c) The centering module. Whether the centering is performed optical or through laser, the metrological approach is the same.
d) The leveling module. It usually consists of two devices: a circular level which is mechanical or circular level coupled with an electronic compensator (playing the dual role of electronic levelling and mathematically processing the residual levelling errors of the instrument). The metrological approach is again the same: a homogenous one by comparison with a vertical reference (geometric or optical).
e) The laser guidance module
f) The automatic prism search module
g) The automatic prism tracking module
h) etc.

If the first 4 devices in the above list are found in most of the electronic total stations, the following modules are modern electronic facilities existing only in electronic stations from the top range of each instrument manufacturer. Each facility must be treated separately in terms of metrology. The main advantage, from a metrological point of view, derived from this modular approach is that metrology procedures (on field or laboratory) can be set up to treat each module individually. When a new module is emerged the related metrology procedures will be added to the existing set of procedures. By using this approach the entire process becomes one with successive improvements (updates approach).

Within the specialized team inside the Faculty of Geodesy from Bucharest and with the help of students (working on their bachelor's degree) a series of metrology on-field procedures have been developed which can solve most of the problems - that until now could be solved only inside a metrology laboratory:

a) Finding the resolution power of an *EDM* device that works with infrared and, respectively, visible light (*EDM* specialized tools, electronic total stations).
b) Computing the resolution power of a reflectorless *EDM* device (laser distance meter, *EDM* instruments, electronic total stations, laser scanning system).
c) Computation of the resolution power of the angular device (classic theodolite, electronic total station)
d) Computing the parallax of the energetic *IR* beam (or visible light beam) of the *EDM* devices inside the electronic total stations – in relation to the optical line of sight.
e) Computing the parallax of the energetic reflectorless beam of the *EDM* devices inside the electronic total stations – in relation to the optical line of sight.
f) Computing the parallax of the energetic beam determined by the laser guidance system inside the electronic total stations – in relation to the optical line of sight.
g) Estimating cyclical errors for *EDM* devices by assessing residual errors (obtained through specific procedures) of the additional constant.
h) Computing the scale errors of *EDM* devices using eccentric distance measurements.
i) Computing additional constants for various reflective surfaces depending on the chemical composition of the materials from which these surfaces are made.
j) Finding the precision and accuracy functions and work range for the *EDM* devices using *IR* and visible light
k) Finding the precision and accuracy functions and work range for the *EDM* devices using *IR* and visible light – depending on the distance measurement modes
l) Finding the precision and accuracy functions and work range – for *EDM* Reflectorless devices – depending on the reflectivity degree of the reflective surfaces (actually depending on the color of the reflected surface)
m) Finding the precision and accuracy functions and work range for *EDM* reflectorless devices depending on the distance measurements modes
n) Establishing the degree of correlation between angular and *EDM* devices for electronic total stations
o) Computing relatively the additional constants for different retro-reflector systems (even from different manufacturers)
p) etc.

All these new procedures are added to the existing metrology procedures included in the metrology standards (*EDM* device checking through optical-mechanical alignments, checking the angular device through the "series method", checking leveling instruments through geometric configurations etc.).

As it was already mentioned, the geodetic metrology procedures are in continuous development, in order to keep up with the developments implemented by geodetic instruments manufacturers. Depending on the available resources, the professor titular of geodetic metrology disciplines from the Faculty of Geodesy from Bucharest will aim to complete the set of on-field metrology procedures to offer their students the best training in dealing with such problems.

Unfortunately, field procedures, no matter how well thought and well implemented, cannot replace in certain situations laboratory procedures. To illustrate this idea, the procedural difference in determining the energetic parallax of the *EDM* beam, in relation with the optical line of sight will be presented further.

Inside the geodetic metrology laboratory, the angular deviation of the energetic *EDM* beam line from the optical line of sight can be obtained unitary, based on the detected linear components *x* and *y* (measured through the rectangular projection of the eccentricity vector) from the center of the energetic beam – in the coordinate system of the optical calibration system. This process is illustrated in Fig. 1.

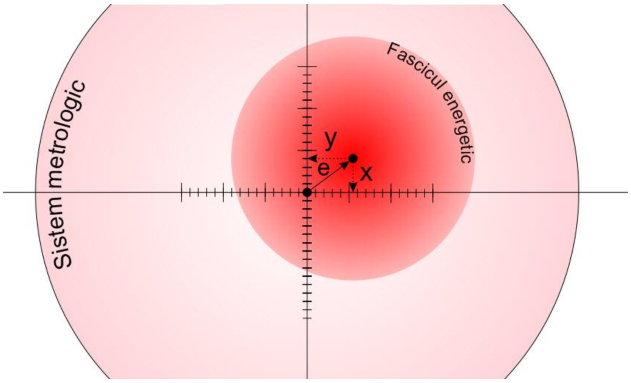

Fig. 1: Visual and analytical inspection of the energetic parallax of the EDM beam relative to the optical line of sight – the case of geodetic metrology laboratory.

Inside the field procedures, the angular deviation of the energetic *EDM* beam is obtained differently: computed through measurements of the angular eccentricity components (under which the linear segments *x* and *y* can be observed) towards the edge of the energetic beam, from which the total angular deviation can be deducted (Fig. 2).

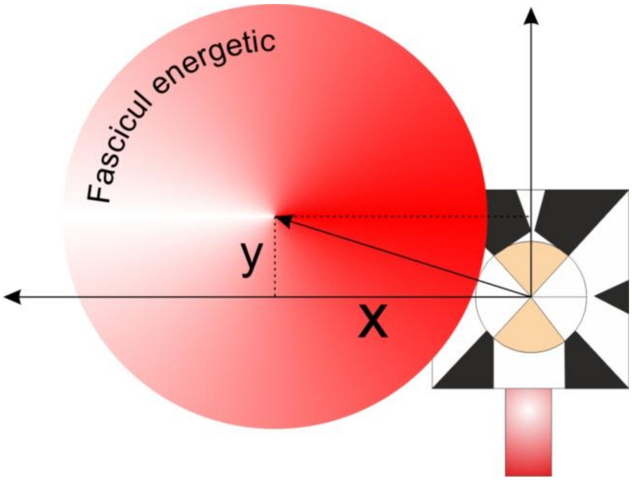

Fig. 2: Detecting the energetic parallax of a *EDM* beam with respect to the optical line of sight – the on-field procedure case

The on-field procedure allows obtaining the parallax value with accuracy – a similar statistically accuracy with the laboratory procedure. However, for some electronic total stations there are certain restrictions imposed by the manufacturers. These restrictions are probably imposed constructively, but from a metrological point of view these restrictions significantly affect the calibration process conducted on field.

Such a restriction refers to the fact that although the *EDM* signal is constructively emitted in a conical shape, it reaches the retro-reflective system (or the target for reflectorless) in a restricted form (truncated in its shape).

In Fig. 3, a projection of an *EDM* signal on a panel is shown (as it exists in a conical shape), the signal being constructively unrestricted by the instrument manufacturers.

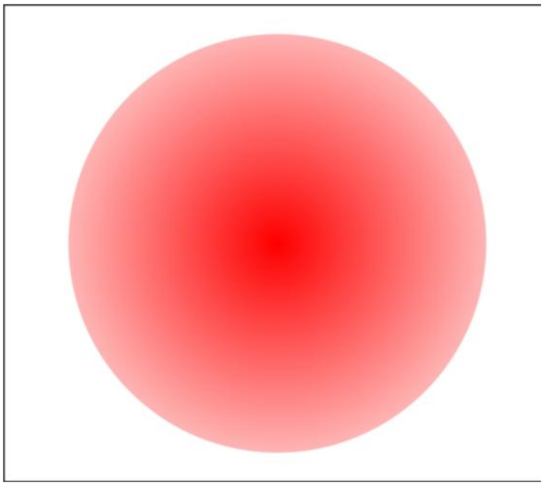

Fig. 3: The unrestricted projection of an EDM signal on a panel (the case for most of the EDM instruments and the electronic total stations)

Fig. 4 shows the projection of the *EDM* signal in a restricted form, as seen in some electronic total stations. The *EDM* signal most probably goes through a rectangular shaped slot before leaving the *EDM* instrument or the electronic total station.

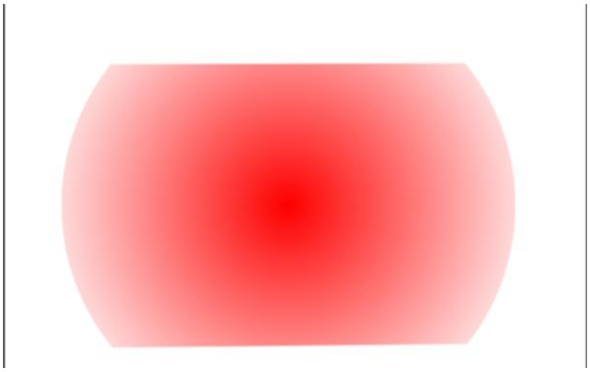

Fig. 4: The restricted projection on a panel of the EDM signal (case found on some of the electronic total stations)

It is not exactly known which of the most utilized electronic total station exhibits such a restriction as presented in Figure 4. In the near future, all the electronic total station owned by the Faculty of Geodesy from Bucharest will go through a metrology testing process and then more conclusions can be drawn. Also, it is unclear if these kind of restrictions is imposed only by one of the manufacturers or by more of them. The future will be able to answer this question also. What can be clearly observed is that the on-field metrological procedure for checking the energetic parallax of the *EDM* beam with respect to the optical line of sight is hindered to the point in which this can be achieved only partially. In these cases (hopefully more rarely), the on field metrology procedures reach their limits, the only appropriate solutions being provided by the geodetic metrology laboratory.

4. Conclusions

The geodetic metrology laboratory represents the optimal solution, solving most of the problems that come up in the calibration process. This laboratory provides (in relation to the on-field procedures) accuracy, a stable environment, reproducible results, savings in the human and financial resources involved and a minimal calibration time (provided by the unitary aspect of the calibration procedures). There are a few problems that cannot be solved in a metrology laboratory and also the issue of the implementation and administration costs of such a laboratory. Overall though, the metrology laboratory represents a necessity both at a national level as well as locally.

The on-field metrology procedures have the advantage of being easily implemented and with minimal costs but the resources involved and the execution time are significant. In addition, the metrological conditions are difficult to achieve, the precision and accuracy of the calibration process depends on external factors, and sometimes the on field procedures cannot solve certain stages of calibration.

Studying the advantages and disadvantages of the two methods of calibration (the laboratory procedures and the on-field procedures) it becomes clear that a smart combination of the two methods is the optimal solution. Hence the need to have both (supplied or available): a geodetic metrology laboratory and the necessity to be acquainted with the main on-field metrological procedures. In the quality control of the instruments (both in the purchase and the metrological monitoring phase), both solutions (laboratory and field procedures) are viable. If these solutions are used in tandem then the metrological calibration process becomes optimal.

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