Journal of Civil Engineering and Architecture 9 (2015) 1210-1216
doi: 10.17265/1934-7359/2015.10.009

Estimation of the Gauging and the Calibration Time Interval for the Modern Total Stations

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Abstract: The modern TSs (total stations) have reached a very high level in the provided reading and reliability (accuracy and precision) of their measurements. The evolution of the digital technology has helped in this direction. Thus, the TSs can support all requirements for the stake out and monitoring of modern survey engineering and constructions projects. Their complicated manufacturing process and the sensitivity of their components require gauging, adjusting and calibration at certain time intervals. This appears to be the only way in order to assure the precision of measurements provided by the manufacturer and the reliability of the works they are used for. The goal of this paper is to propose a method for the estimation of the gauging time interval for modern TSs, which could be used by any user. More specifically, the indispensable need for the TSs gauging is elevated and documented. All the parameters that influence their operation are registered. A model expressed by a scale of grades is defined, leading thus to an equation for the calculation of the time interval for the next needed gauging and calibration.

Key words: Total station, metrological check, gauging, calibration, time interval.

Nomenclature

σ	Standard deviation
{ }	Set
°C	Degrees Celsius
"	Arc second

1. Introduction

The revolution in the manufacturing and the operation of the modern TSs (total stations) began about 30 years ago [1, 2], but their development has accelerated over the last decade.

The cost of this development reflects, and it is directly related to the increased sensitivity of modern TSs with respect to the old optical-mechanical theodolites. This sensitivity is due to:

- the improvement of the uncertainty of the TSs, which is provided in the single sighting-measuring and not after several measuring periods;
- the fact that nowadays the TSs integrate an electronic unit for measuring distances.

Modern TSs consist of many complex electronic components, each of which acts independently and collectively to extract the final result.

These electronic parts are rather sensitive and affected by several factors. In order to properly execute this part of calculations and get a measurement, it is necessary to carry out a prior gauging, adjustment or even calibration of them.

Mechanical controls of the parts of the TS as well as lubrication of specific points all become more necessary to ensure its proper functioning.

Station gauging is the process by which it can be determined if the errors in terms of its measurements (i.e., the deviation from its nominal characteristics) are within the limits of its specifications. As long as they are within the allowable limits, they may be stored in the internal memory of the station so that

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these values correct the indications received and provide right value measurements. In case errors are outside the specification limits, then adjustment, probably calibration and finally the issuance of the respective certification, should take place [3]. Sometimes this is referred as TS collimating and trunnion axis tilt testing or service.

Calibration of a station or a system is the process of comparing the measuring indications provided by the station with a corresponding standard reference station and the determination of their relationship. This determination as well as the correction of indications takes place with the use of an appropriate measuring method [4-7].

The calibration process takes place only in officially recognized and accredited metrological calibration laboratories with the necessary infrastructure, metrological equipment, appropriate space, and by using special methodologies—procedures applied by trained technicians [8]. Usually, every manufacturer has such a laboratory. The TSs manufacturers recommend a gauging time of one year or less without any documentation about the time calculation. But the users are not induced and they are not following this recommendation.

As already mentioned, there are several parameters that affect the proper operation of TS. These parameters are independent of each other, whereas the effect of each one of them is not always equivalent and equal in amount. Thus, there is a fluctuation of their influence which should be expressed more or less.

The aim of this paper is to suggest a new and convenient methodology for the TSs' users, in order to easily determine the appropriate gauging time interval by themselves. This methodology is defined through a grade scale system, which expresses the grading of each parameter effect. The effect of each parameter is directly linked to the TS gauging time interval.

2. Grade Scale System

The main idea to come up with the gauging (service) time interval is to quantify the effect of each parameter in such units linked to the time. Thus, the effect of each parameter corresponds to a grade which represents months. The bigger the grade (more months), the later the gauging (service) should be done. That means minor parameter's influence.

The scale of grades is defined from 1 to 7, it is different for each parameter and also there are not all grades linked to each parameter. This helps the grade scale system to be more realistic. The minimum grade of the scale (of each parameter) refers to the maximum impact of the parameter to the proper TS operation, which indicates that gauging should take place in a shorter time interval. Respectively, the maximum grade of the scale (of each parameter) refers to the minimum impact of each parameter, which means lengthening of the gauging time interval.

The basic parameters, which determine the correct and reliable operation of modern TSs and the respective scale of grades for each one of them, are presented in the following sections. Moreover, for each parameter, a different cluster of TSs is tested in order to support the grade scale system. The goal of these tests is to independently check the appropriate TSs for each parameter, which are mainly influenced by this parameter and to eliminate the influence of the others.

2.1 Precision (p)

It is obvious that the smaller the uncertainty a TS provides, either in direction and distance measurements, the more sensitive it is. In addition, this is directly related to the applications in which the TS is used. It has been found that the vertical index is more sensitive than the horizontal. The vertical index error in a TS used on a regular basis can take values from 2" to 3" per year.[1] So, it is certain that a TS which provides high accuracy in the angles and

[1]Alvanos, M., 2008, personal notes, Topcon non paper, and Andonakakis, A., 2010, personal notes, Leica instructions for TS calibration.

distance measurements easily gets over the strictly acceptable errors of this category. Twelve TSs are checked (three of each one of the following categories) after one year of normal use. It is proved that those of the low and medium categories, namely direction uncertainty ≥ ±5″, have errors in the horizontal and vertical index which do not surpass their nominal uncertainty. The rest of them, which belong to the high category TSs and mean that direction uncertainty ≤ ±3″, they overcome by far this limit. Also, the error of their compensator does not influence the distance measurements except of those that had distance uncertainty ≤ ±2 mm ± 1 ppm. Table 1 presents the grades G_p owing to the TS's precision.

2.2 TS's Age (a)

The age of TS starts counting since the time of manufacturing in the factory and not since the time of purchase. As an example, we can mention the aging of the frequency emitting crystal. The frequency emitting crystal is the main component of an EDM (electromagnetic distance measurement) which emits the electromagnetic wave at the right frequency. It has been found that aging brings about a change up to 200 Hz per annum in the length measurement, equivalent to 2 ppm. The older the TS is, the smaller and more constant the value of this error (depreciation).[2]

Ten TSs of ±1″ to ±3″ uncertainty on directions, after the first year of their manufacturing, present frequency deviation which fluctuates between 163 Hz and 320 Hz. For the same TSs after three years of use, the frequency deviation fluctuates between 17 Hz and 85 Hz. Thus, the newer a TS is, the more frequent the gauging should be, so as to be adjusted. Table 2 presents the grades G_a owing to the TS's age.

2.3 TS's Time of Use (t)

The TS's time of use is measured after the last (most recent) gauging. During this time interval, the role of the user's sensitivity skills is of great importance.

This parameter is added to the model as the majority of the users do not abide at least to the general directive of manufacturing companies for annual or twice-a-year service. So, they use TS3 or TS5 or even 10 years after the last service. Thus, it is obvious that the errors are accrued if they are not corrected in a justifiable time. So, five TSs of several categories under mild use, which are checked after five years of use, present errors in horizontal and vertical index of the order of threefold upwards of their uncertainty. Table 3 presents the grades G_t owing to the TS's time of use.

2.4 Compensator Decalibration (c)

The compensator is a device, which calculates the instantaneous deviations from the correct position of the TS and establishes the conditions to be applied so that the measurements obtained are correct [9, 10].

If that is not in its proper position, then wrong deviations are calculated and the measurements are wrongly corrected. The compensator error or its decalibration depends mainly on the use of the TS, the movements and vibrations it might suffer during movements.[3] Not all compensators have the same sensitivity. Usually, TSs that provide less uncertainty in angle measurements have more and more sensitive compensators. It has been found that a typical compensator error is approximately ±1″ (compensator sensitivity).[4]

Seven TSs which are used in several projects and had undergone of hard movements for about one year, produce compensator error in both directions between 5″ and 8″. On the contrary, 12 TSs, which are used in the laboratory or at the university campus after one year of use, had almost zero compensator error. Table 4 presents the grades G_c owing to the TS's compensator decalibration.

[2]Andonakakis, A., 2010, personal notes, Leica instructions for TS calibration.

[3]Alvanos, M., 2008, personal notes, Topcon non paper, and Andonakakis, A., 2010, personal notes, Leica instructions for TS calibration.

[4]Alvanos, M., 2008, personal notes, Topcon non paper, and Andonakakis, A., 2010, personal notes, Leica non paper.

Table 1 The grades owing to the TS's precision.

G_p	Precision (p)
7	±7″, $\sigma \geq$ ±5 mm ± 5 ppm
5	±5″, ±2 mm ± 2 ppm $\leq \sigma <$ ±5 mm ± 5 ppm
4	±3″, ±2 mm ± 2 ppm $\leq \sigma <$ ±5 mm ± 5 ppm
2	±1″, $\sigma <$ ±2 mm ± 2 ppm

Table 2 The grades owing to the TS's age.

G_a	Age (a)
1	Does not exceed two years
2	Ranges between 2 and 5 years
4	Exceeds five years

Table3 The grades owing to the TS's time of use.

G_t	Time of use (t)
3	Less than one year
2	1 to 2 years
1	More than two years

Table 4 The grades owing to the TS's compensator decalibration.

G_c	Compensator decalibration (c)
4	Moving only a few times
3	Moving as usual, in a good road network, with minimal vibrations
2	A few strenuous movements, in inaccessible areas with earth-roads and quite a few vibrations
1	Many strenuous movements in inaccessible areas with earth-roads and much vibrations

Table 5 The grades owing to the TS's environmental conditions of use.

G_{ec}	Environmental conditions of use (ec)	
3	Favorable	i.e., temperatures from 15 °C up to 35 °C and clear atmosphere with absence of humidity or dust
2	Average	i.e., temperatures from 0 °C up to 15 °C and 35 °C up to 45 °C and slightly dusty atmosphere
1	Difficult	i.e., temperatures lower than 0 °C and higher than 45 °C and atmosphere with a lot of dust and humidity

Table 6 The grades owing to the TS's maintenance conditions.

G_m	Maintenance conditions (m)	
3	Good conditions	i.e. in a clean, dry place, with a temperature of 25 °C
2	Average conditions	i.e., humid environment with a temperature from 10 °C up to 35 °C
1	Bad conditions	i.e., dirty and humid environment, with temperatures lower than 0 °C or higher than 35 °C

2.5 Environmental Conditions of Use (ec)

These conditions include temperature, humidity, dust, etc. [11]. It has been observed that TSs are more sensitive to low temperatures.[5] Five TSs of ±1″ that had been used for one year under hard conditions and temperatures of the order of 0 °C in tunnelling infrastructure, work at the northern Greece region and produce errors in the horizontal and vertical index between 10″ and 15″ as the compensator error fluctuates between 3″ and 1″. Thus, the difficulty level of the environment during the station's use can be defined. Table 5 presents the grades G_{ec} owing to the TS's environmental conditions of use.

2.6 Maintenance Conditions (m)

The maintenance conditions (m) of TS presents whether it is stored in a right temperature and humidity environment.

Three TSs were kept unused in the laboratory environment for about one year. They present less error than their nominal uncertainty in both circles. On the contrary, two others that were kept unused at work site for about the same time produce errors upwards their nominal uncertainty. Table 6 presents the grades G_m owing to the TS's maintenance conditions.

Additionally, it is useful to mention that TS should be gauged and calibrated even if only stored and not used for some time. Two TSs, which are not used for longer than three years stored in the laboratory's locker had errors of 3″ and 5″ respectively on their horizontal and vertical circles.

The significance of the above mentioned parameters are clearly referred in any TS instruction manual. In this way, manufacturers inform users and make them more careful in the use and maintenance of their TSs [12-15]. However, none of them impose to the users the gauging time interval.

[5] Andonakakis, A., 2010, personal notes, Leica instructions for TS calibration.

3. Gauging Time Interval Determination

Our new scheme and proposal for the determination of the gauging or calibration or service time interval uses the aforementioned grade system.

The mathematical model that reflects modern TS's gauging time interval, exploiting the basic parameters mentioned in the previous section, can be defined as follows:

It is considered that the gauging time interval $f(t)$ is a function of the following form:

$$f(t) = f\{p, a, t, c, ec, m\} \quad (1)$$

Therefore, for each parameter indicated in the previous section, each user adds the grade G that corresponds to his own TS, according to the measurement uncertainty, time of use, etc.

The function $f(t)$ is linear as the parameters are independent of each other. Any of the parameters does not depend on another and none of them charge another with additional error. Thus, Eq. (2) gives the total of the grades G_{Total} for each TS, according to its characteristics and use:

$$G_{\text{Total}} = G_p + G_a + G_t + G_c + G_{ec} + G_m \quad (2)$$

The total of the grades G_{Total} that will occur can be linked to the time interval for the next gauging or calibration of the station, where each grade corresponds to a month:

$$T_{\text{months}} = G_{\text{Total}} \quad (3)$$

The values of the variable G_{Total} range as $7 \leq G_{\text{Total}} \leq 24$. If the gauging time interval for a modern TS is estimated with the aid of this method, we get a minimum time of seven months and a maximum of 24 months.

For example, Fig. 1 shows the gauging time interval for five virtual TSs in order to explain the use of the proposed method. In this figure, TS1 and TS5 represent intentionally the minimum and maximum gauging time interval, respectively.

4. Discussions

In an earlier optical-mechanical theodolite which measures only angles on a mechanical circle, its measuring setups were little affected by the use conditions or the continuous use. The mechanical theodolite has not electrical circuits or electronical

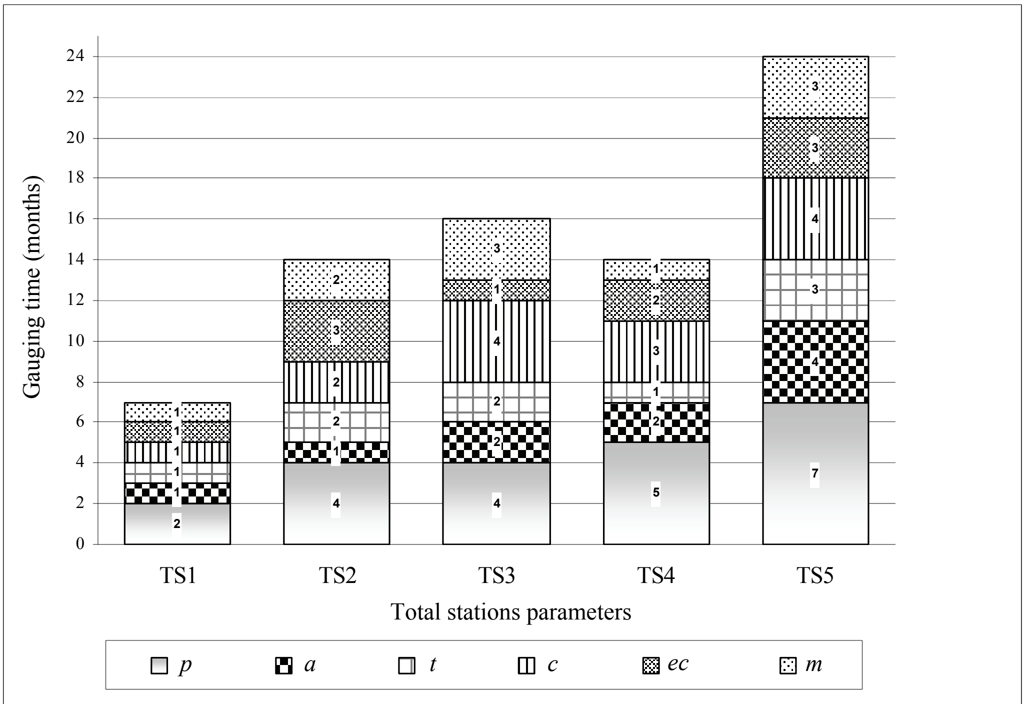

Fig. 1 Illustration of the gauging or service time interval for five virtual TSs according to the proposed method.

Table 7 The gauging costs for modern total stations in 2014 by three different brands.

Brand	Low class TS (€)	Medium class TS (€)	High class TS (€)
X	200	320	500
Y	120	180	300
Z	160	250	450

components, thus, it is more resistant. The uncertainty of measurements did not change over time and environmental variations have minor contribution to the derivatives. For modern TSs or digital levels, unfortunately or fortunately, this is not the case.

This fact has not been well understood by the majority of users. As a result, problems in measurements or derivatives arise, posing a serious risk of error for any project.

All users should understand that the gauging process is not an additional service cost for those TSs and it does not imply manufacturing error or a poor quality product, but a process that assures their work and the reliability of the derivatives that they provide as engineers.

Furthermore, this will guarantee the resale value of a well-maintained TS, an important element for a professional.

Eventually, it can be considered as a sign of responsibility to address the demanding modern works of our time.

Since the TS operation mode depends on various parameters and is directly linked to the possibility of error growth and the provided accuracy, there has been no specific estimation of its gauging and calibration time interval until today.

A general directive that comes from the quality assurance departments of manufacturing companies provides that generic TS gauging should take place once annually or twice annually for TSs that are characterized by small uncertainties (high category) which are used in specialized works such as displacement monitoring, stake out of railway lines, tunneling, etc. [16].

The adequacy of the aforementioned directive is not proven. On the contrary, there are cases where gauging should be more frequent or less frequent depending on the use and maintenance of the TS.

The proposed model, for the gauging time interval determination, enables and helps professionals to calculate it in an easy way, especially for each TS.

The model uses easy calculations as well as needs data of TS's use which are known by users.

Finally, Table 7 presents the service cost for modern TSs nowadays, depending on the category (namely the nominal accuracy and the features) of the TS. It is proved that the referred cost is neither deterrent nor the determining factor for the negligence of regular service by the calculated time according to the suggested model of the grade system.

5. Conclusions

As the modern TSs consist of complex and sensitive electronic components at regular intervals, must be maintained, gauged, adjusted and calibrated, so as to give measurements in accordance with their specifications.

The manufacturers avoid fixing the gauging time interval as obligatory. Some TSs only notify via a warning on the display when the time came to have serviced. This time is approximately a year after its last maintenance regardless of the using parameters.

The gauging and calibration time interval of each modern TS depends on various parameters. These parameters affect each station in a different way.

The grades which are given to each parameter are derived from thorough study of real data, which are obtained by the evaluation of sufficient TSs' number.

Actually, these grades represent the exact TSs behavior.

Thus, the model developed in this paper allows each user to estimate the objective gauging time interval independently, according to the evaluation of these parameters relative to TS.

The proposed model includes the more significant parameters, it fits to all the TSs models, and it is easy to apply by any user.

According to the model of the grade scale system suggested, there can be an objective—realistic definition of the gauging and the calibration time interval for modern TSs.

This time interval ranges from seven months to two years.

Acknowledgments

The authors gratefully acknowledge the generous support of the technical personnel of Metrica S.A and Tree Company Co., which are authorized distributors in Greece of Leica-Geosystems and Topcon, respectively, for the rendering, their patience and insistence in the collection of all the referred statistical confidential data above which are kept in their archives. The most of the referred TSs comprise instrumentation of the laboratory of General Geodesy at the School of Rural and Surveying Engineering at the National Technical University of Athens. However, some of them are owned to other private structural companies. The data related to 31 TSs, which are used in different circumstances and had been checked in a 5-year period.

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