COMPARING THE CONCEPTS OF MODERN COMPARATORS OF CODE LEVELLING RODS AS EXEMPLIFIED BY THE HORIZONTAL COMPARATOR OF LEVELLING RODS UNIBWM (MUNICH) AND THE VERTICAL COMPARATOR OF "LEVELLING SYSTEMS" TUG (GRAZ)

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INTRODUCTION

At present, in such research centers as the Institute of Geodesy and Geodetic Astronomy (Warsaw University of Technology) or the Mining University of Krakow, there is experimental equipment to compare code levelling rods and research is being carried out involving the instrumentation and calibration methods. However, this equipment can hardly be termed as fully automatic research stations. For this reason, in my opinion, the construction of the above type of instruments in the future is justified both scientifically and economically.
Relying on the available literature on the subject, it can be fairly easy to define general traits that a modern comparator should possess. However, the selection of the concept according to which it should be built is not a simple question. For the selection to be appropriate one has to analyze, first of all, the construction and results of the research done with the existing constructions and consider all the benefits and constraints of each research method.
Below you will find a tentative comparison of two completely different concepts of automatic stations to test levelling rods, in particular, involving the requirements imposed on the equipment used for engineering measurements. The above comparison was based on the analysis of research involving two comparators and lasting many years, which might be considered "model" for the comparison concept they represent.

1. VERTICAL COMPARATOR OF "LEVELLING SYSTEMS" TUG (GRAZ)

The construction in question, which reflects the newest trends in equipment design and rod calibration, was developed at the Technical University of Graz. (Fig.1.).

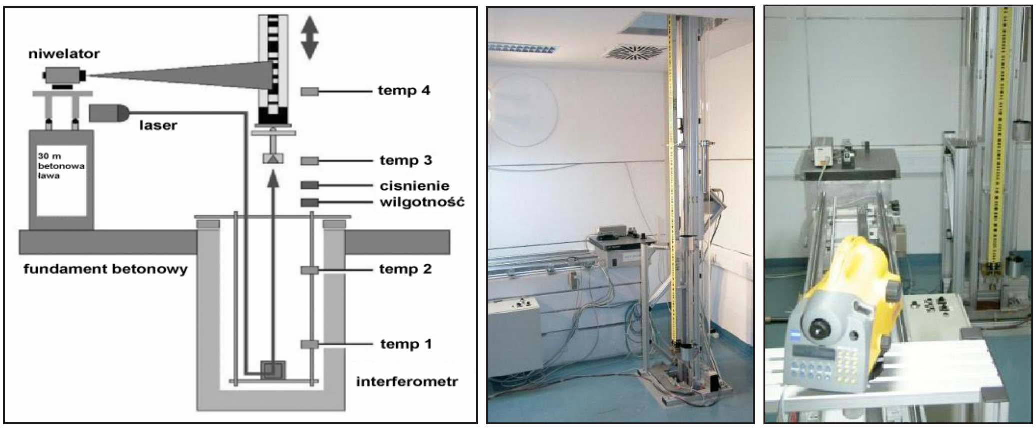

Fig. 1. Vertical comparator of "levelling systems" TUG (Brunner, Woschitz 2002).

The creators of the above concept think that during the measuring process, the final result of which is the difference between two points, both the levelling rods and the levelling instrument are involved, thus constituting a "measuring system" which as a whole should undergo calibration. Further, an integral part of the system, besides the measuring equipment itself, is the environment where the measurement is made.

The basic idea of this system is, first of all, to read out the heights from the levelling rod with a levelling instrument and next to compare them with the real displacement values of the rod registered by the laser interferometer.

The estimation accuracy of *"System calibration"* was based on comparing calibration results of precise Zeiss code levelling rods made with a horizontal comparator of the geodesic laboratory in Munich with the results obtained in Graz. As a result of this comparison, the accuracy of determining the coefficient value of rods scale with short targets (3.3m) was specified at about ± 1 ppm (Brunner, Woschitz, 2002).

1.1 Advantage of the concept:

- **The possibility to compare the "levelling system" consisting of a levelling rod, levelling instrument and the environment in which the measurement is made – theoretically, it is the most appropriate calibration method as it involves most of the factors occurring during the measurement (including possible errors caused by the levelling instrument) and most certainly it will be the best solution in the case of levelling measurements involving targets of constant length and the read-out place roughly defined on the rod (e.g. the central section of gradation). It should be assumed that this method of comparison will yield the best results in the form of precise amendments relating to measured overheights over long levelling traverses where height differences between individual stations are not so big.**

- **The possibility of a wide range of instrumental research (e.g. of the levelling instruments only) – such studies can provide a lot of very important information about the influence of various factors on measuring accuracy (lighting, algorithms of calculating the readout, vibrations, telescope focusing, aging effects of the CCD matrix, etc).**

1.2 Disadvantage:

- **Extremely high costs of building the comparator – high accuracy of comparison and a wide range of possibilities to conduct instrumental research stem, first of all, from a very well-thought out construction design of the comparator and perfect operational conditions provided for the device. The accessories to monitor atmospheric conditions and keep them under control, with which the laboratory was provided, cost as much as € 600,000. An extremely meticulous approach to the device construction and conditions control, under which the comparison is made, resulted in discovering a large number of systemic mistakes that accompany levelling measurements and have a great influence on the final result of "*levelling system*" comparison. Giving up their monitoring or simplifying the comparator's construction due to the lack of funds, would make such a high level of calibration accuracy inaccessible, and by the same token, question the device feasibility. For this reason I think that the application of a levelling instrument as a tool to test the metricity of code graduation is only seemingly easy (although one can have a different impression reading numerous theoretical studies on the subject) and will yield good results only in precisely defined conditions.**

- **No possibility to compare traditional graduation - it is a serious drawback of the comparator as rods with traditional graduation are widely used and will certainly remain to be used for measurements for a long time, especially wherever digital levelling instruments are very difficult to use (poor lighting conditions, vibrations, etc.),**

- **Determination of the scale coefficient is based only on a fragment of graduation – leaving out the final fragments equaling half of the graduation section "seen" by the instrument (connected with the distance between the levelling instrument and the compared rod). For this reason it is not possible to compare short (of several dozen centimeters) engineering rods - errors in he read-outs near the rod ends amount to ±0.7 mm (Woschitz, 2002).**

- **The lack of an unambiguous solution to the problem of target length, at which read-outs should be made during the comparison – in the case of levelling instrument made by Topcon there are discrepancies between research results (Woschitz 2002), caused by the algorithm that the instrument uses to calculate the read-out with, i.e. for short or long targets.**

- **The lack of unambiguously defined influence of the graduation lighting type on the final result of comparison – during the research carried out with a horizontal TUG comparator it was confirmed (Woschitz 2002) that lighting has an essential influence on measurement results, which stems from the fact that CCD matrixes of different sensitivity range are used by the main producers of measuring accessories. The comparison is made in laboratory conditions and artificial lighting, the color temperature of which oscillates within the 3000-4200˚K range and differs considerably from the daylight temperature, the value of which may be within 5000-8000˚K range. Even with the assumption that artificial lighting is used within the daylight range, we are able to ensure only a narrow selected range of its color temperature (e.g. 5600˚K light bulbs).**

- The determined value of a scale coefficient concerns the whole *"levelling system"*, i.e. the levelling instrument and a specific set of levelling rods – for this reason every interference in the electro-optic system of a levelling instrument (e.g. any damage caused or repairs thereof, software updates) necessitates a new comparison of the whole measuring set.

2. HORIZONTAL COMPARATOR OF LEVELLING RODS UNIBWM (MUNICH)

The comparator located at the Institute of Geodesy of the University in Munich is a very precise instrument to test levelling rods in a horizontal position.

The comparator which is housed in an air-conditioned laboratory consists of a base with two mobile trolleys, to which a tested rod is fixed. The rod support points ensure minimal length changes of an invar tape during the calibration process, whereas the comparator construction enables to measure the distance between all identified edges of the code elements.

Fig. 2. Horizontal comparator UNIBWM. Fig. 3. Zeiss MPV Compact.

The position of the edges of graduation elements is defined with an MPV Zeiss Compact microscope mounted above the moving rod, the horizontal movement of which is checked by an interferometric measurement (Fig.3).

The accuracy with which the scale coefficient value of tested graduation is defined oscillates in the ±0.3ppm range and is the highest among all European devices of that type.

2.1 Advantage of the concept:

- Not a very complicated and easy to apply concept of calibration - it does not require a complex system of sensors monitoring atmospheric conditions in the laboratory, complicated software calculating and accounting for appropriate amendments to measured values and additional accessories in the form of advanced lighting or a structure, to which the levelling instrument is attached.

- Very high accuracy of determining the scale coefficient of rod graduation.

- **Possibility to determine the graduation scale of any required length within the code range (of all elements).**

- **Autonomous determination of scale coefficient values of rod graduation.**

- **Universal solution enabling to test traditional graduation.**

- **Relatively easy adaptation of the comparator to testing the coefficients of thermal graduation as compared to the *"calibration system"*, where selecting atmospheric conditions (temperature) only for the tested graduation is practically impossible.**

2.2 Disadvantage:

- **No possibility to make comparison of the *"levelling system"*, i.e. the rod together with the levelling instrument.**

- **Comparing rods horizontally – in the case of code rods, which are only produced by the NEDO company, this drawback does not have a very great effect now on the comparison process as the difference in graduation length between the horizontal and vertical position is not very big, being estimated, after long research, at +0.9ppm (Maurer, Schnadelbach 1995). Additionally, the above research suggests that due to high quality standards during the rod production it does not fluctuate greatly. The results of this research have an essential influence on a general approach to rod comparison as they are sufficient evidence that we should give up the idea to design comparing devices for testing levelling rods in their working (vertically) position, which simplifies the construction considerably, and at the same time substantially reduces the construction costs of a comparator or its possible laboratory adaptation.**

3. CONCLUSIONS

Analyzing the construction of the devices and research results obtained for both comparators, it is difficult to make a decisive conclusion as to which concept of rod calibration is better. The vertical TUG comparator of *"levelling systems"* has become a powerful research tool, mainly due to many years of constructors' experience in the field of levelling equipment testing (especially levelling instruments) and huge financial investments. However, even such an advance construction does not give a straight answer to several important questions which are directly connected with the results of the comparison made (i.e. lighting and calculating algorithm).

From an economic point of view, the Munich construction has a clear advantage. In my opinion, it is much more universal (it enables to test all kinds of graduation), it provides higher accuracy of comparison and is far less expensive to apply in the Polish economic situation.

Further, what favors the tradition way of testing graduation is the fact that comparing calibration results of several sets of rods made with the Munich comparator and the same rods together with the levelling instruments (different specimens and software version), tested in Graz as *"levelling system*s" showed only very small differences in the obtained scale coefficient values (max.1.4 ppm, Woschitz 2002), which, for instance, in the case of the measurement of a height difference of the 100m range would result in a mere difference of 0.14mm. As can be deduced from this comparison, this part of the

"levelling system" **that is constituted by the levelling instrument has only a slight influence on the final value determined for the scale coefficient of the** ***system.*** **However, final verification of this thesis requires wider and more detailed research.**

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