Assumptions of construction of linear calibration bench for geodetic distance measurement equipment

Lauryna Šiaudinytė[1], Domantas Bručas[2], Mindaugas Rybokas[3]

[1,2,3] *Vilnius Gediminas Technical University, Institute of Geodesy, Saulėtekio al. 11, LT-10223 Vilnius, Lithuania*
[1] *lauryna.siaudinyte@vgtu.lt,* [2] *dobr@kmti.lt,* [3]*mindaugas.rybokas@vgtu.lt*

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Abstract. Geodetic measurement instrumentation plays an important role in both linear and angular measurements used in land surveying, legal metrology and recently - machine building. Calibration of such equipment plays the essential role in ensuring the measurement accuracy. Most recent developments on this topic are observed in the field of non-contact distance measurement devices such as laser trackers as well as their calibration. This paper presents the assumptions for automated calibration of non-contact distance measurement instrumentation as well as preliminary design of linear test bench being developed at Vilnius Gediminas Technical University.

I.   Introduction

Geodetic measurement instrumentation have long been used for land surveying, legal measurements and recently widely implemented in machine building (instrumentation like laser scanners, laser trackers etc.), however measurement accuracy and precision questions are still uncertain in many cases. Geodetic measurement instrumentation is composed of angle measurement (vertical and horizontal) and linear measurement units. During last few years angle measurement control and calibration equipment has been under development at the Institute of Geodesy of Vilnius Gediminas Technical University and recently it is focused on the development of the distance measurement calibration equipment.

Geodetic distance measurement equipment as well as angle measurement instrumentation is applied very widely nowadays. Such instruments as laser distance meters, total stations, laser trackers etc. implement non-contact distance measurements for 3 axis coordinate determination. Therefore, the accuracy of distance measurement has a great influence on general measurement results and is especially relevant in case of the legal metrology. Due to these reasons the accuracy of distance measurement equipment has to be controlled and corrected if needed.

II.   Overview of length measurement methods and instrumentation

Preservation of the primary length standard - the meter - is the main role of length metrology. It also has to ensure the infrastructure needed for dimensional and positional measurements traceability to the meter.

Optical comparator is the most common piece of equipment used for precision line scale calibration. It is based on optical or X-ray interferometry and provides length standard calibration with uncertainties ranging from as low as nanometers up to tens of nanometers when working with length significantly larger than the wavelength of the source. However, complications get in the way when the dimensions of the measured structure match the order of the wavelength. In such cases comparative methods, such as X-ray diffraction or microscope scanning come in hand. This is particularly used for micro electro mechanical system, lithography and similarity investigation [3].

The meter is defined as the length of the path traveled by light in vacuum during the time interval of 1/299 792 458 of a second. An interferometer is an instrument There are a few main types of laser interferometers used in laboratory measurements – homodyne and heterodyne laser interferometers are the most commonly used. Homodyne interferometers are based on the interference of two beams (one split beam) of the same frequency. The optics of homodyne interferometers is similar to Michelson interferometer's, however it produces a low signal due to the high noise ratio compared to heterodyne interferometer. Heterodyne interferometers are based on two beams with different frequencies (weak and strong), different polarization mixed with each other and in non-linear combination creating two new frequencies (heterodynes). The double frequency interferometers measure the relative displacement of two reflectors by splitting the beam. Then 2

beams are directed to different retroreflectors and resultant signals are returned to a photodetector [7]. The working principle of laser interferometer is shown is Fig.1.
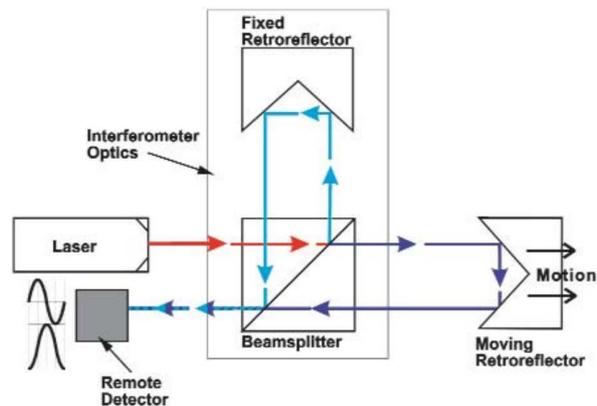

Fig.1. Working principle of laser interferometer

Heterodyne interferometers are very sensitive and usually more accurate than homodyne interferometers.

There are environmental factors such as temperature, pressure and humidity influencing linear measurements. The most important factor of length measurement accuracy is temperature. The sensitivity of the interferometric systems to varying temperature can significantly influence the measurement results because of linear expansion of materials affecting the stability of structural geometry. Precision measurement systems are usually placed in controlled environment with a constant temperature of 20°C±0.2°C. To meet such requirements the interferometric system should be placed in a special chamber with many parameter measuring sensors to keep the effective thermal and pressure isolation. These sensors as well as temperature fluctuation can bring in the uncertainty in such precise length measurements [2]. Another important uncertainty source in dimensional metrology is abbe error which occurs due to angle deviation of measurement object axis in respect of measuring device axis. This error can also be caused by the motion of the measurement object [6].

Many linear comparators are developed in world famous metrology institutes. An interferometric calibration system for end and line standards up to 2000 *mm* was developed in KRISS (*Korea Research Institute of Standards and science*). In this comparator Abbe error reduction to less than *2nm* is performed by compensation using a three axis interferometer setup regarding the Abbe configuration. The measurement speed is increased by using high-performance controllers along with control algorithms. The thermal drift is reduced by short measurement time. This system has a minimized size, so it can be easily installed in a thermally controlled environment to increase the stability. The main components of this calibration system are stages, controller along with the environment condition monitoring equipment and displacement sensors that include laser interferometers and probes. This configuration enables achieving high efficiency and accuracy of the calibration. The angular motion errors were reduced to ±0.2" [5]. Another similar scale comparator was developed by Nikon. This comparator was improved by employing a continous autofocus system and the error of defocus was determined 4 *nm* [8].

Although each of these comparators have their own specific nuances, the me main working principle is very similar for all of them. The linear distance measured by the microscope is compared with the distance measured by an interferometer. One part of interferometer is fixed and the other is moving along the measurement object with the interferometer mirrors and microscopic optical system.

Previously mentioned length comparators are sutable for less than 2*m* precise scale and gauge block measurements. However, total stations and other geodetic length measurement instrumentation is ususaly designed for longer distance measurements. The focusing range of total station usually varies from 1.7 *m* to 2.0 *m*. Therefore, such comparators would be inconvenient and not sufficient to use for the calibration of total stations. An electronic distance measuring device (EDM) of a total station can perform distance measurements with the resolution of 0.1 mm in the range of 1 kilometer. These instruments are very widely used in civil engineering and survey, therefore their calibration is essential to ensure accurate measurements.

In the national metrology institute of Germany (Physikalisch-Technische Bundesanstalt) there is a 50 *m* long geodetic base which is also a comparator established for the calibration of length measuring instruments where the principle of Michelson's interferometer is used as a length standard. The carriage is mounted on the rails which are fixed along 50 m base. The stationary part of an interferometer is placed on a stabile base in front of the rails. The laser beam is split into two path is created by fixing the reflector which consists of three single mirrors arranged on the surface of an imaginary cube to the moving carriage. The zero point of the

interferometer in respect of the rangefinder is defined by means of a gauge block. The measurement error of the distance measuring device can be determined the comparison of distance measured by an interferometer and calibrated instrument [9]. In KRISS the 50 *m* long bench was developed for the calibration of surveying tapes. The main components of this system are the interferometer and the carriage moved by the servo motor attached to it along steel rods and controlled by a computer through wireless communication. The interferometer axis is set in the center between the rails where the tape is placed. There is an optical system with the microscope installed in the moving carriage to detect the graduation of the tape. The distance measured by the interferometer is compared to the distance determined by the tape being calibrated [4].

Analyzed examples show that 50 *m* long comparators can be used for the calibration of the geodetic distance measuring instrumentation. Some modifications are needed to perform reflector and total station measurements.

III. The design of the proposed linear calibration bench

Distance measurement equipment have long been tested and controlled by implementing non automated measurements and measuring objects at certain well-known distances. At the Institute of Geodesy such principle has been used by implementing multiple fixed indoor pillars for short distance measurements and cyclic error correction, as well as several fixed outdoor pillars were used for long distance measurement control. Nonetheless, implementation of such instrumentation requires a lot of human interaction in the process which slows down the process considerably and introduces multiple operator related errors. Additionally, since modern standard measurement equipment (distance meters, total stations etc.) can determine enormous amount of measurement data with a very high resolution, implementation of fixed pillars for error determination is not fully correct. The distances between fixed pillars might include possible potential errors which are left uncovered by calibration. These issues are neither covered in the international standards (i.e. ISO).

Implementation of automated measurement and control of the process would allow increasing of both the speed and the accuracy of the measuring process. However, automated systems are available mostly for short distances. Although mentioned automation brings in lots of benefits to the measurement process, it still remains costly, complex and not always affordable for some organizations. Therefore, in Institute of Geodesy a linear test bench implementing standard and comparatively low cost components is under development.

The test bench implements the distance meters cyclic correction stand composed of multiple well established pillars as the base for linear movement rail. The rail itself is a standard aluminum profile made for steel roller bearing linear guides to roll the mounted moving car. Implementation of aluminum profiles ensures lower total mass which is relevant due to implementation of older installation as the base. However, some inaccuracies due to the lower stiffness are unavoidable. The profile rail is flexibly connected to each pillar (with the step of 1 meter) and precisely levelled. Preliminary design of linear calibration bench and its components (a – moving carriage, b – rails, c – reflector for total station measurements, d – corner cube fixed to the moving car to create the path for split laser beam, e – pillars established every l=1 *m*) is shown in Fig.2.
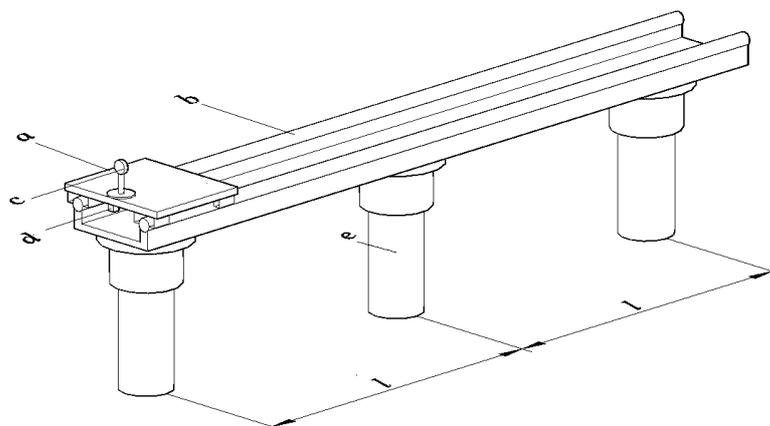

Fig.2. Preliminary design of linear calibration bench

The moving carriage of the bench is an aluminum body plate moving on the precise ball bearings. A motorized linear air-bearing would be the main component ensuring a smooth motion of the carriage. Therefore, vertical and horizontal straightness as well as rotational error motions have to be determined before using the

carriage for the calibration of length measuring instruments [1]. Implementation of aluminum here is preferable due to the decrease of moving mass its inert influence on the rail profile. The movement of the car is automated by step motors (with coarse distance determination) and the car can be positioned at practically any linear position within the distance of the bench. The precise position of the car is determined by stationary fixed Renishaw interferometer and its mirror mounted on the moving car.

IV. Conclusions

The assumptions of using fixed cyclic error determination pillars as a base for development of a linear calibration bench with an automated moving carriage are presented in the paper. The advantages of this proposed bench are light weight construction as well as it is a cost saving solution, however it is more complicated to precisely control the environment where the calibration is performed.

The main purpose of this linear bench is to reduce human interaction in the process and to determine cyclic and other distance measurement errors by performing measurements at a desired distance within the length of the bench.

Acknowledgement

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