Precision Engineering xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

Precision Engineering

journal homepage: www.elsevier.com/locate/precision

System for automatic gauge block length measurement optimized for secondary length metrology

Zdeněk Buchta[a,*], Martin Šarbort[a], Martin Čížek[a], Václav Hucl[a], Šimon Řeřucha[a], Tomáš Pikálek[a], Štěpánka Dvořáčková[b], František Dvořáček[c], Jan Kůr[d], Pavel Konečný[d], Martin Weigl[d], Josef Lazar[a], Ondřej Číp[a]

[a] *Institute of Scientific Instruments, Academy of Sciences of the Czech Republic, Královopolská 147, 612 64 Brno, Czech Republic*
[b] *Department of Machining and Assembly, Faculty of Mechanical Engineering, Technical University of Liberec, Studentská 2, Liberec, Czech Republic*
[c] *Regional Inspectorate Liberec, Czech Metrology Institute, Slunečná 23, Liberec, Czech Republic*
[d] *Mesing spol. s r.o., Šámalova 60a, 615 00 Brno, Czech Republic*

ARTICLE INFO

Article history:
Received 22 December 2016
Received in revised form 14 March 2017
Accepted 16 March 2017
Available online xxx

Keywords:
Low-coherence interferometry
Laser interferometry
Gauge block
Metrology

ABSTRACT

This paper presents a contactless system for automatic gauge blocks calibration based on combination of laser interferometry and low-coherence interferometry. In the presented system, the contactless measurement of the absolute gauge block length is done as a single-step operation without any change in optical setup during the measurement. The optical setup is combined with compact gauge block changer with a capacity of 126-ga blocks, which makes the resulting system fully automatic.

The paper also presents in detail a set of optimization steps which have been done in order to transform the original experimental setup into the automatic system which meets secondary length metrology requirements. To prove the measurement traceability, we conducted a set of gauge block length measurement comparing data from the optimized system and the established reference systems TESA NPL A.G.I. 300 and TESA–UPC operated in Czech Metrology Institute Laboratory.

1. Introduction

In the field of industrial metrology, a gauge block (GB) stands for a length standard [1]. The gauge block is used there for verifying of the length measuring instruments used in all branches of mechanical manufacturing. Alike all other mechanical measuring tools, gauge blocks need to be calibrated periodically.

Nowadays, the GB calibration methodology is described in the international standard EN ISO 3650. For primary mechanical length standards, the document presents a method of calibration employing multiwavelength single-ended interferometry (SEI). In this case, calibrated GB is wrung to a reference plate and the length of the GB is calculated as a combination of its nominal length and a length fraction, measured as a phase shift between the plate and the other face of GB by multiwavelength interferometry [2–4]. For secondary mechanical length standards, the above mentioned international standard introduces full-contact comparative measurement technique, comparing the secondary standard against primary standard using incremental length gauges.

Both mentioned conventional approaches to the GB calibration involve mechanical contact between the GB and the system for its measurement. Therefore, the research in the field of contactless calibration techniques has been pursued incessantly.

Most contactless measuring techniques are based on a double-ended interferometry (DEI) principle where different kinds of light (white, monochromatic, coherent) are used for measurement of the gauge block length [5–9]. Most of these techniques are based on some changes of the optical setup (i.e., using shutters for disabling some beams) during the measuring process. Our team put together a contactless method published in [10] combining laser interferometry and low-coherence interferometry [11,12] and carrying out the absolute GB length measurement as a single-step operation without any change in optical setup during measurement, giving complete information of the gauge block length. The contactless method employing just light for the object length measurement eliminates the unwanted mechanical interaction between the object and the measurement setup.

---

* Corresponding author.
E-mail address: buchta@isibrno.cz (Z. Buchta).

http://dx.doi.org/10.1016/j.precisioneng.2017.03.002
0141-6359/© 2017 Elsevier Inc. All rights reserved.

Please cite this article in press as: Buchta Z, et al. System for automatic gauge block length measurement optimized for secondary length metrology. Precis Eng (2017), http://dx.doi.org/10.1016/j.precisioneng.2017.03.002

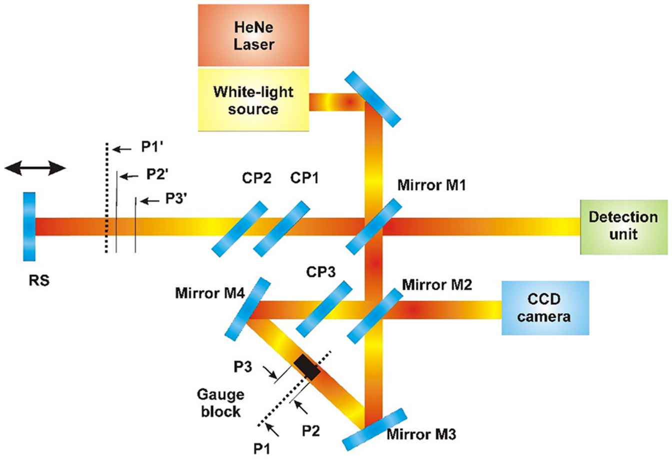

Fig. 1. Optical setup for gauge blocks measurement. CP1, CP2 and CP3 are compensating plates and RS is a reference surface.

2. Methodology

The optical setup is a combination of a Michelson interferometer and a Dowell interferometer [13], which is placed in the reference arm of the Michelson interferometer. The sketch of the setup is shown in Fig. 1 and described in detail in [10].

A collimated beam, combining radiation of a broad-band (e.g. white-light) source and a single-frequency source (e.g. HeNe laser), is divided into two parts by a semireflecting mirror M1. The first part of the beam passes through a couple of compensating plates CP1 and CP2 and then it is reflected back by a reference mirror RS. The second part of the initial collimated beam plays a role of the primary beam for a Dowell interferometer. This beam is divided by a semireflecting mirror M2 into two beams passes through the Dowell interferometer in opposite directions. These both beams are partially reflected by gauge block faces and partially pass alongside the measured gauge block.

The principle of the measurement is based on low-coherence interferometry taking advantage of low-coherence properties of the broadband light source. In the range of the movable reference surface RS shift, there are three balanced positions of the setup (in Fig. 1 marked as P1′, P2′ and P3′).

In the P1′ position, the beam reflected of RS interferes with the pair of beams passing alongside the measured gauge block. In fact, this is equivalent to a configuration with a mirror in the position marked as P1 (see Fig. 1). P1 is located at the mean optical path length of the Dowell interferometer and it plays a role of the reference position in the setup.

In the positions P2′ and P3′, the beam reflected of RS interferes with the beams reflected of the gauge block faces (marked as P2 and P3 in Fig. 1). Then, the measured gauge block length is equal to the sum of distances between the measuring positions P2′ and P3′ and the reference position P1′:

$$\mathrm{GBL} = \left|\mathrm{P1}' - \mathrm{P2}'\right| + \left|\mathrm{P1}' - \mathrm{P3}'\right| \qquad (1)$$

where GBL stands for the gauge block length.

For incremental interferometric measurement of the distance between the reference position P1 and measuring positions P2 and P3, the red HeNe laser radiation is used [13–15]. In the presented system, a broad-band radiation is generated by supercontinuum NKT laser (1.5-W SuperK Extreme Versa, NKT Photonics, Denmark). To ensure exactly the same conditions for both types of radiation, both single mode and broad-band radiation are combined by an optical fiber coupler into a single large-diameter beam, which is able to cover entire gauge block face.

Since just a single beam containing two different types of radiation is used in the setup, the key component of the detection unit is a dichroic mirror, reflecting 633 nm HeNe radiation and transmitting the near infrared broadband radiation (shown in Fig. 2).

For interference signal detection, the detection unit employs a couple of 16-elements photodetector arrays of PIN silicon photodiodes (PBD-C154SM, Advanced Photonics, Inc.). The detected signals are amplified with three-sequential amplifier and digitized by a couple of data acquisition cards (USB-6361, National Instruments). In this configuration, each beam is spatially divided into 16 autonomous interferometers, 8 of which are providing the information about the measured gauge block and the remaining 8 of those are monitoring the part of the beam, which is not blocked by the measured gauge block.

The array of photodetectors related to the broad-band radiation detects low coherence interference signals. By proper data processing of these signals employing Quadratic polynomial fitting technique [16], there are calculated the above mentioned positions P1, P2 and P3. The array of photodetectors used in the HeNe radiation way detects interference fringes generated by the reference mirror RS movement in order to measure relative distances among balanced positions P1, P2 and P3. Detection of interference phase is ensured here by digital computation of quadruple signals [17].

3. Experimental setup

A block diagram of the automatic system for gauge block calibration is shown in Fig. 3. Except for the optical setup itself, the system includes various types of electromechanical modules making the system automatic such as a gauge block changer, an optical module for gauge block position monitoring, a subsystem for gauge block

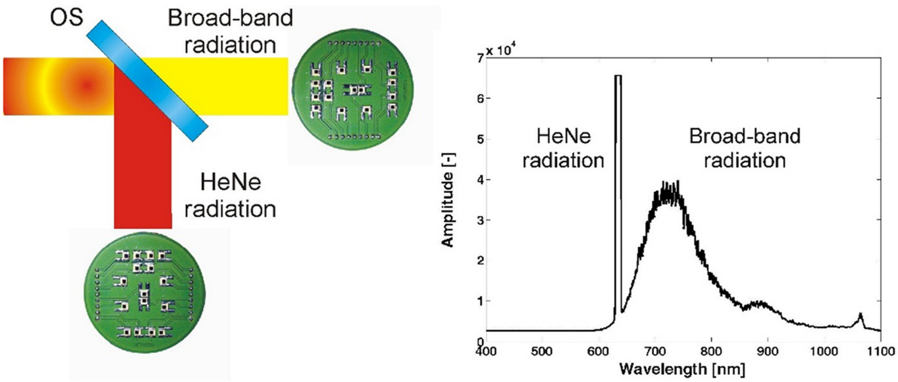

Fig. 2. Detail view of the detection unit used in the designed measuring system. OS is an optical splitter. On the right hand side, there is shown a spectrum profile of the combined laser beam taken at the input of the detection unit.

Please cite this article in press as: Buchta Z, et al. System for automatic gauge block length measurement optimized for secondary length metrology. Precis Eng (2017), http://dx.doi.org/10.1016/j.precisioneng.2017.03.002