Fully automatic optical system for gauge block calibration

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This paper presents a novel principle for a contactless gauge block measurement using a combination of low-coherence interferometry and laser interferometry. The measurement is fully automatic, with no operator influence. The designed setup is supplemented by an automatic handling system designed for a set of 126 gauge blocks (up to 100 mm) to allow the automatic contactless calibration without a human operator.

1 Introduction

In the field of industrial metrology, a gauge block 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. Like all other mechanical measuring tools, gauge blocks need to be calibrated periodically. At present, their calibration methodology is described in the international regulation EN ISO 3650. The methods described there are based on using of mechanical length gauges or laser interferometry, but none of them is a full contactless method.

Most contactless measuring techniques which have been developed are based on a double-ended interferometry principle where different kind of lights (white, monochromatic, coherent) are used for detection of the gauge block length [2–4]. 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. Previously, we put together a contactless method published in [5] combining laser interferometry and low-coherence (white-light) interferometry [6]. In this case, the contactless measurement of the absolute gauge block length is done 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 light for the object length measurement eliminates the measurement error caused by a mechanical interaction between the object and the measurement setup. On the other hand, the precise measurement is conditioned by perfect alignment of the block-shaped object (gauge block) to the measuring beam. If the axis of the gauge block is not parallel with the beam axis, the result of the measurement is influenced by a cosine error. Elimination of the cosine error requires employing of a powerful control technique ensuring the proper object positioning in the experimental setup during its length measurement. This article describes the technique which was designed for our system for contactless gauge block length measurement.

2 Experimental setup

The optical setup combines a Michelson interferometer and a Dowell interferometer, placed in the reference arm of the Michelson interferometer. The principle of the measurement is illustrated in Figure 1 and described in detail in [5].

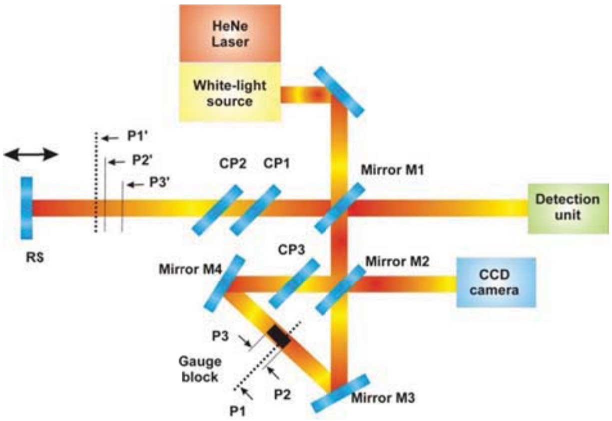

Fig. 1 *Optical setup for gauge blocks measurement. CP1, CP2 and CP3 are compensating plates and RS is a reference surface.*

In the P1’ position, the Michelson interferometer measuring beam interferes with the pair of beams passing alongside the measured gauge block. In fact, this is equivalent to a configuration with a mirror in a position marked as P1 (see Figure 1). P1 is at the mean optical path length of the ring interferometer and for the gauge block length measurement, it plays the role of the reference position. As for positions P2’ and P3’, the Michelson interferometer measuring beam interferes with the beams reflected by the gauge block faces (marked as P2 and P3 in Fig. 1). Then, the measured gauge block length is equal to the sum of

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distances between the measuring positions P2' and P3' of the reference position P1':

$$GBL = |P1' - P2'| + |P1' - P3'| \qquad (1)$$

3 ACTIVE STABILIZATION OF GAUGE BLOCK IN THE SETUP

In a double-ended optical measurement of a gauge block length, the proper position of the gauge block in the measuring system is a critical parameter [1]. The measuring axis of the gauge block in the interferometer should be kept in a strictly parallel position with the propagating beams in the Dowell interferometer. If the gauge block is in the right parallel position to the propagating coherent beams in the Dowell interferometer then we observe a surface interference fringe at the unused output of the Mirror M2 (see Fig. 1). An inspection CCD camera records the interference fringes structure given by the two reflected beams from the gauge block faces and the interference pattern is then analyzed in order to get the information about the gauge block misalignment. The image analysis employs the "flooding technique" working with gray scale images. In the first step, the value of the mean intensity in the investigated area is determined. Then, the value is used as a threshold separating areas of higher and lower intensity. The resulting image is then analyzed again to identify of areas representing interference fringes – minor areas (up to 100 pixel clusters) are regarded to be a noise and they are not taken into account. Finally, the image analysis procedure gives a number of identified interference fringes in the longitudinal and lateral direction. If the number is greater than 1 or if the number of interference fringes cannot be evaluated, the software readjusts the voltage on an adequate PZT transducer built into the gauge block holder to optimize the gauge block position in the system. For each image, several X and Y sections are analyzed for clear identification of all interference fringes and their orientation. For cases of gauge blocks with shape imperfections, the number of iterations is limited to 10. Then, the software carries out the length measurement or marks the gauge block as defective.

In the output of the triangular optical setup, the relation between the mutual angle of interfering beams axis and a period of a spatial interference structure is in case of two-beam interference given by Equation (2):

$$P = \frac{\lambda}{2 \cdot \sin(\alpha)} = \frac{\lambda}{2 \cdot \sin(4 \cdot \beta)} \qquad (2)$$

where P is a period of a spatial interference structure (period of interference fringes), λ is a laser radiation wavelength and α is the half of mutual angle of interfering beams axes and β is the angular change of the gauge block placed in the triangular optical setup. In the designed experimental setup, the gauge block holder contains PZT transducers with a maximal stroke of 15 μm, which allows alignment of the gauge block axis to the measuring beam axis in a range of tenth of milliradians.

The method resolution represents the tilt value adequate to the difference between one and two generated interference fringes. In case of two interference fringes in the longitudinal section (gauge block length 30 mm, adequate period of interference fringes $P_{\text{longitudinal min}}$ = 15 mm), the unwanted tilt value is 5×10^{-6} rad (0.287×10^{-3}). In case of two interference fringes in the lateral section (gauge block width 9 mm, adequate period of interference fringes $P_{\text{lateral min}}$ = 4.5 mm), the unwanted tilt value is 17×10^{-6} rad (0.974×10^{-3}). In our system, the algorithm is able to compensate the gauge block lateral tilt up to 0.121 mrad and the longitudinal tilt of the gauge block up to 0.141 mrad.

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References

[1] T. Doiron, J. Beers, „The gauge block handbook". <http://emtoolbox.nist.gov/Publications/NISTMonograph180.pdf> (accessed on 13 July 2015).

[2] V. M. Khavinson, „Ring interferometer for two-sided measurement of the absolute lengths of end standards," in *Appl. Opt.* **38**:126–136 (1999).

[3] A. Abdelaty, A. Walkov, P. Franke, R. Schödel, „Challenges in double ended gauge block interferometry unveiled by the study of a prototype at PTB," in *Metrologia* **49**:307–314 (2012).

[4] M. Dobosz, O. Iwasinska-Kowalska, „A new method of non-contact gauge block calibration using a fringe-counting technique: Theory basis," in *Opt. Laser Tech.* **42**:141–148 (2010).

[5] Z. Buchta, S. Rerucha, B. Mikel, M. Cizek, J. Lazar, O. Cip, „Novel principle of contactless gauge block calibration," in *Sensors* **12**:3350–3358 (2012).

[6] T. Pikálek, T. Fořt, Z. Buchta, „Detection techniques in lowcoherence interferometry and their impact on overall measurement accuracy," in *Applied Optics* **53**:8463–8470 (2014).

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