10th IMEKO TC14 Symposium on
Laser Metrology for Precision Measurement and Inspection in Industry
Braunschweig, GERMANY, 2011, September 12-14

System for Gauge Blocks Diagnostics

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Abstract:

In this paper, a novel principle of contactless gauge blocks calibration is presented. The principle of contactless gauge block calibration combines low-coherence interferometry and laser interferometry. An experimental setup combines Dowell interferometer and Michelson interferometer to ensure a gauge block length determination with a direct traceability to the primary length standard. By monitoring both gauge block sides with digital camera gauge block 3D surface diagnostics is possible too.

Introduction

The use of length measuring instruments is a usual part of everyday life and these instruments are used in almost all branches of human activity. In general, a suitable length measuring instrument could be arbitrarily chosen with respect to the measurement range and accuracy needed. The accuracy of a length measuring instrument is ensured and verified by an instrument calibration process.

As for calibration of the length measuring instruments, there is no liberty in choice of a calibration instrument. Due to the basic principle of length metrology, the calibration instrument has to be more accurate by one order than the instrument which is calibrated.

In work practice branch of mechanical engineering, gauge blocks are at the end of the calibration chain. Gauge blocks are used as mechanical length etalons for an accurate calibration of length measuring instruments such as micrometers and calipers. Gauge blocks are made of steel, metal carbide or ceramics. In all cases, the gauge blocks wear away because of the mechanical contact between the gauge block and the calibrated instrument. For this reason, a regular gauge blocks calibration is necessary and it is a hot topic for the fundamental and industrial metrology.

The methodology of the gauge blocks calibration is defined by the international standard EN ISO 3650 describing two principal ways of calibrating gauge blocks.

The first one is the contact method. In this case, the gauge block length is compared against the reference gauge block. The measured gauge block is probed from both sides with a couple of incremental length gauges.

The second method employs laser interferometry, white-light interferometry or multiwavelength interferometry [1,2]. The gauge block is adhered to the reference surface, as in the first case. Then the length of the gauge block is measured by one of the interferometric techniques mentioned above.

From a practical point of view, a contactless calibration technique could be a useful alternative to the techniques used nowadays. The main advantage is a possible automatization of the calibrating process.

The presented optical setup for contactless gauge blocks diagnostics is based on a combination of laser interferometry and low-coherence interferometry and is presented as an alternative to similar configurations published before [3-5].

Low-coherence interferometry is a powerful diagnostic technique which has become an attractive and a useful method for a fast and accurate 3D inspection of macroscopic objects. Typical branches of application of the white-light interferometer are contactless surface diagnostics of macroscopic objects, surface roughness and quality assurance, thickness of thin film measurement and optical tomography.

The principle of white-light interferometry stems from classical laser interferometry. The main difference between these two techniques is the type of the radiation source. In case of white-light interferometry, a low-coherent light emitter (halogen lamp, Xenon lamp, superluminescent LED diode) instead of a highly-coherent laser is used.

The principle of white-light interferometry is given by the white-light source. Its coherence length is a few micrometers (typically from 3 μm to 5 μm) [6]. The white-light source coherence length defines the range of the reference mirror movement in which the reference beam and the measuring beam interfere. This property predetermines the white-light interferometer to be an indicator of the reference interferometer arm and the measuring interferometer arm balance.

System for gauge blocks diagnostics description

The presented optical setup combines Michelson interferometer and Dowell interferometer [7], placed in the reference arm of the Michelson interferometer. The principle of the measurement is illustrated in Fig. 1. A parallel beam, generated by a white-light source, is divided into two parts by semireflecting mirror no. 1. The resulting measuring beam goes through a couple of compensating plates CP1 and CP2 and after that is reflected back by a reference surface RS.

The resulting reference beam of the Michelson interferometer plays a role of the primary beam for the Dowell interferometer. This beam is divided by mirror no. 2 into two beams going in the Dowell interferometer in opposite directions. One of them passes through compensating plate CP3 and is reflected by mirror no. 4 onto a gauge block face. The other beam passes through the beamsplitter (mirror no. 2) and then is reflected by mirror no. 3 onto the other face of the gauge block. One part of both mentioned beams illuminating the gauge block is reflected back by the gauge block faces and the other part of both beams passes along the gauge block.

At the output of the Michelson interferometer, there are five beams which could possibly interfere – the first one is the measuring beam of the Michelson interferometer reflected by the reference surface RS, then there is a couple of beams reflected by the gauge blocks and a couple of beams passing along the gauge blocks.

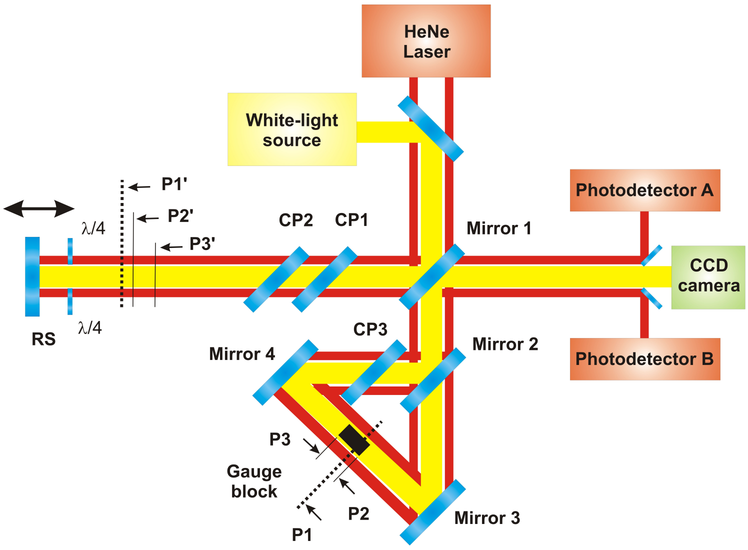

Fig. 1: Optical setup for gauge blocks diagnostics. CP1, CP2 and CP3 are compensating plates, RS is a reference surface, λ/4 is a retardation quarterwave plate.

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 shift, there are three positions where the white-light beams interfere. In the block diagram of the experimental setup shown in Fig. 1, these positions are marked as P1', P2' and P3'.

In the P1' position, the Michelson interferometer measuring beam interferes with the couple of beams passing along the measured gauge block. In fact, it is adequate to a configuration with a mirror in a position marked as P1 (see Fig. 1). For the gauge block length measurement, it plays a role of the reference position.

As for P2’ and P3’ positions, the Michelson interferometer measuring beam interferes with the beams reflected by the gauge block faces (in Fig. 1 marked as P2 and P3). Then, the measured gauge block length is equal to the sum of distances between the measuring positions P2’ and P3’ of the reference position P1’.

For illustration, there is an interference detecting signal (IDS) record shown in Fig. 2. The signal was recorded during a pilot experiment with gauge block diagnostics and it represents a correlation coefficient value resulting from a comparison of two following samples of the output beam intensity. In the designed system, this signal is used for an automatic detection of the measuring positions. In the case shown in Fig. 2, a gauge block with the length 10.5 mm was measured.

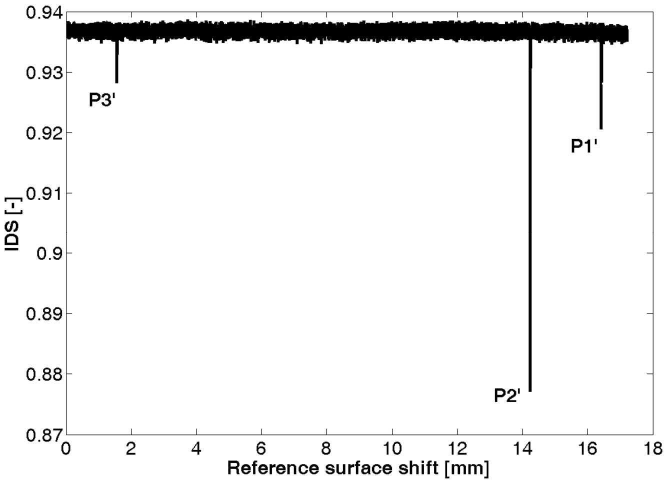

Fig. 2: The Interference Detecting Signal (IDS) recorded during a pilot experiment with gauge block diagnostics. In the case shown in this figure, a gauge block with the length 10.5 mm was measured.

The process of gauge block diagnostics is controlled by special software which was designed for the reference surface RS positioning control and the online acquisition of the signals from photodetectors and a CCD camera. The measuring control process is based on the monitoring of the IDS signal during a fast positioning of the reference surface. The interference of the output beams is detected as a drop of the IDS signal. In this case, the motorized stage is switched off and the interference signal is measured by means of PZT driven stage. The measuring positions P1’, P2’ and P3’ are localized by a central point detection algorithm implemented in the measurement control software. Furthermore, the measured gauge block length (GBL) is calculated by the equation no. 1.

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

By using the CCD camera as a photodetector, this measuring principle allows performing online surface diagnostics of gauge block faces.

For precise gauge block diagnostics it is necessary to acquire the measuring positions with nanometer range precision. In the designed experimental setup, it is ensured by an incremental laser interferometer which complements the low-coherence interferometer described above. As a source of laser radiation, a 633 nm He-Ne laser is used. Its output beam is collimated into an optical fiber, then splitted by a 50/50 fiber splitter and resulting two laser parallel beams are used for the incremental interferometric measurement as shown in Fig. 1. In general, it works as the classic Michelson interferometer. In the reference arm of the interferometer, the laser beams pass along the measured gauge block and at the output of the interferometer, they are put together with the laser beams passing through the measuring interferometer arm. The detection unit (DU) used as a photodetector A and B (see Fig. 1) receives two associated beams from the measuring and reference arm of the interferometer [8].

The measurement setup is shown in Fig. 3. It is arranged on a massive base plate made of gray iron with thermal expansion coefficient 12.3×10^{-6} K^{-1}. The optical components are put into 3” gimbal transmitting mounts TRANS 90G (OWIS) optimized for a maximum aperture. These transmitting mounts are combined with goniometers with the range of adjustement ±10° designed and made for precise rotation of the optical components around a defined optical axis. The final adjustment can be fixated with a screw.

For the measurement process, the gauge block is placed by an automatic handling system into a gauge block holder supplemented by three PZT screw actuators (Thorlabs) used for gauge block adjusting before its measurement.

The positioning of the reference surface is ensured by a combination of a motorized positioning stage LIMES 80-100-HiDS (OWIS) and a reference surface holder supplemented – like the gauge block holder – by three PZT screw actuators (Thorlabs). The travel of the Limes stage is 105 mm with a spindle pitch 1 mm and 2000 steps per revolution. The screw actuator with PZT provides 4 mm of a manual coarse travel via a 0.25 mm pitch leadscrew. The 150 V internal piezo stack provides 15 µm of an open-loop piezo travel and an 18-bit DA converter used in control electronics allows extremely fine positioning of the reference surface.

The combination of these two types of actuator matches up to the requirement of the reference surface positioning in 100 mm range with subnanometer resolution. In addition, using three PZT screws allows an online correction of the stage pitch and yaw deviations.

Except for the main part of the optical setup, the measurement system was designed as a modular device. The sources of white-light and laser radiation and the detection system are made as separate modules to allow precise adjustment out of the system.

The base plate with the optical setup, shown in Fig. 3, is oriented to the vertical position to respect the international standard EN ISO 3650 which requires the vertical calibrating position for gauge block of length up to 100 mm.

The whole optical setup is covered by a double shielded housing for minimization of refractive index of air fluctuations. The value of the refractive index of air is calculated from measured atmospheric parameters by means of Edlen formula and it is used for an online correction of HeNe laser wavelength with precision 10^{-6} [9]. In addition to an ambient temperature measurement, there are three temperature sensors monitoring the base plate temperature for corrections of the optical path dilatation during the gauge block measurement process.

Acknowledgement

This work was supported mainly by Grant Agency of CR project GP102/09/P293 and partially by GAP102/11/P819 and GP102/10/1813. The pilot set-up of the method was funded by Ministry of Industry and Commerce, project No: 2A-1TP1/127. The background of the research was supported by European Commission and Ministry of Education, Youth, and Sports of the Czech Republic project No. CZ.1.05/2.1.00/01.0017 and projects LC06007.

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