Device for Ring Gauges Calibration

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Abstract. *A diameter measurement of the precise cylinder bores is the specific problem of the length metrology. In industrial practice this operation is being realised by means of three-pointed bore gauges - inside micrometers. The ring gauges - setting rings are used for testing of the inside micrometers. Ring gauges are manufactured from the wear resistant steel or zirconium ceramic with tolerance diameter of 1 μm and form tolerances according to DIN 2250. Since the setting rings of highest accuracy are the reference standards of the 2nd order, their precise calibration is of special interest. This article describes the optical design of the device for the ring gauges calibration.*

Keywords: Traceability, Setting rings, Interferometric resolution

1. Introduction

In the Slovak Republic, the length unit metre is realised by the radiation of the National Standard of Length (NSL No. 002/1997 SMU-1), HeNe/I_2 laser with stabilised optical frequency 473 612 353 607.9 kHz, corresponding to the vacuum wavelength of λ_o = 632 991 186.81 fm. Within the international comparison (BIPM.L-K11, 2005 – femtosecond comb measurements of HeNe/I_2 lasers), its frequency/vacuum wavelength was determined with the expanded uncertainty of 4,8 kHz or 0.063 fm respectively. This value was confirmed by the measurements at CMI one year later, using the fs comb again.

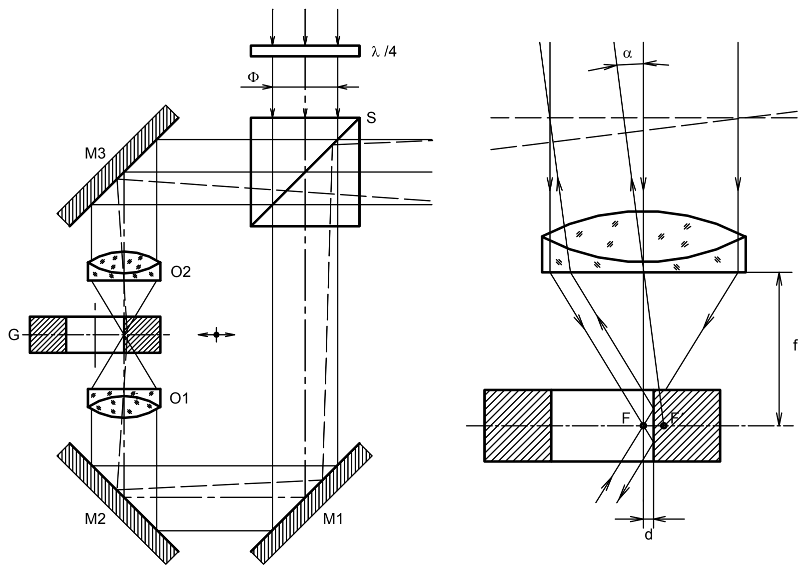
According to the traceability scheme [1], the length unit transfer from the NSL to the length of gauge blocks is realized by the Standard Interferometer Comparator (SIC), using the dynamic interference method, i.e. the counting of standard wavelength fractions. The standard gauge blocks then serve for the direct comparison for the tested gauge blocks of lower orders or for the calibration of the ring gauges up to 0.2 m on the interference device (IRG). It is well known that each step of the unit transfer results in the increase of the final measurement uncertainty. Therefore when IRG is the standard device of the 1st order, even in the ideal case the setting rings of the highest accuracy can be no better than of the 2nd order. In accordance with the MRA (Mutual Recognition Arrangement) among National Metrological Institutes (NMIs) and BIPM Sèvres, the proof of traceability of the National standards with declared uncertainties is strictly required. The device described in this paper is directly traceable to the NSL via frequency stabilized HeNe laser 633 nm, without intermediate stage of calibrated gauge blocks.

2. Laser interferometer

Special meachanical and optical instruments were developed for the calibration of the ring gauges many years ago [2]. One of them was the *Universal Komparator 200 mit Perflectometer Leitz Wetzlar*. Our design of laser interferometer is based on the principle of the mentioned Leitz Komparator-Perflektometer. The diameter of ring gauges can be observed from the shift of line scale by the measuring microscope of the Leitz comparator [3].

The measuring table carries the ring gauge. The line scale is fixed on the movable table in the direction of the vertical guide axis. The perflectometric optical part of instrument is serving for the localisation of the functional surfaces of the calibrated measure - ring gauges [4]. The perflectometric principle is based on the projection of cross wire plate to the gauge functional surface. After the reflection from the gauge surface, the reflected picture is projected to the reference cross wire plate. The coincidence of both cross wires indicates the localised position of the gauge functional surface. In such a way, we can localize the initial and final points of the vertical displacement of the table in line scale and thus determine the diameter of gauge rings.

According to our proposal, the device is directly traceable to the NSL. It consists of two optical parts. One part is represented by the laser interferometric measuring system LOS Limtek, Blansko, CZ. LOS serves for the measurement of the table displacement with resolution of 1.25 nm (□/512). The frequency of the HeNe laser from system LOS has been calibrated at Swiss NMI (National Metrological Institute) METAS with expanded uncertainty of U = 2.10-8 (k = 2). It means that the length of table displacement (i.e. the reading of a ring gauge diameter) is traced to the length standard of Swiss NMI. It would seem that the laser interferometry with resolution of about a few nanometres is able to solve a majority of problems in length metrology. However, a general problem in such application of the laser interferometry in an engineering industry lies in the insufficient localisation of the mentioned initial and final points. This problem is solved by the second part of our device, being a laser system localizing the initial and final position of the ring gauge edges during the vertical shift of the table. A simplified optical scheme of this part is on the Fig. 1A.



A B

Fig.1

The expanded linear polarised laser beam passes through the $\lambda/4$ plate, transforming the linear polarisation to the circular one. By means of the non-polarising beam splitter S the beam is divided into two directions. One beam passes to the mirrors M1, M2, through objectives O1, O2, to the mirror M3 and again through the splitter S to the output. The second one is reflected by the splitter S to the mirror M3, passes through objectives O2 and O1 to the mirrors M2, M1 and then is reflected by the splitter S to the output. The path travelled by both beams is of the same optical length and therefore at the output no phase shift occurs between them, provided the gauge ring is not located in their path. In the case when the wave fronts of beams are strictly plane, both halves (upper and down) of the output viewing field have the same illumination. If the edge of gauge coincides with the optical axis from the right side, then left side of the beam passes down from the mirror M3 and right side of beam having been reflected from the mirror M2 is shaded by the gauge. The non-shaded parts of beams do not interfere, because the beams after their reflection from bright face of gauge are passing independently from upper and bottom halves of the output. If the asymmetrical beam splitter is used (e.g. ratio R/T = 30/60), the upper half of viewing field will be starker as the bottom half. It makes possible to distinguish that position when the gauge coincides with optical axis from the left or right side.

If the inside edge of the ring gauge is located closely to the optical axis of objectives at the distance d (Fig. 1B), then FF' = 2d and the inclination angles of output beams with respect to optical axis are $+\alpha$ and $-\alpha$ respectively. The angle between output wave planes W and W' is 2α (Fig. 2) and the Fizeau interference fringes (fringes of equal thickness) can be observed in the output visual field. Interference minimum corresponds to the odd number of half waves at the path difference Δ:

$$\Delta = (2k+1)\frac{\lambda}{2}, \text{ where } k = 1, 2, 3, \ldots \tag{1}$$

If the k +1 dark fringes in the visual field of a diameter Φ are observed, then for the angle 2α between both wave fronts it follows:

$$tan\, 2\alpha = \frac{(2k+1)}{\Phi} \cdot \frac{\lambda}{2} \tag{2}$$

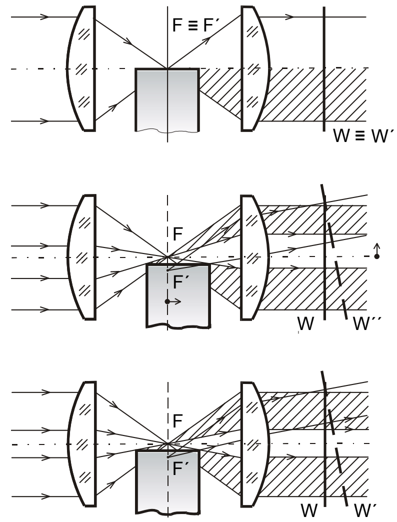


Fig. 2 Principle of a creation the interference fringes

The distance between two neighbouring fringes (interference minima) x is:

$$x = \frac{\lambda}{tan\, 2\alpha} \tag{3}$$

From the Fig.1B follows that $tan2\alpha = 2d/f$, where f is the focal length of objectives.
For small angles, $tan2\alpha$ = 2 $tan\alpha$. Therefore at the distance d of the gauge from the optical axis, the distance of neighbouring minima is:

$$x = \frac{\lambda . f}{4d} \tag{4}$$

If the number k + 1 fringes is observed at the output, then the distance d is given by the expression:

$$d = \frac{f.tan\alpha}{2} = \frac{(2k+1)}{8\Phi} \qquad (5)$$

The resolution limit d_{min} is determined by the condition of k = 0, i.e. when the first interference minimum appears at the output.

$$d_{min} = \frac{\lambda.f}{8\Phi} \qquad (6)$$

The output image can be scanned by the B/W CCD Camera. For example, the camera ORCA II-ER Hamamatsu has the following parameters:

Active area of CCD array is 8.67 mm (H) x 6.6 mm (V), (1344x1024 active pixels), high sensitivity, objective Canon T01-J624-000 f = 16 mm 1:1.6 (choice of lens system depends on the size of Φ), Peltier cooling, external control RS 232C, output signal RS 422A, pixel clock rate 10 MHz/ pixel, square pixel structure 10x10 μm.

At the wavelength of 633 nm we obtain the resolution limit d_{min} for objectives O1, O2 :

- Apochromat Meopta 10x0.30, f = 15.65 mm, free working distance 10.58 mm, Φ = 10 mm, d_{min} = 0.126 μm. The resolution of the table shift measurement by the system LOS is 1.25 nm.

For the comparison, the parameters of Perflectometer Leitz were:

- The uncertainty of the gauge edge localisation is 0.2 μm. The resolution of the table shift reading on the line scale by the measuring microscope is 0.3 μm.

3. Conclusion

In our arrangement the microscope objectives 10x0.30 have been used. The better resolution can be achieved by using of microscope objectives having both larger magnification and aperture (e.g. 20x0.45, 30x0.65, or 45x0.65). However, in practice it is not possible since it is limited by the height of calibrated ring gauges, well exceeding the working distance of the listed objectives (below 1 mm vs. the height of the ring gauges being up to 8 mm). Other way can be involving of the photographic camera objectives. The most frequently used objectives have the focal length of ~50-60 mm and diameter of visual field $\Phi \sim$ 42-50 mm. It corresponds to the aperture of 1:1.2. For example:

- Photographic objective Nikkor S, Nikon: f = 55 mm, free working distance 47.2 mm, input diaphragm Φ = 46.2 mm, d_{min} = 0.094 μm.
- Camera objective Tevidon, Zeiss: f = 25 mm, free working distance 12.3 mm, input diaphragm Φ = 18 mm, d_{min} = 0.109 μm.

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