

# Laser-interferometric device for calibration of ring gauges

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The measurement of the diameter of cylinder bores is a specific problem of the length metrology. In practice, this operation is realised using three-pointed bore gauges – inside micrometers. The ring gauges-setting rings are used for testing of the inside micrometers. Such ring gauges are manufactured from the wear resistant steel or zirconium ceramic with diameter tolerance of 1  $\mu\text{m}$  and shape tolerances according to DIN 2250. Since the setting rings of highest accuracy are the reference standards of the second order, it is necessary to carry out their precise calibration. This article describes the optical design of a device for the calibration of ring gauges.

Keywords: traceability scheme, setting rings, gauge blocks, interferometric resolution.

## 1. Introduction

In the Slovak Republic, the length unit of 1 metre is obtained by radiation of the National Standard of Length (NSL) HeNe/I<sub>2</sub> laser SMU B2 with stabilised frequency 474 THz (the corresponding nominal value of the vacuum wavelength 633 nm). According to the traceability scheme [1], the unit is transferred from the NSL to the Standard Interferometer Comparator (SIC) used for the gauge block calibration by direct comparison of the wavelength multiples to the length of gauge blocks. These gauge blocks are used for direct recalibration of instruments for the ring gauge diameter measurement (IRGDM). It is well known that each step of the unit transfer results in increasing uncertainty. Therefore if IRGDM is the standard device of the first order, the setting rings of highest accuracy can be the standards of the second order only. In accordance with the Mutual Recognition Arrangement (MRA) among the National Metrological Institutes (NMI) and Bureau International des Poids et Mesures (BIPM) Paris, the proof of traceability to the national or international standards with evaluated uncertainties is strictly required. The device described in this paper is directly traceable to the NSL without intermediate stage of the gauge block measurement.

## 2. Laser-interferometer

Special contact and optical instruments were developed for calibration of ring gauges many years ago [2]. Such instruments were, *e.g.*, Universallängenmesser ULM 02-600 Präzisionskoordinatenmessgerät ZKM 250 CNC ZEISS Jena and Universal Komparator 200 mit Perflektometer LEITZ Wetzlar. Our design of laser-interferometer is based on the Leitz Komparator-Perflektometer. The ring diameter or length of gauge block can be observed from the shift of line scale by the measuring microscope of the Leitz comparator [3], [4]. The measuring table carries the ring gauge or gauge block. The line scale is fixed on the movable table in the direction of a V-guide axis. The "perflektometric" part of instrument was developed for localisation of the functional surfaces of the calibrated measure-gauge block or setting ring. The

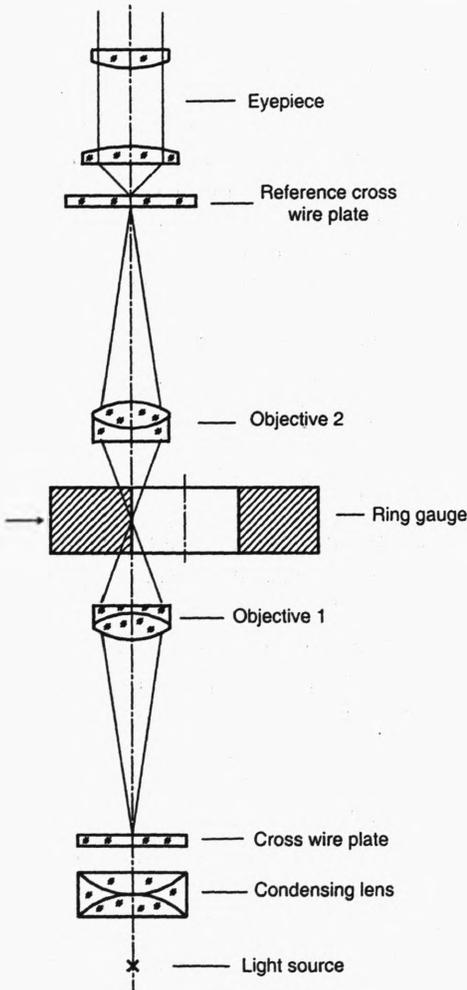


Fig. 1. Optical scheme of the perflektometer.

“perfectometric” principle is based on the projection of cross wire plate (Fig. 1) to the gauge plane and after its reflection from the functional surface of gauge the reflected picture is projected to the reference cross wire plate. At the moment both cross wires coincide, the initial and final points for reading the length on the line measure are determined.

In our arrangement, the length of the shift of the table is to be evaluated by the Laser Measurement System LOS LIMTEK, Blansko. LOS is the laser-interferometer for accurate measurement with resolution of 1.25 nm ( $\lambda/512$ ). The radiation frequency of its He-Ne laser has been calibrated at Swiss National Metrological Institute (METAS) with expanded uncertainty  $U = 2.10^{-8}$  ( $k = 2$ ). This means that the length of table shift (*i.e.*, the reading of a diameter) will be traced to the length standard of Swiss NMI.

It might seem that laser-interferometry with resolution of about few nanometers is able to solve a majority of problems in length metrology completely. However, one of the general problems of laser-interferometry in engineering industry lies in the insufficient localisation of both initial and final points during dimensional measurements. This problem is solved by the special optical part in our device. This part of device is the interferometer locating the initial and final positions of the ring gauge edges. A simplified optical scheme of this part is in Fig. 2. The expanded linear polarised laser beam passes through the  $\lambda/4$  plate, transforming the polarisation from the linear to the circular one. By means of the non-polarising beam splitter the input beam is divided into two directions. One beam passes down to the bottom mirrors and then through both objectives to the upper mirror. This beam is reflected to the splitter and passes to the output. The second one is reflected by the beam splitter to the upper mirror, passes in the opposite way and afterwards it is reflected by the beam splitter to the output. The path travelled by both beams is of the same optical length and therefore at the output there is no phase shift between them, provided there is no gauge located in their path. In the case when the wave fronts of beams are strictly plane, both halves of output viewing field have the same illumination (see position 1 in Fig. 2). If the edge of gauge coincides with the optical axis from the right-hand side, then the left side of the beam passes down and the right side of the beam reflected to the upper mirror is shaded by the gauge. The non-shaded parts of beams do not interfere, because the beams after their reflection from the bright face of gauge are passing independently from upper and bottom parts of the output (position 2 in Fig. 2c). If the asymmetrical beam splitter is used (*e.g.*, ratio  $R/T = 30/60$ ), the upper half of viewing field will be darker than the bottom one. This enables us to distinguish positions 1 and 2 and also to see whether the gauge coincides with the optical axis from the left or right side.

If the inside edge of ring gauge or gauge block is located closely to the optical axis of objectives at a distance  $d$ ,  $FF' = 2d$ , the inclination angles between output beams and optical axis are  $+\alpha$  and  $-\alpha$ , respectively (position 3 in Fig. 2). The mutual angle between output wave planes  $W'$  and  $W''$  is  $2\alpha$  and the Fizeau interference fringes (fringes of equal thickness) can be observed (Fig. 3). Interference minimum creates the odd number of half-waves at the path difference  $\Delta$  equal to

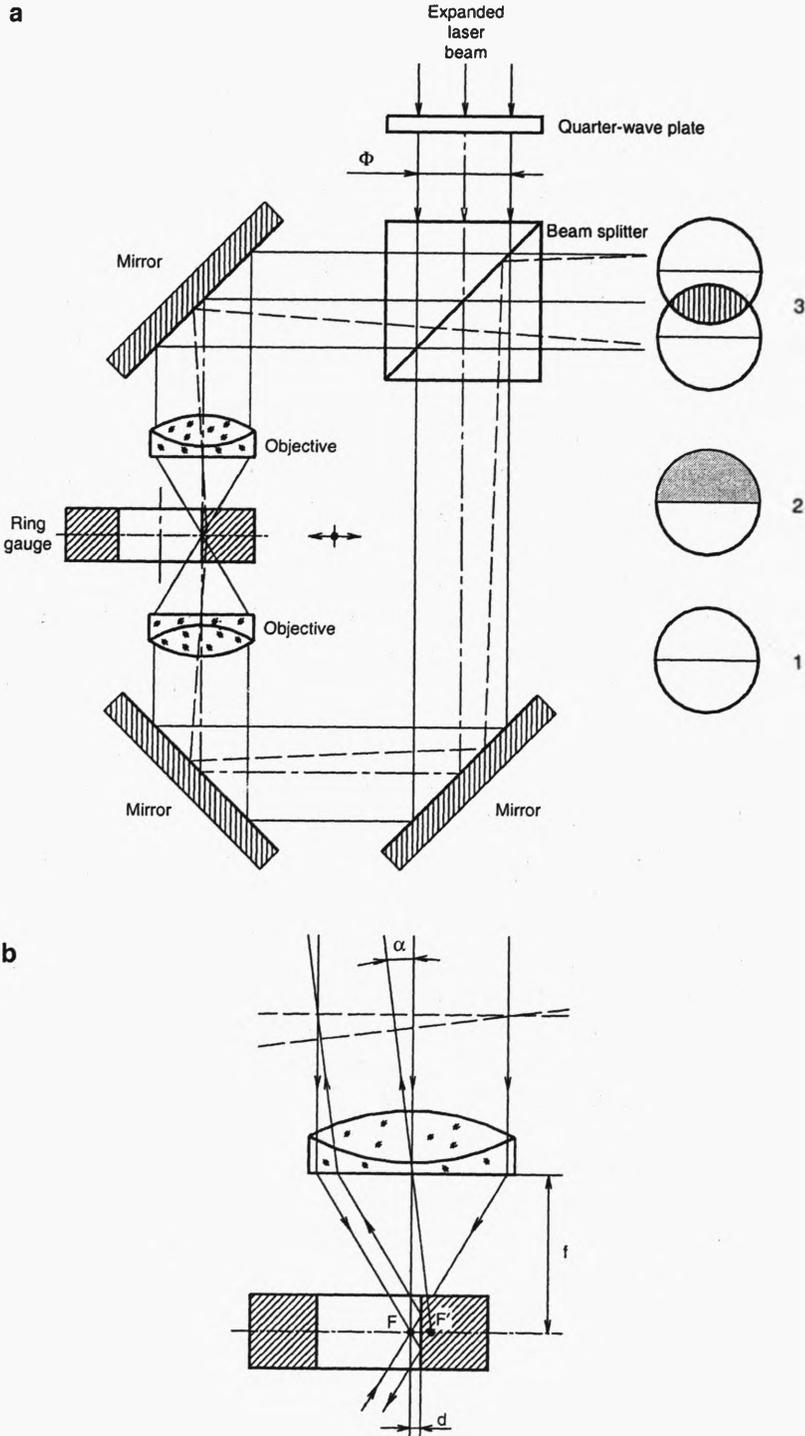


Fig. 2. Part of optical scheme for localisation of the gauge edge (a), enlarged fragment (b).

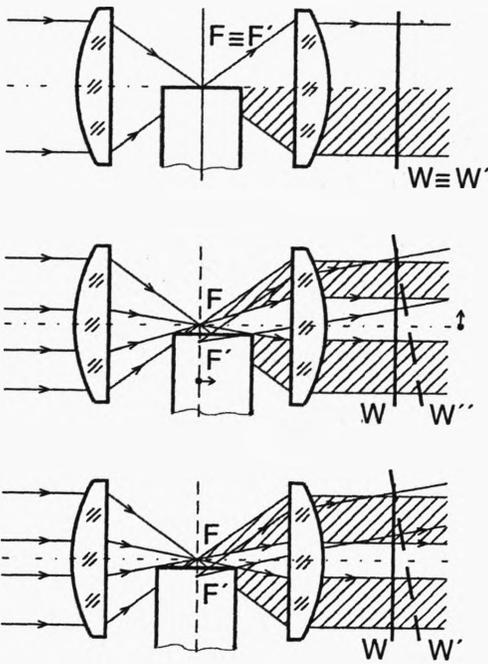


Fig. 3. Principle of creating interference fringes.

$$\Delta = (2k + 1) \frac{\lambda}{2}, \text{ for } k = 1, 2, 3, \dots \quad (1)$$

If the number  $k + 1$  dark fringes in the viewing field of a diameter  $\Phi$  is observed, then the angle  $2\alpha$  is between both wave fronts. For this angle,

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

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

$$x = \frac{\lambda}{\tan 2\alpha} \quad (3)$$

and from Fig. 2, we have  $\tan \alpha = 2d/f$ , where  $f$  is the focal length of objectives.

For small angles  $\alpha$ ,  $\tan 2\alpha = 2 \tan \alpha$ . Then at a distance  $d$  of gauge to the optical axis the distance of neighbouring minima is

$$x = \lambda f / 4d. \quad (4)$$

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

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

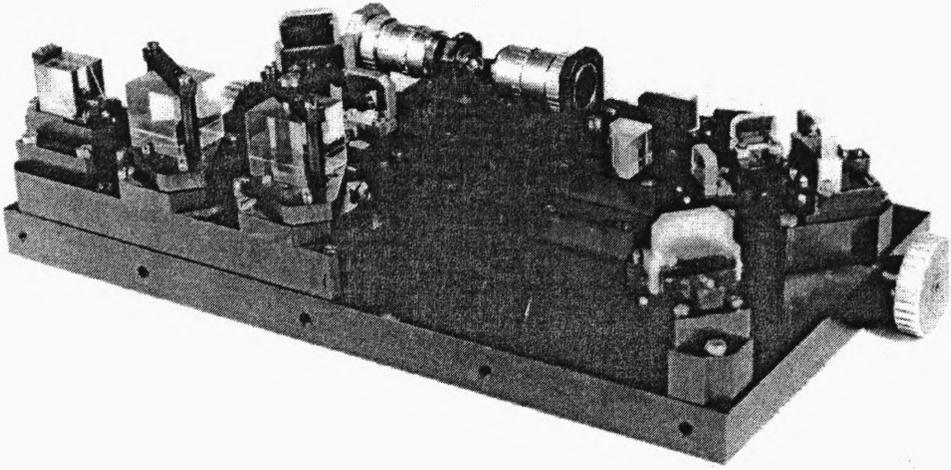


Fig. 4. Model of the device. Part for locating gauge edge.

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

$$d_{\min} = \lambda f / 8\Phi. \quad (6)$$

The output picture will be scanned by the high resolution B/W CCD Camera ORCA II-ER HAMAMATSU. The CCD array C4742-98-24ER has the following parameters: active area – 8.67(H) mm  $\times$  6.60 (V) mm (1344 $\times$ 1024 active pixels), high sensitivity, lens mount C (choice of lens system will depend on the size of  $\Phi$ ), Peltier cooling, external control RS 232C, output signal RS 422A, pixel clock rate 10 MHz/pixel, square pixel structure (10 $\times$ 10  $\mu$ m).

In the following some examples at the wavelength  $\lambda = 633$  nm are shown:

- microscope objective Apochromat, Meopta 10 $\times$ 0.30,  $f = 15.65$  mm, free working distance 10.58 mm,  $\Phi = 10$  mm,  $d_{\min} = 0.126$   $\mu$ m;
- photographic objective Nikkor S, Nikon  $f = 50$  mm, free working distance 47.2 mm,  $\Phi = 47$  mm,  $d_{\min} = 0.094$   $\mu$ m;
- CCD camera objective Tevidon, Carl Zeiss  $f = 16$  mm, free working distance 11.3 mm,  $\Phi = 18$  mm,  $d_{\min} = 0.070$   $\mu$ m.

For the comparison purposes, the parameters of Perflektometer Leitz were the following [3]:

- resolution of reading of the gauge dimension on the line scale 0.3  $\mu$ m,
- the uncertainty of the gauge edge localisation 0.1  $\mu$ m.

### 3. Conclusions

Theoretically, the better resolution is possible to reach by the application of microscope objectives 20 $\times$ 0.45, 30 $\times$ 0.65, 45 $\times$ 0.65. However, in practice it is not possible since

the working distance of these objectives is below 1 mm and the height of gauges is up to 8 mm. Another solution consists in the application of photographic camera objectives. The most frequently used objectives have the focal length 50–60 mm and diameter of viewing field  $\Phi \sim 42\text{--}50$  mm. It corresponds to the aperture ratio of 1:1.2. Such an optical arrangement would make it possible to measure the rings of internal diameter from 5 mm onwards. The laser interferometric localisation of the gauge edge offers possibilities of keeping the direct traceability materialised measures such as ring gauges or gauge blocks to the NSL.

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