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New possibilities of flatness measurement of sealing elements

Nowe możliwości pomiaru płaskości elementów uszczelnień

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In the paper are presented new possibilities of accurate measurement of flatness deviation with use of TOPOS interferometer. Methods of measurements of flatness deviation of sealing rings which are used so far, were discussed. Paper presents principle of measurement and construction of interferometer with equipment (with rotary table) which allow to significantly extension of measuring range. Examples of results of tests and measurements were presented.

KEYWORDS: flatness deviation, interferometer, mechanical sealing

The process of manufacturing of the leading mechanical seals (fig. 1) is very difficult due to the technological machines, tooling, tools, measuring equipment and production organization needed for it [1]. The article focuses on measuring equipment, because measurements are crucial in the process of manufacturing the accurate parts of the seals - without accurate measurements it is impossible to make products that meet the high requirements in terms of flatness of the surface.

The accuracy of the performance of the seal as a whole is primarily determined by the accuracy of the slip rings, which are made of various materials difficult to process and to measure (fig. 2).

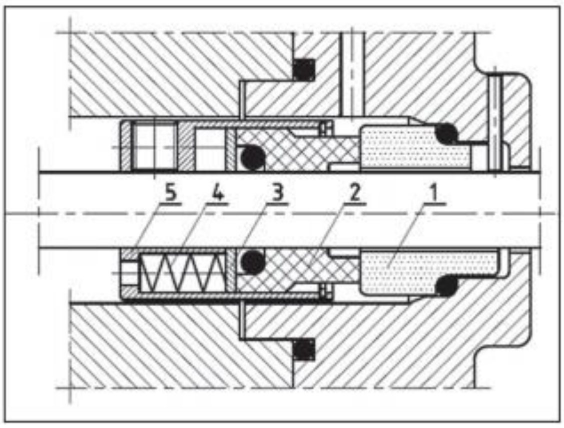

Fig. 1. Mechanical seal: 1 - fixed ring, 2 - rotating ring, 3 - resistance ring, 4 - spring, 5 - seal body

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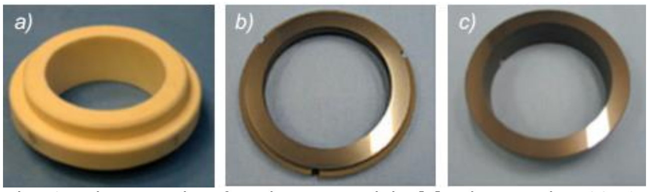

Fig. 2. Rings made of various materials [1]: *a*) ceramics 99.5% Al_2O_3, *b*) antimony impregnated coal, *c*) sintered silicon carbide SiC

The notion of the accuracy of the slip rings is understood primarily as small tolerances of flatness.

The working surfaces of the slip rings are obtained in the lapping process, carried out in the following cycle: lapping - measurement - assessment. This cycle is repeated until the required flatness is obtained. For this reason, the measurement time is an important criterion for the selection of equipment for measuring flatness deviations.

Previous possibilities of measuring flatness deviations

Measurements of flatness deviations are particularly complicated and require special measuring equipment. In the case of objects such as a shield or ring with diameters ranging from several dozen to several hundred millimeters, classical methods of measuring flatness deviations are available:

- Measurement using a coordinate measuring machine. It is a contact measurement, in which the measured object is fixed using forces that can cause its deformation. Achieved measurement uncertainties are on the order of 1÷3 μm.
- Measurement using devices with a rotary table, intended for measuring roundness deviations. It is a contact measurement in which the object is fixed using forces that can cause its deformation. The uncertainty of measurement is 0.8÷2 μm.
- Measurement using profilometers designed to measure surface roughness and waviness. In the general case, it is possible to perform contact measurements (pointing blade) and contactless measurements (optical methods). In 3D (optical and contact) measurements, a very small surface is covered. Replacing the measurement of flatness with straightness measurements in addition to restrictions on the length of rectilinear segments brings additional interpretive difficulties [1]. In contact measurements, scratching of surface may occur. Due to the risk of surface damage and the inability to assess the global flatness deviation, this technique has a very limited application.

- Measurements using flat interference glasses, performed manually and with a visual assessment of the character and value of shape deviation [7, 8]. Such measurements are used successfully for small surfaces, e.g. micrometer measuring surfaces or reference plates. The uncertainty of measurement of flatness deviations is then of the order of 0.3 μm. With larger surfaces, there are two major technical limitations related to manual manipulation of the mutual position of the interference glass and the measured object, and a visual interpretation of the fringe pattern. Visual interpretation is particularly difficult in the case of ring-type objects, where due to the lack of continuity of the stripes, it is not possible to assess the global shape deviation. Measurements of objects with dark surfaces are difficult due to poor visibility of the fringes. An important disadvantage is the time-consuming and limited possibilities of interpreting the measurement results. In the best variant of this method, flatness deviation measurements are made using monochromatic (sodium) light. For correct interpretation, it is necessary to move the interference lenses by hand, not very precisely, up or down in relation to the measured surface. Even for simple surfaces, the interpretation of interference fringe images is not easy. The picture of the stripes can be ambiguous - the concave and convex surface gives difficult to distinguish images of the fringes. In the visual assessment, it is impossible to obtain a sufficiently good resolution. In addition, small changes in the shape of the surface and changes limited to a small area are difficult to detect.

New needs

In the case of slip rings for contactless seals with increased operating parameters, greater accuracy of the surface structures causing the gas-dynamic effect is necessary, which implies the need for more accurate measurement methods. Therefore, it is reasonable to use the latest available interferometer for measurements, which, in comparison with existing solutions, ensures higher accuracy and a definitely shorter measurement time. As a result, it is possible to produce contactless seals with improved operating parameters (including seals with slip rings protected with carbide coatings and with amorphous diamonds made in CVD technology), intended for use in process compressors. The use of the interferometer to measure sealing elements provides more detailed information on the nature of the flatness deviation of the slip rings, which determines the quality of this element of the gas dynamical seal. The flatness of this element affects the parameters and effectiveness of the entire seal, determining the critical values of its strength.

Possibilities of TOPOS interferometer

The measurement principle of the interferometer is based on interferometry, based on the angle of incidence of light (fig. 3). As a result, it is possible to measure the flatness of both polished and non-reflective surfaces that would not be measurable with traditional flatness interferometers.

The interferometer software allows to select the sensitivity of the device operation (0.5, 1, 2 and 4 μm/fringe) and thus - for the proper setting of the measuring system relative to the properties of the measured surface. Due to this, surfaces with very high accuracy, such as polished mechanical seals, can be measured with the highest sensitivity (0.5 μm/fringe), while lower sensitivity settings also enable measurement of unevenness, uneven or worn surfaces [6].

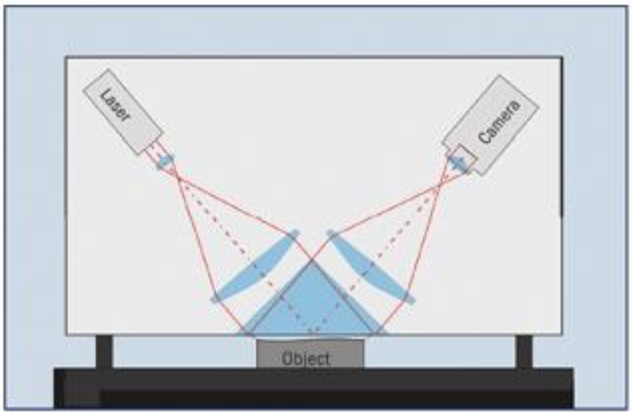

Fig. 3. Principle of operation of the TOPOS interferometer [6]

Fig. 4. Appearance of the interferometer with a rotary table

Computer evaluation provides three-dimensional, fast and objective testing of parts. According to the principle of the interferometer operation, several images of phase shifted fringes are obtained by means of a built-in camera. On the basis of these images, the shape of the measured part is determined. The measurement takes less than 2 seconds for a maximum of 300,000 points. The measured area to be evaluated can be detected automatically by the software or determined by the user based on the selection of the appropriate geometric shape (e.g. circle, ring or rectangle). The position and size of this area can be determined by the boundary line that is superimposed on the part image. The exclusion from the measurement of the edges of the object can be set separately for the outer and inner contour [6].

The interferometer is suitable for measuring details made of various materials (such as: metal, glass, polymers, ceramics) and in various technologies (e.g. grinding, lapping or polishing). The measurement results are in numerical form. The interferometer uses high-intensity light, which allows illumination of the whole surface and gives a clear picture of the fringes. During the measurement, there is no need to manipulate the object in order to obtain an appropriate fringe pattern (the light phase modulation is used instead). The picture of the bands in digital form can be subjected to any development, the possibility of filtration being especially important, causing separation (depending on the needs) of the low or high frequency components.

The interferometer with a rotary table is shown in fig. 4.

The TOPOS interferometer (Lamtech) uses laser light. Phase modulation is carried out by changing the angle of incidence of light and replaces the manual movement of the object. Interpretation of interference framing is performed by specialized interferometer software, thus avoiding ambiguity of interpretation and accurately measuring even very small changes in the shape of the surface. The interferometer allows to measure parts (without moving it) with a maximum diameter of 100 mm.

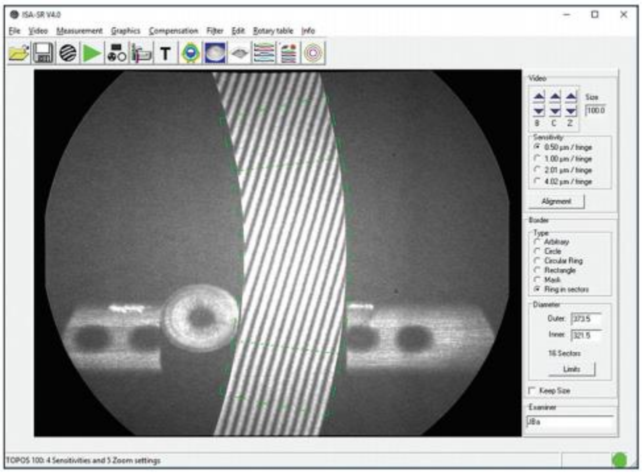

Fig. 5. Picture of a fragment of the measured ring on the interferometer computer screen

Thanks to the equipment of the interferometer with a precise rotary table, it is possible to measure rings with an outside diameter of up to 400 mm. In this case, several shots are taken at different angular positions of the table. The selection of the number of shots, angular displacements of the table and joining of individual fragments takes place automatically - the employee only determines the shape and dimensions of the area measured in one cycle (fig. 5).

The measurement results are presented graphically and include: flatness deviation values (FL_{Tt} and H95%) [4, 5], 3D visualization and surface topography, histogram of profile points' height in relation to the reference plane and profile diagrams in four cross-sections. Flatness deviations can be determined relative to the mean plane or as the width of the minimum zone. The H95% parameter means the maximum difference in elevation heights after rejection of 2.5% of the highest and 2.5% of the lowest points of the profile. Graphic representation of the measurement result makes it easier for the operator to interpret the results. The 95% value is given as an example - operator can set any other.

Sample results of measurements

Sample results of the ring measurement are shown in fig. 6. Already a cursory analysis of these results indicates the high performance of the instrument in terms of accuracy. The value of the observed flatness deviation (below 1 µm), after all, includes both the accuracy of the measurement and the measurement errors, and the ring has a large diameter (over 370 mm) - for this reason rotation table (16 positions) has been used. The apparent triangularity of the deviation is a reflection of the deformations of the ring supported at three points (measurement error coming from the limited rigidity of the measured object).

In order to ascertain the possibility of interferometer, measurements of calibrated interference glass and working surfaces of two gauge blocks were performed. The results of measuring the flatness deviation of the interference glass are shown in fig. 7. A result comparable to that given on the calibration certificate was obtained. In addition, repeatability tests were performed on the gauge block. The standard deviation for 11 measurements made at different positions on the instrument table and in different orientations for parameter F is 22 nm, and for H95% - 19 nm.

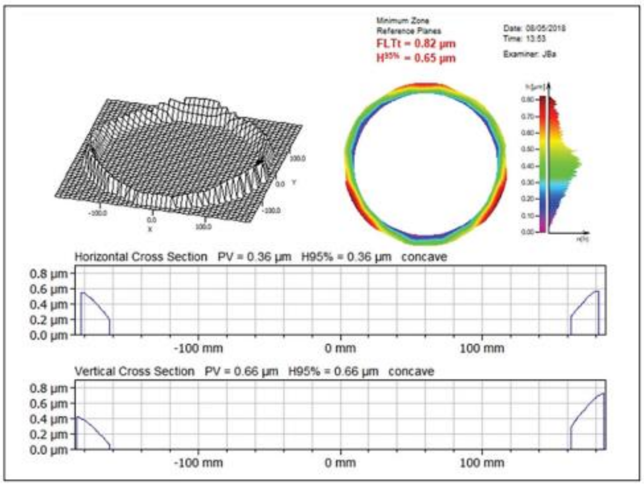

Fig. 6. Example of a ring measurement protocol

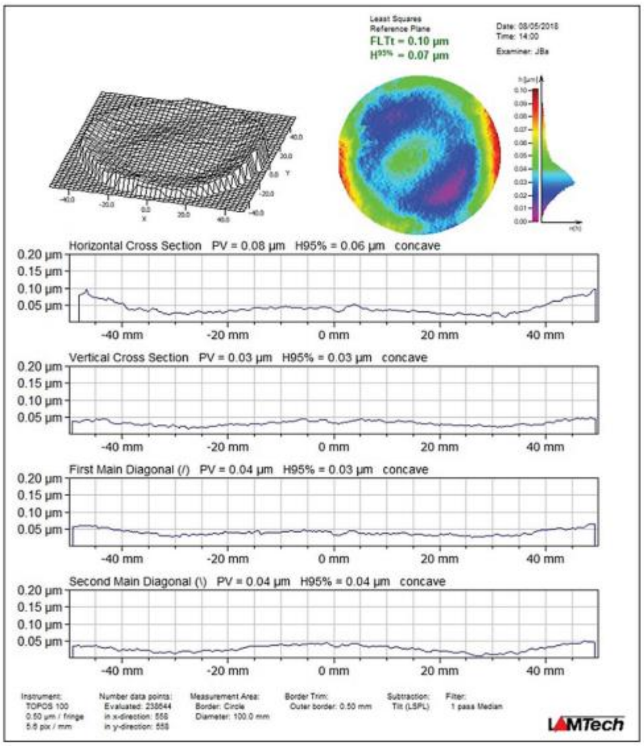

Fig. 7. Example of the interference glass measurement protocol (in the lower part of the protocol there are straightness profiles in four cross-sections spaced every 45°)

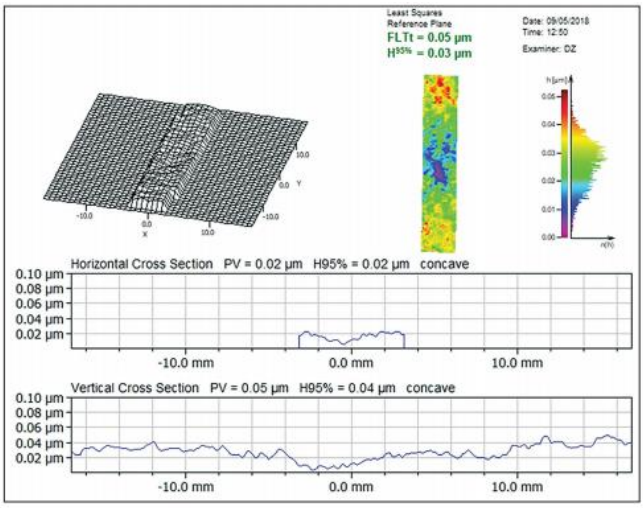

Fig. 8. Results of measurement of flatness deviation of a 0 grade gauge block (bottom part shows straightness profiles in two mutually perpendicular cross-sections)

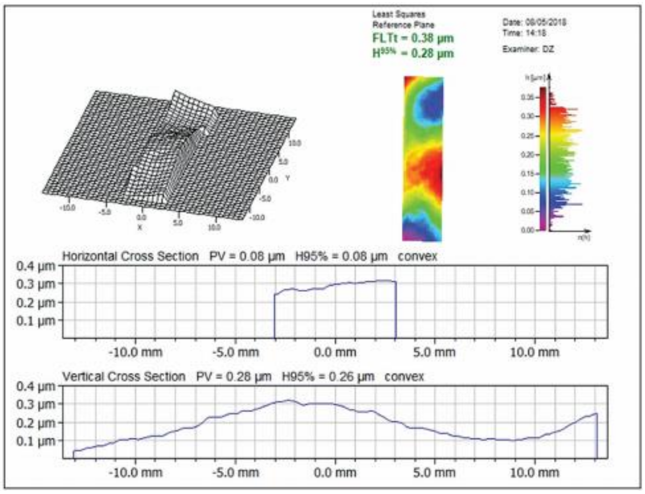

Fig. 9. Results of flatness deviation measurement of the 2 grade gauge block (bottom part shows straightness profiles in two mutually perpendicular cross-sections)

The results of flatness deviation measurements for two gauge blocks are shown in fig. 8 and fig. 9. It is worth reminding that the flatness tolerances of the reference blocks for grades K, 0, 1 and 2 are: 0.05; 0.1; 0.15 and 0.25 µm [3].

The surface profiles given by the device software were compared with analogous ones obtained using a contact profilometer. Due to the large spreads, the obtained results do not allow for unambiguous confirmation of the comparability of these two measurement methods.

Conclusions

The tests carried out confirm the high accuracy parameters of the interferometer, which can be seen especially on the example of the measurement results of the reference elements: interference glass and gauge blocks.

The results have a graphic form that is easy to interpret. The influence of the person operating the device is very limited.

The use of an interferometer in the process of sealing production allows obtaining much more accurate information about the nature of flatness deviation of slip rings - key elements of gas-dynamic seals. The flatness of these elements translates into the parameters and effectiveness of the entire seal.

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