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MULTI-SENSOR COORDINATE MEASURING MACHINE AND INTERNET VIRTUAL MULTI-SENSOR MEASURING MACHINE IN CMI PRAGUE

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Abstract: *The Czech Metrological Institute in Prague started the research in the field of measurement of shapes, dimensions and position with the accuracy falling into the sub-micron field. It is being equipped with new measuring equipment and engages into international projects, such as, e.g. the project Nano CMM.*

On the other hand, after the experience with high prices of measuring technical equipment, the institute comes with the idea to offer the possibility of measurement for practically everybody. The Internet virtual multi-sensor measuring machine has been developed for processing and measurement of two-dimensional pictures made by CCD camera, digital photographic apparatus, microscope or AFM and other devices. The virtual measuring machine serves also for modelling measurement, navigation of measurement and for teaching.
Key words: *Multi-sensor coordinate measuring machines*

1. INTRODUCTION

A new **800 x 400 x 200 mm WERTH video check HA** multi-sensor measuring machine was delivered to the Technical Length Department of the Laboratories of Fundamental Metrology (LFM) of the Czech Metrology Institute (CMI) in Prague **with the following measuring parameters:** the best measuring ability? (MPE) **at bi-directional measurement E1: (0.50 + L/900) µm,** (Fig.1). The acquisition of this machine by the Czech Metrology Institute has launched submicron dimensional metrology research and meeting of the needs of the Czech industry. The machine is equipped with optical reading, a Renishaw TP 200 contact head and an optical contact fibre terminated with a little glass ball. Besides the SIP CMM5 coordinate measuring machine, which has been the most precise measuring machine of this type in the Czech Republic so far, the WERTH video check HA device is one of the most accurate optical machines. With its optical fibre and CCD camera the WERTH machine is capable of measuring very small hole diameters and thin-wall products by a low-thrust contact. The probe itself consists of an optical fibre terminated with a ball of the diameter of down to 15 µm. Lights passes through the fibre, lighting the ball. A CCD camera monitors this point of light from above through a set of lenses, evaluating the position of the point at contact. It is the fibre bend flexibility only that creates thrust, which is in the order of several µN. The glass ball movement can be observed with the internal illumination off, too. In that case, the ball gets displayed as a dark (black) circle. It is because CMI joined a new EU project in late 2006 called shortly Nano CMM (its full name is: Universal and Flexible Coordinate Metrology for Micro and Nano Components Production). The project shall solve dimensional metrology tasks with the accuracy

Fig.1 WERTH video check HA 800x400x200 mm

of several tens of nanometres. The above mentioned machine will be used for calibrating miniature artefacts.

2. MEASURMENT ON THE WERTH VIDEO CHECK MACHINE

First of all, the machine is equipped with optical measuring system that has missed in ČMI so far in the above-mentioned accuracy. Its utilization is in practical measurements for the machine, electro-technical industries and also in other fields. Optical methods are able to find the interface of two materials, measure sections of multi-core cables, printed joints, spraying, etc. This measuring machine can measure a single part in multi-sensor manner, i.e., with all sensors gradually. There exist parts and units, where it is suitable and fit to measure a part by contact and the rest that cannot be measured by contact is measured optically. E.g., with a coin made of two metals (one ring pressed inside the second one), the outer diameter of the whole coin can be measured by contact, but the interface of the metals can be measured optically only.

The machine WERTH, as said above already, has at its disposal, apart from the classic contact and optical sensor, a very interesting (patented) measuring system based on the use of glass fibre and CCD camera (Fig. 2). That system is marked by the possibility to measure by contact also very small diameters of openings and thin-walled products with minimum thrust. The probe itself is formed by optical fibre at the end of which is a ball of the diameter minimum up to 15 µm. Passing through the fibre is the light that will illuminate the ball. That light point is observed from top through a system of lenses by a CCD camera that assesses the position of the point on contact. The thrust is formed only by the flexibility of the fibre bend that is calculated in the order of µN units. The movement of the glass ball can be observed also with the inside illumination switched off. Then the glass ball shows on the screen like a dark (black) circle. E.g., the Spanish firm Unimetrik made use of that

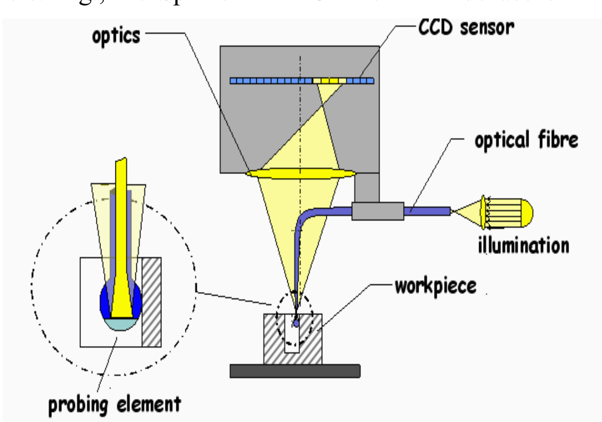

Fig. 2 Glass fibre measuring system

machine with optical fibre for the measurement of the openings of injection jets of Diesel engines of the firm Caterpillar in the USA.

The equipment of the machine WERTH with that contact was one of the decisive moments for its selection. In fact, at the end of 2006 ČMI entered a new project of the European Union under the abbreviated name Nano CMM (the full name is: Universal and Flexible Coordinate Metrology for Micro and Nano Components Production). Application in the project will be the tasks of dimensional metrology with the accuracy of several tens of nanometres. The above-mentioned machine should serve, e.g., for calibrations of miniature artefacts.

The linkage of the optical system was performed by means of a glass plate with intentional figures calibrated in PTB. The plate of the dimensions 110 x 110 mm was measured at the places of work of PTB and CMI using different measurement procedures, Fig. 3. The graphic

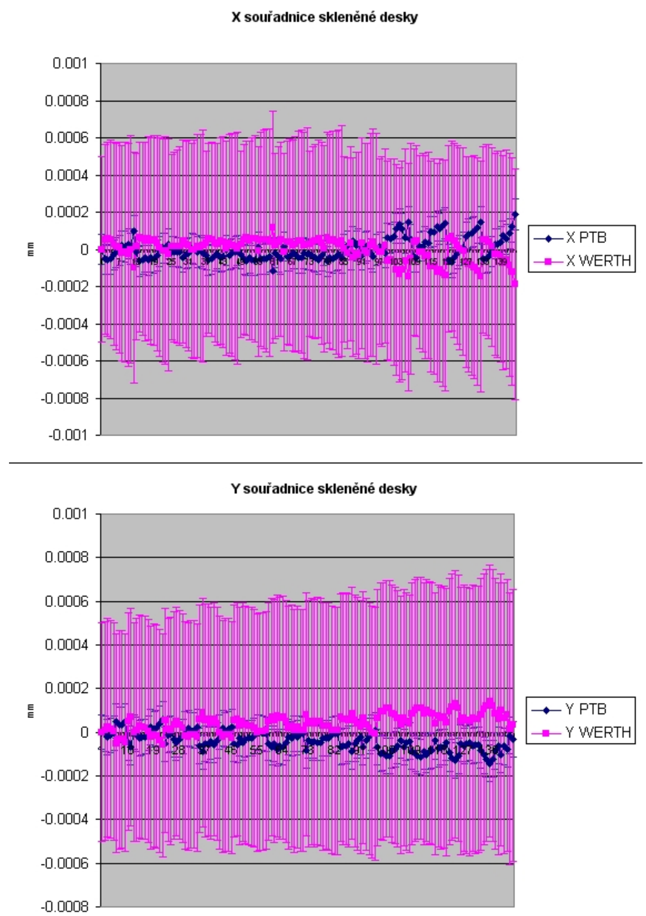

Fig. 3 CMI – PTB comparison

depiction of the results depicts the measured deviations always with the relevant uncertainties of measurement. Very good compliance was achieved.

At present the most frequently used method for calibration of coordinate measuring machines with optical reading is the use of glass rulers of different lengths and of different density of division lines. Those rulers are offered by a number of manufacturers. Calibration is performed by ČMI. Usually, the measurement is performed in parallel with the axes and in plane diagonals. That manner is in compliance with standard VDI 2617, always the positions of the lines are measured in relation to the calibration values, on the whole 3x. Glass rulers, as the single-dimensional etalon have an analogical artefact for the machines with contact, namely the degree gauge.

The advantage of the multi-sensor machine is the possibility to measure the object (the part) by different sensors: by contact with a ball, in the combined manner by contact and optically with a glass fibre or purely optically.

Fig. 4 Opto-mechanical steel hole plate

However, how to compare the quality of measurements performed by the individual sensors?

Interesting seems the use of plane two-dimensional bodies, such as opto-mechanical steel plate with openings (Fig. 4). ČMI gained that plate within the framework of the Easytrac project from the partner Danish Technical University. That plate is adapted well both for contact and contact-less measurements. It is given by the use of the plate with openings of the thickness of only 0.1 mm fixed between two plates 6 mm thick. By the use of steel the artefact gets close to the common manufacture in industrial enterprises.

The plate was measured by means of all sensors at 8 “identical” measuring points. The results depict deviations from reference values that were obtained by calibration on the SIP machine with contact sensor. The best compliance was achieved with the measurement by means of the contact probe Renishaw TP 200, where the largest deviation was measured as 1.4 µm. With regard to the shape deviation of the openings themselves that achieves the values up to 2.7 µm and the impossibility to guarantee the sensing of the points at the absolutely identical place, that result is excellent. With the measurement by optical sensor the deviation 1.8 µm occurred already which, with regard to the absolutely different assessment of measured points detection, is also a trustworthy value. Surprising was that with the measurement from the opposite side of the plate the distribution of deviations was different, but the overall value 1.7 µm comparable. The only reason for that different distribution can be seen in the non-perpendicularity of the openings, despite the fact that their length is more a 100 µm. The measurement of the positions of the openings by means of the optical fibre with the ball of the diameter 100 µm showed that the measurement with such a small diameter of the contact ball is already burdened by the micro-structure of the surface and, therefore, the maximum roundness of the opening 4.0 µm was measured. Therefore, the natural filter of surface unevennesses in the form of a ball with a large radius did not occur in that case any more. Despite that, the maximum deviation was 1.5 µm which got close to the measurement with the TP200 probe, Fig. 5.

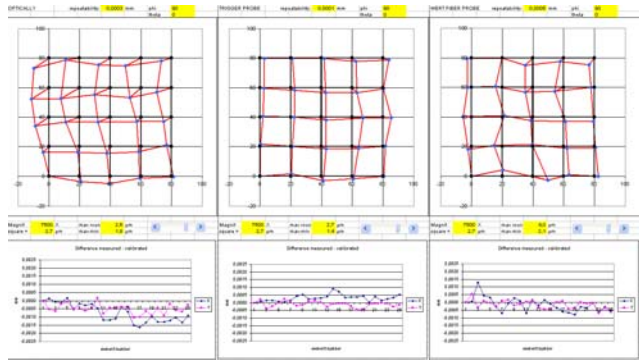

Fig. 5 Measurements with using all three systems

Consequently, it ensues in the conclusion that the quality of the artefact surface is the decisive factor for the successfulness of measurement in the sub-micron field and the calibration performed by means of the contact system is not always capable adequately for the use on measuring machines with optical sensor.

3. INTERNET VIRTUAL MULTISENSOR MEASURING MACHINE

The name implies the notion of Internet. All measurements are transmitted on-line and processed in real time on a remote server using the Internet. The user can retrieve the measuring software through the Internet. *Another question is why a virtual machine?* Most of us are equipped with a PC and an Internet connection. There are several reasons why to create a virtual machine: Involve the client in the measuring process. Enable the wide public to make measurements in dimensional metrology without owning a dimensional measuring machine. Communicate on-line with partners during research project measurements. Make the machine a helpful measurement simulating aid. Teach the trainees the principles of measurements with coordinate machines and foundations of dimensional metrology, Fig. 6.

Fig. 6 Head of virtual machine control panel

The next word included in the name is *multi-sensor.* A virtual machine contains tips of various shapes and sizes, contact balls, probes terminated with contact balls, an optical aiming cross (reticle), circles and circular rings that can be magnified and diminished according to the shape to be measured, straight lines with an increasing tolerance field, an option to rotate the object to be measured, etc. (Fig. 7). To control all these features you need a PC mouse (or keys). Hence, this virtual machine is a two-dimension picture processing software tool and, at the same time, a real measuring machine.

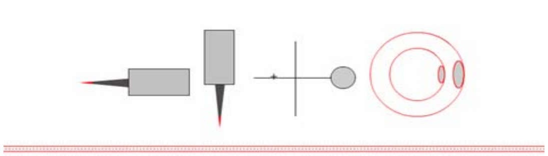

Fig. 7 Tools of virtual CCM

How to measure: You can insert the picture in the measuring machine area from a CCD camera, photograph, scanner, CAD drawings, and similar media. With the virtual measuring machine you can make relative measurements in monitor pixels, or real length measurements in length units (m, mm, µm, nanometres). First find the point to be measured with the optical cross, contact point and enter the x,y coordinates of this point. Then move to another point and repeat the procedure. Data are immediately transmitted onto a remote server for processing. The virtual machine "measures" even such shape deviations as linearity, circularity, etc. In real measurements, insert the length or planar dimension in the picture using glass gauges or 2D artefacts (Fig. 8). Both the glass gauges and 2D masks are calibrated using the WERTH machine in LPM CMI Prague. Experience shows that, together with the artefact being scanned, a standard digital camera or a CCD camera produces a photograph of such quality that it can be used for dimensional measurement.

Fig. 8 Glass gauge

Achieved accuracy level: The measurement accuracy of a real measuring machine is affected by 21 geometric uncertainties of the machine, gauge errors, temperature fluctuation, optical scanning deviation, and picture processing quality. The virtual machine measurement accuracy is mainly based on the picture quality together with the inserted length or planar dimension. Furthermore, the accuracy level depends on the CCD camera and monitor resolution, picture distortion, picture magnification, and degree of grey levels on the object edges, and so on. Applicability: Suppose you transfer the picture of a coin (Fig. 9) into the area measured in such a manner that it covers almost the whole screen, the picture can be divided into approximately 1,000 pixels. Theoretically, you can consider the resolution of 0.001.

This accuracy, however, may deteriorate due to bad photograph quality, the degree of grey on the object edges, etc. On the other hand, you can process the picture quite easily as proportions of width and length, relative distance, etc. If a CCD camera output with a microscope, e.g., is available, you can process pictures of the size of tens or even hundreds of micrometers. The figure shows the ball termination of a glass optical fibre. This type of contact is used in the WERTH coordinate measuring machine. The picture of the ball with a gauge with a line pitch of 0.2 mm, was transferred into a virtual measuring machine (Fig. 10). In such environment, variable relations can be measured with respect to the measure transferred using the gauge. The object to be measured can be calibrated by comparison with the length inserted, can be magnified, diminished and rotated. This allows for modelling of over-determined measurements, new measuring strategies, use of such well-known functions as best fit, max min, and similar. One and the same point can be measured simultaneously with multiple sensors. This software tool, developed at CMI, can be applied in maps, X-ray diagrams, evaluations of medical photographs of dermal diseases, quality checks of bar codes, printed circuit boards, electric multi-wire cable cross sections, etc. Application opportunities lie in on-line Internet consultations with clients, project colleagues, or trainees.

Fig. 9 Coin in the virtual CMM

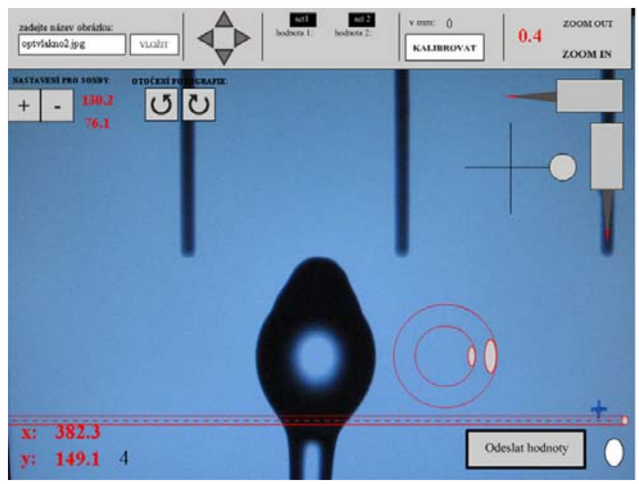

Fig. 10 Glass optical fibre in the virtual CMM

4. CONCLUSION

The presentation compares the results of measurements of very small artefacts using a real measuring machine SIP and the WERTH machine. In addition, it introduces an Internet virtual measuring machine. The Internet-based dimensional measuring using a PC, where the real length is inserted in the picture, is an effective dimension, distance, length, shape and relative position measuring tool. These measurements can be taken either separately or as an addition to real multi-sensor measurements.

5. REFERENCES

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