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[1.]Michal WIECZOROWSKI, [2.]Miroslaw GRZELKA, [3.]Bartosz GAPINSKI,
[4.]Lidia MARCINIAK, [5.]Izabela OLSZEWSKA

FIDELITY OF OPTICAL TECHNIQUES FOR GEOMETRICAL INSPECTION OF CRANKSHAFTS

[1-4.] POZNAN UNIVERSITY OF TECHNOLOGY, INSTITUTE OF MECHANICAL TECHNOLOGY, DIVISION OF METROLOGY AND MEASUREMENT SYSTEMS, PIOTROWO 3, POZNAN, POLAND
[5.] FOS POLMO LODZ SA, PRZYBYSZEWSKIEGO 99, LODZ, POLAND

ABSTRACT: *In the paper optical measurements of geometrical features on crankshafts were presented. The requirements of contemporary customer are getting higher and higher. It is particularly visible in aviation and automotive industry. For truck manufacturers it means efficient work with no repairs for hundreds thousand kilometers. It means also more measurements in every batch and on each workpiece. In this project we investigated possibility of use optics for fast inspection of diameters, lengths and form deviations. It was necessary to prepare a measurement strategy and elaborate uncertainty evaluation.*
KEYWORDS: *tactile measurement, optical measurement, CMM, measurement strategy, uncertainty*

INTRODUCTION

Present economical situation enforces manufacturers to ensure very high Quality of their products. It further implies cost reduction of the whole production process including following expenses connected with e.g. malfunctioning claims. These facts make it necessary to invest in machine tools that can produce fast, efficiently and precisely. Meanwhile, it is crucial to develop control and measurement systems and procedures to continuously monitor suppliers and own production. FOS POLMO Lodz, a co-author of this paper, is an example of a company that fulfils these requirements. History of the enterprise reaches year 1908, while present production portfolio comprises components for compressors and turbo compressors and assembly of the whole systems (fig. 1).

Figure 1 – Examples of elements manufactured in FOS POLMO SA

FOS POLMO Lodz SA is the biggest in Poland manufacturer of compressors for pneumatic braking systems used in trucks, buses and agricultural machines. These elements are designated for both: primary and secondary market, 80% of them goes abroad. High quality of products and trust of customers are confirmed by numerous awards that were granted to POLMO during last years. Continuous development of the company is possible also thanks to money from EU funds. Looking for new solutions and support from scientists POLMO together with Poznan University of Technology carried out a grant called: Introduction of new measurement technology regarding elements of compressors and turbo compressors. During this project a method for correction of grinding machine by means of a file generated by CMM measurement software was implemented. It was done by a Leitz PMM 12.10.6 [1]. At present another project goes on regarding implementation of contactless measurement methods regarding geometrical features in mass production of crankshafts. Some results of this project are presented in this paper.

THE USE OF TELECENTRIC MEASUREMENT SYSTEM

In contemporary length and angle measurements optical techniques play still more and more important role. Their basic merits are no contact between measuring element and workpiece as well as speed of measurement, what makes it possible to measure more parts and features during the same time. Thanks to this optical devices are getting common in industry. Among optical devices there are optical scanners [2] and traditional coordinate measuring machines equipped with cameras [3], and even surface roughness measuring instruments thought for the future [4], though here their practical application does not always look promising [5, 6]. Among optical measurement methods there are surface techniques (triangulation and space) and projection ones (laser, telecentric, central perspective and central projection) [7]. Telecentric system (used in our research) gives a possibility to identify workpiece geometry, determine lengths and diameters rotate at a given angle during measurement, measure threads and through bores. A measurement itself can be executed statically or dynamically. Workpiece is fastened in working space and measuring system moves along its axis. At one side of the workpiece there is a light source using semi conductive LED diodes and telecentric lenses that form light beam in a proper way. At the other side there is a CCD sensor that reads shape and dimensions on the border between light and dark area (fig. 2).

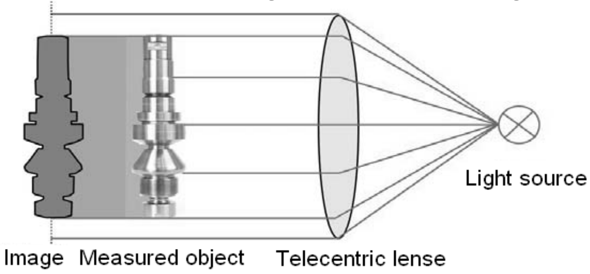

Figure 2 – Measurement principle of optical telecentric system

APPLICABILITY FOR MEASUREMENTS OF AXIS SYMMETRICAL WORKPIECES

FOS POLMO carries on mass production of different type of crankshafts for compressors used in pneumatic brake systems. Requirements put by customers are a challenge for both: production division and measurement laboratory. For some types of crankshafts cylindricity error should no exceed 0.005 mm, what determines choice of strategy and selection of measuring devices. For control a CMM Leitz PMM 12.10.6 is used working in a tactile routine, equipped with the most recent controller and a High Speed Scanning mode (HSS). The machine was shown on fig. 3. Because of great number of different measuring tasks performed on this machine and still growing production, it was necessary to implement a device that could ensure shorter measurement time maintaining accuracy of assessment. Solving the task it was necessary to develop an optical system, that could be able to execute a great number of measurements within a short time, with respective fidelity and independent on the operator. The system was based on Hommel Opticline, that is dedicated to do measurements of outer dimensions and form deviations for axis symmetrical parts, traditionally machined on turning or grinding machines for shafts. It is commonly used in car industry as well as aviation one, while its standard applications are valves, rotor shafts, gear shafts, injectors, turbine shafts, hydraulic pneumatic components, camshafts and crankshafts. It can measure elements with diameter up to 150 mm and 530 mm length, maintaining maximum error of ±(2+D/100) µm for diameters and ±(5+L/100) µm for lengths.

Figure 3 – Tactile coordinate measuring machine Leitz PMM 12.10.6

Opticline is equipped with setting discs and temperature sensors for compensation of thermal variations. Before every measurement the device balances a workpiece. During measurement a part is scanned optoelectronically and identified as a shape that stops light emitted by LED diode. During dynamic mode data regarding contour are collected when a workpiece rotates. Image is displayed on monitor and predefined features are assessed. The standard configuration - Opticline Contour 514 was presented on fig. 4. It is ready to work in workshop conditions, for 100% inspection.

Figure 4 – Optical coordinate measuring machine Hommel Opticline Contour 514

Maximum permissible error MPEE for Leitz CMM is ±(0.8+L/600) µm for the whole measuring space of 1200*1000*600 mm. For research a DEA Global Image Clima 7.7.5 CMM was used that is in Laboratory of

Division of Metrology and Measurement Systems at Poznan University of Technology. MPE_E for this machine is ±(1.5+L/333) µm. So considering all the described devices, CMM DEA is between Opticline and Leitz CMM. Comparison measurements were taken for various types of crankshafts. In all cases measurement times for both CMMs were similar, while measurement time for Opticline was significantly shorter (table 1).

Table 1 – Combination of measurement times regarding a single workpiece with different measuring devices

Measurement device	Leitz PMM 12.10.6	DEA Global Image 7.7.5	Hommel Opticline Contour 514
Measurement time of single workpiece	9 min 20 sec	10 min 25 sec	1 min 8 sec

In every case the same measurement features were considered. Optical devices can execute the same task about ten times faster. It is indeed a very important parameter from control possibilities as well as quality monitoring point of view.

Within a project it was necessary to define measurement uncertainty for optical device, to establish its application possibilities in every day use in the factory. When measuring features with very narrow tolerances, an influence form crankshaft geometry and weight was noticed (location of heavy parts regarding rotation axis - crankshaft may have one or two cranks). As a measurement is a dynamic one, vibrations of the shaft were observed and stick-slip phenomenon on center. To avoid this problem a new concept of center was constructed with two additional pins and fastening screw. This solution eliminated problems (fig. 5).

Figure 5 – Standard centre and new solution with fastening screw and setting pins

Another issue which is crucial at all the optical measurements with narrow field of tolerance is presence of all the kind of dust and liquids. They can significantly distort the result of measurement. Directly before mounting in a holder, a workpiece has to be thoroughly cleaned and dried. This is particularly important when measurement tasks are on the limit of accuracy for the measurement device and uncertainties are lower than maximum permissible errors defined by manufacturer.

MEASUREMENT UNCERTAINTY EVALUATION

Proper presentation of measurement result requires also uncertainty. Assessing uncertainty for coordinate measuring devices is a complex and time consuming process [8, 9]. Because of specific requirements it is necessary to evaluate each feature separately, as there are different ways to establish different features. Such a situation is for both: a CMM and optical system. Guide to the Uncertainty Evaluation (GUM) [10] introduced the term of combined standard uncertainty u_c, which is a parameter showing dispersion of the measurement results. Standard deviation of measurement results could simply be used as combined standard uncertainty. The border lines of this interval are determined by so-called expanded uncertainty U (formula 1). They comprise big, depending on level of confidence, part of distribution, that can be assigned to a measured value [11]:

$$U = k \cdot u_c(x) \qquad (1)$$

where: U – expanded uncertainty,
$u_c(x)$ – combined standard uncertainty,
k – coefficient depending combined standard uncertainty on assumed level of confidence p. Practically, k is assumed to be equal to 2, what stands for level of confidence p = 95%.

Evaluating A type of uncertainty has experimental character and is based on a series of repetition of the inspected value. In this case, experimental standard deviation $s(\overline{x_i})$ is considered as combined standard uncertainty u_c (formula 2).

$$u_c(x) = s(\overline{x_i}) \qquad s(\overline{x_i}) = \frac{s(x_i)}{\sqrt{n}} \qquad s(x_i) = \sqrt{\frac{\sum_{1}^{n}(\overline{x} - x_i)^2}{n-1}} \qquad (2)$$

Experimental standard deviation of sample distribution based on measured values $s(\overline{x_i})$ is an assessment of standard deviation of σ distribution. Mean value = $\overline{x} = \frac{1}{n}\sum_{1}^{n} x_i$ from certain number of results n where every result is x_i is an assessment of correct mean value µ of the distribution.

Table 2 – List of measurement features for which uncertainty was evaluated

1 – diameter of short pin 1; 2 – roundness of short pin 1;
3 – diameter of short pin 2; 4 – roundness of short pin 2;
5 – diameter of crank pin 1, 6 – roundness of crank pin 1,
7 – diameter of crank pin 2, 8 – roundness of crank pin 2,
9 – diameter of long pin 1, 10 – roundness of long pin 1,
11 – diameter of long pin 2, 12 – roundness of long pin 2,
13 – stroke

According to the above mentioned rules, assessment of measurement uncertainty by means of A method was performed for all three measuring devices. For this, each feature was measured 30 times. List of features is shown in table 2, while uncertainty values are presented on figure 6.

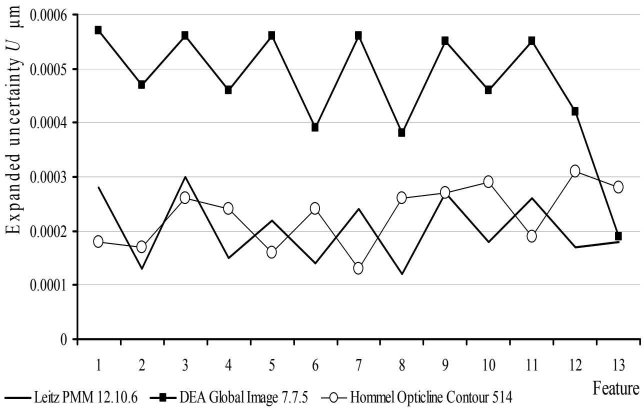

Figure 6 – Measurement uncertainty of particular features according to Table 2

As it was expected basing on maximum permissible error, uncertainty for CMM DEA is higher than for CMM Leitz. However, in both cases obtained values are smaller than MPE_E declared by manufacturers. Values obtained for Opticline are on the level of the respective ones for CMM Leitz. This fact was not expected, as comparing declared values of MPE_E the optical device has much worse parameters than both used CMMs. It means that right measurement strategy and proper use of the device with necessary modifications lead to obtaining much better uncertainty specs than showed in leaflets. It is also worth mentioning, that values for CMM Leitz and Opticline were obtained in production laboratory of FOS POLMO Lodz.

CONCLUSIONS

In the paper application of optical telecentric measurement system for inspection of geometrical features of crankshafts was presented. Some aspects connected with implementing it to control quality in production process were also shown. Basing on the obtained results it is clear, that the device is fully useful for the measuring tasks it should do, for accuracy and time of measurement. Duration of measurement process is about 10 times smaller with accuracy on the same level required to determine inspected features. Uncertainty for these features was also elaborated.

Some modifications regarding crankshaft holder was proposed. The overall project shows that specialized optical measuring device can be a good solution for quality control of crankshafts.

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