Contemporary Quality Management System With 3d Surface Analysis, Dimensional Inspection And Non-Contact Thermal Diagnostics

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Abstract: *In the paper, the main characteristics of the Quality Management System have been presented. Some problems of the surface topography analysis have been pointed out, because the shape of surface is one of the crucial characteristics of many responsible details in motor industry. Moreover, some methods of 3D surface measurement in nanoscale have been described. As one of the solutions for the in-process control, the air gauges controlled by PNEUTRONIK devices has been presented. Air gauging could provide a non-contact measurement with high resistance to dirt, wear and tear, vibrations and so on, but of high accuracy and reliability. Also, the thermal diagnosis has been introduced as an important tool ensuring supervision on the manufacturing process.*

Key words: *air gage, dimensional measurement, Quality Management, surface topography, thermal diagnostics*

Introduction

According to standards ISO 9000:2001 the supervision of whole manufacturing process should be done. The purpose of the Standard had been creation of better solutions of combined quality systems (PN-EN ISO 9001:2001), environmental management (PN-EN ISO 14001) and work safety (PN-N-18001) [1, 2, 3]. According the Standard PN-EN ISO 9001:2001, Quality Management covers the whole life-cycle of product, from the market investigations up to after-sale service. Various parameter may be pointed out and underwent thorough inspection and analysis. Among others, they are parameters of the roughness and 3D surface topography or dimensions. Also the thermal diagnostics could become a part of the Quality Management System and provide important information on the functional abilities of the machines, their malfunctions and inaccuracy.

The main principles of the quality management

Any process may become a subject of Quality Management. The Standard PN-EN ISO 9001:2001 considers as a process any operation which accepts the input goods and transform them into output ones. Hence, all the actions and operations with products or services are processes. The general process model is shown in the Fig. 1.

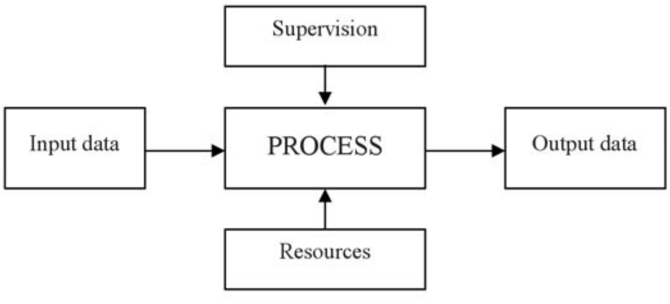

Fig. 1. General model of the process

The process approach of the Standard should help to conduct the enterprise and its processes management. Often the result of one process is the input for the next one. So, the systematical identification and proper management of various processes and their connections is required. Process model ensures the content and logical connection between particular elements of system with emphasize of quality planning. The cycle P → D → C → A is introduced (planning, execution, measurement and analysis, correction and improvement).

The main principles of the Quality Management may be specified as following [4]:

Principle 1: Customer focus.
Principle 2: Leadership.
Principle 3: Involvement of people.
Principle 4: Process approach.
Principle 5: System approach to management.
Principle 6: Continual improvement.
Principle 7: Factual approach to decision making.
Principle 8: Mutually beneficial supplier relationships.

Basing on the presented principles, the system must be created, documented and implemented in the enterprises willing to experience the full advantage of the Quality Management.

In most manufacturing processes, the measurement is involved. Quality Management system requires the supervision, adjustment and keeping the measuring devices in order to prove measurement reliability. The measuring tools may perform their task only when they are appropriate for the particular purpose, are available at the time and their reliability is proven.

Supervision includes all the activities began with the introduction of the equipment in factory and finished only when it is removed. The time between legalization of the measuring tools should be determined and kept. Only continually checked and adjusted equipment may provide reliable results and, hence, keep the quality on required level. The capability of the equipment should be determined with statistical methods. The particular elements of the measuring system should be supervised, too, in order to provide reliability of whole system. There are three basic methods of analysis of measuring system: Range Method (RM), Average and Range Method (ARM), Average and Standard Deviations Method, and method ANOVA (Analysis of Variance) as it is specified in [2].

Air gauging dimensional inspection

In many industrial applications air gauge is still irreplaceable, especially in the in-process control of workpiece dimensions. In the air gauges for dimensional measurement, the linear dimension (slot width) has impact on one of the air parameters: pressure, velocity and flow [5]. Phenomena on which the operation of particular types of air gages is based are the subject of classification of the pressure, velocity or flow type air gages. Probably most often in industry are used high-pressure air gages, where the changes of the back-pressure is in some extend proportional to the changes of slot width.

The high-pressure air gauge works as a flapper-nozzle valve (Fig. 2, left). It consists of the inlet nozzle (1) with diameter d_w, outlet or measuring nozzle (3) with diameter d_p, which is distanced from measured object (4), and the measuring chamber (2). The static metrological properties of the typical air gauge may be described by the relationship between the clearance *s* and the pressure in measuring chamber p_k (see Fig. 2, right). There is an area, where the relation is close to linear, which is used as the measuring range z_p. For air gauges of different geometry both sensitivity *K* and measuring range z_p may vary and should be analyzed in order to obtain the best metrological properties of the sensor.

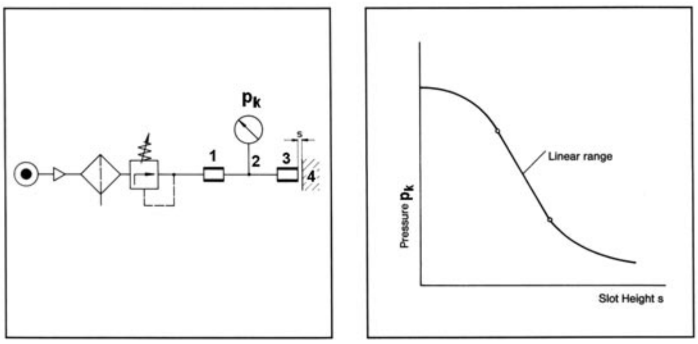

Fig. 2. Typical high-pressure open jet type air gauge (left) and his static characteristics (right) (based on [6])

The open jet air gauge provides non-contact measurement, high accuracy, high sensitivity, high resistance to the external conditions influence and adaptability for the wide range of different measuring applications [7]. In order to fully exploit the advantages of pneumatic measurement, the devices of PNEUTRONIK type has been developed and tested, and introduced to the market in cooperation with Institute of Advanced Technology (Cracow, Poland) [8]. They are destined to work both in measurement laboratory (especially B25 and B50) and in the production lines (especially C2K). Typical PNEUTRONIKs are shown in the Fig. 3. The devices are designed to being fed from standard industrial pressure air net. They are quipped with filters and pressure stabilizers. In the PNEUTRONIK, the piezoresistive transducer enables to gain electronic signal, further converted into digital and processed by microprocessor. The results of measurement are presented digitally or in analogue way, as well as are being transmitted through the interface RS232C to the computers for further analysis or directly to the printer.

The systems of measurement and signal processing ensure high resolution of the measurement, and the accuracy on the level of ±0.4 μm. The device may cooperate with any measuring head delivered by other producers.

Unlike the most of available in the market pneumatic gages, PNEUTRONIK has no mechanical correction of zero point. It is done electronically. From the economical point of view, it is important advantage, because in typical pneumatic devices zero is adjusted through additional valve letting the pressured air out. Then, the pressured air is being lost even when the measurement is not performed. Similarly, the adjustment of tolerances and control signals is available from the keyboard, and the characteristics of particular measuring head could be recorded for further use.

Fig. 3. PNEUTRONIK devices type B50 (left), B25 (middle) and C2K (right) with master rings

The concentrator is reading the data from the disc. After transmission, the data could be analyzed in the computer. For the analysis, the program PNEUSTAT was worked out. It is able to calculate a range of the statistical parameters for achieved data, correlated with the production identification (date, working shift, week or particular time period for analysis) from the given technological devices or lines. It is possible to chart $\overline{X} - R$ graph with the process capacity coefficients C_p and C_{pk}; the calculation of the machine capacity coefficients C_m and C_{mk} is possible, too. Besides of that, a range of other data could be calculated like number of the details for given class, number of the breaks in the work process, summed time of the work breaks, and so on. The results could be printed directly from the program, or recorded as uneditable graph files, ready to be printed. For those files, the file viewer is added to the program. The electronic unit based on the independent microprocessor enables to control all needed functions of the system electronically. So the integrated device could work as an autonomic air gage, and it could be included to the Quality Management System as well [9].

3D surface analysis

In the world around us, all the surfaces are rough. Most of surfaces in mechanics are very complicated, and in order to describe it with certain values, the measurement and analysis of some parameters should be performed. Before 1980th, roughness analysis consisted of 2D measurement, which gave two-dimensional characteristics of the surface [10]. During the last decades, many scientists and constructors became convinced that the third dimension should be added to the analysis [11]. At present, 3D analysis of the surface geometry is widely accepted, though some disorder in terminology and in 3D parameters classification is still present. But it should be noted that the works on the standards are going on, and finally 3D topography measurement will be clear and unambiguous.

In order to complete the comparative analysis of the surface topography, the program of 3D measurement application had to be created. It was based on Matlab software, but our team worked out original program for surface analysis, 2D and 3D alike. Four software modules were worked out: the initial data processing module, basic parameters calculating module, data visualization module, and digital filtration module [12]. Examples of filtration are shown in the Fig. 4 and 5.

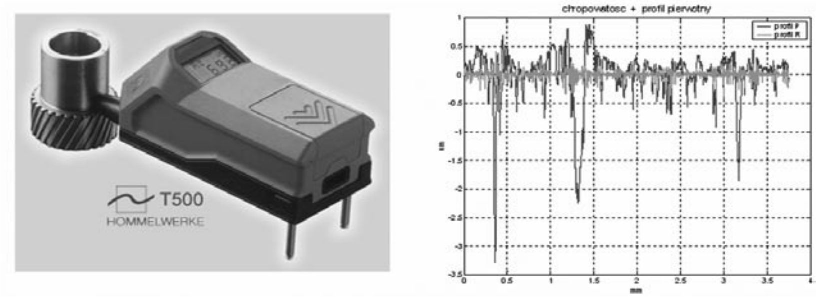

Fig. 4. Portable profilometer HOMMELWERKE T50, and the measured profile unfiltered and filtered

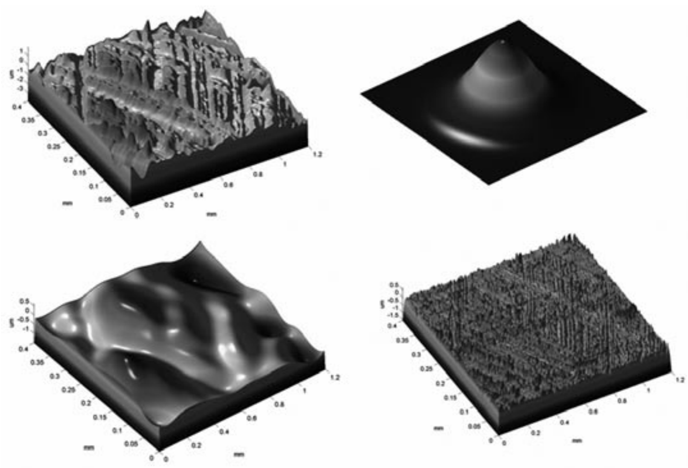

Fig. 5. Gaussian digital filtration – example with surface after honning

In order to measure nanotopography of surface, more accurate devices should be used. Division of Metrology and Measurement Systems is equipped with the interference microscope, NT1100, made by VEECO, and with Atomic Forces Microscope diCaliber type. Both devices undergo investigations on measurement accuracy and abilities. For example, the microscope NT1100 has vertical measuring range 1 mm with vertical resolution 10 nm. However, the scanned area is limited, especially when the spherical surface is measured. For example, the Fig. 6 (left) shows the topographical map of the calibrating sphere made by DEA, and the Fig. 6 (right) shows its profiles with filtered roundness. It is clearly seen that outside of the area 300×200 µm shown in the Fig. 6, measurement goes out of range.

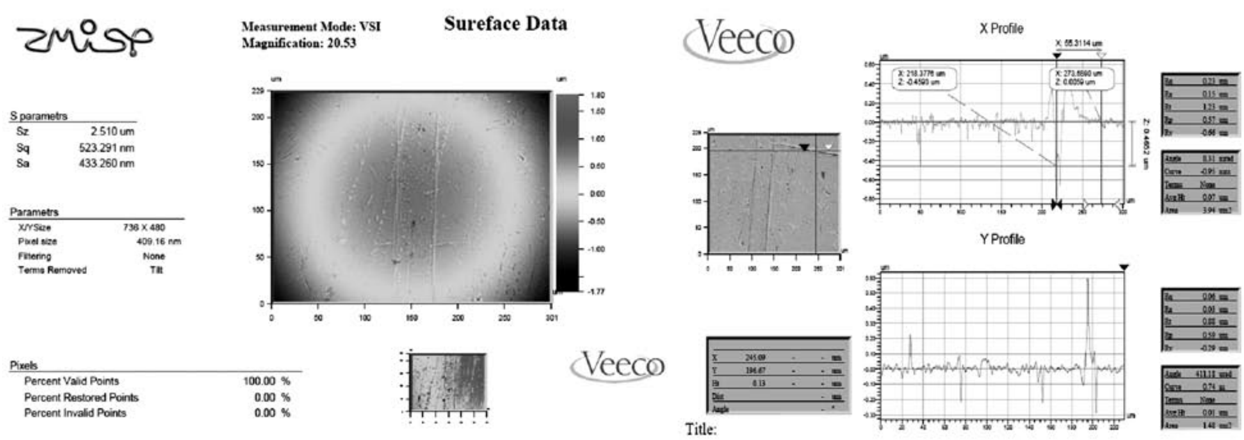

Fig. 5. Surface of the calibrating sphere (left) and its filtered profiles (right)

One of the opportunities is a stitching option provided by the described device. However, in that particular measurement it is not fully applicable. For example, when the sphere of 25 mm diameter is measured using stitching mode, the central area (its radius is 1.93 mm) of gained map contained 94 % of correctly collected measuring points. The next one of radius 3.3 mm was approximated from only 16 % of measuring points, while the rest of points were unreliable. Outer area, larger than 3.3 mm radius, allowed to collect no more than 4 % of measuring points which makes such a measurement not reasonable at all. For the spheres of the same material (same light dispersion coefficient) the reliably measured area will vary according to the obvious geometrical formula:

$$a = \sqrt{(2r - s)s} \qquad (1)$$

where: a – radius of the measured area, r – radius of the sphere, s – height of the cone related to the sphere.

The s parameter depends on the material and roughness of measured object. VSI WYKO NT1100 with objective ×5 ensures value of s ca. 0.04 for ceramic sphere and 0.25 for steel sphere.

Thermal diagnostics

One of the most obvious applications of thermal diagnostics in industrial processes is the supervision of the functionality of the machines. Fig. 6 shows the example of the malfunction of the electric motor, where higher temperature caused by damaged bearing is clearly seen in the thermal picture. The detected problem could be solved well before it affected the manufacturing process.

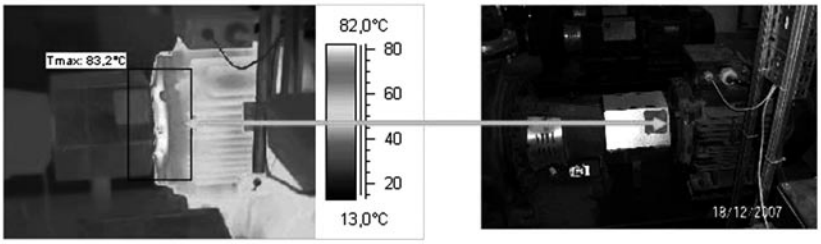

Fig. 6. Thermal imaging of the electric motor with damaged bearing

On the other hand, the thermal diagnostics could be applied in the situations where the temperature correction should be introduced. Solids with geometrically defined shapes are the principal product of many branches of manufacturing industry, including the manufacturing of machines and scientific apparatus. In order to ensure the replaceability of their component parts, it is necessary to keep their dimensions and physical characteristics within narrow margins of tolerance. Temperature is a factor that produces a particularly profound effect on both the execution of industrial processes by means of manufacturing machines and that of the processes related to the measurement of geometrical quantities by means of measuring machines [13]. While the disturbing impact of temperature on the operation characteristics of manufacturing machines (mainly machine tools) has been laboriously studied since the mid-1960s, much less attention has been paid to the significance of this factor in the area of the designing and application of measuring instruments used in the metrology of geometrical characteristics. The situation has been changing over the last several years in view of the noticeable trend toward a marked improvement of the quality of the production of such branches of industry as the machine-building industry, the automotive industry or the precision engineering industry. It is possible to produce mechanical components with a prescribed precision and a prescribed (usually high) output of the manufacturing processes only if exact inter-operation or on-line (active) measurements can be taken. The measuring machines (especially coordinate measuring machines CMMs) used for this purpose must be stable, non-susceptible to environmental factors (particularly to the temperature) and highly accurate.

Generally, if there are changes in the ambient temperature, thermal expansion or contraction occurs in each part of CMM, which results in deterioration of the measurement accuracy. Two different approaches have been adopted to achieve high accuracy, namely error avoidance and error compensation. A new approach is to compensate for thermal expansion and thermal distortion errors with mix of hardware and software solutions that include a web of sensors placed at critical points in the machine structure. The sensors read the temperature on the structure of the machine and a powerful algorithm extrapolates expansion and distortion values from the date. With this data the software is able to compensate for the current thermal state of machine so that the influence of temperature variations is virtually canceled over a wide range The question is how to find the representative temperature-measuring points in the machine. By using the IR thermography for the testing of the thermal condition of measuring machines and methods using correlation functions between locally measured temperature and displacements of the probe stylus tip, time required to find of the points that have reasonable correlation with that displacements, could be significantly reduced.

A number of tests have been conducted concerning the determination of thermal distortions in a CNC milling machine. They were conducted in compliance with the demands set out in the project of the ISO 230/3 standard. The integral part of the measurement post consisted of a ThermaCAM 2000 thermographic system which recorded the thermal stages of the examined milling machine. The results of the examination of linear distortions in three axes and angles of torsional deflection in two axes of the milling machine were recorded. The thermographic system was used for the localization of points in which contact temperature sensors should be placed in order to monitor the machine's thermal condition.

The Fig. 7 presents the algorithm for the selection of the points of temperature measurement with the use of contact sensors [14]. According to the algorithm, such points in the machine are sought, in which the changes of temperature in time are best correlated with the changes (measured also as the function of time) of position of the cutting tool (or a chosen point of the fixed headstock) to the milling table. For chosen elements of the machine, parametric images of surface distribution of coefficient values of the correlation of the above functions are created and the coordinates of the point with the best coefficient are determined.

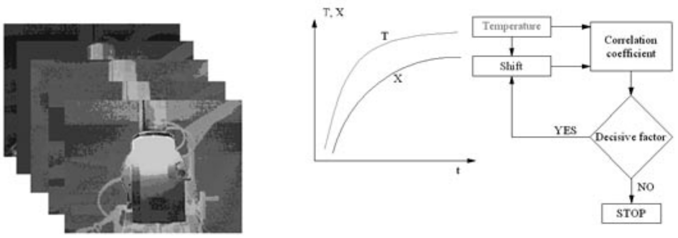

Fig. 7. Algorithm aiding the choice of thermal sensor locations giving the best correlation between recorded increases of temperature and unintended shifts (thermal deformation) [14]

When selecting the points of distribution of the sensors, the accompanying limitations and conditions connected with the machine's construction (e.g. there must be enough space for a sensor in the chosen spot) have to be taken into consideration. Temperature values read from thus situated sensors are used for correcting the trajectory of the tool's movement. This enables one to decrease the thermally generated shifts of the tool with respect to the processed object by several degrees [15].

Conclusions

Metrological supervision of the measuring tools is an important part of the Quality Management System. Provided by Standards methods of key characteristics for the motor industry (FMEA) and hazard control points for food industry (HACCP) enable to ensure control for whole lifetime of the product. The devices of PNEUTRONIK type based on air gaging are fully in line with the requirements of the process supervision and documentation. They provide all needed data for the Quality Management System. In cases the micro or nano scale analysis of the surface topography is needed, the appropriate devices equipped with advanced software may be used. Thermal diagnostics could be applied both for the detection of the failures or malfunction, and for the improvement of the accuracy of some devices in the thermal conditions different from reference temperature.

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