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THE DEVELOPMENT OF THE “IN-LINE” MEASUREMENT OF THE SURFACE TEXTURE

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Abstract: *Surface metrology "on-machine" and "in-process" is important for quality control in the production of precision surfaces. Classifications, requirements, and tasks of surface metrology "on the machine" and "in-progress" are processed. The most modern measuring systems "on-machine" and "in-process" and sensor technology are presented. Debugging algorithms for machine debugging, which are especially needed in surface metrology "on-machine" and "in-process", are reviewed, followed by a discussion of calibration and traceability. Then advanced techniques in sampling strategies, the interface of measuring systems-machine tools, data flow, and analysis, as well as feedback for compensation production are demonstrated. Future challenges and development trends are also discussed.*

Keywords: *surface topography, wear tools, in-line measurement, CNC milling, monitoring*

1. INTRODUCTION

Surface metrology is an important discipline in the field of production metrology. It is defined as the deviation of the workpiece from the intended shape specified in the project drawing [1]. Surface metrology implies measuring the topography of the surface and surface defects, such as roundness, flatness, etc. The workpiece can be considered an integral element of the machine or mechanical system. Therefore, surface metrology plays an important role as an area because the surface topography of the workpiece affects its function and performance in the production process.

A large number of commercially available workpiece surface testing instruments and software can be used to obtain cross-sectional or surface topography data. Examples of mentioned instruments are mechanical pencil profiles [1, 11], non-contact instruments [2, 12], probe scanning microscopes [3], etc.

Surface metrology is an important part of the post-production inspection of the produced workpiece. This type of test is usually performed in a metrologically well-controlled room to determine whether the workpiece surface parameters meet the design requirements. Maximum efficiency of quality control is achieved when the measurement is performed at the nearest possible point of the production process [4].

Surface metrology is, also, effective for control of manufacture (on-machine and in-process) through optimizing the manufacturing process and the machine tool settings. The surface texture of the workpiece represents the characteristics of the process. Disadvantages of machine tools, vibrations, movements of geometric errors, and thermal distortions are reflected through surface form errors [1]. In recent years, an indispensable part of the chain of traditional production processes (cutting, grinding and polishing for precise workpieces of complex shapes and / or extremely narrow tolerances) is metrology on the machine and during the process [5, 7, 11]. Similar trends were noticed in manufacturing processes such as additive manufacturing [6] and nano-manufacturing [8].

This paper presents the tasks, classifications, and requirements of the surface metrology on the machine and during the process for precise production, appropriate measuring instruments, and sensor technologies as a supplement to previous CIRP papers on surface measurement.

2. ACTIVITY OF THE MEASUREMENT IN THE MANUFACTURING

In addition to the terms "on-machine" and "in-process", terms such as "in-situ" and "in-line/on-line" are often used to describe thestate of measurement activities in production metrology, Figure 1 [9]. One of the motives of this paper is to classify these terms in order to distinguish and use them correctly in the manufacturing engineering community [10].

In order to avoid possible ambiguities in the use of the term "process", we would note that this term refers to the fundamental process of the production, and not to the entire process chain or to the iterative process cycles.

Figure 2 shows a production line that is based on a production chain in a factory where environmental conditions cannot be strictly controlled, such as temperature, vibration, and humidity. Instruments for measuring the topography of the surface on the workpiece are placed in different places inside the factory. There is an ecologically isolated metrology room in many factories. In these rooms, it is possible to better control the measurement conditions and the influence of the environment on the measurement. From the environmental conditions point of view, it is possible to classify measuring instruments into two groups, namely: those that are located in the metrology room and those that are not [9].

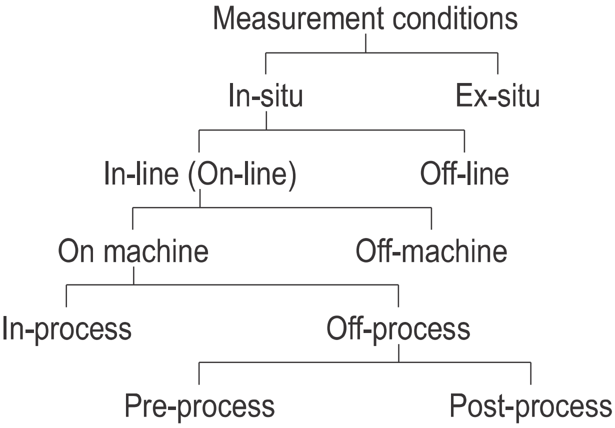

Figure 1. Conditions for precision manufacturing [9, 10]

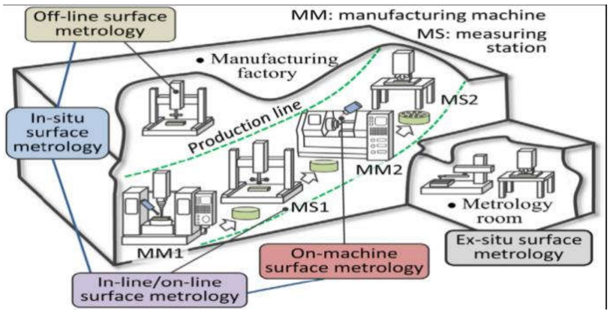

Figure 2. Scheme of the surface metrology in a factory with a production line [9]

Depending on the method of the workpiece surface measuring, there are "ex-situ" surface metrology and "in-situ" surface metrology. The "ex-situ" surface metrology means that the measurements were performed in the different conditions from a production process, while the "In-situ" surface metrology: a measurement of a part surface that is carried out inside the same manufacturing floor/shop floor without isolating the measurement process outside the manufacturing line.

Measuring instruments outside the metrology room can be, also, classified into two groups depending on their location in relation to the production line. Some of them are placed outside the production line. In some cases, the workpiece needs to be taken out of the production line and measured (with one or more instruments), and then returned to the line if it is necessary for further production. This measurement can be classified with the term "off-line" surface metrology. It is possible to use the terms "In-line/on-line" surface metrology: a measurement of a part surface that is carried out in a production or manufacturing line either inside (on-machine) or outside (off-machine) a production machine. Off-line is the measurement is carried out outside the production or manufacturing line, but still inside the same manufacturing floor.

When surface metrology is performed on a production line, the workpiece can be measured either when it is mounted on the machine or when it is taking out of the machine. When the workpiece is moved from the machine and measurements are made, such measurement can be classified according to the term "non-machine" surface metrology. "On-machine" surface metrology: a measurement of a part surface that is carried out inside a production machine that manufactures the part. The measurement can be carried out in-process (during the process) or off-process (before or after the process).

The above-mentioned classifications are made on the basis of the place where the workpiece surface measurement is carried out. The term "on-machine" surface metrology relates to the measurement carried out on the manufacturing machine. Because of that, it is necessary to identify this term according to the manufacturing process on the machine.

As shown in fig. 3, "on-machine" surface metrology can be performed before the production process, which can be classified as "pre-process on-machine" surface metrology. Also, "on-machine" surface metrology can be performed after the production process. In that case, the term “post-process on-machine" surface metrology can be used. These two can be grouped as “off-process” on-machine or simply “off-process” surface metrology. The corresponding “in-process” surface metrology, which is classified as another subcategory of on-machine surface metrology, can then be referred to as: "In-process" surface metrology: the on-machine measurement of workpiece surface carried out while the manufacturing process is taking place.

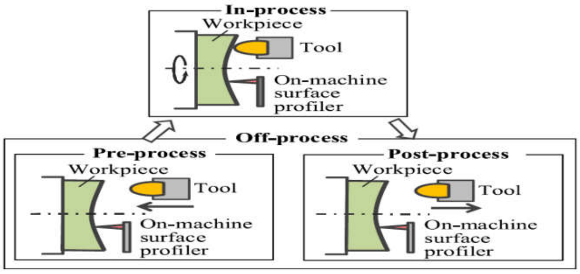

Figure 3. Classification of the “on-machine” surface metrology [9]

Fig. 4 represents a schematic of an "on-machine" surface metrology system. The most straightforward task of the "on-machine" surface metrology is to replace conventional post-manufacturing surface inspection of the workpiece made on a stand-alone surface measuring instrument. The "on-machine" inspection is performed soon after the production process and without taking off the workpiece from the machine. Therefore, the time interval from the end of the production process to the beginning of the inspection can be shortened in order to improve the efficiency of the inspection. The first step in this task is to set up the surface measuring instrument on the machine. Taking into consideration the limited space of the machine and the accessibility of the workpiece surface, the measuring instrument usually needs to be compact.

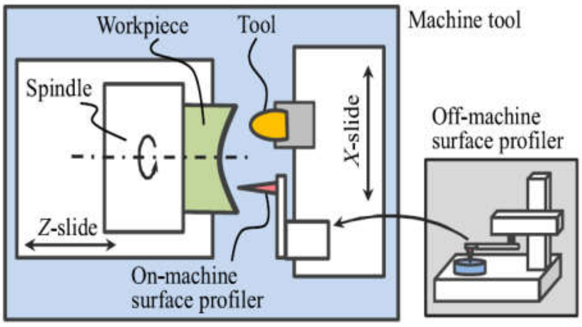

Figure 4. Schematic example of an “on-machine” surface metrology system [9]

In the case of the surface profile with probe scanning, only the instrument height sensor (Z) is mounted usually. Scanning movement relative to the workpiece surface, in the XY plane, is provided by the slider and by the spindle of the machine or by the transmission inside the probe measuring device. In order to construct topographic data of the surface workpiece, it is necessary to use data related to the position of the sliders and of the spindle from the machine NC controller, or directly from the output of the rotary and linear sensors of the spindle and sliders.

A significant difference can be noticed between "on-machine" and "off-machine" surface metrology by using a stand-alone surface measuring instrument. That difference is the result of the machine errors (including spindle/slide motion errors), thermal deformations, and/or vibrations. A sensor head alignment error on the machine tool is also an additional source of error. The reduction and separation of such errors from the "machine" surface measurement results, as well as related calibration and traceability issues must also be considered.

3. EXPERIMENTAL RESEARCH

The present research shows a part of the research results of the development an in -line measuring system for measuring machined surface topography and tool wear. Aluminum alloy workpiece AlMg4.5Mn (EN AW 5083) is mounted on a dynamometer "Kistler - Typ 9265A1".

Figure 5 shows measuring device positions used to measure the parameters of the topography (surface roughness) and the microscope of the camera used to measure tool wear.

Figure 5. Position of the measuring devices

The measuring device *ISR-C002 INSIZE* used to measure parameters of the surface roughness is mounted in a special bracket and attached to the main spindle carrier of the machine. In this way, it was possible to bring the measuring probe to the measuring position after milling using a predefined path in the NC code.

Figure 6 shows videos with microscope cameras and part of the measuring results of the roughness of the treated surface.

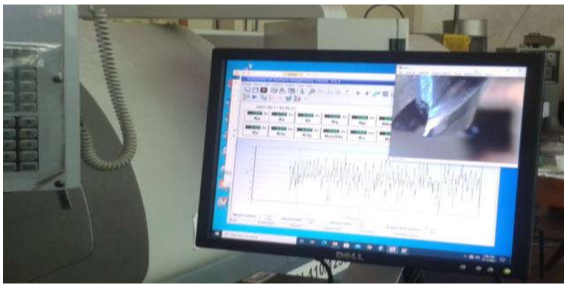

Figure 6. Video of the milling teeth and measured surface roughness

End milling cutter (10mm in diameter), HSS.E, with three teeth was used for the experiment. Aluminium processing was performed. Processing parameters were:

- milling width: 0.5 mm,

- milling depth: 10 mm,
- rpm: 1000 o/min,
- speed of the auxiliary movement: 100 mm/min,
- processing length: 100 mm.

The 10mm wide groove was made with 20 passes. The NC program was created in a way that the tool after processing is brought to a position that allows automatic placement of the probe of the roughness measuring device in a horizontal measuring position. At that moment execution of the NC program stops and waits for the adequate command to continue, fig. 7. During the program execution pause, the device for measuring surface roughness activates. By continuing to execute the NC program, the tool is automatically brought in front of the microscope camera to record the level of the cutter teeth wear.

Figure 7. Measurements of the roughness parameters after the first milling pass

Figure 8 shows the worn tooth of the used tool after the last processing pass and the removal of the deposits that occur during the machining of this aluminium alloy. The maximum width of the worn belt of the one tooth is 0.18mm.

Figure 8. A worn tooth of the tool

Table 1 shows the results of measuring the wear width of the tooth (h) and the surface roughness parameters for machining with a new and worn milling cutter.

Table 1.

	h mm	Ra µm	Rz µm	Rmax µm
1	0	1.227	7.715	9.286
2	0,18	1.662	9.821	13.557

Table 1 shows that there has been an increase in the surface roughness or that there have been deterioration in the quality of treatment with tool wear.

4. CONCLUSION

In modern industry that does not suffer from downtime, errors and time losses, it is very important to ensure the correct method of monitoring the accuracy of machining (accuracy of measurements and quality of the machined surface) and the process of wear of the cutting tool. This is especially important in large-scale and mass production, such as in the automotive industry and others. For these reasons, the development of CNC machines is accompanied by the development of various monitoring methods. Monitoring the accuracy of the machining and the wear is becoming increasingly important, so that the new machines with factory-integrated monitoring systems are emerging, such as special cameras, dynamometers, acoustic devices, etc. In this way, the possibility of downtime or damage is minimized.

This paper presents experimental research that shows that measuring systems can be installed on a CNC machine, which provides online information on the roughness of the machined surface and the wear of the tool. Further research is directed towards the development of automated systems with integrated systems for monitoring the quality of the processed surface using laser non-contact measuring systems and recognizing the level of tool wear.

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