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IMPACT OF MACHINED WORKPIECE POSITION IN WORKSPACE ON PRECISION OF MANUFACTURING USING AN ANGULAR ROBOT

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Abstract

Use of an industrial robot in the production process as a spindle carrier is currently an interesting topic. However, if the stiffness of the robot is not sufficient, various imprecisions may occur during machining. The article deals with monitoring and evaluating the impact of cutting conditions and positions of the workpiece in the working area on the machined surfaces oriented in orthogonal planes. The aim of the experiment was to analyse the precision of simple planar surfaces milled using a robot.

Key word

robot, machining, system, position

INTRODUCTION

The current trends in the machining of various materials as a part of the manufacturing process bring the need for continuous improvement of productivity, economic efficiency and quality of workpieces. Such a requirement, along with the continuous development of robotics, information systems and technologies, constantly offers new insights into not only the use of robots in the assembly, but also in the machining process. In addition to the use of robots for the purpose of workpiece handling and welding, there is an effort to engage a robot directly for machining. The current development in technical equipment leads to the need to find and explore other alternatives, different from the conventional methods, for the removal of the material, for example CNC milling. The main disadvantage of conventional CNC machines is their limited workspace and the resulting restriction in the production of components of various complex shapes. Conceptually, industrial technologies which will be able to use the robot can provide a good basis for machining that will be flexible and cost-effective. Industrial robot can meet the needs of manufacturing industries, which are now, and also will be in the future, imposed on it and which include for example costs, working time, efficiency and flexibility during the processing of materials (1).

Robots in robotised system should serve as a multi-purpose facility. They should be able to machine and, after the detachment of the spindle and automatic fitting of a gripper, to handle a machined part.

In addition to this valuable benefit, the robot should be able to cooperate with the positioner, and thereby achieve exceptional flexibility and access to the entire workpiece. At the same time, the robot should be able to machine large workpieces or a large number of smaller workpieces on the pallets placed in different positions on the table. Due to this capability, the robots could in many cases replace the large and expensive cutting machines and CNC centres. On the basis of market requirements, the companies have launched not only use of already developed types of robots with end-effectors. However, current trends suggest development of special design robots designed specifically only for machining. Various analyses have further showed that one of the additional obstacles to a greater acceptance of the robots designed for machining is not just the design of robot, but it was and still is also a general lack of knowledge of the end users when it comes to the information about the benefits of robots in machining in terms of their control (2). Based on this fact, the world's leading manufacturers of industrial robots started to provide robots with the corresponding software.

MATERIALS AND METHODS OF RESEARCH

The design of current experiment was based on the theoretical knowledge of planned experiments. The role of the experiment based on definition of the input process parameters was in monitoring and analysing the accuracy during the production of simple planar surfaces by milling. The analysed surfaces were machined by angular robot, i.e. the tool is carried by robot. The plan of the experiment was based on the condition that the workpiece is firmly positioned and fixed on a table via an adapter. Toolpath is provided by the movement of the arm of the angular robot. According to the authors (3), movements during manufacturing the general surface, as shown in Fig. 1, is affected by the cutting forces. The cutting tool deviates from its programmed toolpath. The amount of deviations is affected by the cutting forces that are generated during the machining process. The forces are further transmitted to the robot frame (free-play in the joints, stiffness of the whole structure, etc.).

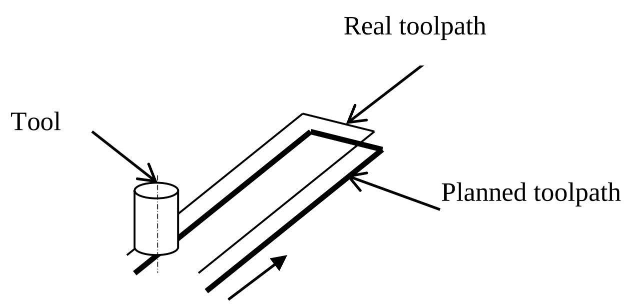

Fig. 1 *Toolpath scheme (3)*

The aim of the experiment, based on the observation and measurement of selected parameters, was to monitor the impact of the workpiece position on the table on the achievable precision of machined surfaces and determination of measured inaccuracies rising from a load of the robot according to the surface of the machined part.

The following input parameters were defined for the planned experiment:
- Rotational speed *n*,
- Cutting depth a_p,
- Feed rate of the cutting tool clamped at the end of the robot arm v_r,
- Machined surface of the component,
- Distribution of monitored workpieces at different locations on the table (Fig. 2).

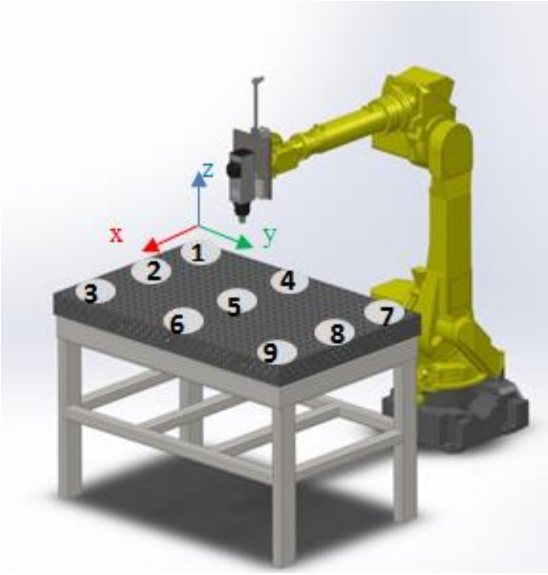

Fig. 2 *Model of position distribution on table*

The aim of the experiment was to create maps of precision of the table for a defined speed of the arm as a tool carrier. The map will be a graphical representation of achieved accuracies depending on the position of workpieces on the table and the plane with corresponding machined surface with respect to the robot coordinate system for two types of materials.

Experimental samples were cuboidal in shape with square cross-section and characteristic dimensions of 50x50 mm and height of 85 mm. The material of workpieces used in the experiment was ERTACETAL-C (POM-C) and AA2024 alumina alloy.

The aim of the experiment was to monitor machined surfaces in three orthogonal planes for the same technological parameters with a tool attached to the spindle at the end of the angular robot arm.

The conditions of the experiment:
- Rotational speed *n*, n = 10 000 rpm^{-1},
- Cutting depth a_p, ap = 0.5 mm,
- Feed rate of the tool attached to the robot arm in different planes v_r, v_{r10} = 10 $mm.s^{-1}$,
- Distribution of sample positions on the table (Fig. 3).

Surface area of the workpiece was machined by a milling tool with diameter d = 8 mm and label 512XL080Z2 SIRON-A of the Secco Company. The priority task of the robotic workstation which was used in the experiments is laser welding. Exchange of the end-effector on the arm allowed the robot to be used for sample machining. High-speed motor C41-47 of Teknomotor was used as a spindle for machining with an industrial robot of Fanuc M-710iC / 50.

As the tool is carried by robot, toolpath is defined by the movements of the robot arm. Its positioning was defined by the method of online programming in each of the planes defined in the coordinate system of the "World" robot. Path of the tool clamped at the end of the robot arm was programmed by consecutive definition of all tool targets. The program was developed successively for the three perpendicular planes *x-y*, *x-z*, *y-z* (Fig. 2, Fig. 3).

We began with the assumption that the guaranteed positioning accuracy is the same for all planes in the coordinate system of the robot as declared by the manufacturer of robots. Regarding this fact, only single-plane machining was executed on each sample (Fig. 3), while neglecting other symmetrical planes. The planes defined for milling are shown in Fig. 3.

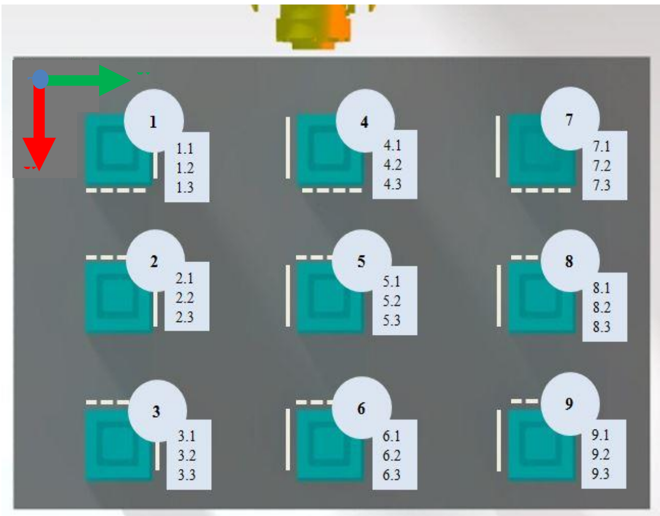

Fig. 3 *Identification of sample and plane distribution on the table for planned experiment*

In each plane (*x-y*, *x-z*, *y-z*), the feed rate of machined surfaces v_{r10} = 10 mm.s^{-1} was defined in the program of the robot. Tool axis was always oriented perpendicular to the work surface. Toolpath overlay of two opposite directions was 1 mm.

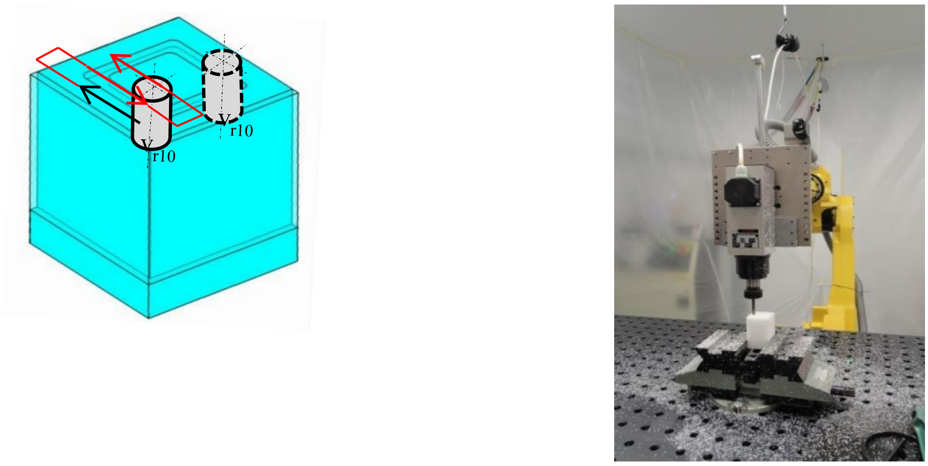

Fig. 4 *Scheme of toolpath in x-y plane, manufacturing of x-y plane*

The movement of the tool in the *x-y* (Fig. 4), *x-z*, *y-z* plane was defined in the program for speed of the arm with the tool as shown in Fig. 5, Fig. 6 and Fig. 7. Successive definition of target positions defined the entire toolpath.

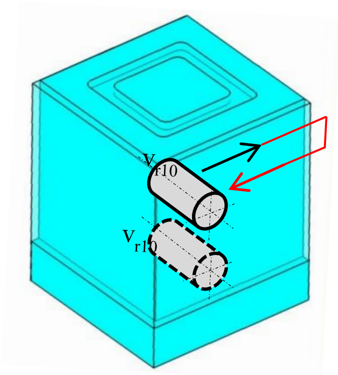

Fig. 5 *Scheme of toolpath in X-Z plane*

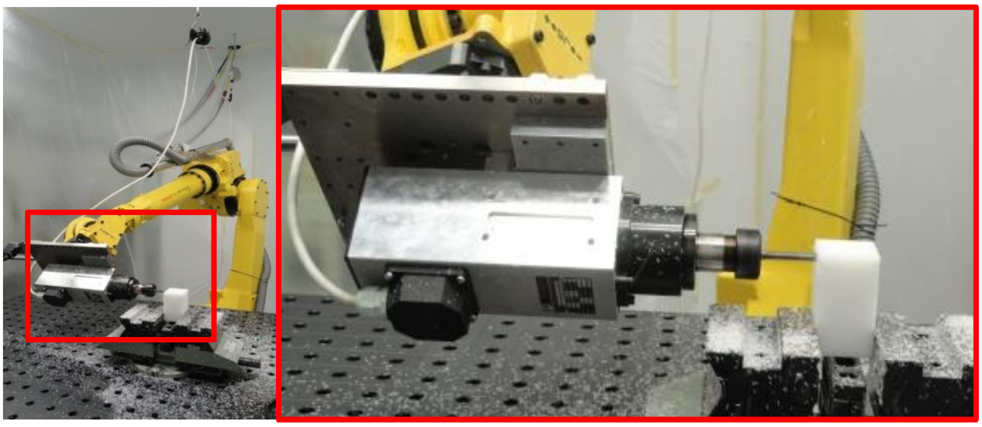

Fig. 6 *Image of the Y-Z plane production*

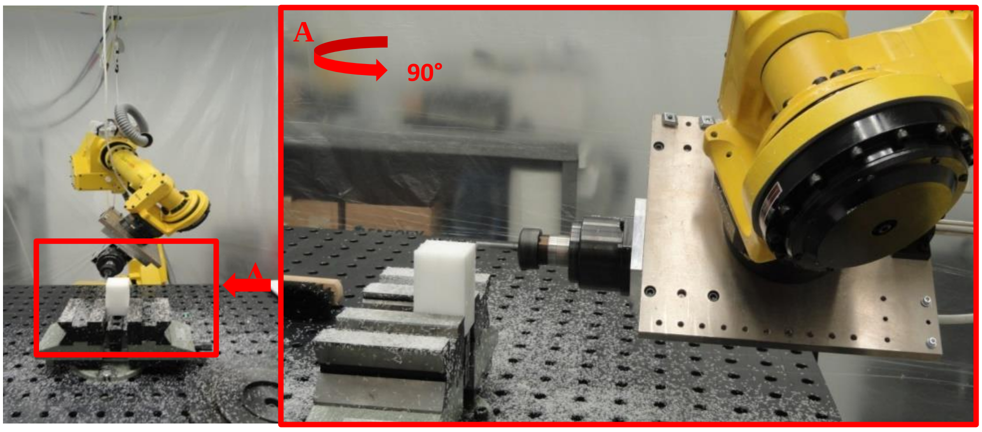

Fig. 7 *Image of the X-Z plane production*

MEASURED AND EVALUATED VALUES

In terms of applications of each of the machining equipment, it is important to monitor and define the required degree of accuracy for simple as well as complex machined surfaces. It follows that it is important to what degree of accuracy a component can be produced using monitored robotized workplace. On the basis of the partial measured and evaluated values, the table map of robotic workstation was developed. The table map includes the division of the table to the areas. Based on literature data (4), the average surface roughness values Ra of each area were assigned with the degree of accuracy that can be achieved. Fig. 8 shows a precision map of flat work table of robotized workplace for Ertacetal-C material for feed speed v_{r10} without taking into account the partial contributions of individual planes. The graph shows that with technological parameters which were defined and the feed rate v_{r10} = 10 mm.s^{-1} of robot arm motion, in which the tool is clamped, it is possible to produce parts in the precision grades from IT7 to IT10.

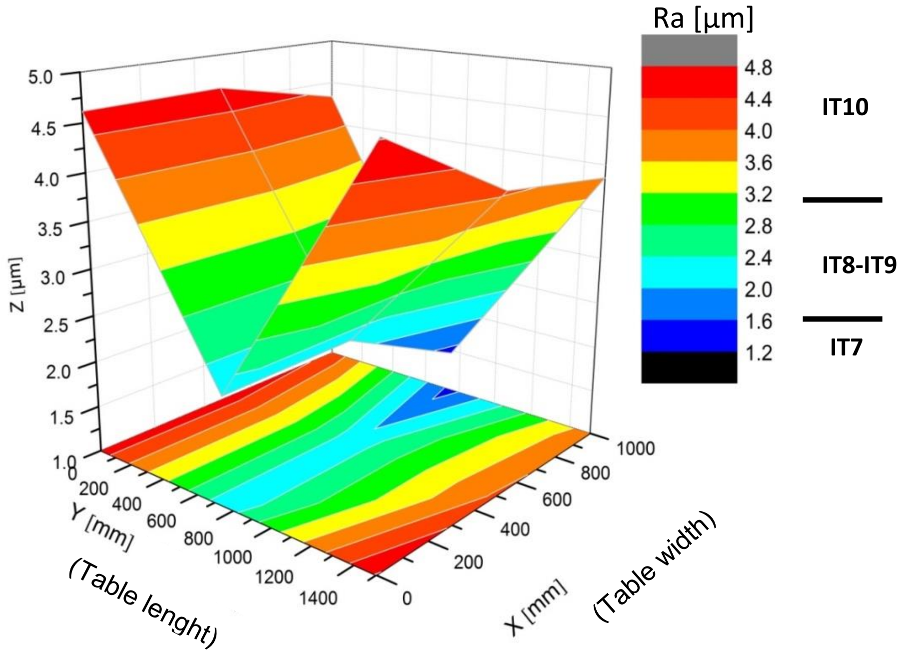

Fig. 8 *Map of the working table with defined precision grades for feed rate* v_{r10} *and Ertacetal-C material*

In a similar manner, all the experimental data obtained after machining the AA2024 alloy workpieces were analysed and evaluated. The average values of surface roughness Ra corresponding to positions on working table 1-9 were evaluated in the form of a graphical map of the working table of the robotic workstation. Graphical map for AA2024 alloy and speed VR10 is shown in Fig. 9.

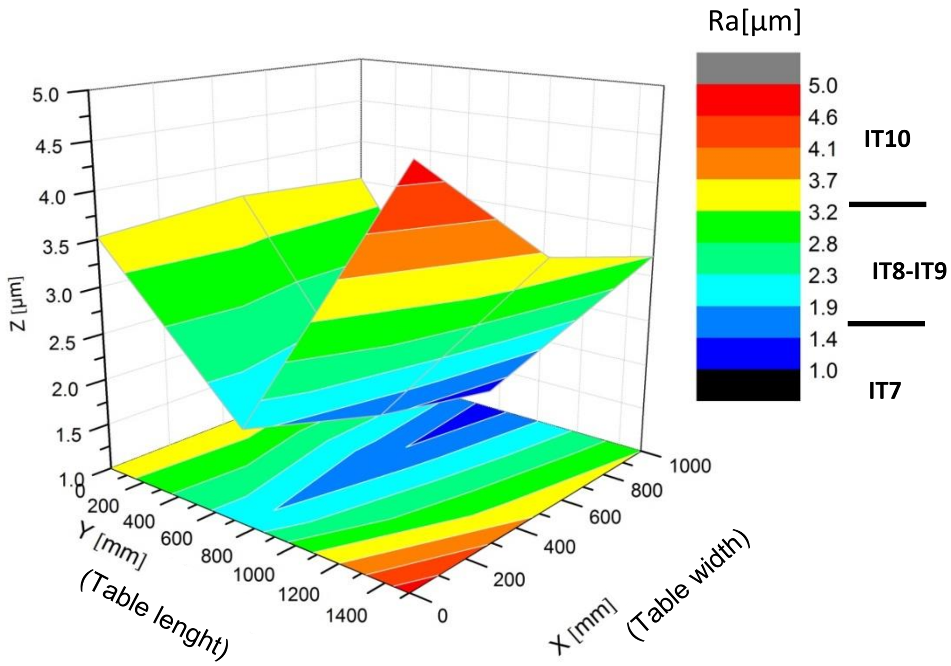

Fig. 9 *Graphical map of table with assigned precision grades for* v_{r10} *and AA2024 material*

The surface quality of machined planes is, however, strongly influenced by the fact that the machining takes place while robot arm is moving in the direction outwards or towards the robot base, making the macroscopic steps between toolpaths on the machined surface at the constant processing parameters.

It is possible to conclude that the experiment of machining of three orthogonal surfaces oriented in x-y, x-z and y-z planes shows that the robot is able to manufacture surfaces within predefined precision grades aand taking into account all process parameters. When machining the Ertacetal - C material and the AA2024 material at the feed rate of movement of the robot arm VR10, the precision grade from IT7 to IT10 can be achieved depending on the position of the workpiece on the table and the resulting arrangement of the robot joints.

CONCLUSIONS

Machining by industrial robots has a capability to improve the efficiency of machining operations. Today, however, there is still non-standard utilization of industrial robots in manufacturing facilities. Their high degree of flexibility and wider ranges for defining a workspace can overcome conventional cutting machines. Having more degrees of freedom, they may also be used for more machining operations. Another advantage of using robots in the field of machining is that they offer the possibility of dual use. Robot arms may either carry the spindle with cutting tool or workpiece clamped in the end-effector of the robot in conjunction with an extended range of the external device. Robots, however, have also disadvantages compared to the machining by CNC machines, especially in terms of accuracy, repeatability and handling during the machining process. The main disadvantages of robots are currently being compensated via the development of advanced simulation techniques and intelligent programming software.

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