INFLUENCE OF COMPONENT POSITION ON THE TABLE DURING ANGULAR ROBOT MACHINING ON ACCURACY IN AUTOMATED SYSTEMS

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Abstract: *Use of an industrial robot in the automatic 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 evaluation of the impact of cutting conditions and positions of the workpiece in the working area on machined surfaces oriented in orthogonal planes. The aim of the experiment is to analyse the precision of simple planar surfaces milled using a robot.*

Keywords: SYSTEM, POSITION, ANGULAR ROBOT, MACHINING

1. Introduction

The current trends in the machining of various materials as a part of the automatization 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 disadvantage of conventional CNC machines is their limited workspace and the resulting restriction in the production of components of various complex shapes. 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 (Pires, J. N.).

Robots in automatized 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 flexibility and access to the entire workpiece.

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 (www.robotics.org). Based on this fact, the world's leading manufacturers of industrial robots started to provide robots with the corresponding software.

2. 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 (Rong-Shine, L.), 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.).

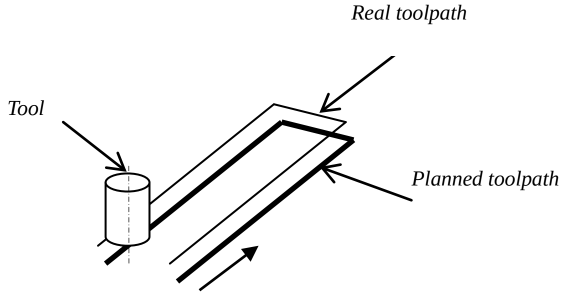


Fig. 1 *Toolpath scheme* (Rong-Shine, L.)

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 ap,
- Feed rate of the cutting tool clamped at the end of the robot arm vr,
- Machined surface of the component,
- Distribution of monitored workpieces at different locations on the table (Fig. 2).

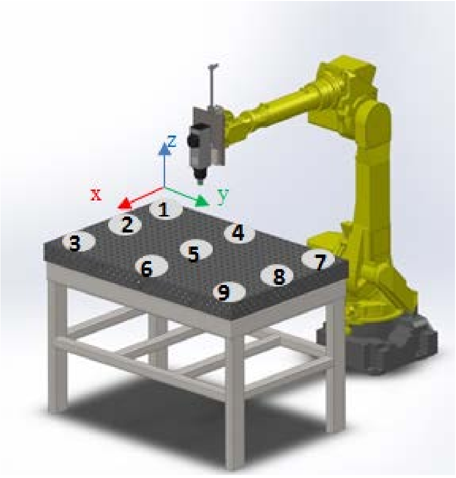


Fig. 2 *Model of position distribution on table.*

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, a_p = 0,5 mm,
- Feed rate of the tool attached to the robot arm in different planes v_r, v_{r20}= 20 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.

3.1 Robot Fanuc M-710iC/50

The main purpose of the robotized workplace development is to take into account the requirements for such a specific type of equipment. The Fanuc M-710iC / 50 Robot is capable of carrying 50 kg of load and is suitable for large workpieces such as glass sheets and steel panels. In its class, it has the highest speed of movement in individual axes, which makes it possible to handle larger and heavier workpieces and thus reach the pallets. Due to its high mechanical rigidity, it is appropriate to use this type of robot for applications requiring constant forces (eg polishing, machining, deburring) and for process applications (eg arc welding, spot welding, laser welding, gluing, handling, cleaning of components...). Its installation in the working process is possible on the floor or on the ceiling, allowing for easier access to the serviced equipment and, of course, the maximum utilization of the robot workspace. The air and electric lines to the J3 and J1 axes and their interconnection are standardly integrated, providing a short connection to the tool and increasing cabling reliability. By being installed from the factory, its reliability is also checked. There are no electrical components on the wrist of the robot as all wrist movement motors are mounted on the J3 arm. This position reduces the risk of wrist motor damage due to high temperatures or the working environment. Another advantage is the compact design that allows access to narrow spaces, and last but not least, such storage affects the quality of engine cooling by air, allowing for high load and high number of duty cycles. The used robot has the option of turning the J3 axis, which shortens the cycle time, and allows the flexibility of the working cell. Its working space is not limited by the robot's mechanical unit (Fanuc Robotics).

4.2 High-speed motor C41-47

The high-speed C 41-47 engine from Teknomotor (Fig. 3) was designed for the experiment. The rotation speed of this engine is from 7000 to 18000 rpm, with the prevailing radial load.

The motors of this series are designed for the highest performance, with the smallest dimensions. For these properties and high speeds, they are especially suitable for wood, aluminum, PVC.(OPISEngineering k.s.)

Fig. 3 *The high speed motor and its clamping mechanism*

2.3 Methods of research

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.

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. 4), while neglecting other symmetrical planes. The planes defined for milling are shown in Fig. 4.

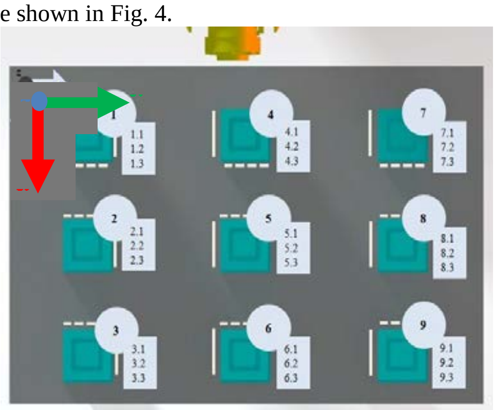


Fig. 4 *Identification of sample and plane distribution on the table for planned experiment*

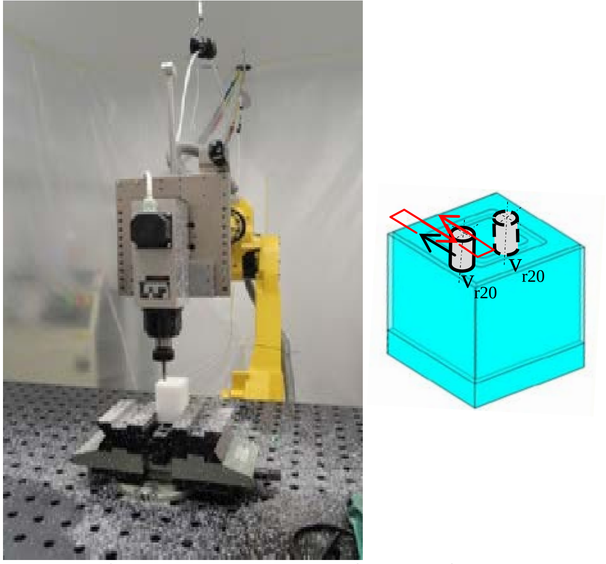
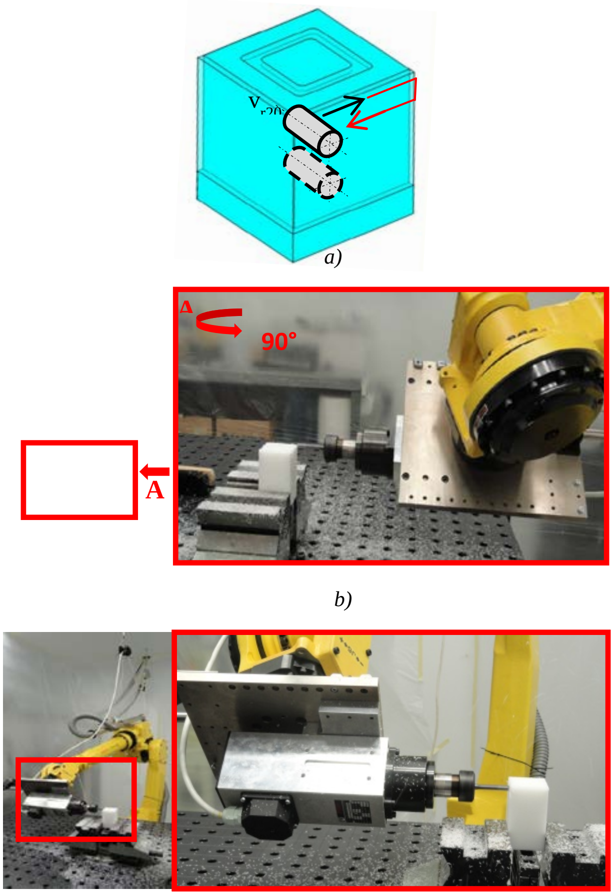


Fig. 5 *Scheme of toolpath in x-y plane, manufacturing of x-y plane*

In each plane (*x-y*, *x-z*, *y-z*), the feed rate of machined surfaces v_{r20}= 20 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.

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



a)

b)

c)

Fig. 6 *a) Scheme of toolpath in X-Z plane*
b) Image of the X-Z plan production, c) Image of the Y-Z plane production

3. Measured and evaluated values

A machining experiment using a tool carried and led by a robot arm was used to machine in total 52 separate samples made of two different materials. Samples were containing in case of each material a total of 81 machined surfaces divided into three groups according to the plane orientation relative to the robot coordinate system: x-y, x-z, and y-z on Ertacetal-C and alloy AA2024. The roughness of the Ra surfaces in the x-y, x-z and y-z planes was evaluated on the produced surfaces.

3.1 Characterization of measurement procedures and instruments – surface roughness measurement

Measurement of surface roughness on observed machined surfaces was performed using a Surtronic 3+ roughness meter from fy. Taylor Hobson (Fig. 7). Roughness meter Surtronic 3+ combines advanced measurement technology with high precision to get effective measurement of different surfaces, whether in the workshop or in the laboratory.

The roughness meter output is available from the built-in LCD display. Operation of this roughness meter is very simple, and when measuring, the advantage is that the measurement cycles are short. Control of the roughness meter is through the keypad membrane located on its panel. The instrument can be used to measure surface roughness for horizontal, vertical or even oblique surfaces. Roughness meter Surtronic 3+ is particularly suitable for measuring surfaces in holes and in inaccessible areas where conventional measuring instruments cannot be used. (Zimmerman)

Fig. 7 *Surface roughness measurement using roughness meter Surtronic3+*

3.2 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 (Medvecký, Š. et al.), 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_{r20} 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_{r20}= 20 mm.s^{-1} of robot arm motion, in which the tool is clamped, it is possible to produce parts in the precision grades from IT8 to IT10. After processing the measured values and their evaluation it was found out that the most suitable position for machining the Ertacetal-C material appears to be position no. 6. This is the most distant point in the center line of the table. The disadvantage of this position is that the robot end effector does not reach the component in the y-z plane averted from the robot.

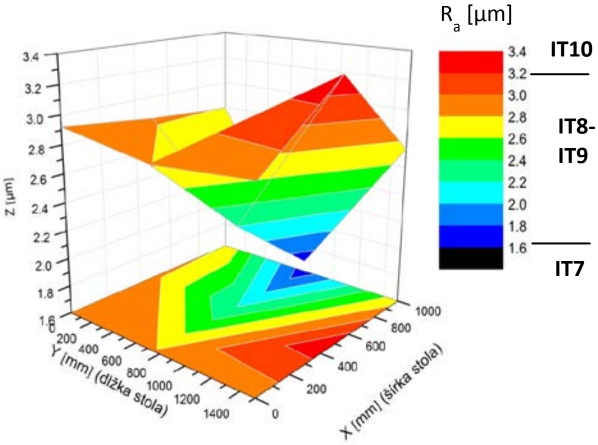


Fig. 8 *Graphical map of table with assigned precision grades for* v_{r20} *and Ertacetal-C material*

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 v_{r20} is shown in Fig. 9.

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.

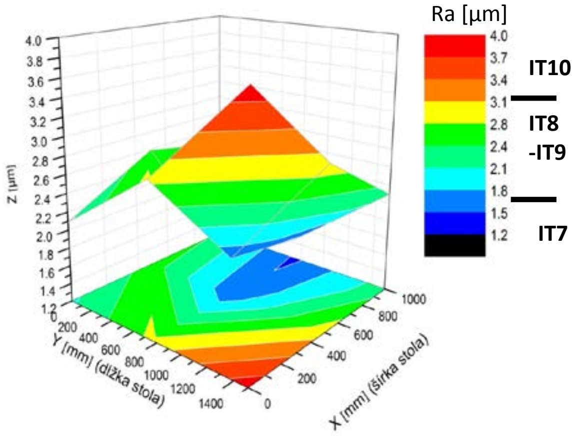


Fig. 9 *Graphical map of table with assigned precision grades for* v_{r20} *and AA2024 material*

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 and 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 v_{r20}, 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.

The experiment has shown that achieving the highest degree of precision on a machined part is related to the specific position on the work table and hence the resulting configuration of the robot joints.

4. 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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