Machining operations using Yamaha YK 400 robot

A Pop¹, A Pop¹, D Savu¹ and V Dolga¹
¹Mechanical Engineering, Mechatronics and Robotics Department, Universitatea Politehnica Timisoara, Romania
E-mail: nask_pop@yahoo.com

Abstract. This paper addresses the topic of industrial robots built for handling processes used in cutting machining applications. The study discourses the machining of a globe calotte made of komatex using a Yamaha YK 400 SCARA robot. Are presented aspects regarding the capabilities of Yamaha YK 400 robot, the development of the robot program, analyses of the proposed system and methods of improvement. A set of experimental analyses was conducted in order to identify correlations between the robot speed variation and distance between the points that describe the trajectory of the motion.

1. Introduction
Industrial robots have become tempting for industry, with the advent of the need to increase efficiency and flexibility in production processes [1]. Among the benefits of using industrial robots, we can include: increasing productivity and product quality while the costs are reduced, quantities of materials used and space consumption [2]. Today, the main operations carried out using industrial robots are: Handling (38%), welding (29%), the assembly (10%), dispensing (4%) and only 2% processing processes [3].

The first research on the use of industrial robots in machining processes have emerged since 1990, but the potential use of robots in this direction has not yet been reached [4]. Kalpakjian & Scmid (2006), states that manual deburring operations can increase with 10% the cost of production. In manual grinding, in general, working conditions are difficult. Workers must wear protective equipment (goggles, gloves and guards sonic) [5]. The scientific literature addresses the problems presented in various aspects, [6], [7], [8], [9]. The paper is structured in five parts: The first section Introduction presents notions regarding the milling process. The second section, milling applications using Yamaha YK 400 robot, describe the experiments and presents the experimental stand. The third sections, analyzes further programming possibilities and execution of movements in the robot workspace. The fourth section, highlights the dependence between the number of points that describe the trajectory and the speed of the characteristic point. The fifth section describe the working procedure. In the sixth section conclusions and main observations are emphasized. In the end of the paper the references are presented.

2. Milling applications using Yamaha YK 400 robot
To demonstrate the possibility of using Yamaha YK400 robot in applications of milling the following steps are taken:
2.1 Description of the experiment
Milling is the operation of removal of the material as swarf, using the multi-point cutting tools of various shapes to create smooth surfaces or profiles on a piece of regular or irregular section [10]. To obtain spherical calotte through the milling process using robot Yamana YK400, was performed the simulation and implementation of simple path proposed in order to demonstrate the possibility of creating complex surfaces. Generating spherical surface with a diameter of 50 mm and height 15 mm, it was carried out by successive passages at the different planes in the form of a circle according to figure 1. The advance between the milling plans was 0.1 mm. In order to obtain the part 150 successive passages were performed. Position the start point for each layer incremented the value corresponding to circular arc.

![Figure 1. Generation of surface in layers.](image)

In order to achieve spherical cap, the angular velocity of the cutter finger was set at 23,500 rev / min, with an advance of $S = 5$. Feed speed of the robot can vary, depending on the number of points that describe the work of the cutter path.

With the increasing complexity of the part, increase the number of terms that describe the trajectory of motion. In order to analyze the feed rate variation depending on the number of points that describe the trajectory was designed a test.

2.2 Description of experimental stand
To achieve the proposed objectives, YK400 Yamaha robot was integrated into a milling experiment. Experimental stand is shown in figure 1. The experiment was performed in the laboratory of sensors and transducers of the Faculty of Mechanical Engineering of the Polytechnic University of Timisoara.

![Figure 2. Experimental stand.](image)

The experimental stand consists of:
- milling machine LUND 79 314, with the possibility to change the speed in steps;
YAMAHA YK400 robot
- Yamaha robot controller
- Processed material (Komatex)
- Worktable

Milling robot assembly, was equipped with a Dremel mill cutter,

Figure 3. Dremel cutter [11].

3. Simulation and development of trajectories with Yamaha YK400

Were analyzed further programming possibilities execution of movements in the robot workspace for Yamaha YK 400. The analysis is based on availability hardware and software system studied. Yamaha YK400 robot software can define points in coordinate polar and Cartesian coordinates.

In figure 4, is the Yamaha YK 400 robot working scene, executing a path made up of line segments between points P1, P2 and P3., figure 5 illustrates a detail of the robot during movement executed.

Figure 4. Graphical representation of movement.  
Figure 5. Working robot scene.

Complex movements of the robot in the workspace can be decomposed into simple movements: straight line and circle. In order to analyze the way to generate movements, eight tests were conducted. In these tests, the robot characteristic points describe simple geometric trajectories, with different speeds and the points were defined in cartesian and polar coordinates. In order to view the path described by the characteristic points of the robot in the workspace to the end effector was fixed a pen (figure 5). With it the trajectories described in the eight tests were mapped.

During the 8 tests it was observed that the trajectory described by the prescribed target points, and interpolation between two successive points.

Table 1 box "b" is shown how the prescription of points target for the two cases mentioned above. Table 1 box "a" present the trajectories described mentioned above of the robot in the workspace between P1 and P2. Table 1 displays the path described by the robot characteristic point in the workspace between P1 and P2 in two cases (tests 1 and 2).

- Table 1. box "a" illustrates the trajectory of characteristic point made in response to command motion in a straight line between two points P1 and P2 (box "b").
- Movement representation, between points P1 and P2 in point to point mode, is illustrated in the "c" box based on motion control box "d".

Table 1

| Case | Trajectory Description |
|------|------------------------|
| a    | Characteristic point   |
| b    | Command motion         |
Table 1. Trajectories definition and execution.

In order to analyze how to make circle-shaped trajectory was developed tests 3 and 4 (table 2)
- In T_CER_C program (table 2 box "b") P1, P2, P3 and P4 have been defined in Cartesian coordinates. The described route between these points is presented in Table 2. box "a")
- T_CER_P program (table 2 box "d") defines P1, P2, P3 and P4 in polar coordinates. The image of the block "c") table 2 illustrates the typical path followed by the point in this case.

Table 2. Path described by the characteristic point.

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- T_CER_P program (table 2 box "d") defines P1, P2, P3 and P4 in polar coordinates. The image of the block "c") table 2 illustrates the typical path followed by the point in this case.
Table 3. The path described by the characteristic point.

Table 3 summarizes the cases analyzed in tests 5-8. The tests aimed to show how a trajectory between 3 points is generated, at two different speeds.

- The image in the box "a" illustrates the trajectory of characteristic points in response to command motion in a straight line between the three points with a speed of 60% (box "b")
- The image in the box "c" illustrates the described route between points P1, P2 and P3 by minutiae, point to point mode with a speed of 60% (box "d")

```
T_TRI_C
P1= 400.00 0.00 70.00 0.00 0.00 0.00
P2= 345.00 23.00 70.00 0.00 0.00 0.00
P3= 352.00 82.00 70.00 0.00 0.00 0.00
P0= 400.00 0.00 0.00 0.00 0.00 0.00
MOVE L,P1, S=20
MOVE L,P2, S=60
MOVE L,P3, S=60
MOVE L,P1, S=60
MOVE P,P4, S=20
HALT
```

```
T_TRP_C
P1= 400.00 0.00 70.00 0.00 0.00 0.00
P2= 345.00 23.00 70.00 0.00 0.00 0.00
P3= 352.00 82.00 70.00 0.00 0.00 0.00
P0= 400.00 0.00 0.00 0.00 0.00 0.00
MOVE P,P1, S=20
MOVE P,P2, S=60
MOVE P,P3, S=60
MOVE P,P1, S=60
MOVE P,P4, S=20
HALT
```

```
T_TRV_C
P1= 400.00 0.00 70.00 0.00 0.00 0.00
P2= 345.00 23.00 70.00 0.00 0.00 0.00
P3= 352.00 82.00 70.00 0.00 0.00 0.00
P0= 400.00 0.00 0.00 0.00 0.00 0.00
MOVE L,P1, S=20
MOVE L,P2, S=10
MOVE L,P3, S=10
MOVE L,P1, S=10
MOVE P,P4, S=20
HALT
```

```
T_TPV_C
P1= 400.00 0.00 70.00 0.00 0.00 0.00
P2= 345.00 23.00 70.00 0.00 0.00 0.00
P3= 352.00 82.00 70.00 0.00 0.00 0.00
P0= 400.00 0.00 0.00 0.00 0.00 0.00
MOVE P,P1, S=20
MOVE P,P2, S=10
MOVE P,P3, S=10
MOVE P,P1, S=10
MOVE P,P4, S=20
HALT
```
• The image in the box "d" illustrate the path described by the minutiae response to command motion in a straight line between the three points with a speed of 10% (box "f")
• The image from the 'g' box illustrates the described route between points P1, P2 and P3 of the characteristic point in the point to point mode at a rate of 60% (box "h").

4. Determination of travel speed variation
In order to determine the speed variation of the characteristic point of the robot in the workspace based on the number of points that describe a trajectory an experiment was conducted:

Characteristic point of the robot describes a straight line in space with a length of 330 mm. The first test is described the straight line by a total of 330 points with 1 mm distance between them, for the second test the straight line was generated by a total of 660 points with 0.5 mm distance between them. The third test used was 6600 points with a distance between them of 0.1 to describe the straight line.

In table 4 are presented the time and speed that characterize the characteristic point into space. Points were generated using Excel software and loaded into the robot controller.

| Table 4. The travel speed. |
| Drive speed depending on the number of points |
| Number of points | Distance [mm] | Distance between two points [mm] | Time [s] | Speed [mm/s] |
|------------------|---------------|-------------------------------|---------|--------------|
| 330              | 330           | 1                             | 41,00   | 7,99         |
| 660              | 330           | 0,5                           | 66,10   | 4,98         |
| 6600             | 330           | 0,1                           | 194,00  | 1,7          |

Figure 6. Speed movements/ number of points.

Figure 6 highlights the dependence between the number of points and the distance between points that describe the trajectory and speed of the characteristic point.

5. Making a spherical shape with Yamaha YK400 robot
As a continuation of the previous analysis and as a materialization of research carried out are examples of machining using robot YK Yamaha 400.
Selected for example, from the tests, it relates to the processing of a spherical cap of a blank Komatex. As the robot end-effector was used a cutter LUND 79 314.

Figure 7 shows the logical structure that led to the writing of the "CALOTA" in the working environment of the robot Yamaha YK 400.

![Logical structure of the program "CALOTA".](image)

In the first part of the program are defined geometric parameters that define spherical cap, followed by defining the start point in the workspace of the robot. Machining module aimed flowchart specified and materialized by:

- Description of first circle through the points specified in the program;
- Increment the X, Y, Z, the equation of the circle and 0.2 mm increments with each circle described to create the new plan;
- It runs until completion incrementing the number of repetitions;
- If you are satisfied number of repetitions for creating the plan goes forward unless it returns to its current position;
• If the number of repetitions are not met to create the sphere returns in the current position;
• If are satisfied number of passes to achieve the program stops sphere.

During milling process were observed the following:
• The program runs without deviation from the predetermined path;
• The program runs without deviation from the predetermined path;
• The program runs successfully.

```
L=1
L=INCREMENTUL PE Z
Q=5
'O INALTIMEA CALOTEI
DIFERITA DE RAZA
K=10
'INCREMENTUL PE
CERCURILE PLANE
'A VANS PE Z IN FORMULA
'I NCREMENTUL PE X SI Y
R=10
'R AZA SFEREI
P405=227.50 0.00 20.00 0.00
0.00 0.00 0
P406=230.00 2.50 20.00 0.00
0.00 0.00 0
P407=232.50 0.00 20.00 0.00
0.00 0.00 0
P408=230.00 -2.50 20.00 0.00
0.00 0.00 0
P401=P403
P402=P406
P403=P407
P404=P408
MOVE P,P401,Z=0
MOVE C,P402,P403,P404,P401,S=5
FOR J=1 TO 8
GOSUB *CERC
NEXT J
FOR N=1 TO 150
GOSUB *ARC
NEXT N
*ARC:
LOCZ(P404)=LOCZ(P405)+N*
0.1
LOCX(P404)=LOCX(P405)-
SQR(50*2-(50-N*0.1)^2)
FOR I=1 TO 8
GOSUB *CERC
NEXT 1
RETURN
*CERC:
LOCX(P401)=LOCX(P401)-1
MOVE L,P401,S=5
LOCY(P402)=LOCY(P402)+1
LOCX(P403)=LOCX(P403)+1
LOCY(P404)=LOCY(P404)+1
MOVE C,P402,P403,P404,P401,S=5
LOCX(P401)=LOCX(P401)-1
LOCX(P402)=LOCX(P402)-1
LOCX(P403)=LOCX(P403)-1
LOCX(P404)=LOCX(P404)-1
MOVE C,P402,P403,P404,P401,S=5
LOCX(P401)=LOCX(P401)-1
LOCX(P402)=LOCX(P402)-1
LOCX(P403)=LOCX(P403)-1
LOCX(P404)=LOCX(P404)-1
RETURN
HALT
```

**Figure 8.** The program code "CALOTA".

**Figure 9.** Image during the milling process of the sphere.

### 6. Conclusions

The use of industrial robots SCARA model presents multiple advantages for use in machining applications. The integration of such robotic equipment must comply with the scope and subject to a set of multiple trials and expanded over time.

It has confirmed the possibility of the use made robot YK Yamaha 400, the cutting machining operations. The main constraints are determined by: the programming language model of the robot controller RCX 240 industrial and limitations of SCARA robots workspace.

After analyzing machined parts we can say that the resulting surfaces are of good quality.
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