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THE FLEXIBLE MANUFACTURING CELL SERVED BY THE TRTTRR1 ROBOT

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Abstract: *In this paper the authors presents a study for the configuration of a flexible manufacturing cell version. Firstly, are determine the working cycles of the robot. Secondly, is determined the final positions of the flange for each working phase using the relations resulted in [1].*

Finally, having all this dates it can be configured the version of manufacturing cell given the fact that the flange axis of symmetry must coincide successively with the axes of symmetry of the clamping jaws of the machine tools, respectively with the axis of symmetry of the back devices.

Key words: *manufacturing cell, machine tools, final position, axis of symmetry, coordinate points, parameters.*

1. INTRODUCTION

According to [2], [3] and [4], the study made on the initial and final positions of the flange that will be processed in the robotic flexible manufacturing cell is very complex.

This flexible cell will be designed after the calculations elaborated in [1] and by imposing the constructive and kinematic parameters of the robot.

The part that will be processed in the proposed cell is a flange, of the type shown in figure 1. Its dimensions according to STAS 2119-75, are:

$d_1 = 200$ mm, $d_2 = 160$ mm,
$d_3 = 18$ mm, $d_4 = 116$ mm, $d_5 = 80$ mm,
$b = 24$ mm, $h = 100$ mm, $s_1 = 18$ mm,
$n = 8$ mouting holes.

As the flange to be processed, in the paper [1], calculations were made about the dependency relations that exist between the initial and final positions of the flange.

Thus, we chose the initial positions flange resulting in figure 2 and are represented by points $M(1)_6$, $M(2)_6$, $M(3)_6$, according to [4], [5] and [6].

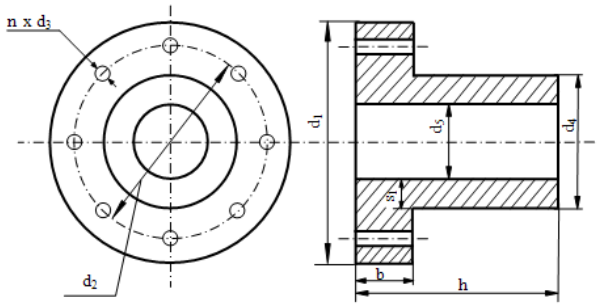

Fig. 1. The flange from cast steel

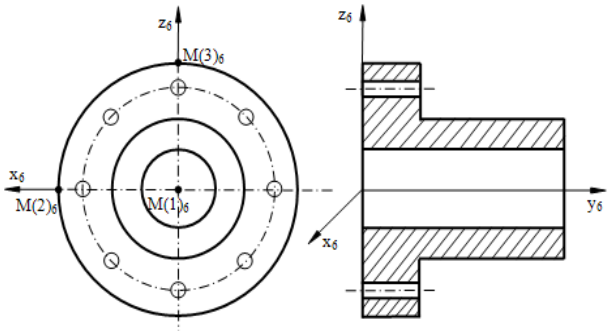

Fig. 2. The initial position of the flange

These points are recorded to system 6 which is jointly with the clamping device. The position of these points will be defined by the initial position of the flange, followed by calculation to determine the final position.

It's required that the characteristic point to be on the symmetry axis of the flange manipulated by the robot.

Finally, the clamping jaws axis of the machine tools coincides with C_6y_6 axis in the final position.

To configure a version of manufacturing cell is necessary firstly to establish a working cycle of the robot TRTTRR1 and secondly to apply the calculation algorithm presented in paragraph 5.4, according to [1], requiring constructive and kinematic parameters of robot.

2. THE FLEXIBLE CELL VERSION HAVING AS MAIN OPERATOR THE TRTTRR1 ROBOT

In the following is presented the robot TRTTRR1 working cycle in a flexible cell with the machine tools for the same operation on either side of the robot, according to [3], [7], [8]. The cycle route made by the robot so that the flange to be processed, is divided into phases. There are 20 stages to go in this flexible cell, followed by determining the final positions of the flange, it's possible to locate the machinery tools in the cell.

The working cycle is as follows:

1. The TRTTRR1 robot takes the first flange from the conveyor and put in the first clamping jaws of the CNC lathe. Corresponding to this phase of the working cycle of the robot, the following constructive and geometric-kinematics parameters are necessary: $l_0 = 500$ mm; $l_1 = 200$ mm; $l_2 = 300$ mm; $l_3 = 300$ mm; $l_4 = 200$ mm; $l_5 = 400$ mm; $l_6 = 300$ mm; $l_7 = 300$ mm; $l_8 = 80$ mm; $\varphi_2 = 180^o$; $\varphi_4 = 0^o$; $\varphi_5 = 90^o$; $q_1 = 0$ mm; $q_2 = -90^o$; $q_3 = 250$ mm; $q_4 = 400$ mm; $q_5 = 90^o$; $q_6 = 0^o$. (1)

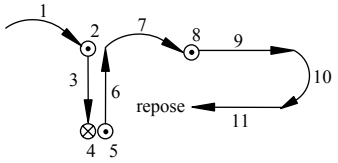

Fig. 3. Working cycle: I phase

The working cycle of the robot in the first phase is presented in the figure 3.

According to the relations from [1], the numerical data from the relation (1) and the characteristic points which defines the initial positions from the reference system 7,

$$M(1)_7=(0,0,0),\quad M(2)_7=(100,0,0),\quad M(3)_7=(0,0,100), \qquad (2)$$

the flange reaches to the final position registered to the fixed system at the base of the robot.

The final position points of the flange were determined using the program Matlab 7.1, according to [7], [9] and [10]. After the calculations of the coordinates $x_2(i)_0$, $y_2(i)_0$, $z_2(i)_0$, (i = 1, 2, 3), the final position have the following values:

$$x_2(1)_0 = -1300{,}98 \text{ mm};\ y_2(1)_0 = 500{,}1 \text{ mm};\ z_2(1)_0 = 1050{,}11 \text{ mm};\ i=1,$$
$$x_2(2)_0 = -1299{,}98 \text{ mm};\ y_2(2)_0 = 500{,}1 \text{ mm};\ z_2(2)_0 = 1050{,}11 \text{ mm};\ i=2,$$
$$x_2(3)_0 = -1197{,}5 \text{ mm};\ y_2(3)_0 = 602{,}14 \text{ mm};\ z_2(3)_0 = 950{,}76 \text{ mm};\ i=3. \qquad (3)$$

After the introduction of the flange in the clamping jaw of the CNC lathe, the robot with draws in waiting position or perform other manipulations in the cell.

2. The robot takes the second flange from the conveyor and puts in the second CNC lathe to achieve the same processing operation as the first lathe. The constructive and geometric-kinematic parameters corresponding to the second phase are:

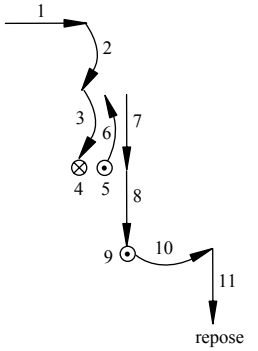

Fig. 4. Working cycle: phase II

$l_0 = 500$ mm; $l_1 = 200$ mm; $l_2 = 300$ mm; $l_3 = 300$ mm; $l_4 = 200$ mm; $l_5 = 400$ mm; $l_6 = 300$ mm; $l_7 = 300$ mm; $l_8 = 80$ mm; $\varphi_2 = 180^o$; $\varphi_4 = 0^o$; $\varphi_5 = 90^o$; $q_1 = 0$ mm; $q_2 = -90^o$; $q_3 = 250$ mm; $q_4 = 400$ mm; $q_5 = 90^o$; $q_6 = 0^o$. (4)

Having defined the initial position of the characteristic points by the relation (2), whose coordinates are the same throughout the working cycle of the robot, are obtained, according to relations (4) and [1], the final

position coordinates corresponding to this phase. These are:

$$x_2(1)_0 = 1300{,}98 \text{ mm};\ y_2(1)_0 = 500{,}1 \text{ mm};$$
$$z_2(1)_0 = 1050{,}11 \text{ mm};\ i=1,$$
$$x_2(2)_0 = 1299{,}98 \text{ mm};\ y_2(2)_0 = 500{,}1 \text{ mm};$$
$$z_2(2)_0 = 1050{,}11 \text{ mm};\ i=2,$$
$$x_2(3)_0 = 1197{,}5 \text{ mm};\ y_2(3)_0 = 602{,}14 \text{ mm};$$
$$z_2(3)_0 = 950{,}76 \text{ mm};\ i=3. \quad (5)$$

3. The robot takes first flange of the first clamping jaw lathe and puts in the back device DI 1, who turn the flange with 180°. Then again flange is taken by the robot and placed in the third lathe, according to figure 5. The parameters coresponding to this phase are:

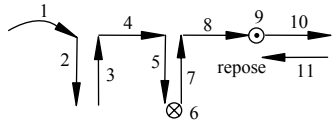

Fig. 5. Working cycle: phase III

$l_0 = 500$ mm;
$l_1 = 200$ mm;
$l_2 = 550$ mm;
$l_3 = 300$ mm;
$l_4 = 200$ mm;
$l_5 = 400$ mm;
$l_6 = 300$ mm;
$l_7 = 300$ mm; $l_8 = 80$ mm; $\varphi_2 = 180^o$; $\varphi_4 = 0^o$;
$\varphi_5 = 90^o$; $q_1 = 1800$ mm; $q_2 = 0^o$; $q_3 = -350$ mm;
$q_4 = 400$ mm; $q_5 = 0^o$; $q_6 = 0^o$. (6)

After calculations, the final position of the flange is determined by the following coordinates:

$$x_2(1)_0 = -1300{,}98 \text{ mm};\ y_2(1)_0 = 1800 \text{ mm};$$
$$z_2(1)_0 = 700{,}76 \text{ mm};\ i=1,$$
$$x_2(2)_0 = -1276{,}8 \text{ mm};\ y_2(2)_0 = 1900 \text{ mm};$$
$$z_2(2)_0 = 699{,}8 \text{ mm};\ i=2,$$
$$x_2(3)_0 = -1299{,}98 \text{ mm};\ y_2(3)_0 = 1800 \text{ mm};$$
$$z_2(3)_0 = 700{,}76 \text{ mm};\ i=3. \quad (7)$$

4. The robot returns to the conveyor and it picks up the third flange and puts in clamping jaw lathe. The work cycle corresponding to this phase may be follow in figure 6. The parameters that require this phase are:

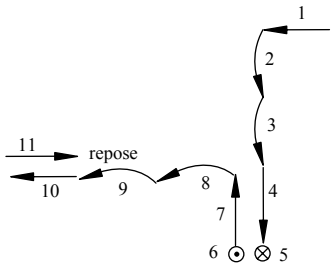

Fig. 6. Working cycle: phase IV

$l_0 = 500$ mm;
$l_1 = 200$ mm;
$l_2 = 300$ mm;
$l_3 = 300$ mm;
$l_4 = 200$ mm;
$l_5 = 400$ mm;
$l_6 = 300$ mm; $l_7 = 300$ mm; $l_8 = 80$ mm; $\varphi_2 = 180^o$;
$\varphi_4 = 0^o$; $\varphi_5 = 90^o$; $q_1 = 0$ mm; $q_2 = -90^o$;
$q_3 = 250$ mm; $q_4 = 400$ mm; $q_5 = 90^o$; $q_6 = 0^o$. (8)

The flange coordinates points in final position are:

$$x_2(1)_0 = -1300{,}98 \text{ mm};\ y_2(1)_0 = 500{,}1 \text{ mm};$$
$$z_2(1)_0 = 1050{,}1 \text{ mm};\ i=1$$
$$x_2(2)_0 = -1299{,}98 \text{ mm};\ y_2(2)_0 = 500{,}1 \text{ mm};$$
$$z_2(2)_0 = 1050{,}11 \text{ mm};\ i=2,$$
$$x_2(3)_0 = -1197{,}5 \text{ mm};\ y_2(3)_0 = 602{,}14 \text{ mm};$$
$$z_2(3)_0 = 950{,}76 \text{ mm};\ i=3. \quad (9)$$

5. The robot takes first flange from the back device DI 1 and puts in the third lathe. The numerical data coresponding to this phase are:

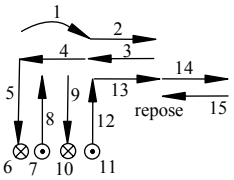

Fig. 7. Working cycle: phase V

$l_0 = 500$ mm; $l_1 = 200$ mm; $l_2 = 300$ mm;
$l_3 = 300$ mm; $l_4 = 200$ mm; $l_5 = 400$ mm;
$l_6 = 300$ mm; $l_7 = 300$ mm; $l_8 = 80$ mm;
$\varphi_2 = 90^o$; $\varphi_5 = 90^o$;
$\varphi_6 = 90^o$;
$q_1 = 1700$ mm;
$q_2 = 0^o$; $q_3 = 250$ mm; $q_4 = 400$ mm; $q_5 = 0^o$;
$q_6 = 0^o$. (10)

The final position of the flange is given by the following coordinates of three points belonging to the flange:

$$x_2(1)_0 = -1299{,}99 \text{ mm};\ y_2(1)_0 = 3500{,}67 \text{ mm};$$
$$z_2(1)_0 = 1050{,}2 \text{ mm};\ i=1,$$
$$x_2(2)_0 = -1157{,}8 \text{ mm};\ y_2(2)_0 = 2506{,}89 \text{ mm};$$
$$z_2(2)_0 = 966.64 \text{ mm};\ i=2,$$
$$x_2(3)_0 = -1300{,}01 \text{ mm};\ y_2(3)_0 = 3500{,}68 \text{ mm};$$
$$z_2(3)_0 = 1050{,}2 \text{mm};\ i=3. \quad (11)$$

The robot working cycle in this phase is shown in figure 7.

6. The robot takes the second flange of the CNC 2 and puts in the back device DI 2, who turns the flange with 180°. According to this operations, are impose the following parameters: $l_0 = 500$ mm; $l_1 = 200$ mm;

$l_2 = 550$ mm; $l_3 = 300$ mm; $l_4 = 200$ mm;
$l_5 = 400$ mm; $l_6 = 300$ mm; $l_7 = 300$ mm;
$l_8 = 80$ mm; $\varphi_2 = 270^o$;$\varphi_5 = 90^o$; $\varphi_6 = 90^o$;
$q_1 = 1800$ mm; $q_2 = 0^o$; $q_3 = -350$ mm;$q_4 = 400$
$q_5 = 0^o$; $q_6 = 0^o$. (12)

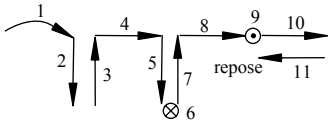

Fig. 8. Working cycle: phase VI

The coordinates points that defines the final position of the flange at this phase, according [11], are:

$$x_2(1)_0 = 1300{,}98 \text{ mm}; \quad y_2(1)_0 = 1800 \text{ mm};$$
$$z_2(1)_0 = 700{,}76 \text{ mm}; \; i=1,$$
$$x_2(2)_0 = 1276{,}8 \text{ mm}; \quad y_2(2)_0 = 1900 \text{ mm};$$
$$z_2(2)_0 = 699{,}8 \text{ mm}; \quad i=2,$$
$$x_2(3)_0 = 1299{,}98 \text{ mm}; \; y_2(3)_0 = 1800 \text{ mm};$$
$$z_2(3)_0 = 700{,}76 \text{ mm}; \; i=3. \qquad (13)$$

In the figure 8 can be tracked the robot working cycle at this phase.

7. In this process, the robot takes the fourth flange from the conveyor and puts in the second lathe. The parameters impose to this phase are: $l_0 = 500$ mm; $l_1 = 200$ mm;$l_2 = 300$ mm; $l_3 = 300$ mm; $l_4 = 200$ mm; $l_5 = 400$ mm; $l_6 = 300$ mm; $l_7 = 300$ mm; $l_8 = 80$ mm; $\varphi_2 = 180^o$; $\varphi_4 = 0^o$; $\varphi_5 = 90^o$; $q_1 = 0$ mm;$q_2 = -90^o$; $q_3 = 250$ mm; $q_4 = 400$ mm;

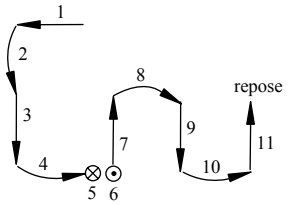

Fig. 9. Working cycle: phase VII

$q_5 = 90^o$;$q_6 = 0^o$. (14)

The final position of the characterized points coresponding to this phase are defined by the coordinates:

$$x_2(1)_0 = 1300{,}98 \text{ mm}; \quad y_2(1)_0 = 500{,}1 \text{ mm};$$
$$z_2(1)_0 = 1050{,}11 \text{ mm}; \; i=1,$$
$$x_2(2)_0 = 1299{,}98 \text{ mm}; \; y_2(2)_0 = 500{,}1 \text{ mm};$$
$$z_2(2)_0 = 1050{,}11 \text{ mm}; \; i=2,$$
$$x_2(3)_0 = 1197{,}5 \text{ mm}; \; y_2(3)_0 = 602{,}14 \text{ mm};$$
$$z_2(3)_0 = 950{,}76 \text{ mm}; \; i=3. \qquad (15)$$

The robot working cycle at this phase is shown in figure 9.

8. The robot takes over the third flange from the clamping jaw of the first CNC and places it in the DI 1, which perform turning, will be then taken back by the robot, according to figure 10. The constructive and geometric-kinematic parameters corresponding to this phase are:

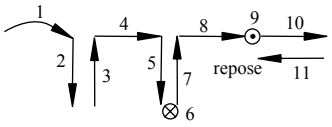

Fig. 10. Working cycle: phase VIII

$l_0 = 500$ mm; $l_1 = 200$ mm; $l_2 = 550$ mm; $l_3 = 300$ mm; $l_4 = 200$ mm; $l_5 = 400$ mm; $l_6 = 300$ mm; $l_7 = 300$ mm; $l_8 = 80$ mm; $\varphi_2 = 180^o$; $\varphi_4 = 0^o$; $\varphi_5 = 90^o$; $q_1 = 1800$ mm; $q_2 = 0^o$; $q_3 = -350$ mm; $q_4 = 400$ mm; $q_5 = 0^o$; $q_6 = 0^o$. (16)

The coordinates points in final position of the flange at this phase, are determine according to [1] and relation (16). Thus,

$$x_2(1)_0 = -1300{,}98 \text{ mm}; \quad y_2(1)_0 = 1800 \text{ mm};$$
$$z_2(1)_0 = 700{,}76 \text{ mm}; \; i=1,$$
$$x_2(2)_0 = -1276{,}8 \text{ mm}; \; y_2(2)_0 = 1900 \text{ mm};$$
$$z_2(2)_0 = 699{,}8 \text{ mm}; \; i=2,$$
$$x_2(3)_0 = -1299{,}98 \text{ mm}; \; y_2(3)_0 = 1800 \text{ mm};$$
$$z_2(3)_0 = 700{,}76 \text{ mm}; \; i=3. \qquad (17)$$

9. The robot TRTTRR1 takes the first flange of the third CNC and puts on drilling machine table. The constructive and geometric-kinematic parameters impose to this phase are:
$l_0 = 500$ mm; $l_1 = 200$ mm; $l_2 = 550$ mm; $l_3 = 300$ mm; $l_4 = 600$ mm; $l_5 = 400$ mm; $l_6 = 300$ mm; $l_7 = 300$ mm; $l_8 = 80$ mm; $\varphi_2 = 90^o$;

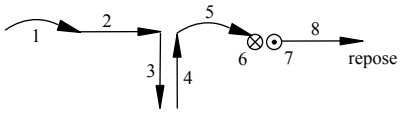

Fig. 11. Working cycle: phase IX

$\varphi_5 = 90^o$; $\varphi_6 = 90^o$; $q_1 = 0$ mm; $q_2 = -90^o$; $q_3 = -350$ mm; $q_4 = 0$ mm; $q_5 = -90^o$; $q_6 = 0^o$. (18)

The working cycle is presented in figure 11. The final position of the points corresponding to this phase are defined according to [11], [12] and [13], by the coordinates:

$$x_2(1)_0 = 0{,}01 \text{ mm}; \; y_2(1)_0 = 4801{,}25 \text{ mm};$$
$$z_2(1)_0 = 700 \text{ mm}; \; i = 1,$$

$$x_2(2)_0 = 0{,}15 \text{ mm};\ y_2(2)_0 = 4766{,}84 \text{ mm};$$
$$z_2(2)_0 = 650{,}18 \text{ mm}; i = 2,$$
$$x_2(3)_0 = 0{,}01 \text{ mm};\ y_2(3)_0 = 4776{,}25 \text{ mm};$$
$$z_2(3)_0 = 700 \text{ mm}; i = 3. \quad (19)$$

10. The robot takes the second flange from the back device DI 2 and puts in the clamping jaw of CNC 4, to be processed. The numerical data coresponding to this phase are:

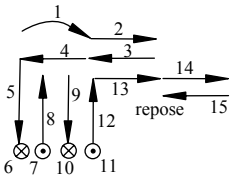

Fig. 12. Working cycle: phase X

$l_0 = 500$ mm; $l_1 = 200$ mm; $l_2 = 300$ mm; $l_3 = 300$ mm; $l_4 = 200$ mm; $l_5 = 400$ mm; $l_6 = 300$ mm; $l_7 = 300$ mm; $l_8 = 80$ mm; $\varphi_2 = 270^o$; $\varphi_5 = 90^o$; $\varphi_6 = 90^o$; $q_1 = 1700$ mm; $q_2 = 0^o$; $q_3 = 250$ mm; $q_4 = 400$ mm; $q_5 = 0^o$; $q_6 = 0^o$. (20)

The final position of the flange is expressed by the coordinates:

$$x_2(1)_0 = 1299{,}99 \text{ mm};\ y_2(1)_0 = 3500{,}67 \text{ mm};$$
$$z_2(1)_0 = 1050{,}2 \text{ mm};\ i=1,$$
$$x_2(2)_0 = 1157{,}8 \text{ mm};\ y_2(2)_0 = 2506{,}89 \text{ mm};$$
$$z_2(2)_0 = 966.64 \text{ mm};\ i=2,$$
$$x_2(3)_0 = 1300{,}01 \text{ mm};\ y_2(3)_0 = 3500{,}68 \text{ mm};$$
$$z_2(3)_0 = 1050{,}2 \text{mm};\ i=3. \quad (21)$$

11. The robot takes the fourth flange from the CNC 2 and places it in the DI 2, for perform the turn. According to this phase, are impose the following parameters: $l_0 = 500$ mm; $l_1 = 200$ mm; $l_2 = 550$ mm; $l_3 = 300$ mm; $l_4 = 200$ mm; $l_5 = 400$ mm; $l_6 = 300$ mm; $l_7 = 300$ mm; $l_8 = 80$; $\varphi_2 = 270^o$; $\varphi_5 = 90^o$; $\varphi_6 = 90^o$; $q_1 = 1800$ mm; $q_2 = 0^o$; $q_3 = -350$ mm; $q_4 = 400$ mm; $q_5 = 0^o$; $q_6 = 0^o$ (22)

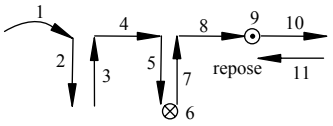

Fig. 13. Working cycle: phase XI

and result the working cycle in figure 13. The coordinates points in final position of the flange in this working cycle, phase XI are:

$$x_2(1)_0 = 1300{,}98 \text{ mm};\ y_2(1)_0 = 1800 \text{ mm};$$
$$z_2(1)_0 = 700{,}76 \text{ mm}; i=1,$$
$$x_2(2)_0 = 1276{,}8 \text{ mm};\ y_2(2)_0 = 1900 \text{ mm};$$
$$z_2(2)_0 = 699{,}8 \text{ mm};\ i=2,$$
$$x_2(3)_0 = 1299{,}98 \text{ mm};\ y_2(3)_0 = 1800 \text{ mm};$$
$$z_2(3)_0 = 700{,}76 \text{ mm};\ i=3. \quad (23)$$

12. The robot takes the first flange from the drilling machine after the mounting holes were made and placed it on the out conveyer. The numerical data corresponding to this phase are:

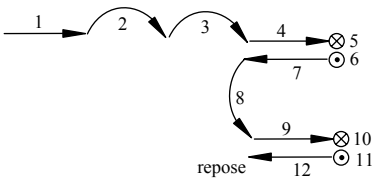

Fig. 14. Working cycle: phase XII

$l_0 = 500$ mm; $l_1 = 200$ mm; $l_2 = 550$ mm; $l_3 = 300$ mm; $l_4 = 200$ mm; $l_5 = 400$ mm; $l_6 = 300$ mm; $l_7 = 300$ mm; $l_8 = 80$; $\varphi_2 = 0^o$; $\varphi_5 = 0^o$; $\varphi_6 = 90^o$; $q_1 = 0$ mm; $q_2 = 30^o$; $q_3 = 250$ mm; $q_4 = 400$ mm; $q_5 = 0^o$; $q_6 = 0^o$. (24)

The working cycle corresponding, is the one shown in figure 14. The coordinates points in final position of the flange, in this phase are:

$$x_2(1)_0 = -650{,}29 \text{ mm};\ y_2(1)_0 = 4768{,}61 \text{ mm};$$
$$z_2(1)_0 = 699{,}77 \text{ mm};\ i=1,$$
$$x_2(2)_0 = -634{,}59 \text{ mm};\ y_2(2)_0 = 4689 \text{ mm};$$
$$z_2(2)_0 = 650{,}23 \text{mm};\ i=2,$$
$$x_2(3)_0 = -649{,}87 \text{ mm};\ y_2(3)_0 = 4763{,}22 \text{ mm};$$
$$z_2(3)_0 = 699{,}78 \text{ mm};\ i=3. \quad (25)$$

13. The robot takes the third flange from the back device DI 1 and puts in the CNC 3 (figure 15). The numerical data corresponding to this phase are: $l_0 = 500$ mm; $l_1 = 200$ mm; $l_2 = 300$ mm; $l_3 = 300$ mm; $l_4 = 200$ mm; $l_5 = 400$ mm; $l_6 = 300$ mm; $l_7 = 300$ mm; $l_8 = 80$ mm; $\varphi_2 = 90^o$; $\varphi_5 = 90^o$; $\varphi_6 = 90^o$; $q_1 = 1700$ mm; $q_2 = 0^o$; $q_3 = 250$ mm; $q_4 = 400$ mm; $q_5 = 0^o$; $q_6 = 0^o$. (26)

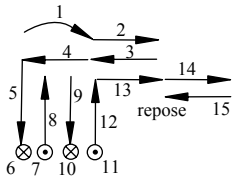

Fig. 15. Working cycle: phase XIII

According to equation from [1], the coordinates points of the flange which is after this phase of work in the final position, are expressed by relations (27). Thus,

$$x_2(1)_0 = -1299{,}99 \text{ mm};\ y_2(1)_0 = 3500{,}67 \text{ mm};$$
$$z_2(1)_0 = 1050{,}2 \text{ mm};\ i=1,$$
$$x_2(2)_0 = -1157{,}8 \text{ mm};\ y_2(2)_0 = 2506{,}89 \text{ mm};$$
$$z_2(2)_0 = 966.64 \text{ mm};\ i=2,$$
$$x_2(3)_0 = 1300{,}01 \text{ mm};\ y_2(3)_0 = 3500{,}68 \text{ mm};$$
$$z_2(3)_0 = 1050{,}2\text{mm};\ i=3. \quad (27)$$

14. After this operation the robot is turns, go to CNC 4 to take the second flange from the lathe and put it in the drill machine fot the drilling operation (figure 16). The constructive and geometric-kinematic parameters for this phase are expressed as follows: $l_0 = 500$ mm;

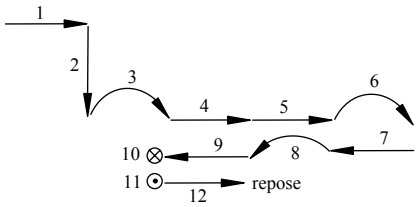

Fig. 16. Working cycle: phase XIV

$l_1 = 200$ mm; $l_2 = 550$ mm; $l_3 = 300$ mm; $l_4 = 600$ mm; $l_5 = 400$ mm; $l_6 = 300$ mm; $l_7 = 300$ mm; $l_8 = 80$ mm; $\varphi_2 = 270^o$; $\varphi_5 = 90^o$; $\varphi_6 = 90^o$; $q_1 = 0$ mm; $q_2 = 90^o$; $q_3 = -350$ mm; $q_4 = 0$ mm; $q_5 = 90^o$; $q_6 = 0^o$. (28)

The coordinates points in final position of the flange are given by the relations:

$$x_2(1)_0 = 0{,}01 \text{ mm};\ y_2(1)_0 = 4801{,}25 \text{ mm};$$
$$z_2(1)_0 = 700 \text{ mm}; i = 1,$$
$$x_2(2)_0 = 0{,}15 \text{ mm};\ y_2(2)_0 = 4766{,}84 \text{ mm};$$
$$z_2(2)_0 = 650{,}18 \text{ mm}; i = 2,$$
$$x_2(3)_0 = 0{,}01 \text{ mm};\ y_2(3)_0 = 4776{,}25 \text{ mm};$$
$$z_2(3)_0 = 700 \text{ mm}; i = 3. \quad (29)$$

15. The robot takes the fourth flange from the back device DI 2 and puts in the clamping jaw of CNC 4, to be processed (figure 17). The numerical data coresponding to this phase are expressed by the relations: $l_0 = 500$ mm; $l_1 = 200$ mm; $l_2 = 300$ mm; $l_3 = 300$ mm;

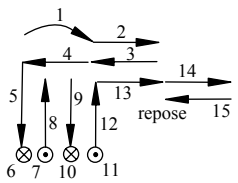

Fig. 17. Working cycle: phase XV

$l_4 = 200$ mm; $l_5 = 400$ mm; $l_6 = 300$ mm; $l_7 = 300$ mm; $l_8 = 80$ mm; $\varphi_2 = 270^o$; $\varphi_5 = 90^o$; $\varphi_6 = 90^o$; $q_1 = 1700$ mm; $q_2 = 0^o$; $q_3 = 250$ mm; $q_4 = 400$ mm; $q_5 = 0^o$; $q_6 = 0^o$. (30)

After the calculations made with the program Matlab 7.1 and [14], have result the coordinates points of the flange in final position expressed by relations (31). Thus

$$x_2(1)_0 = 1299{,}99 \text{ mm};\ y_2(1)_0 = 3500{,}67 \text{ mm};$$
$$z_2(1)_0 = 1050{,}2 \text{ mm};\ i=1,$$
$$x_2(2)_0 = 1157{,}8 \text{ mm};\ y_2(2)_0 = 2506{,}89 \text{ mm};$$
$$z_2(2)_0 = 966.64 \text{ mm};\ i=2,$$
$$x_2(3)_0 = 1300{,}01 \text{ mm};\ y_2(3)_0 = 3500{,}68 \text{ mm};$$
$$z_2(3)_0 = 1050{,}2\text{mm};\ i=3. \quad (31)$$

16. The robot takes the second flange from the drilling machine, after the mounting holes were made and placed it on the out conveyer. The numerical data corresponding to phase XVI are: $l_0 = 500$ mm; $l_1 = 200$ mm; $l_2 = 550$ mm;

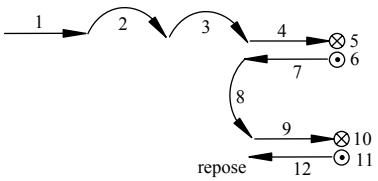

Fig. 18. Working cycle: phase XVI

$l_3 = 300$ mm; $l_4 = 200$ mm; $l_5 = 400$ mm; $l_6 = 300$ mm; $l_7 = 300$ mm; $l_8 = 80$; $\varphi_2 = 0^o$; $\varphi_5 = 0^o$; $\varphi_6 = 90^o$; $q_1 = 0$ mm; $q_2 = 30^o$; $q_3 = 250$ mm; $q_4 = 400$ mm; $q_5 = 0^o$; $q_6 = 0^o$. (32)

The coordinates points of the flange in the final position after this phase of work, are expressed by relations (33).

$$x_2(1)_0 = -650{,}29 \text{ mm};\ y_2(1)_0 = 4768{,}61 \text{ mm};$$
$$z_2(1)_0 = 699{,}77 \text{ mm};\ i=1,$$
$$x_2(2)_0 = -634{,}59 \text{ mm};\ y_2(2)_0 = 4689 \text{ mm};$$
$$z_2(2)_0 = 650{,}23 \text{ mm};\ i=2,$$
$$x_2(3)_0 = -649{,}87 \text{ mm};\ y_2(3)_0 = 4763{,}22 \text{ mm};$$
$$z_2(3)_0 = 699{,}78 \text{ mm};\ i=3. \quad (33)$$

The working cycle is presented in figure 18.

17. The robot TRTTRR1 takes the third flange from the third CNC and puts it on the drilling machine table (figure 19). The constructive and geometric-kinematic parameters impose to this phase are: $l_0 = 500$ mm; $l_1 = 200$ mm; $l_2 = 550$ mm; $l_3 = 300$ mm;

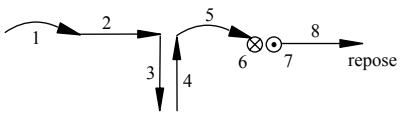

Fig. 19. Working cycle: phase XVII

$l_4 = 600$ mm; $l_5 = 400$ mm; $l_6 = 300$ mm;

$l_7 = 300$ mm; $l_8 = 80$ mm; $\varphi_2 = 90^o$;
$\varphi_5 = 90^o$;
$\varphi_6 = 90^o$;
$q_1 = 0$ mm; $q_2 = -90^o$;
$q_3 = -350$ mm; $q_4 = 0$ mm; $q_5 = -90^o$; $q_6 = 0^o$. (34)

The final position of the characteristic points of the flange corresponding to this phase, are defined by coordinates: The

$$x_2(1)_0 = 0{,}01 \text{ mm}; \; y_2(1)_0 = 4801{,}25 \text{ mm};$$
$$z_2(1)_0 = 700 \text{ mm}; \; i = 1,$$
$$x_2(2)_0 = 0{,}15 \text{ mm}; \; y_2(2)_0 = 4766{,}84 \text{ mm};$$
$$z_2(2)_0 = 650{,}18 \text{ mm}; \; i = 2,$$
$$x_2(3)_0 = 0{,}01 \text{ mm}; \; y_2(3)_0 = 4776{,}25 \text{ mm};$$
$$z_2(3)_0 = 700 \text{ mm}; \; i = 3. \quad (35)$$

18. The third flange is taken by the TRTTRR1 robot from the drilling machine, after the mounting holes were made and placed it on the out conveyer. The parameters corresponding to phase XVIII are highlight below: $l_0 = 500$ mm; $l_1 = 200$ mm; $l_2 = 550$ mm; $l_3 = 300$ mm; $l_4 = 200$ mm; $l_5 = 400$ mm; $l_6 = 300$ mm; $l_7 = 300$ mm; $l_8 = 80$; $\varphi_2 = 0^o$; $\varphi_5 = 0^o$; $\varphi_6 = 90^o$; $q_1 = 0$ mm; $q_2 = 30^o$; $q_3 = 250$ mm; $q_4 = 400$ mm; $q_5 = 0^o$; $q_6 = 0^o$. (36)

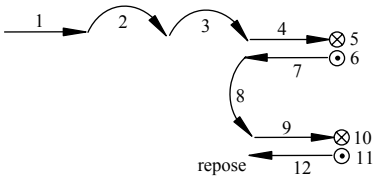

Fig. 20. Working cycle: phase XVIII

According to [1], result the coordinates points in the final position of the flange, corresponding to this phase of work:

$$x_2(1)_0 = -650{,}29 \text{ mm}; \; y_2(1)_0 = 4768{,}61 \text{ mm};$$
$$z_2(1)_0 = 699{,}77 \text{ mm}; \; i = 1,$$
$$x_2(2)_0 = -634{,}59 \text{ mm}; \; y_2(2)_0 = 4689 \text{ mm};$$
$$z_2(2)_0 = 650{,}23 \text{ mm}; \; i = 2,$$
$$x_2(3)_0 = -649{,}87 \text{ mm}; \; y_2(3)_0 = 4763{,}22 \text{ mm};$$
$$z_2(3)_0 = 699{,}78 \text{ mm}; \; i = 3. \quad (37)$$

19. After this operation the robot is turning back, goes to CNC 4 to take the fourth flange from it and puts it in the drilling machine for the drilling operation.

The constructive and geometric-kinematic parameters for this phase are expressed by relations: $l_0 = 500$ mm; $l_1 = 200$ mm; $l_2 = 550$ mm; $l_3 = 300$ mm; $l_4 = 600$ mm; $l_5 = 400$ mm; $l_6 = 300$ mm; $l_7 = 300$ mm; $l_8 = 80$ mm; $\varphi_2 = 270^o$; $\varphi_5 = 90^o$; $\varphi_6 = 90^o$; $q_1 = 0$ mm; $q_2 = 90^o$; $q_3 = -350$ mm; $q_4 = 0$ mm; $q_5 = 90^o$; $q_6 = 0^o$. (38)

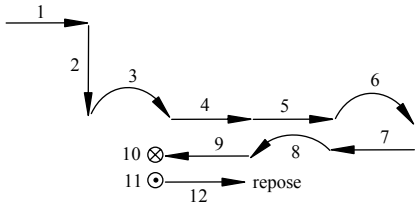

Fig. 21. Working cycle: phase XIX

The coordinates points of the flange in the final position, are expressed by relations:

$$x_2(1)_0 = 0{,}01 \text{ mm}; \; y_2(1)_0 = 4801{,}25 \text{ mm};$$
$$z_2(1)_0 = 700 \text{ mm}; \; i = 1,$$
$$x_2(2)_0 = 0{,}15 \text{ mm}; \; y_2(2)_0 = 4766{,}84 \text{ mm};$$
$$z_2(2)_0 = 650{,}18 \text{ mm}; \; i = 2,$$
$$x_2(3)_0 = 0{,}01 \text{ mm}; \; y_2(3)_0 = 4776{,}25 \text{ mm};$$
$$z_2(3)_0 = 700 \text{ mm}; \; i = 3. \quad (39)$$

20. After the mounting holes were made on the drilling machine, the robot takes the fourth flange and turns 30° to position the on the out conveyer. The numerical data corresponding to phase XX are constructive and geometric-kinematic parameters, play by relations (40), and the work cycle proposed is shown in figure 22. Thus,

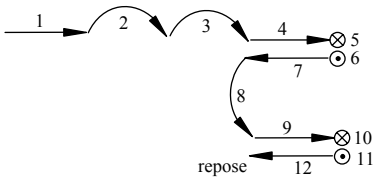

Fig. 22. Working cycle: phase XX

$l_0 = 500$ mm; $l_1 = 200$ mm; $l_2 = 550$ mm; $l_3 = 300$ mm; $l_4 = 200$ mm; $l_5 = 400$ mm; $l_6 = 300$ mm; $l_7 = 300$ mm; $l_8 = 80$; $\varphi_2 = 0^o$; $\varphi_5 = 0^o$; $\varphi_6 = 90^o$; $q_1 = 0$ mm; $q_2 = 30^o$; $q_3 = 250$ mm; $q_4 = 400$ mm; $q_5 = 0^o$; $q_6 = 0^o$. (40)

According to relation (40) and relation from [1], can be determined the coordinates points in

final position of the flange. These coordinates are:

$$x_2(1)_0 = -650{,}29 \text{ mm};\ y_2(1)_0 = 4768{,}61 \text{ mm};$$
$$z_2(1)_0 = 699{,}77 \text{ mm};\ i=1,$$
$$x_2(2)_0 = -634{,}59 \text{ mm};\ y_2(2)_0 = 4689 \text{ mm};$$
$$z_2(2)_0 = 650{,}23 \text{ mm};\ i=2,$$
$$x_2(3)_0 = -649{,}87 \text{ mm};\ y_2(3)_0 = 4763{,}22 \text{ mm};$$
$$z_2(3)_0 = 699{,}78 \text{ mm};\ i=3. \qquad (41)$$

As has been done in other versions of flexible cell, the phases of the working cycle together with the relations determined in chapter 5 of [1] on the coordinates points of the flange in final position and the constructive and the geometric-kinematic parameters of the robot, have leds to determining the position of each machine tools, device or conveyor from the flexible manufacturing cell.

The third version of cell, together with the components namely: four CNC, two back devices, one drilling machine, two conveyors, the robot and the flange, are shown in figure 23, in accordance with [15] and [16].

The machine tools and back devices are placed into the manufacturing cell so that the axes of symmetry of their clamping jaw to coincide with the axis of symmetry of the flange manipulated by robot.

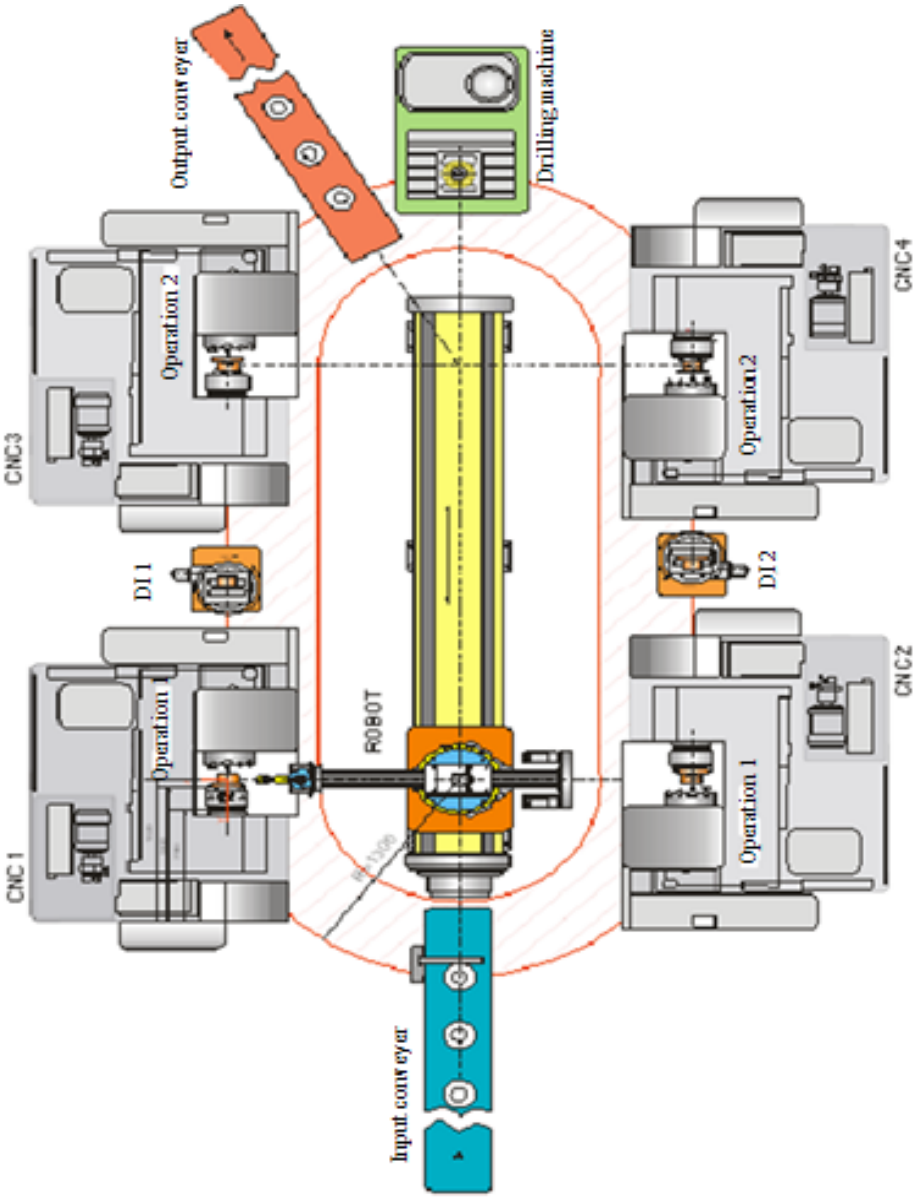

Fig. 23. The flexible manufacturing cell

3. CONCLUSION

In order to configure these manufacturing cells, it was necessary firstly to established the working cycles of the robots, followed by the imposition of constructive and geometric-kinematic parameters of the robots and the calculation algorithm presented in chapter 5, according to [1].

For location of the machine tools, the bak devices and the other components, are followed the phases of the working cycles of robots, but for their positions to be correct, it must that their axis of symmetry to overlap on the symmetry axis of the flange.

Finally have result three different versions of manufacturing cells, each with different machine tools installed, back devices and conveyor.

4. REFERENCES

[1] Gui (Lung), R.M., Teză de doctorat: *Contribuţii la prelucrarea robotizată a reperelor de tip flanşă*, Cluj-Napoca, 2011.

[2] Ispas, V., *Manipulatoare şi roboţi industriali*, Editura Didactică şi Pedagogică, ISBN 973-30-1349-8, Bucureşti, 2004.

[3] Khalil, W., Dombre, E., "*Modeling, identification and control of robots*" Taylor & Francis, Inc. Bristol, PA, USA, 2002.

[4] Popescu, P., Ispas, V., Fodor, G., „*Studiul cinematic al unei celule flexibile robotizate*", a VIII-a '' Sesiunea de comunicări şi referate I.M. Aiud, 7-8 iunie, 1985.

[5] Plitea, N., „*Studiul deplasărilor finite ale unei plăci în mişcare plană când sunt cunoscute poziţiile a două puncte aparţinând plăcii*", În: mecanica. Îndrumător de lucrări, pag.90-94, Atelierul de multiplicare al I.P. Cluj-Napoca, 1984.

[6] Popescu, P., *"Mecanica. Cinematica"* Atelierul de multiplicare al I.P. Cluj-Napoca, 1978.

[7] Ispas, V., Ispas, S.I., „*Metode generale de calcul în problema deplasărilor finite ale solidului rigid*", „Sesiunea de comunicări tehnico-ştiinţifice C.U.G." Cluj-napoca, martie 1981.

[8] Sandler, B.-Z., *"Robotics. Designing the mechanism for automated machinery"*, Prentice-Hall, second edition, S.U.A., 1999.

[9] Ursu-Fischer, N., Ursu, M., "*Metode numerice în tehnică şi programe în C/C++*", Editura Casa Cărţii de Ştiinţă, vol.II, Cluj-Napoca, 2003.

[10] Makarow, I.M., "*Modeling of Robotic and Flexible Manufacturing Systems*", Hemisfere Publishing Corporation, USA, 1990, ISBN 0-89116-964-4.

[11] Gui, (Lung) R.M., Ispas, V., – "*Study on the occupied positions by the flange handled by the industrial TRTR robot*", Acta Technica Napocensis, ISSN: 1221-5872, vol.III, Nr.53, pag.561, Editura U.T. PRESS, Cluj-Napoca, noiembrie 2010.

[12] Ispas, V., „*Contribuţii la studiul deplasărilor finite ale solidului rigid"*, Simpozionul "Creativitatea în construcţia, fabricaţia şi exploatarea automobilelor", vol. II, partea I, pag. 87-92, Piteşti, 1979.

[13] Marcus, M., "*Matrices and Matlab: a Tutorial*", Prentince Hall, New Jersey, 1993.

[14] Gui (Lung), R.M., "*Calculul şi configurarea unor celule de fabricaţie robotizată a reperelor de tip flanşă*", Raport de Cercetare III, Cluj-Napoca, 2010.

[15] Sandin, P.E., "*Robot Mechanisms and Mechanical Devices*", The McGraw-Hill Companies, New York, 2003.

[16] Joshi, P. H. „*Machine Tools Handbook, Design and Operation*", Editura McGraw-Hill Inc., ISBN 9780071494359, 2007.

Celulă flexibilă de fabricație deservită de robotul TRTTRR1

Rezumat:. În această lucrare autorii prezintă un studiu pentru configurarea unei variante de celulă flexibilă de fabricație.

În primul rând se determină ciclurile de funcționare ale robotului. În al doilea rând se determină poziția finală a flanşei pentru fiecare fază de lucru prin utilizarea relațiilor rezultate în [1]. În final având toate aceste date se poate configura celula flexibilă de fabricație ținând cont de faptul că axa de simetrie a flanşei să coincidă succesiv cu axele de simetrie ale universalelor maşinilor unelte, respectiv cu axa de simetrie a dispozitivelor de întoarcere.

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