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THE INFLUENCE OF ACCURACY IN ESTABLISHING THE ORIGIN OF THE PART ON THE MACHINING ACCURACY

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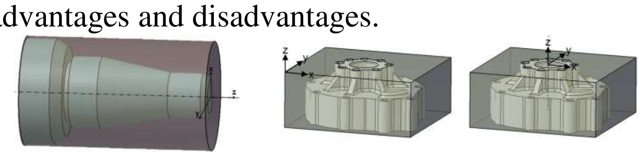
Abstract: *While machining parts, the errors occurs due to factors with a systematic or a random character. Among these factors, the errors due to clamping devices have a systematic character and are qualitatively significant. There are some parts which, in order to be processed, need to be inclined after one or two angles. These parts need devices that allows the rotation based on certain angles. Establishing the origin of the part for machining, on numerically controlled machines is difficult if are not used machines in 4 or 5 axis. This article presents the causes of the errors which occurs when the origin of the part is established incorrectly and the way in which is correctly established the part origin..*
Key words: *CNC machines, clamping devices, fixing error, zero point.*

1. INTRODUCTION

The manufacturing of parts on numerically controlled machines is currently predominant in industry. In order to process a part, is used a technological system, which has in its componence the machine, a tool, a device, and a piece. Each of these elements, are introducing errors which influence the quality of the manufactured part, as it results in the studies presented in [1] [2] [3].

In the case of CNC machines, the origin of the part is determined after the part is fixed to the clamping device of the machine`s table. The origin of the part represents a coordinate system associated with the part, which is referenced for all movements performed during machining. This Op point can be chosen arbitrarily, anywhere on the part. It is usually chosen at the one end of the piece, at the center of the piece, whether it is symmetrical or a point that makes part programming easier [4]. For the revolution parts, the origin of the part is at the intersection between the axis of rotation and a certain front surface, perpendicular to the axis of rotation of the part (see Figure 1 a)).

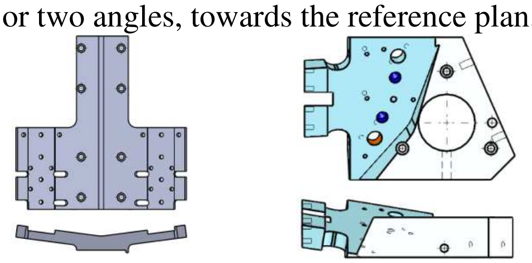
When processing prismatic parts on milling machines and CNC machining centers, the origin of the part is chosen in one of its corners or in a reaming (Figure 1 b)). For parts requiring multiple clamps, there are several origins of the part that are different for each clamp. There are several ways to take the zero point on the surface of the part. It is usually taken with the tool, the control pin, the touch probe, the mechanical or electronic 3D tester [4]. Each way has its advantages and disadvantages.



a) b)

Fig. 1. Zero point, a)for turning, b)for milling

There are often parts where certain processed surfaces are inclined towards the reference surfaces of the part. Two examples of such parts are presented in Figure 2, where the reaming hole axis or certain surfaces are inclined at an one or two angles, towards the reference plan.



a) b)

Fig. 2. Inclined parts a) one angle, b) two angles

In order to clamp these parts for machining, clamping devices are required to allow changing its position by turning and tilting. The most common devices of this kind are: the tilting table, the tipping table, the rotating table, the indexing devices (rotating table, the dividing head), the 4th and 5th 4th axis rotary table. The most efficient machining method for these types of parts is the use of machines that allow the processing in 5th axis rotary table.

The advantage of using the 4th axis rotary table is that the exact position of the axis of rotation is known or can be easily determined, and the software of the CNC machine automatically calculates the position of the origin of the part after its tilting. Due to cost reasons, these types of CNC machines are not always available, so the usual clamping devices (tilting table, tipping table, etc.) are used.

The problem which is occurring, while processing parts with inclined surfaces after one and especially two angles, is that the zero point cannot be taken in the machining position. Therefore, for good machining precision, it is recommended to take the zero point in the parallel position of the part with the reference plan. Subsequently, the part is shifted to the working position and the new position of the origin, that moved from the original position $O_p$in to the $O_p$fin position, is analytically established and entered into the CNC machine tool settings.

The origin of the part is established in two ways:

- directly on the inclined part at the required angles, the way being less accurate and not recommended.
- by analytical calculation, knowing the initial position of the origin of the part, the rotation angle and the distance between the original origin and the rotation axis.

This paper aims to illustrate how the incorrect setting of origin influences the machining accuracy of the part. Also, it presents the analytical way in which the calculation of the movement of the origin $O_p$in in $O_p$fin position is done.

2. ANALYTICAL MODEL FOR TRANSFORMATION OP ORIGIN IN E3

For the analytical determination of the movement of point 0 in space, from the initial position $O_p^{in}x^{in}y^{in}z^{in}$, in which point 0 was taken, at the final position of $O_p^{fin}x^{fin}y^{fin}z^{fin}$, in which the point was moved for processing, the Cartesian space E_3 is used. In the E_3 space, the O_p position is invariably linked to an Oxyz reference system. The calculation of the movement of the O_p point in the E_3 space is done easily, using the 4x4 transformation matrix [5]. The O_p point is described in the Cartesian space using homogeneous coordinates by a column vector shown in expression (1)

$$O_p = \begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix} \quad (1)$$

The final position and orientation of the O_p point with respect to the Oxyz reference system is the result of a composed movement, consisting in translation and rotation [6]. For the translation of the Op point from the initial position ($O_p$in) into the final position ($O_p$fin), the equation (2) is used as.

In (1) it have been marked x^{fin}, y^{fin}, z^{fin} the final position of the point in the E_3 space t_x, t_y, t_z the distance between the fixed reference point and the point O_p to be translated.

$$TranO_p^{fin} = \begin{bmatrix} x^{fin} \\ y^{fin} \\ z^{fin} \\ 1 \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & t_x \\ 0 & 1 & 0 & t_y \\ 0 & 0 & 1 & t_z \\ 0 & 0 & 0 & 1 \end{bmatrix} \cdot \begin{bmatrix} x^{in} \\ y^{in} \\ z^{in} \\ 1 \end{bmatrix} \quad (2)$$

For the rotation of the Op point from the initial to the final position, the equations (3) are used, in the most general case, when there are rotations after all three axes [7].

In (3) the parameters are: $Rot\,O_p(x,\alpha)$ the rotation of the part around x axis with angle α, $Rot\,O_p(y,\beta)$ the rotation of the part around y axis with angle β, and $Rot\,O_p(z,\gamma)$ the rotation of the part around z axis by angle γ.

$$Rot\,O_p(x,\alpha)=\begin{bmatrix}1 & 0 & 0 & 0\\ 0 & \cos\alpha & -\sin\alpha & 0\\ 0 & \sin\alpha & \cos\alpha & 0\\ 0 & 0 & 0 & 1\end{bmatrix},$$

$$Rot\,O_p(y,\beta)=\begin{bmatrix}\cos\beta & 0 & \sin\beta & 0\\ 0 & 1 & 0 & 0\\ -\sin\beta & 0 & \cos\beta & 0\\ 0 & 0 & 0 & 1\end{bmatrix}, \qquad (3)$$

$$Rot\,O_p(z,\gamma)=\begin{bmatrix}\cos\gamma & -\sin\gamma & 0 & 0\\ \sin\gamma & \cos\gamma & 0 & 0\\ 0 & 0 & 1 & 0\\ 0 & 0 & 0 & 1\end{bmatrix}$$

In Figure 3, is schematically shown how a part with a particular shape, that is contained in a parallelepiped, can move in the Euclidian space, by rotating around one or two angles, depending on the kinematics needed for the part to be processed.

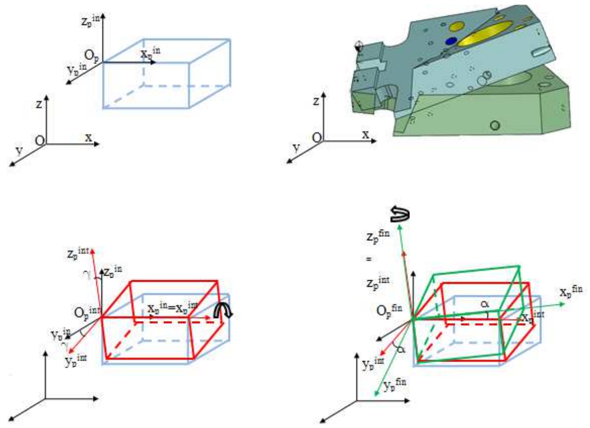


Fig. 3. The movement of part origin in E_3

For the calculation of the movement of the point into space, there is used the equation, given in (4) as:

$$O_p^{fin}=TransO_p^{fin}\cdot Rot\,O_p^{f}((x,y,z),(\alpha,\beta,\gamma))\cdot Rot\,O_p^{s}((x,y,z),(\alpha,\beta,\gamma)) \qquad (4)$$

In (4), the parameters are: O_p^{fin} the final position of the point, $TransO_p^{fin}$ the matrix of translation of the point in E_3, $Rot\,O_p^{f}((x,y,z),(\alpha,\beta,\gamma))$ the rotation matrix of the first tilting angle of the part, established from equation (3) based on the rotation axis, $Rot\,O_p^{s}((x,y,z),(\alpha,\beta,\gamma))$ the rotation matrix of the second tilting angle of the part, established from equation (3), based on the rotation axis.

If the part tilts only at an angle, then equation (4) is reduced to equation (5).

$$O_p^{fin}=TransO_p^{fin}\cdot Rot\,O_p^{f}((x,y,z),(\alpha,\beta,\gamma)) \qquad (5)$$

The analytical calculation method of the final position of the O_p origin of the part in space is presented in the scheme from Figure 4.

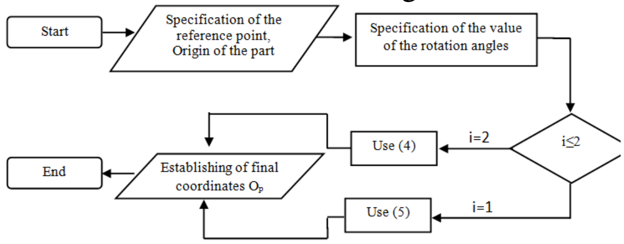


Fig 4. Schematic representation of the procedure for calculating the trajectory of origin O_p

Following the steps of the logical scheme shown in Figure 4, it is possible to analytically, in a simple and fast way, the coordinates of the origin of a part, moving in space due to its rotation, with one or two angles. The calculation method has not been extended to the possibility to tilt the part at three angles, because the probability of processing such a part on common machines in 2.5, 3 or 4 axes is extremely low.

3. EXPERIMENTAL SETUP

The purpose of this paper is to show how the processing accuracy is influenced by how the origin of the part is determined. A 3D WERC30FG40 3D tester, with a 0.001 [mm] accuracy, was used in order to determine the origin of the part. The research have been performed on the 3-axis machining center DMG 333 and on the CNC machining center, in 4th axis rotary table, FGT 2345. Two tilted tables, GFH 300x400 [mm], with an inclination between 0-90^0 and with a positioning accuracy of 0.02 [mm], have been used.

Table 1

Number of tilting angles	Device	Mood of establishing for the origin	
		Empirical	Analytical
One angle	Tilting table	Yes	Yes
	4th axis rotary table	No	Yes
Two angles	Two tilting tables	Yes	Yes
	4th axis rotary table and tilting table	No	Yes

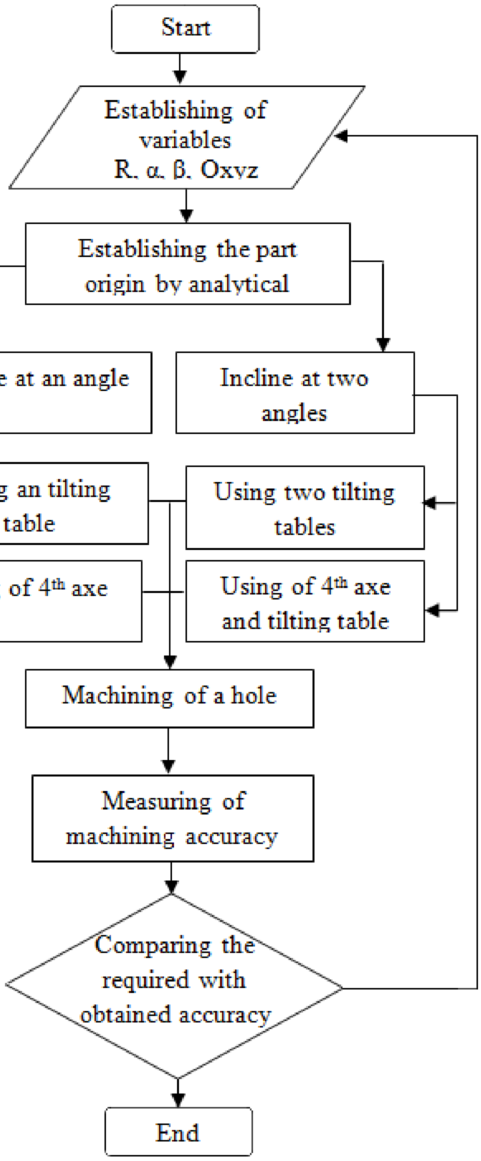


Fig. 5. The methodology of work

One 300 [mm] length part, 5 holes have been performed, at a distance of 200 [mm] from the origin. The inclination of the part was made after the first angle $\alpha=30^0$ and after the second angle $\beta=15^0$.

The methodology for carrying out the experiments is shown in Figure 5.

4. REZULTS

The processing of the data has been done after processing the parts. Table 2 presents the average data obtained from the processing of measured data.

The measurement accuracy was influenced by the precision of the measuring instrument, considered at 0.005 [mm] for distances between 200-400 [mm].

Table 2

Number of tilting angles	**Device**	**Mood of establishing for the origin**	
		Empirical	**Analytical**
One angle	Tilting table	0.1	0.04
	4th axis rotary table	0	0.01
Two angles	Two tilting tables	0.15	0.06
	4th axis rotary table and tilting table	0	0.03

From the data presented in Table 2, it can be observed that the analytical method of determining the origin of the part is superior to the empirical method. The way in which the empirical determination of origin influences the precision of machining is presented in the following paragraph.

5. DISCUSSION

The precision of determining the origin of the part for processing, directly influences the machining precision. If the origin is determined analytically, as shown in Figure 4, then the precision of origin is influenced only by the precision of the device used, in this case the tilted table and the 4th axis.

If the origin is determined empirically, through direct touching of the intersection point between the three reference planes that determine the Op position on the piece, as shown in Figure 6, then a palpation error results, as shown in Figure 7.

Figure 8 shows how the rotation angle of the part influences the position precision of the part`s origin. This influence is manifested by the movement of the theoretical zero point O_t of the part, that the operator wishes to set at a practical point O_p. This movement, although varying from 0 to the maximum value of the palpation error, can influence the position accuracy of certain surfaces. Practically, as the angle of rotation β of the part and the palpation error is higher, the more precisely the positioning accuracy is influenced. Figure 9 shows the variation of the tolerance field of the linear dimensions according to DIN ISO 2768- mk, for the middle precision class, and SR EN 20286-2: 1997 for nominal sizes to be machined in the IT9, IT8 and IT7 precision class. The choice of the dimension range between 0-400 [mm] and the IT7, IT8, IT9 precision classes, and also the free mK allowances, have been made because this range and precision classes are common for parts that are machined by cutting.

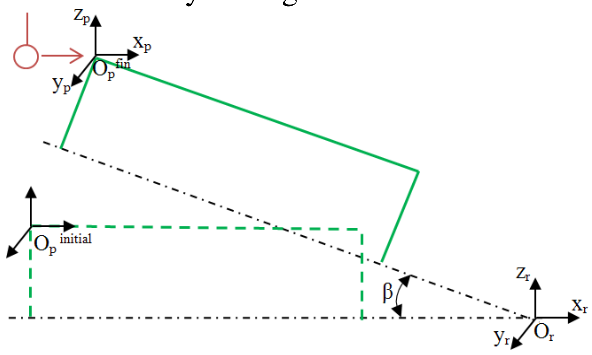


Fig. 6. Part inclined by an angle

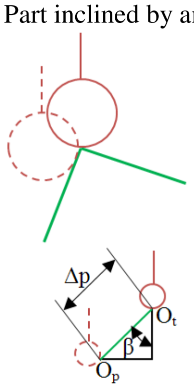


Fig. 7. The way the palpation error results

For the processing of parts that requiring tilting the part after one or two angles, the processing precision required on the drawing must be taken into account. As shown in Figure 9 and Figure10, the precision of establishing the zero point decisively influences the precision of processing.

For example, if is taken a part with a maximum dimension of 200 [mm], showing tolerated functional quotas in the IT7, IT8 precision class and the free allowances are in mK in accordance with DIN ISO 2768, the following data will be obtained, as presented synthetic in Table 4.

Table 3 shows that, for a value of 0.05 [mm] of the Δp value of the palpation error that we take on a part inclined at a angle β =30°, it result that the quotas in the IT7 precision class will be rebated only due to the precision of establishing the zero point.

In order to avoid this phenomenon, it is recommended to use the method of taking the zero point in the position of fixation with a angle β=0 °, after which the part is inclined at the desired angles and the origin is calculated analytically by the method described in paragraph 2 of the paper, and it is entered in the settings of the machine.

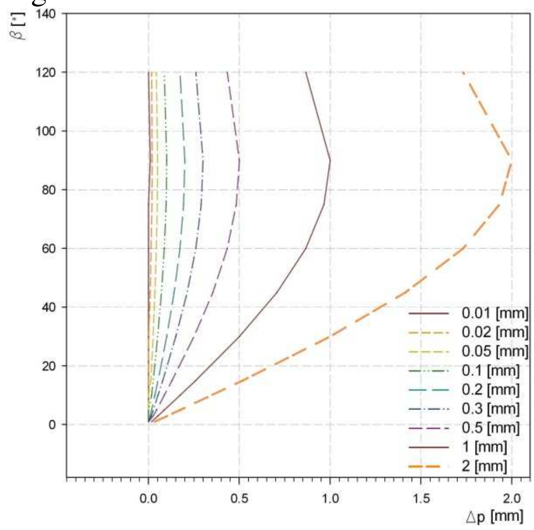


Fig. 8. The variation of precision

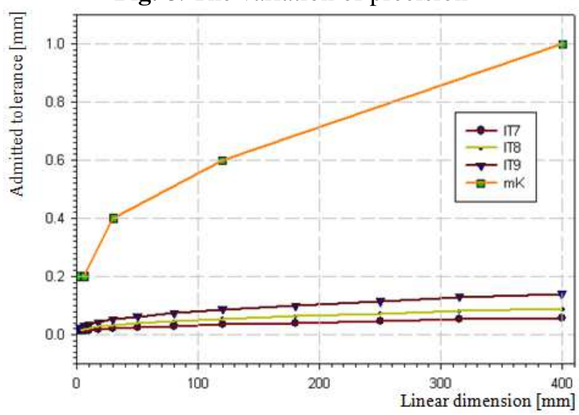


Fig. 9. The value of the tolerance field for linear usual dimensions

Table 3

<table>
<tr><th rowspan="2">β [deg.]</th><th colspan="5">Palpation variation Δp [mm]</th><th rowspan="2">IT7</th><th rowspan="2">IT8</th><th rowspan="2">mK</th></tr>
<tr><th>0.01</th><th>0.02</th><th>0.05</th><th>0.1</th><th>0.2</th></tr>
<tr><td>5</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0.017</td><td rowspan="5">0.021</td><td rowspan="5">0.033</td><td rowspan="5">±0.5</td></tr>
<tr><td>15</td><td>0</td><td>0</td><td>0.013</td><td>0.026</td><td>0.052</td></tr>
<tr><td>30</td><td>0</td><td>0.01</td><td>0.025</td><td>0.05</td><td>0.1</td></tr>
<tr><td>45</td><td>0</td><td>0.014</td><td>0.035</td><td>0.071</td><td>0.141</td></tr>
<tr><td>90</td><td>0.01</td><td>0.02</td><td>0.05</td><td>0.1</td><td>0.2</td></tr>
</table>

Thus, the palpation error can be avoided. This work is recommended for CNC machines that do not have the 4th axis. For machines with a 4th and 5th axis, the zero point is made, from the beginning, in the way previously described, the difference being that it is not necessary to perform the spatial movement calculation of the origin, this calculation being made by the machine's software.

6. CONCLUSION

This paper aims to show how machining precision is influenced by determining the origin of the part, in the case of parts being processed after it had been initially inclined by one or two rotation angles. Although machine tool manufacturers have solved the way for determining the origin of the part in usual cases, for such parts, we have the inconvenience that it is necessary to use CNC machines, with a minimum of 4th axis rotary table. In the absence of such equipment, the results presented in this paper are useful for obtaining high precision.
These results can also be used in other engineering situations where is asked rapid and accurate calculation of the way a body moves into space.

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INFLUENTA PRECIZIEI DE STABILIRE A ORIGINI PIESEI ASUPRA PRECIZIEI DE PRELUCRARE

Rezumat: La prelucrarea pieselor apar erori datorate unor factori ce au character systematic sau aleator. Dintre acesti factori erorile datorate dispozitivelor de fixare au un character systematic si sunt de inseminate calitativ. Exista anumite piese care pentru a fi prelucrate este necesar sa fie inclinate dupa unul sau doua unghiuri. Aceste piese necesita dispositive ce permit rotatia lor dupa anumite unghiuri. Stabilirea origini piesei in vederea prelucrarii pe masini cu comanda numerica in aceste situatii este dificila daca nu se utilizeaza masini cu 4 sau 5 axe. Acest articol prezinta cauzele erorilor care apar cand originea piesei este stabilita gresit si modul in care se stabileste corect originea piesei.

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