AN ANALYSIS OF THE MANUFACTURING PRODUCTIVITY WHEN THE SAME PIECE IS PERFORMED ON 3 VERSUS 4 AXES MACHINING CENTERS

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Abstract: In this paper two technological manufacturing variants of a part are presented, one for fabrication on a vertical manufacturing centre with 3 axes YMC type and another one for fabrication on a horizontal manufacturing centre with 4 axes MCM type. The numerical control programs for the two manufacturing centers were made by using the CAD and CAM modules from the TopSolid software. The necessary times for doing the manufacturing were determined by their simulation, and by clocking the fabricating time of the products on the machines. After the analysis, there has been found for this case of study that, although there have been used the same cutting tools with the same cutting conditions, the higher number of fixings is not the most important factor for decreasing the productivity.

Key words: manufacturing centers, productivity, simulation, TopSolid

1. Introduction

The manufacturing centers with numerical control are technological equipments with a high productivity and precision that make possible special achievements. The advantages of these machines in relation with the universal ones are expressed in productivity terms, precision, shape complexity, manufacturing cost or the flexibility at the product change[1,4]. These advantages are due to the numerical control, the high number of machining operations that can be made at a single fixing of the product, the automatically changing of the cutting tools, the fast and accurate positioning of the cutting tools in relation with the workpiece etc.

It is well known that, for products with difficult configuration, with a high number of machining that must be done and with a high number of cutting tools in several different fixings, the manufacturing centers are several times more productive than the classical machines. The price difference of a product manufacturing increases with the complexity of the machined surfaces geometry.

A milling manufacturing centre is the result of the adding at a milling machine of a storage hopper provided with an automatically system for their change and other devices for their handling. There are more manufacturing centers types, the number of programmable axes, the main shaft position etc. make the difference between them.

Other examples show that the shapes complexity that can be made and the machine price increase with the increase of the control axes number [4,5].

In this paper we want to analyze the technological changes that interfere in the practical case of a part performing on two different manufacturing centers and their implications in the manufacturing time. To make this analysis, the TopSolid software for manufacturing simulations was used, and for validation, a group of 25 pieces were performed on the horizontal manufacturing centre with four axes MCM and also on the vertical manufacturing centre with three axes YMC1050.
For these technological equipments choosing, there has been considered that for the manufacturing centre MCM type, the product can be obtained at a single fix in the device, and after manufacturing only the surface, that contain the connection with the product, finish machining must be made, and in the case of YMC manufacturing centre the piece obtaining assumes more fixings.

2. The used method and equipments

In this study we have considered a piece made from aluminum alloy 6082, whose surfaces can be obtained on the horizontal manufacturing centre MCM with four axes [11], and also on the vertical manufacturing centre with three axes YMC1050 [12].

The 3D piece model was made with TopSolid Cad, and the TopSolid Cam was used for simulation and for performing of numerical control program [6, 7, 8, 9, 10].

To establish the manufacturing time, a group of 25 pieces were considered, and in order to easily compare the results, the same cutting tools set and cutting conditions were used for both machining centers.

The necessary normalized time for the piece fabrication, \( t_n \), has two components: one named unitary time \( t_u \), which is consumed at the fabrication of each piece, and another one that consumes one time for all the \( n \) pieces from the group named as the preparing-finishing time \( t_{pi} \). Between these terms there are the relations [2, 3]:

\[
t_n = t_u + \frac{t_{pi}}{n} = t_{op} + t_m + t_{des} + \frac{t_{pi}}{n} \quad [\text{min}]
\]

where \( t_{op} \) is the operative or effective time, \( t_{des} \) is the attendance time and \( t_m \) is the time of working disengage, all these times correspond to a product fabrication. In our case, the manufacturing is made in a semiautomatic process, and according to [2] we have:

\[
t_{op} = t_{bm} + t_g + t_a = t_m + t_a \quad [\text{min}]
\]

where \( t_{bm} \) = machine base time, \( t_g \) = is the no load running time (\( t_m = t_{bm} + t_g \) time for machine manufacturing) and \( t_a \) = auxiliary time consumed by fixing the product on the machine. If \( t_{des} \) and \( t_m \) are neglected, from the relations (1) and (2) results the calculus relation of the normalized time necessary for the product fabrication:

\[
t_n = t_u + t_a + \frac{t_{pi}}{n} \quad [\text{min}]
\]

respectively for the whole group of pieces:

\[
t_{tot} = n(t_m + t_a) + t_{pi} \quad [\text{min}]
\]

The indicated times from these relations are determined in this way:
\( t_m \) – is read from the CN console or is determined by simulation with the TopSolid Cam module;
\( t_a \) - is determined by clocking or with the time normative;
\( t_{pi} \) - is established as a times sum for: cutting tools mounting in the tools holder and their measurement in the presetting device (fig. 1), the cutting tools mounting in the storage hopper and the panel insert of the length and radius corrections \( t_2 \), and, finally, considering the workpiece origin and inserting its coordinates from the from the CN panel \( t_3 \).
3. Part modeling

The chosen case study in this paper refers to the modeling of a part that requires the use of the main features of Design module like points, circles, sketch lines, curves, offset contours, axis and coordinate system in the sketch mode and extrude, drilling, boring, tapping, fillet, chamfer and propagate operation in shapes mode. Also the shape of chosen part assumes the use of the main manufacturing processes that usually may be met on a machining center.

The 3D model of the product is presented in figure 2, where we made a surface numbering which will be used to identify the performed surfaces at each manufacturing operation.

4. Horizontal manufacturing centre MCM programming

The manufacturing centre MCM-Z16 is provided with an exterior paddles system where the stock can be fixed in device and prepared for the next work without interruption of the current running process. The platen degrees of freedom allow the machine loading with many products, different of identical, that can be successively manufactured, and its using as a machine with four axes for complex shapes fabrication with a single fixing, resulting a high degree of the manufacturing precision.

For TopSolid Cam modeling we have firstly choose the machine and the clamping device (fig. 3), where the workpiece was loaded and finally the origins were performed (fig. 4).
At each manufacturing operation, the cutting tools, the tool holders and the cutting conditions were chosen. For example, at the first operation where we have made the roughing cut of the side surfaces 5 and the contour 9 (fig. 8), we have chosen a mill with a 63 mm diameter and the adequate tool holder (fig. 5 and 6), after this we have established the cutting conditions (fig. 7).

The provided manufacturing operations and the cutting tools which were used to perform those operations are presented, in the run order in the table from fig. 9. The numbers from the first column refer to the cutting tools position in the storage hopper. Also this table contains information regarding the cutting conditions, the number of the cutting tools teeth and the cutting tools corrections that must be inserted from the machine panel (columns D and L).
The product surfaces were programmed to be manufactured in this way:
Op.1 – rough milling of no. 9 and 5 surfaces (left-right) with the no. 1 cutting tool;
Op.2 – three holes centering for the no.1 and 7 circular bores with no. 2 cutting tool;
Op.3 – drilling of no. 7 surface with no. 3 cutting tool;
Op.4 – rough milling no. 9 and 11 surfaces with no.4 cutting tool;
Op.5 – rough milling no. 6 surface with no. 5 cutting tool;
Op.6 – finishing milling no. 6 surface with no. 6 cutting tool;
Op.7 – chamfering no. 8 surface with no. 7 cutting tool;
Op.8 – finishing milling no. 9, 10, 11 and 2 surfaces with no. 8 cutting tool;
Op.9 – drilling no. 1 surfaces with no. 9 cutting tool;
Op.10 – threading no. 9 surfaces with no. 10 cutting tool;
Op.11 – finishing milling surfaces 3 and 5 (left-right) with no.1 cutting tool;
Op.12 - spreading no. 7 surface with no. 11 cutting tool;
Op.13 - boring no.7 surface with no. 12 cutting tool;
Op.14 – milling separation surface no.4 with no. 4 cutting tool;

The no. 2, 4, 5, 7, 8 si 14 operations are made at two workpiece orientations, and for the operation 1 are necessary three orientations.

The list of the used cutting tools with the part handing scheme and the cutting tools sets made in TopSolid Cam and used at their setting, are presented in figures 10 and 11.
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Fig. 9 – List of operations

<table>
<thead>
<tr>
<th>Numero</th>
<th>Tipp a urmăre</th>
<th>Elemente</th>
<th>Piv</th>
<th>Typ</th>
<th>V</th>
<th>Fr</th>
<th>Nbr</th>
<th>D</th>
<th>L</th>
<th>Comments</th>
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<td>4</td>
<td>4</td>
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<tr>
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<td>65</td>
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<td>5</td>
<td>-</td>
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<td>65</td>
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<td>-</td>
<td>5</td>
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<td>-</td>
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<td>7</td>
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<td>108</td>
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<tr>
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<td>-</td>
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<td>55</td>
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<td>-</td>
<td>12</td>
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<tr>
<td>14</td>
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<td>508</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>Thr. points is here in place</td>
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</table>

Fig. 10 – Part handing schema and origins
Fig. 11 - Setup of the used tools
After the manufacturing simulation in the machine mode, at the last operation the products looks like the one presented in fig. 12, and after the tolerances validation (fig. 13) it is observed that on the no. 4 surface has been left a machining allowance.

5. Vertical manufacturing centre YMC programming

For the product execution on the vertical manufacturing centre with three axes YMC 1050, three fixings in the vice were provided, at the last fixing was used a device for workpiece orientation. At the first fixing the surfaces 3, 4, 5 (left side), 6, 7, 8 (left side), 9, 10, 11 were completely manufactured. The way for making the first fixing on the machine and the origin choosing is shown in figure 14. Into figure 15 is shown the milling of the piece contour.
At the second fixing, the remained material is removed on the surface no. 5 (right side fig. 16) and a circular bore chamfering is performed (fig.17).

At the third fixing, the surfaces 1 and 2 (fig. 18 and 19) are performed by milling, centering, drilling and threading. The detail from fig. 18 shows that the product orientation is made on a vertical planar surface, a short plug that enters in the piece circular bore (no. 7 surface) and a supporting plug with which the product comes in contact through the no. 3 surface.

On the vertical manufacturing centre was used the same cutting tools set, with the same cutting conditions as in the case of the fabrication on MCM machining centre. The tool holders obviously are those that correspond to the YMC 1050 machine, BT 40 type. Their selection was made according to the exemplification from the figures 5..7. There were also realized the operations and the used cutting tools lists like in figures 9..11.
6. Results analysis

The times involved in relation (4), determined on each considered case, by the manufacturing simulation with TopSolid, or by clocking of the consumed times with the practical fabrication of the products, in the both variants of manufacturing on the two manufacturing centers MCM and YMC, for each fixing P, are written in table 1.

<table>
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<td>48</td>
<td>15</td>
<td>15</td>
<td>78/30</td>
<td>23,13</td>
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<td>608,25/10,14</td>
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<tr>
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<td>10</td>
<td>60/20</td>
<td>12,53</td>
<td>1</td>
<td>358,25/5,97</td>
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<td>0</td>
<td>10</td>
<td>10/10</td>
<td>1,23</td>
<td>1</td>
<td>65,75/1,10</td>
<td></td>
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<tr>
<td></td>
<td>3</td>
<td>2</td>
<td>8</td>
<td>3</td>
<td>10</td>
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<td>2,01</td>
<td>1,5</td>
<td>100,75/1,68</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

In the table 1, the NT column contains the number of the cutting tools used at each fixing. At the fixing number two on the manufacturing centre YMC, the two used cutting tools are written between parenthesis because they were also used for the first fixing, reason for which the t₁ times, for the cutting tools montage in the tool holders and their measurement in the presetting device, and the time t₂, for the cutting tools montage in the storage hopper and the panel insert of radius and length corrections, are zero.

By summing the consumed times at the three fixings considered for the manufacturing made on the vertical centre YMC, is obtained: t₁=48[min], t₂=13[min], t₃=30[min], tᵢ₈=91/43[min], tᵢ₆=15,77[min], tᵢ₈=3,5[min], tᵢ₀=524,75[min].

![Fig. 20 Times to achieve 25 pieces on MCM and YMC machining centers](image)
From the table 1, we can see that, although on the MCM manufacturing centre the pieces are fabricated at a single fixing, and the fixing and removing time is zero, overlapping on the manufacturing one, however the necessary time for obtaining 25 pieces is higher than in the case of YMC manufacturing centre.

For a more significant showing of the analyzed situation, with the determined values for the different classes of the involved times, there was built the diagram from fig. 20.

**Conclusions**

From the two manufacturing technological variants analysis of pieces on the machining centers MCM and YMC, presented in this paper we can extract the following conclusions:
- The total necessary time for making the 25 pieces is higher in the case of the vertical machining centre with 4 axes;
- Although both manufacturing centers work with the same set of cutting tools, the preparing-finishing time is higher at the vertical manufacturing centre with 3 axes YMC 1050, which performs the pieces at three fixings, unlike the MCM where the manufacturing is made at a single fixing;
- The consumed time with the fixing and removing of the products is zero for the MCM, which allows the product fabrication at a single fixing, the fixing and removing time overlapping on the manufacturing one;
- Although both machines work with the same cutting tools set and use the same cutting conditions, the time in which the pieces are manufactured on the machine is higher in the case of MCM, the main causes could be: the lower stiffness of the product fixed in the device, a reason for what there were established an extra number for finish machining, the necessity for making a high number of product orientations, and, not least the outlining manufacturing accomplishment in distinct operations in order to make the product at a single fixing.

**References**

[6] *TopSolid Quick references*, Missler software
[8] *Top Tool*, Missler software