RESEARCH ON THE DEFORMATIONS CAUSED BY THE MANUFACTURING DEVICES ONTO THE PARTS WITH LOW RIGIDITY

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Abstract: *This paper presents results of our research on how low rigid parts are deformed in manufacturing devices when clamping forces act onto them. The studies are based on the plate parts deformation mathematical model after which the values obtained from the mathematical calculation are compared with those obtained by measurements undertaken in our laboratory. The results of the studies give us a better indication of the influence of fixing errors on the final accuracy of the part.*
Key words: *manufacturing devices, dimensional accuracy, clamping force, work piece clamping, elastic deformation.*

1. INTRODUCTION

In the current economic conditions, the existence on the market of a company depends on products quality and costs. The costs are influenced by factors like materials cost, direct and indirect production costs, etc. The products quality is closely related to manufacturing technology used for processing and assembly and to workers and operators professional qualification (Liu 2009). No matter how complex is a product, the quality thereof depends on the quality of the parts of which is made. Therefore each part must be manufactured under the highest possible quality.
The parts quality refers to several aspects: dimensional accuracy, shape accuracy, position accuracy and surface quality. The factors that influence parts quality are plentiful and varied. The most important factors that influence part quality during processing are: cutting tools wear, working parameters used, tool machine wear, tool machine precision, thermal deformations of the technological system, vibrations, internal stress, devices precision, correct locating and clamping of the work piece in the technological system, etc. (Feng, 2009, Richter-Trummer, 2012).
Of all these factors, a decisive role on part quality has the correct locating and clamping of the work-piece in device for processing (Ying Huang 2000). This factor influences the dimensional, shape and position accuracy. To minimize this factor, besides the choice of correct clamping mode, it is also necessary the clamping force calculation.

The parts most influenced by clamping forces are plate-shaped work piece. We consider plate-shaped work piece the parts that material thickness is much smaller compared to the other dimensions (length and width). As the difference between the thickness and other dimensions is bigger the part is less rigid. On this type of parts, in many cases must be machining at least one of the largest areas all over the surface. In these conditions, the influence of clamping forces deform the plate-shaped work piece and appearance of form and position errors of worked surfaces (holes, ducts, pockets) which results in influencing part quality.

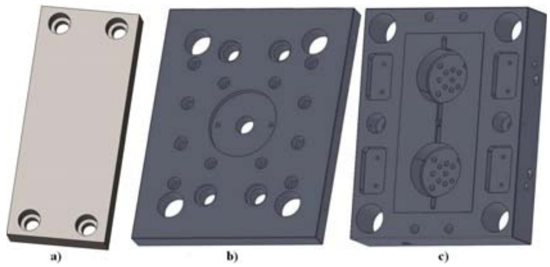

Fig.1. Examples of plate-shaped parts

Figure 1 presents three common types of small rigid plate-shaped parts. These kinds of parts are common in conveyers and mold tooling systems. These parts are characterized by 0.02-0.05 mm tolerances from nominal rate of flatness and parallelism deviation of the largest surfaces and 0.02 mm tolerances from nominal rate of certain functional dimensions (holes, slot guide, pockets) deviations from the most stretched flat surface. Thus, manufacturing precision depends on the quality of this surface cutting.
In this article a few studies have been made on how clamping force needed for clamping parts

influences the final quality of the parts in terms of shape and position accuracy.

2. THEORETICAL CONSIDERATIONS ON THE PLATE-SHAPED WORK PIECES DEFORMATIONS

Clamping force (F_c) acting on parts tend to deform the part. This deformation y_{max} depending on the amount of force may be in elastic or plastic domain, according to Hook's chart.
Part deformation problem does not arise if the parts have a high stiffness, where is possible the deformation in elastic domain only locally on part, without being influenced the part.
If parts present a low stiffness, the size of clamping forces F_c that acts on parts is important because there is the possibility that the part deforms in elastic domain, as shown in Figure 2.
It can be seen from Figure 2.a) that the processing of an elastic deformed plane-shaped work piece leads to obtaining parts that no longer fit into the specified tolerance, and affects parts quality, Figure 2b).

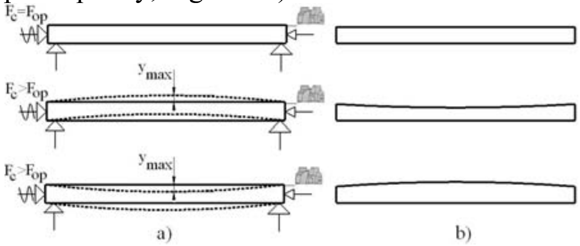

Fig. 2. Deformations caused by the clamping forces

Basically, the parts deformation degree is determined by measuring the deformation y_{max}, and it depends on part stability. For these reasons, it is necessary to know the parts stability. This can be done by calculation or by CAE simulations. Thus, up to certain clamping forces values, when $F_c \le F_{op}$, the equilibrium flat shape of parts is preserved, but if $F_c > F_{op}$, than the flat shape becomes unstable and shape becomes concave and convex depending on the situation.
To calculate the compressive critical force uses equation (1), (Ponomariov 1964):

$$P_{cr} = K\frac{\pi^2 D}{b^2} \tag{1}$$

The buckling coefficient calculation is done with the equation (2), (Ponomariov 1964):

$$K = \left(\frac{1}{m}\frac{a}{b} + m\frac{b}{a}\right)^2 \tag{2}$$

Part bending stiffness is calculated using the equation (3), (Ponomariov 1964):

$$D = \frac{E \cdot h^3}{12(1-\nu^2)} \tag{3}$$

After calculating plates bending rigidity, the buckling coefficient and critical compressive force, it results the force a part can be clamp without being deformed.
For clamping a work part on table is necessary to use a clamping force that respects the relation (4).

$$F_c > F_a \tag{4}$$

In the low stiffness plate-shaped work pieces case there are many cases where in order to respect relation 4 it is necessary to use a clamping force that is greater than the compression critical force (5) and leads to part deformation by bulge phenomenon.

$$F_c > P_{cr} \tag{5}$$

For the part deformation theoretical calculation it is used the relation (6)

$$y_{\max} = \frac{M \cdot (0.5l)^2}{2D(1-\upsilon)} \tag{6}$$

3. EXPERIMENTAL RESEARCH ON THE PLATE-SHAPED WORK PIECES DEFORMATIONS

3.1 Experiment design

For deformation experimental determination of the plate-shaped work piece, were used five different types of plates that were clamped on tools machine table by two clamping methods. These clamping methods are the most common methods used in usual manner.
Schematically, locating and clamping method is done as in the diagram of Figure 3.¶

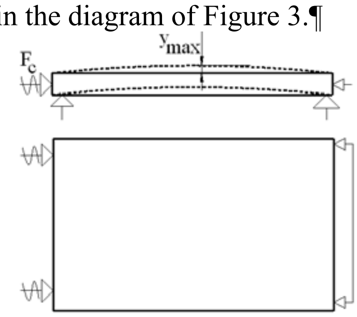

Fig. 3. Locating and clamping methods
Each part is clamped to the machine tool table in two devices. A first clamping solution is in

clamping jaws while the second one is machine vise. For each variant the plate is clamped with a clamping force F_c ranging from 0 to maximum, and is measured the deformation in the middle of the plate with a dial indicator. Clamping force F_c is applied from 0 to a maximum value which is reached for 0.1 mm plate deformation.

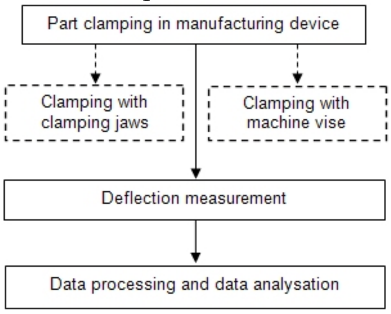

Fig.4. Experimental work plan design

The experiment work plan design is schematically shown in Figure 4.

3.2 Equipment and measurements

In order to achieve the experiments, were used the following devices and equipment:

- Machine vise with the maximum jaws opening of 180 mm, with 40 KN maxim clamping force
- Clamping jaws with 15KN maxim clamping force.
- Machine T-slot table
- Dial indicator with 0.01mm resolution
- Electronic torque wrenches
- Four plate-shaped work pieces:
    - Duralumin 200x200x10 mm;
    - Duralumin 180x130x20 mm;
    - Steel 180x130x20mm;
    - Steel 200x200x10 mm;

3.3 Discussion of the results

3.3.1 Clamp in clamping jaws

All types of plates were mounted on machine table using fixing scheme in Figure 3. Each part was clamp with a force F_c to 0.1 mm maximum deformation in the middle of the plate. It should be noted that not all plates reached 0.1 mm deformation because of technological reasons this was not possible. Where 0.1 mm deformation was not reached, clamping forces values were calculated by extrapolation from existing data.

For each part type were made three successive clamping and the results were statistically processed to obtain an average clamping force F_c for each measured deformation.

From Figure 5 it is observed that there is a significant difference between the theoretical and practical measured deformations. These differences are greater in the case of steel parts as longitudinal elastic module is lower for aluminium alloys than for steel.

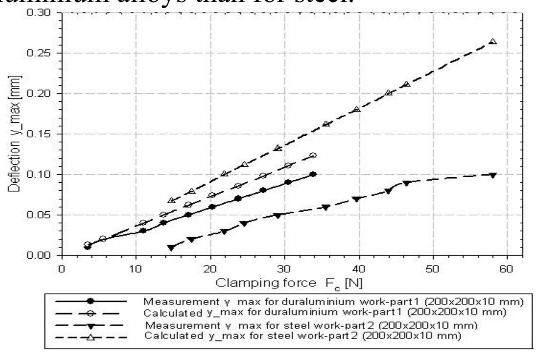

Fig.5. Maximum deformations of the 200x200x10 mm plate-shaped work piece

In case of plate-shaped work piece 2 with 180x130x20 mm overall dimensions, the measured and calculated results are presented in Figure 6.

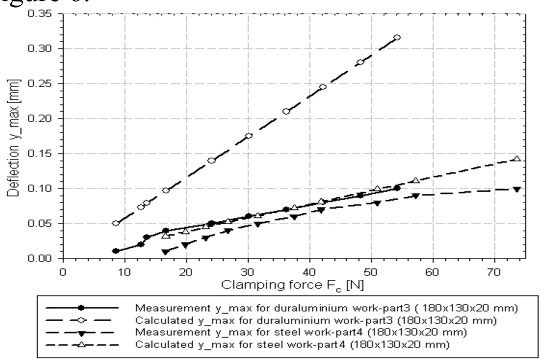

Fig.6. Maximum deformations of the 180x130x20 mm plate-shaped work piece

From Figure 6 it is observed that also in this case there is a significant difference between the calculated and the measured size of deformation.

3.3.2 Clamp in machine vise

In the case of parts in machine vise, the experiment was done only for the 180x130x20 mm dimensions plate. The other type of plate couldn't be clamp because the machine vise does not allow clamping parts over 180 mm. And in this case was simultaneously deformed both a duralumin part and a steel part. For each part, were performed measurements three times and the measured quantities were averaged to obtain an average preload.

Plate-shaped work pieces were clamped in machine vise on their width, namely the 130 mm size. In Figures 7 are graphically presented the values obtained by measurements and calculations.

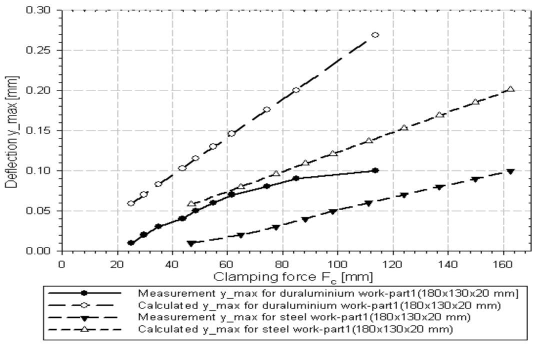

Fig.7. Maximum deformation variation of a 180x130x20 mm plate-shaped work piece by clamping force

From figure 7 is observed that in the case of parts clamping in machine vise, as for clamping in clamping jaws, there is a significant variation of measured deformation of the calculated one.

4. CONCLUSIONS

After experimental tests presented in this paper we can make some observations that have practical use when cutting plate-shaped work piece requiring high manufacturing precision.

A first observation is that there is a significant difference between the calculated value and the practically measured deformations. Thus, there are deviations between 120-300% between the two deformations. There is a lower practical deformation compared to calculated deformations for a given force. This difference is due to several causes:

- Backlash cancelling between different parts of clamping devices (ex. Backlash on pitch circle);
- A certain force is used for contact surface roughness compaction between part and device.
- Plate-shaped work piece flatness error.

A second observation is that you have to calculate the milling force that is characteristic to operation mode chosen for cutting in order to know what clamping force is recommended to use for parts clamping. For example if we calculate a milling force for a milling cutter with 63mm effective cutting diameter, 5 inserts number in the cutter, 120 m/min cutting speed, 0.3 mm axial depth of cut, 40 mm radial width of cut and 0.05 mm feed per tooth. Tangential cutting force calculation was made using the application developed by Kennametal Company and the calculated force was 23.7N. In these conditions, if we want to process a duralumin plane-shaped work piece with 200x200x10mm overall dimensions fixed in clamping jaws, we have a minimal 0.05mm deformation, as in Figure 5. In these conditions it is necessary to analyze what consequence has this inevitable part deformation to the final piece accuracy.

5. ACKNOWLEDGEMENTS

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6. REFERRING

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7. NOTATION

The following symbols are used in this paper:

F_c = clamping force [N];
F_{op} = optimum force for clamping [N];
y_{max} = part deflection [mm];
P_{cr} = compressive critical force [N/mm];
K = buckling coefficient;
D = part bending stiffness [N/mm];
a = length part [mm];
b = width part [mm];
m = half-wave number value of stuffed plate-shaped part;
E = Young’s modulus, [N/mm2];
ν = Poisson’s ratio;
h = thickness part [mm];
l = length part [mm];
F_a = cutting force [N];
M = flexural torque (bending moment) [Nm];