

The use of finite element analysis in studying deformations of parts clamped in machine tool devices

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Abstract. Increasing the productivity and quality of products while reducing production costs are the main objectives of manufacturing companies in the market economy. For companies that produce parts using cutting processes, these objectives are strongly influenced, among other factors, by the devices used during the manufacturing process. Devices must allow the clamping of workpieces to be done in a short period of time, to have simple construction, to be cheap while positioning and installing errors to be minimal to ensure that the parts correspond to the manufacturing documentation. The calculation of clamping errors of workpieces and devices involves complex analysis, therefore in order to accurately determine these errors, data obtained from experiments, sometimes costly and difficult to be done, are used. This paper presents the clamping force calculation of a prismatic part, as well as the study of elastic deformations that appear by clamping it in the device, using finite element analysis.

1. Introduction

Clamping devices are an important component of the technological system that enable complex parts manufacturing, in a short time, at low costs, and ensuring high surface finish [1]. With the increase of computer capabilities and the development of computer-aided design applications, the study of different structures' behaviour during operation can be simulated with acceptable accuracy [2].

The literature [3], [4] in the domain of devices for machine tool processing offers theoretical approaches necessary for the design. There are also researchers who address different device design and operation aspects. In article [5] the authors present a way to reduce workpiece deformations, by minimizing the value of clamping forces, the position and number of pressing points, the mathematical model found being validated by finite element analysis. In article [6], a multi-objective optimization model that allows the reduction of deformation degree and improves the uniformity of deformations' distribution was developed. The researchers [7] study the deformations which appear when clamping parts with thin walls and curved surfaces, using finite element analysis. In article [8] they focus on identifying influencing factors and highlighting the deformations of parts clamped in the device by using finite element analysis. A theoretical approach to improving eccentric clamping device is presented in [9]. The article proposes a mathematical model for calculating an eccentric replacement cam in order to increase the clamping force. Paper [10] presents the finite element analysis stages for establishing optimal construction and loading variant of a modular clamping device for prismatic and circular parts. It shows analysis methodology and the results of its application, under defined loading conditions, in order to identify the most loaded area from the device structure studied.

The paper presents the calculation of the clamping force of a prismatic part, as well as the study of elastic deformations that appear at its installation in the device using finite element analysis.

2. Clamping force calculation

The part to be processed and clamped in the device is shown in figure 1. It is a prismatic piece containing two tolerated holes $\text{Ø}15 \text{ H7}$ and $\text{Ø}20 \text{ H7}$. The part material is an aluminium alloy, Al 6061.

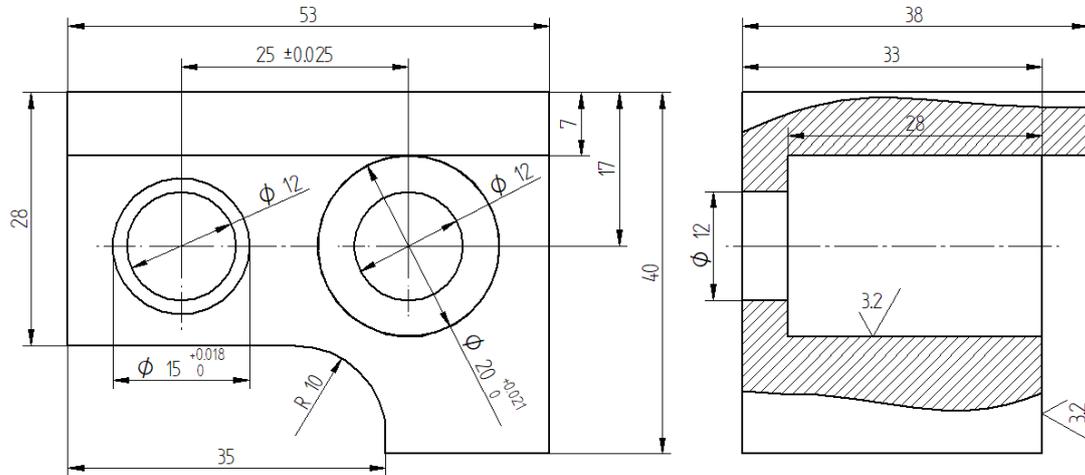


Figure 1. The part to be processed

The machining is done on a milling center. Operations are indicated in table 1, and the cutting parameters in table 2. The outer surfaces had been processed in a previous operation.

Table 1. Machining operations and the tools used.

Machining operation	Tool Description	Tool material	Diameter d [mm]	No. of teeth, z
Face milling la $33^{+0.15}$	End mill	HSS	40	6
Spot drilling	Spot drill	HSS	10	2
Drilling $\text{Ø}12$,	Drill	TiAlN	12	2
Hole milling $\text{Ø}14.7$	End mill	HSS	12	3
Hole milling $\text{Ø}19.7$	End mill	HSS	16	3
Reaming $\text{Ø}15^{+0.018}(\text{H7})$	Reamer	Carbide	15	5
Reaming $\text{Ø}20^{+0.021}(\text{H7})$	Reamer	Carbide	20	6

Table 2. Cutting parameters.

	DOC a_p/cut [mm]	WOC a_c/cut [mm]	Speed v_c [m/min]	Rotation RPM [1/min]	Feed v_f [mm/min]	Torque Mt [Nm]	Power P [kW]	Cutting force Fc [N]
Face milling $33^{+0.15}$	5	37	163	1297	892	16.20	2.20	828.7
Spot drilling	1.5		30	955	134	0.80	0.08	160.1
Drilling $\text{Ø}12$,			225	5968	2268	1.92	1.20	320.0
Hole milling $\text{Ø}14.7$	3	5	338	6724	2440	2.13	1.50	114.9
Hole milling $\text{Ø}19.7$	3	4	348	6923	2742	2.62	1.90	224.1
Reaming $\text{Ø}15^{+0.018}$			60	735	406	2.60	0.20	50.0
Reaming $\text{Ø}20^{+0.21}$			60	955	449	1.00	0.10	100.1

Considering that it is a part with thin walls, the problem of designing an orientation and clamping device appears so that the elastic deformations of parts produced by the clamping force do not affect the precision of the $\text{Ø}15\text{H7}$ and $\text{Ø}20\text{H7}$ after the reaming operation is performed. In order to determine the clamping force, the scheme shown in figure 2 is used, where it was considered that the predominant stress is produced by flat surface milling operation (as shown in table 2).

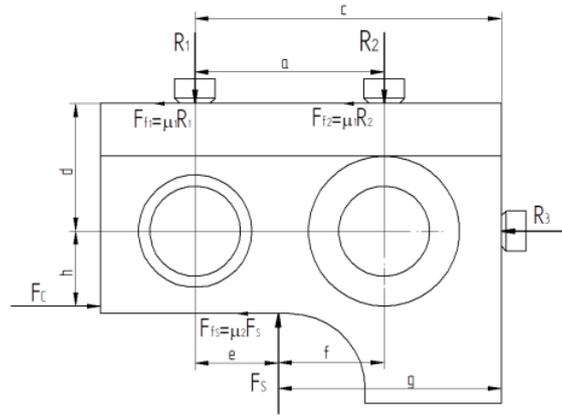


Figure 2. Scheme for retention force and reaction forces calculation.

From force and moment equilibrium expressions one can determine the retention and reaction forces (R_1, R_2):

$$F_s = \frac{k \cdot F_c}{\mu_1 + \mu_2} \quad (1)$$

$$R_1 = \frac{F_c}{c-b} \left(k \frac{g-b}{\mu_1 + \mu_2} - h \right) \quad (2)$$

$$R_2 = \frac{F_c}{c-b} \left(k \frac{c-g}{\mu_1 + \mu_2} + h \right) \quad (3)$$

Where

μ_1 and μ_2 represent the friction coefficient between the workpiece and the support, and between the workpiece and the clamping element, for steel and aluminum $\mu_1 = \mu_2 = 0.45$

F_c – cutting force; $F_c = 828.7$ N

F_s – retention force

a, b, c, d, e, f, g, h – distance between forces' points of application and different characteristic points from the workpiece to be machined

k – safety coefficient, $k=2$ [1]

Replacing the letters in the relations, (1), (2), (3) with the corresponding values in figure 1 and the value of the cutting force for the milling operation in table 2, the values of the retention force and the reaction forces from the supports are obtained (table 3).

Table 3. Calculated values for retention force and reaction forces

Parameter	Symbol	Value
Retention force	F_s [N]	1850.0
Reaction force , support 1	R_1 , [N]	704.5
Reaction force , support 2	R_2 , [N]	1145.5

3. FEM analysis

The assembly that is studied is composed by the part, the support's elements and by the clamping element. NX Nastran is used to solve the equations. For each component, the material, the type of the element (solid) is defined. The discretization of the model with Ctetra 10 3D elements is shown in figure 3, and the mesh properties in table 4. After the calculations, the results regarding the deformations and stresses that appear in the part when clamped in the device are obtained (figure 4 and figure 5). From the results of the analysis it is observed that although the Von Mises stresses are within limits allowed for the AI 6061 material (tensile yield stress 276 MPa), the deformations are approximately 0.006 mm, which in the case of holes with the diameter at the upper limit can be rejected. It can also be observed that the clamping element creates an evident deformation on the contact surface with the workpiece.

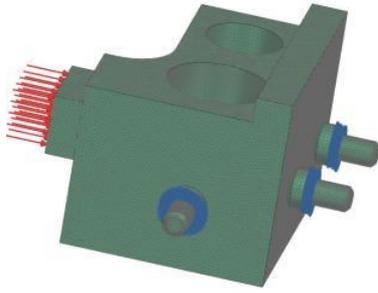


Figure 3. Discretization of 3D model. Applied forces and constraints

Table 4 Mesh information

Type of mesh	3D
Element Type	CTETRA(10)
Element Size	0.5 mm
Number of elements in the mesh	501929
Number of nodes in the mesh	828200

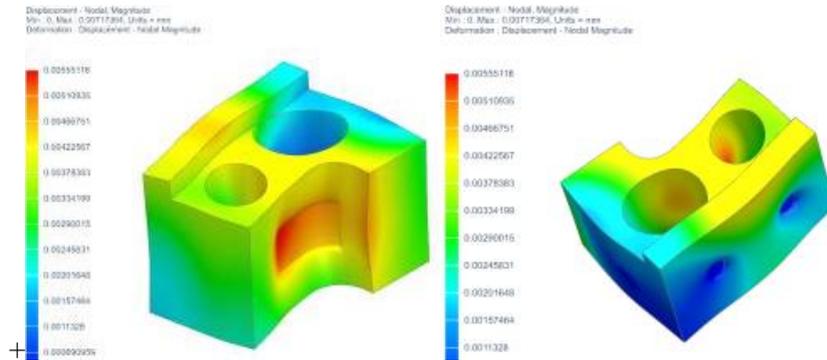


Figure 4. Displacement.

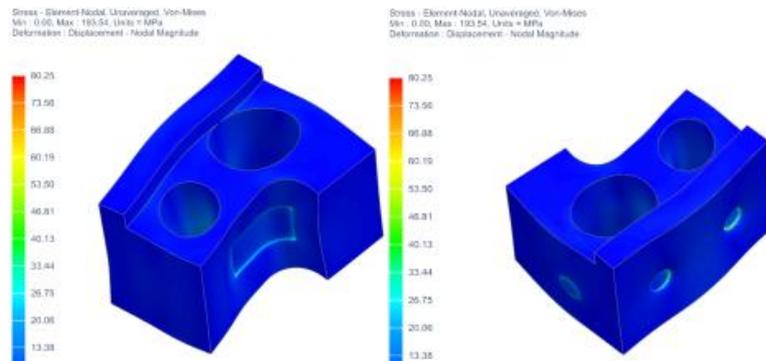


Figure 5. Von Mises stress.

In order to diminish the elastic deformations of the part, it is proposed to make a clamping element with a higher height and at the same time to reduce the clamping force. In order to reduce the retention force, the cutting force for the flat milling operation is reduced by reducing the cutting depth by half, i.e. $t = 2.5$ mm. Table 5 presents the recalculated values of the forces acting on the workpiece.

Table 5. Recalculated forces' values

Parameter	Symbol	Value
Cutting force	F_c [N]	331.3
Retention force	F_s [N]	740.0
Reaction force , support 1	R_1 [N]	282.0
Reaction force , support 2	R_2 [N]	458.0

The finite element analysis is resumed, and the deformations produced by the retention force are analyzed. From figure 6, it can be observed that this time the deformations reduce below the value of 0.001 mm, which is considered acceptable.

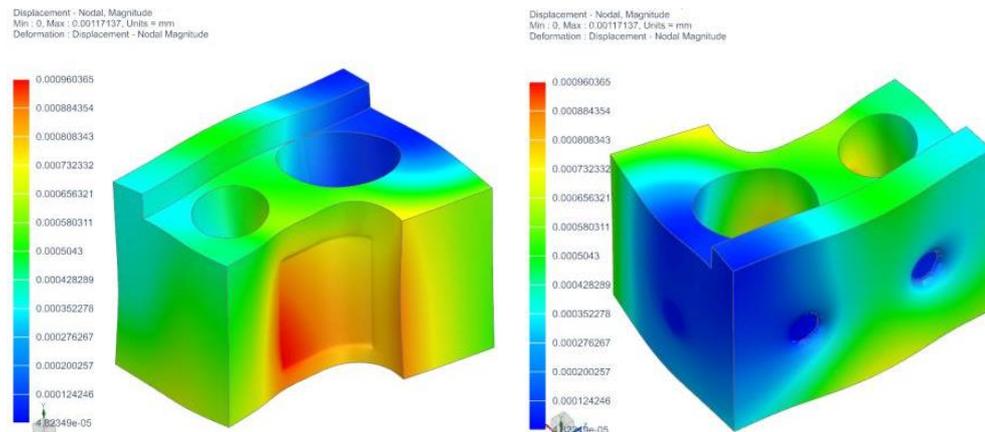


Figure 6. Displacement for recalculated forces.

4. Conclusions

The case study presents the estimation of the deformations that appear when clamping a part with thin walls in a device. Considering the cutting depth 5 mm, the required clamping force and reaction forces from the supports were calculated. The finite element analysis has shown that in this situation, the clamping force produces a deformation of the workpiece by approximately 0.006 mm, which is considered inadequate. In order to reduce this deformation, the contact surface of the clamping element was increased by 100% and the cutting depth to 2.5 mm, which led to a 60% increase of the clamping force. The finite element analysis was resumed, and this time the maximum deformation was below 0.001 mm, which was considered acceptable. Estimating the clamping errors right from the design phase, with the help of finite element analysis, allows the reduction of rejected parts and costs for device modifications.

Acknowledgements

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