International Journal of Manufacturing Economics and Management
ISSN 2784-1278 ISSN-L 2784-1278, Vol. II, No. 1 / 2022
https://doi.org/10.54684/ijmem.2022.2.1.41

SIMULATION OF THE INFLUENCE OF THE TIGHTENING FORCES TO A BUSHING TYPE PART

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Abstract: The MUSDP technological system (machine tool, tool, device, part) consists of several technological equipment modules and creates a surface or a complex of surfaces on a semi-finished product using different processing processes. From one processing to another processed surface will be accompanied by deviations from the nominal dimensions to be obtained. These deviations are called processing errors, which also include fixing errors. The paper presents a study regarding the simulation of the influence of the tightening forces to a bushing type part using Solidworks software. The simulation takes into consideration three material types (DIN1.0406-C25, DIN1.0601-C60, DIN1.2085 - X33CrS16) with eight different wall thikness (3-10mm) and four values of clamping force (300, 600, 900, 1200N). The presented results show the level of displacement and the trend line at different type of materials and different wall thickness. According to the obtained results, it can be specified that from the wall thickness higher than 6 mm, the fixing errors that appear can be neglected.
Key words: Thickness wall, simulation, forces, part, bushing, material.

1. INTRODUCTION

Fixing the half finished products in order to maintain the reciprocal position between the cutting tool edge and the work surface involves determining the direction, direction and size of the forces acting in the system. Thus, under equilibrium conditions, the fixing forces are established, which produce elastic deformations of the half finished products with a direct influence on the dimensional and shape precision of the machined surfaces, introducing processing errors called fixing errors, [1]. The part orientation pattern, the fixing system in the device or on the machine tool table, the size, the direction, the direction and the point of application of the fixing forces influence the fixing errors.
The main causes of the fixing errors are: the elastic deformations of the half finished products produced by the fixing efforts (Figure 1), the elastic deformations of the device elements produced by the fixing efforts and the local contact deformations, [2].

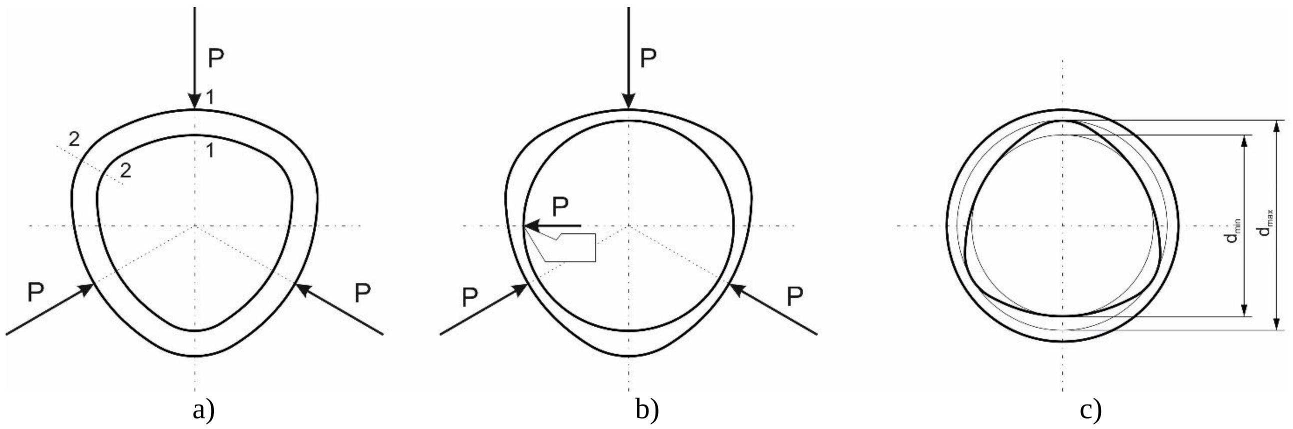


Fig.1. Elastic deformations when fixing in the mandrel with three jaws and machining by turning the inner surface, [2]: a) elastic deformations of the bush after fixing; b) the shape of the surface after processing; c) form error due to fixing; 1-bushing, 2-lathe cutting tool, [3]

The calculation of the shape errors produced by fixing the bushing can be done by determining the deformations caused on the direction of action of the foreign forces (section 1-1, Figure 1(a)) and on the direction 2-2 (Figure 1(a)) between the two forces, by applying energy deformation potentials.
In the case of the orientation scheme proposed in Figure 1(a), the deviation from the circularity measured on the radius direction in section 1-1 is given by the eqiation (1), [1, 2, 4, 5].

$$\Delta_{r(1-1)} = 0.016\frac{PR^3}{EI} \tag{1}$$

where: *P* is the clamping force on a chuck tray, [daN]; *R* represents the average radius of the bush, [cm]; *E* is the modulus of elasticity of the material, [MPa]; *I* is the moment of inertia of the cross section of the bush, [cm^4], $I=bh^3/12$, where *b* is the height of the ring, [cm], and *h* represents the thickness of the wall, [cm].
Taking into account the same orientation scheme in Figure 1(a), the deviation from the circularity measured on the radius direction in section 2-2 is given by the equation (2).

$$\Delta_{r(2-2)} = -0.014\frac{PR^3}{EI} \tag{2}$$

The shape error of the inner surface is determined by the difference of the diameters of the circumscribed and inscribed circles (Figure 1(c)) with the help of the equation (3).

$$\Delta D = d_{max} - d_{min} = 2(|\Delta R_{1-1} + \Delta R_{2-20}|) = 0.03\frac{PR^3}{EI} \tag{3}$$

In this paper, the influence of fixing forces on fixing errors has been studied using SolidWorks software package in order to establish the minimum size of the bush wall thickness, the choice of the respective material and the clamping force over which the shape deviations can be neglected. This approach is useful in the next step of the research, which will consist in hardening the inner surfaces with a hardening head with three deformation rollers, hardening that can be assimilated with the turning operation from the point of view of kinematics and fixing mode.

2. MATERIALS AND METHOD

In order to find out the form errors due to the fixing efforts for a bushing-type part fixed in the mandrel with three jaws (Figure 2), the SolidWorks software package was used with the following factors as input parameters considered (Table 1). In order to minimize form errors, was made a plate where will be defined as fixed one and 3 pins with 0.5 mm diameter and 2 mm height. The pins are placed radially at 120° and the position of these are deviated by the position where the force was applied with 60°.

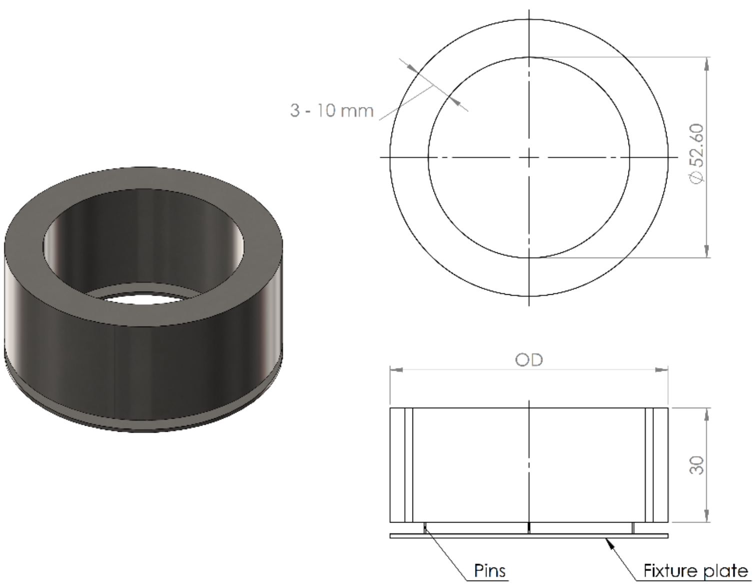


Fig. 2. Part 3D view

Table 1. Input parameters considered in the simulation [6]

Parameter	Type / Values
Material	DIN 1.0406 (C25) DIN 1.0601 (C60) DIN 1.2085 (X33CrS16)
Wall thickness, [mm]	3-10
Forta aplicata, [daN]	30, 60, 90, 120

The material characteristics used in the simulation are presented in Table 2, [6].

Table 2. Materials proprieties

Material 1.0406 (C25)		Material 1.0601 (C60)		Material 1.2085 (X33CrS16)	
Yield strength:	230 MPa	Yield strength:	660 MPa	Yield strength:	950 MPa
Tensile strength:	440 MPa	Tensile strength:	850 MPa	Tensile strength:	1160e MPa
Elastic modulus:	2.1e+05 MPa	Elastic modulus:	2.1e+05 MPa	Elastic modulus:	2.07e+05 MPa
Poisson's ratio:	0.28	Poisson's ratio:	0.28	Poisson's ratio:	0.28
Mass density:	7800 kg/m^3	Mass density:	7800 kg/m^3	Mass density:	7750 kg/m^3
Shear modulus:	7.9e+04 MPa	Shear modulus:	7.9e+05 MPa	Shear modulus:	7.9e+07 MPa
Thermal expansion coefficient:	1.1e-005 /K	Thermal expansion coefficient:	1.1e-005 /K	Thermal expansion coefficient:	1.1e-005 /K

For the presented part the mesh was made automatically with default settings from simulation software. Figure 3 presents the meshing with the parameters listed on Table 3.

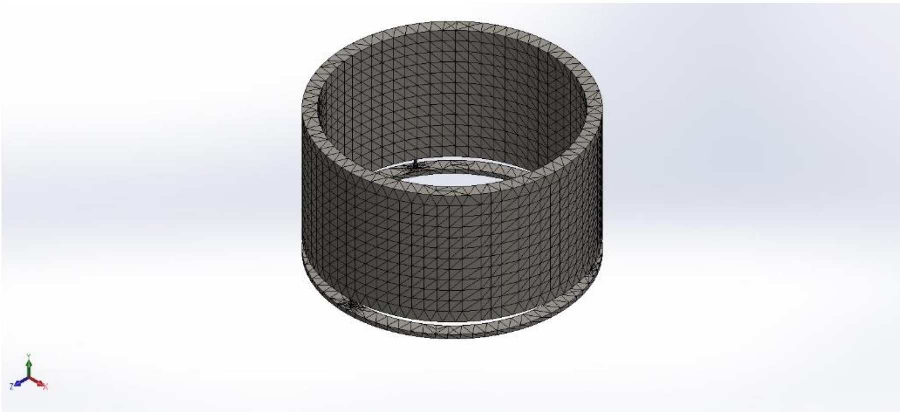


Fig. 3. Solid mesh structure

Table 3. Used meshing parameters

Mesh type	Solid Mesh
Mesher Used:	Standard mesh
Automatic Transition:	Off
Include Mesh Auto Loops:	Off
Jacobian points	4 Points
Element Size	2.53364 mm
Tolerance	0.126682 mm
Mesh Quality Plot	High
Total Nodes	19977
Total Elements	11180
Maximum Aspect Ratio	13.688
% of elements with Aspect Ratio < 3	90.9
% of elements with Aspect Ratio > 10	0.179
% of distorted elements(Jacobian)	0

In order to start the simulation test was used a static study where the part was fixed and the force was applied radially on highlighted zone (Figure 5). Fixing the part corresponds to “Fixture plate” as it can see on the Figure 4.

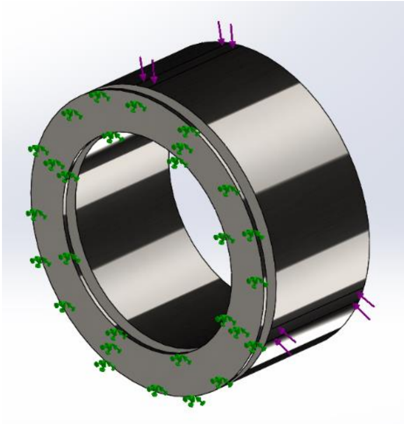


Fig. 4. Part fixing

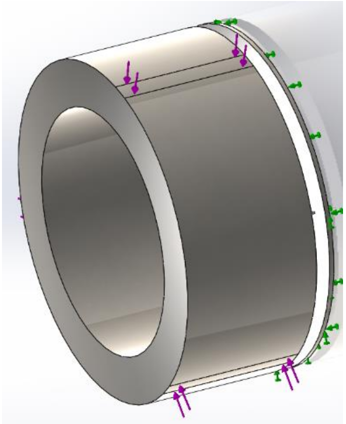


Fig. 5. Loads

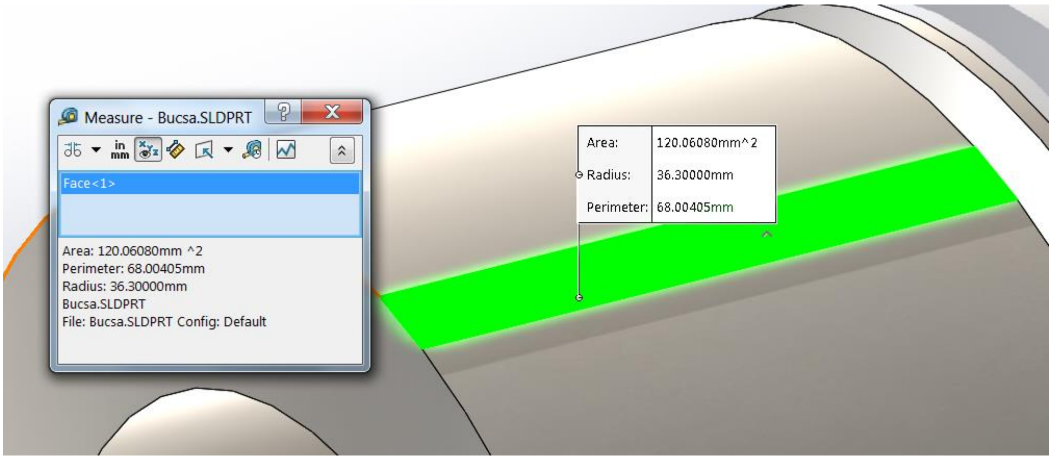


Fig. 6. Loading arrea

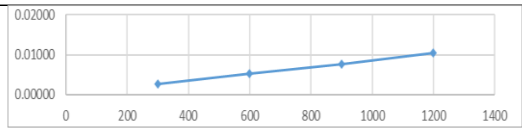
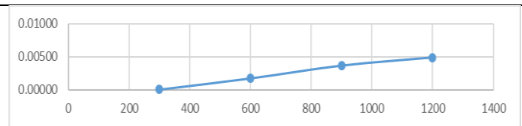
The zone where was loaded the force are presented on the Figure 5. Area of the loading zone is 120.06 mm^2 and the dimension is 4 x 30 mm (Figure 6). The force is applied to the three jaws and the loads are evenly distributed.

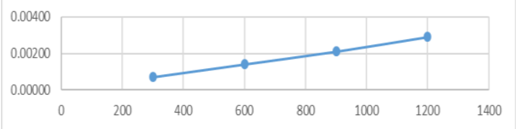
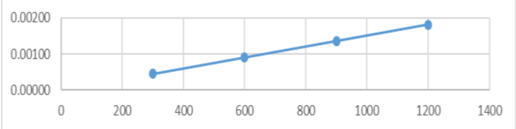
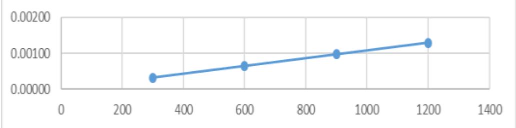
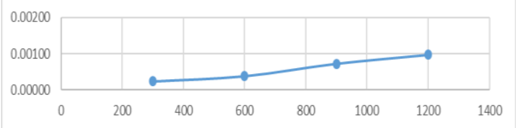
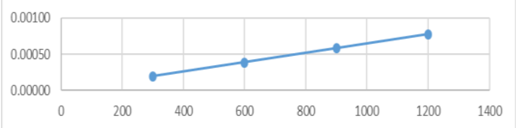
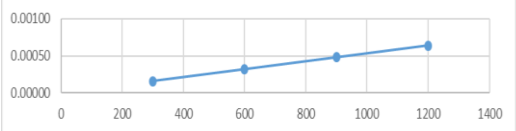
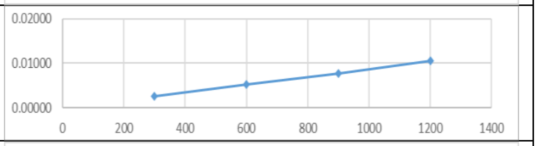
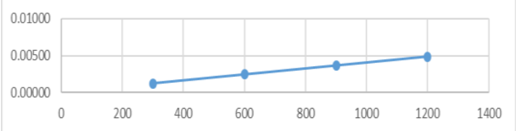
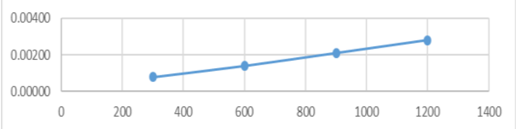
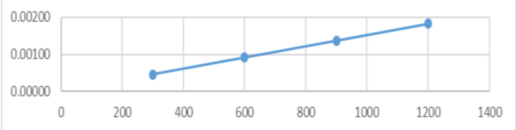
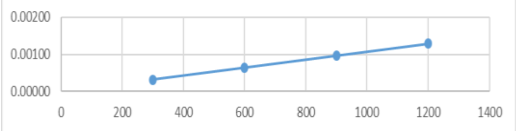
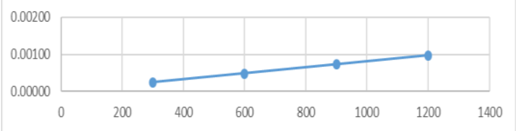
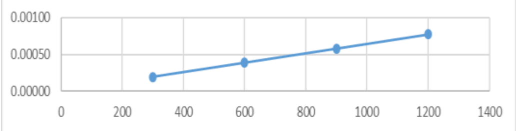
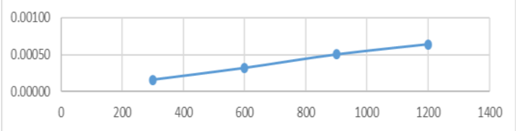
3. RESULTS AND DISCUSSION

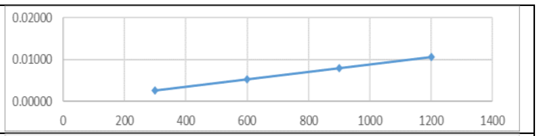
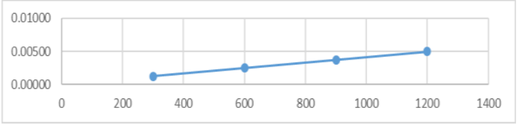
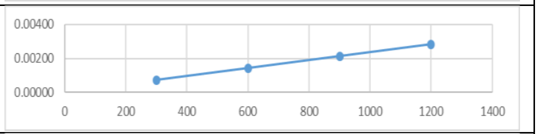
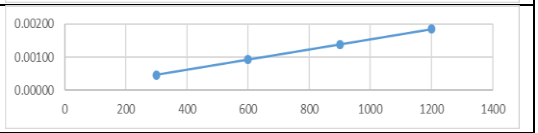
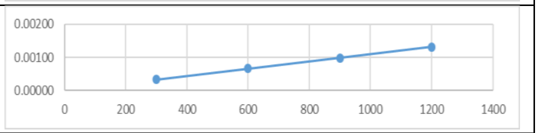
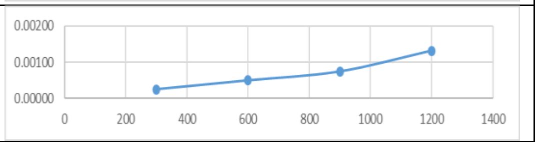
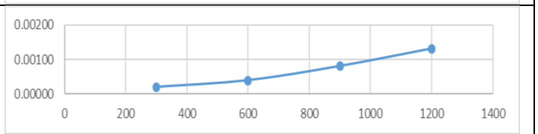
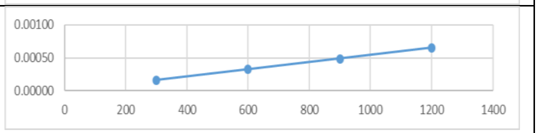
Taking into account the above mentioned parameters, a number of 96 simulations resulted in which the results obtained in terms of maximum displacements can be observed.

The results obtained and diagrams with applied force influence on the displacement are presented in Table 4. Thus, as can be seen from the Table 3 the influence of applied force to the maximum displacement is linear one for all materials regardless of wall thickness.

Table 4. Results obtained

Wall thickness [mm]	Material	Dimensions [mm]	Force [daN]	Maximum Displacement [mm]	The influence of applied force to maximum displacement
3	DIN1.0406 (C25)	ID*: 52,60 OD*: 58,60 H*: 30	30	0.00260	
			60	0.00521	
			90	0.00758	
			120	0.01041	
4	DIN1.0406 (C25)	ID: 52,60 OD: 60,60 H: 30	30	0.00006	
			60	0.00175	
			90	0.00368	
			120	0.00490	

5	DIN1.0406 (C25)	ID: 52,60 OD: 62,60 H: 30	30 60 90 120	0.00070 0.00140 0.00210 0.00290	
6	DIN1.0406 (C25)	ID: 52,60 OD: 64,60 H: 30	30 60 90 120	0.00045 0.00091 0.00136 0.00182	
7	DIN1.0406 (C25)	ID: 52,60 OD: 66,60 H: 30	30 60 90 120	0.00032 0.00065 0.00097 0.00129	
8	DIN1.0406 (C25)	ID: 52,60 OD: 68,60 H: 30	30 60 90 120	0.00024 0.00039 0.00073 0.00097	
9	DIN1.0406 (C25)	ID: 52,60 OD: 70,60 H: 30	30 60 90 120	0.00019 0.00039 0.00058 0.00078	
10	DIN1.0406 (C25)	ID: 52,60 OD: 72,60 H: 30	30 60 90 120	0.00016 0.00032 0.00048 0.00064	
3	DIN1.0601 (C60)	ID: 52,60 OD: 58,60 H: 30	30 60 90 120	0.00262 0.00523 0.00765 0.01047	
4	DIN1.0601 (C60)	ID: 52,60 OD: 60,60 H: 30	30 60 90 120	0.00123 0.00245 0.00367 0.00490	
5	DIN1.0601 (C60)	ID: 52,60 OD: 62,60 H: 30	30 60 90 120	0.00079 0.00140 0.00210 0.00280	
6	DIN1.0601 (C60)	ID: 52,60 OD: 64,60 H: 30	30 60 90 120	0.00046 0.00091 0.00137 0.00182	
7	DIN1.0601 (C60)	ID: 52,60 OD: 66,60 H: 30	30 60 90 120	0.00032 0.00064 0.00097 0.00129	
8	DIN1.0601 (C60)	ID: 52,60 OD: 68,60 H: 30	30 60 90 120	0.00024 0.00049 0.00073 0.00098	
9	DIN1.0601 (C60)	ID: 52,60 OD: 70,60 H: 30	30 60 90 120	0.00019 0.00039 0.00058 0.00078	
10	DIN1.0601 (C60)	ID: 52,60 OD: 72,60 H: 30	30 60 90 120	0.00016 0.00032 0.00050 0.00064	

3	DIN1.2085 (X33CrS16)	ID: 52,60 OD: 58,60 H: 30	30 60 90 120	0.00266 0.00531 0.00797 0.01062	
4	DIN1.2085 (X33CrS16)	ID: 52,60 OD: 60,60 H: 30	30 60 90 120	0.00124 0.00249 0.00373 0.00497	
5	DIN1.2085 (X33CrS16)	ID: 52,60 OD: 62,60 H: 30	30 60 90 120	0.00071 0.00142 0.00213 0.00285	
6	DIN1.2085 (X33CrS16)	ID: 52,60 OD: 64,60 H: 30	30 60 90 120	0.00046 0.00092 0.00138 0.00185	
7	DIN1.2085 (X33CrS16)	ID: 52,60 OD: 66,60 H: 30	30 60 90 120	0.00033 0.00066 0.00099 0.00132	
8	DIN1.2085 (X33CrS16)	ID: 52,60 OD: 68,60 H: 30	30 60 90 120	0.00025 0.00050 0.00074 0.00132	
9	DIN1.2085 (X33CrS16)	ID: 52,60 OD: 70,60 H: 30	30 60 90 120	0.00020 0.00039 0.00081 0.00132	
10	DIN1.2085 (X33CrS16)	ID: 52,60 OD: 72,60 H: 30	30 60 90 120	0.00016 0.00033 0.00049 0.00065	

* ID-inner diameter; OD-outer diameter; H-height.

The Figure 7 presents the deformed bush mode with a 2445:1 deformation scale. The deviation from circularity is presented in Figure 8 are exemplified the deviation from circularity which it can be compared with the specification from the execution drawing and to know if the chosen model it can respect the requested precision or not.
On the Figure 9 was made a comparation between the wall thickness and the maximum displacement for all materials used. The difference between materials is very tight and the displacement rising when the wall thickness is smaller.

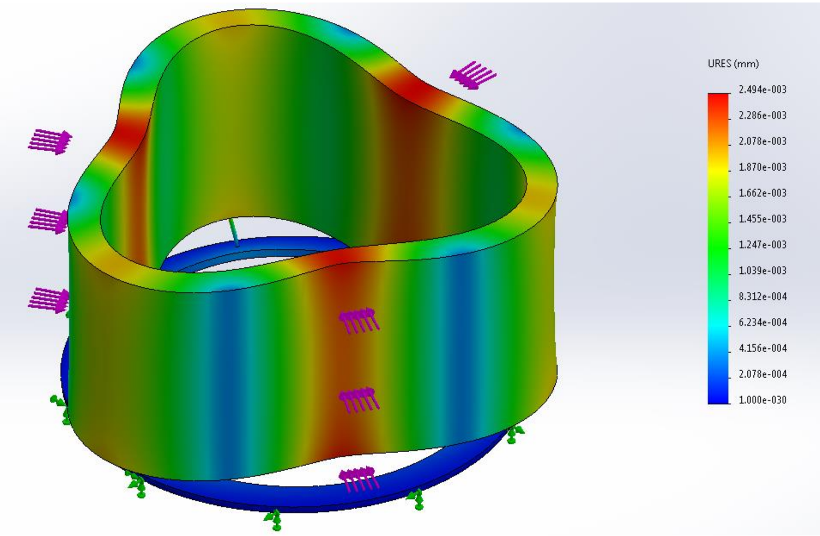


Fig. 7. Deformed part

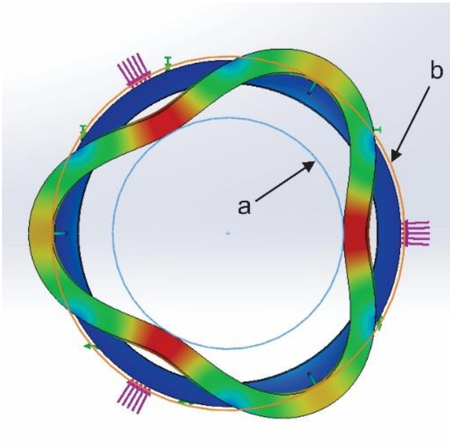


Fig. 8. Circularity deviation: a- inscribed circle; b- circumscribed circle

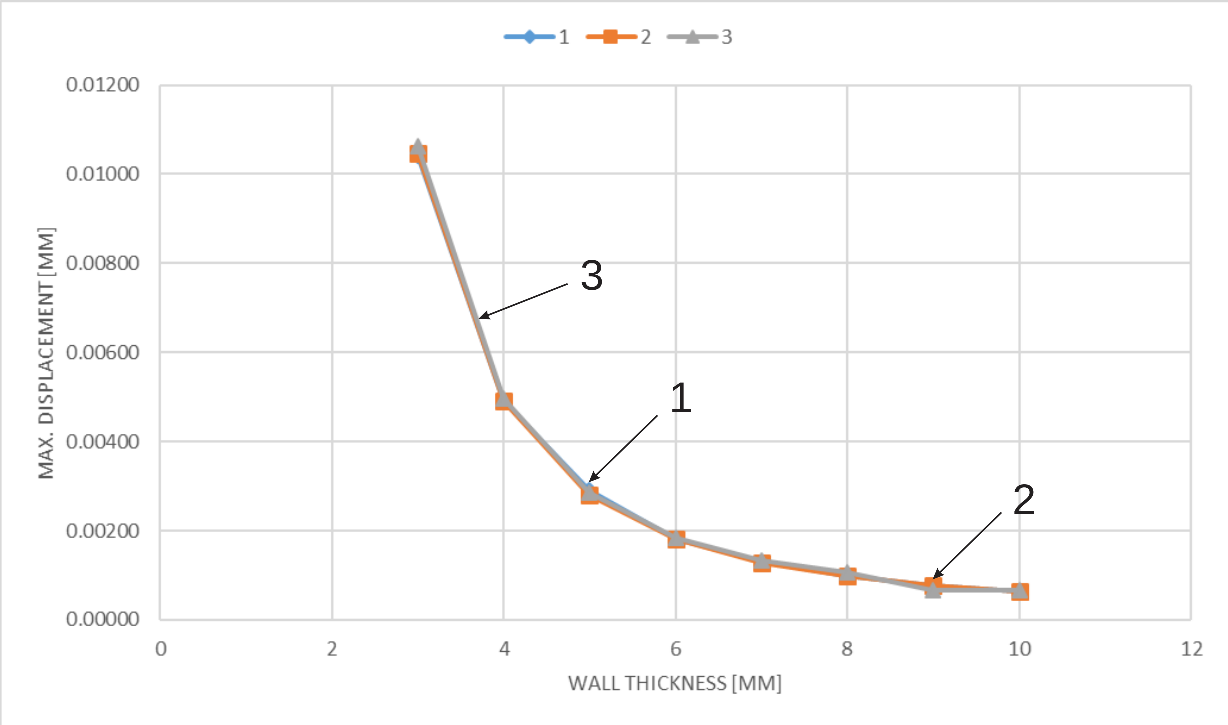


Fig. 9. The influence of wall thickness to maximum displacement
(1 - DIN1.0406 (C25), 2 - DIN1.0601 (C60), 3 - DIN1.2085 (X33CrS16)

4. CONCLUSIONS

In the case of inner surface processing, the appearance of dimensional deviations is encountered from one technological operation to another, deviations called processing errors which also include the errors of fixing in the device or on the table of the machine tool. In the paper, the simulation performed on the three materials (DIN1.0406-C25, DIN1.0601-C60, DIN1.2085 - X33CrS16), using the SolidWorks software package, with eight different wall thickness (3-10mm) and four values of clamping force (30, 60, 90, 120 daN) highlighted the fact that in the case of bushings with thicknesses greater than 6mm the fixing errors that appear can be neglected. Also, the study recommends both the choice of the materials and clamping force respective over which these shape deviations can be neglected or which will not significantly influence the total processing error. The results obtained in this paper are useful in the next stage of the research where it is desired to harden the inner surface with three-roller hardening heads, hardening that can be assimilated with the turning operation from the point of view of kinematics and fixing way.

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Received: March 19, 2022 / Accepted: June 15, 2022 / Paper available online: June 20, 2022 © International Journal of Manufacturing Economics and Management