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FIXTURING DEVICE FOR DRILLING A STRAIGHT SHAFT

Abstract: *The paper presents a fixturing device used for machining by drilling a straight shaft. The shaft was manufactured on EMCO CONCEPT TURN 55 CNC. The blank used was a bar with circular cross-section. The orientation and fixing scheme of the part and the orientation elements for fixturing device are presented as they were drawn in Autodesk Inventor and AutoCAD software.*

Key words*: fixturing device, straight shaft, Autodesk Inventor, AutoCAD, drilling.*

1. INTRODUCTION

A fixturing device is a parts assembly with very precise technical functions which aims to machine by drilling parts from machine building industry which are made of different materials and having specific characteristics.

The use of a fixture device allows an uniformity of the machining, a reduced machining time and machine operator safety [1], [2].

The shafts are parts with cylindrical shape used mainly in machine building industry.

They are supported by knuckles (prisms) and used for supporting the rotation parts (bell wheels, toothed wheels, clutches etc.). The shafts are also stressed to bending, their main purpose is to transmit the torque [3].

By meaning, a software is an intellectual product which consists in programs, procedures, rules and associated documentation used for the functionality of a data processing system [4].

In the last time, numerous software application as AutoCAD [5], Autodesk Inventor [6,7], CATIA, were developed in order to carry out 2D and 3D modeling of some components.

These software were used to design, visualize and simulate the products before manufacturing stage.

The drilling fixture and the straight shaft presented in this paper were drawn using Autodesk Inventor software package, which satisfies all aspects related to design, esthetics and assemblage.

The orientation and fixing scheme, as far as the orientation elements of the fixture device were drawn using AutoCAD designing software, which enables with efficiency accurate 2D modeling of component parts.

2. THE ORIENTATION SCHEMA OF THE PART

The position of the future machined surface is determined in the system of the orienting. This system consists in orientation elements which come in contact with orientation surfaces of the blank [8].

The orientation bases system can be chosen in many options, meaning that the orientation bases can be the same with elevation bases or not, or an orientation base can be the same with different orientation elements if, for a given machining operation, the elevation bases system is unique [8].

Figure 1 presents the orientation schema for the shaft part.

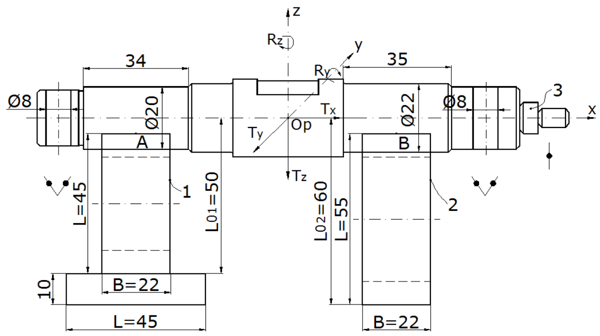

Fig. 1 The orientation schema for straight shaft: 1 – prism with fixing unscrewed holes, 45x22 mm; 2 - prism with fixing unscrewed holes, 55x22 mm; 3 – supporting pin with plate cylindrical head, 16x10 mm.

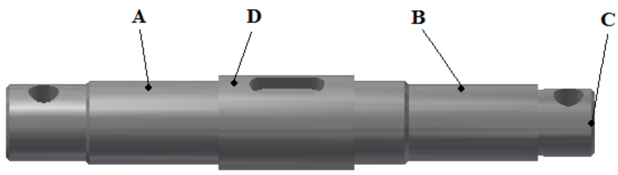

Fig. 2a The 3D view of straight shaft.

Fig. 2b The straight shaft machined on *EMCO CONCEPT TURN 55*.

The shaft presented in Figures 2a, respectively 2b is a straight shaft which is frequently used in mechanical transmissions as a working shaft for the purpose of controlling the stability of the transmission parts as bell teeth, toothed wheel, semi clutches etc.

Another use of this kind of shafts is to fix the machines parts when is used as a main shaft of the machines [9]. The part is 155 mm long and its maximum diameter is Ø25. The shaft has a key channel with 8 mm width, 5 mm depth and 20 mm long which is used for transmitting the rotation of the parts mounted on the shaft. While machining this shaft, the mounting is between centers in centering holes previously machined. There are imposed values of roughness of 6.3 µm, 3.2 µm and 1.6 µm, respectively tolerances of h6 and h8. The chamfers are $1x45^0$ and play a role in easy joining of the parts determining the safety and security while running the machine equipment.

3. THE CHOOSE AND MODELING OF ORIENTATION ELEMENTS

The orientation elements sketches were drawn using AutoCAD software package and their 3D views using Autodesk Inventor Part software (*.ipt*). After that, the parts were assembled, meaning the model drawing.

3.1 The prisms

The orientation schema has 2 prisms with unscrewed fixing holes, Figure 3 and Figure 4, and a supporting pin with plate cylindrical head.

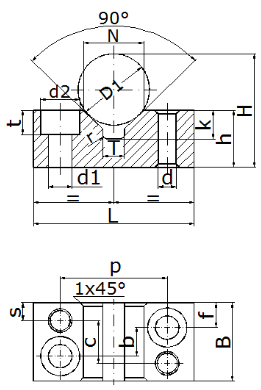

Fig. 3 Prism with holes for Ø20 for surface A.

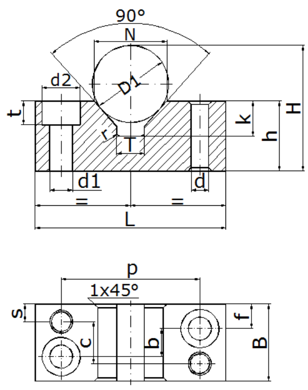

Fig. 4 Prism with holes for Ø22 for surface B.

The bearings presented in Figure 5, respectively Figure 6 were modeled using Autodesk Inventor software as it follows: it is chosen a projection plan, in this case *YZ* plane, in module *Sketch*, in which a sketch is projecting, using *Line* function*,* with dimensions 45x16 mm (Lxh), respectively 55x20 mm. By *Extrude* function, at a width of 22 mm, the virtual model of the two prisms is generated.

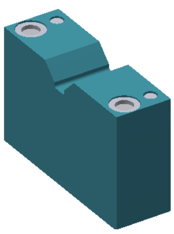

Fig. 5 Prism with holes of Ø20 (3D).

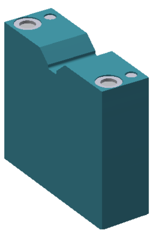

Fig. 6 Prism with holes of Ø22 (3D).

Tables 1 and 2 present the dimensional elements of the two prisms for two diameter dimensions: Ø20 and Ø22.

Table 1

The prism dimensions for Ø20.

D	16-20	**D_1**	20
L	45	**B**	22
h	16	**N**	18
d H7	5	**k**	8
T	6	**p**	30
f	7	**b**	8
s	5	**c**	12
d_1 H13	6,6	**d_2 H13**	11
t +0,2	6,8	**H**	31
r	1	**M**	M6

Table 2

The prism dimensions for Ø22.

D	20-25	**D_1**	22
L	55	**B**	22
h	20	**N**	24
d H7	5	**k**	10
T	8	**p**	40
f	7	**b**	8
s	5	**c**	12
d_1 H13	6,6	**d_2 H13**	11
t +0,2	6,8	**H**	38
r	1	**M**	M6

3.2 The screw with cylindrical head with hexagonal hole and B-type cylindrical pin

For fixing the prisms on the base plate, the cylindrical head screw with hexagonal hole (Figure 7), M8x1 and B-type cylindrical pins (Figure 9), as recommended by [10] and [11].

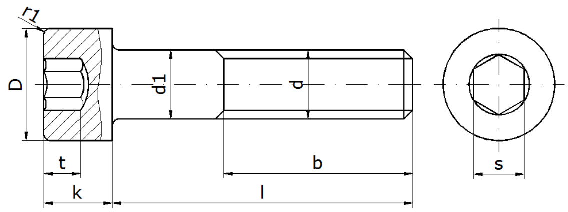

Fig. 7 Screw with cylindrical head with hexagonal hole.

The 3D view of the cylindrical head screw with hexagonal hole and B-type cylindrical pin are presented in Figures 8 and 10.

These are modeled using functions *Line, Circle,* respectively editing functions as *Chamfer* – for chamfering, *Thread* – for threading and *Fillet* – for rounding.

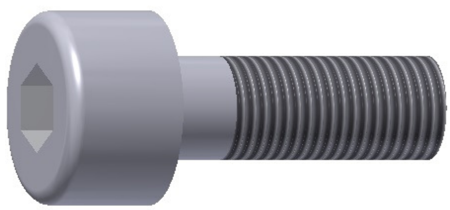

Fig. 8 Cylindrical head screw with hexagonal hole (3D).

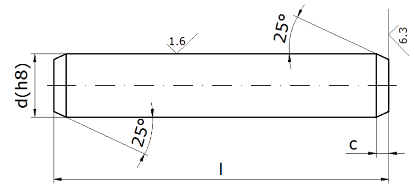

Fig. 9 B-type cylindrical pin.

Fig. 10 B-type cylindrical pin (3D).

The dimensions of these parts are presented in table 3 and table 4.

Table 3

Dimensions of the cylindrical head screw with hexagonal hole.

d	M8x1	**S**	6
D	13	**k**	8
d_1	8	**r_1**	0,8
t	4,3	**b**	18
l	20		

Table 4

Dimensions of the B-type cylindrical pin.

d	c	l
8	1,6	43

3.3 Supporting pin with plate cylindrical head

The dimensions of the supporting pin, Figure 11, are recommended by [10], respectively [11] and are presented in table 5.

The pin presented in Figure 12 is drawn from a sketch in *XZ* plane and by generating 2 circles with function *Circle*, in 3D module of the program with *Extrude* function.

In this manner, the virtual model of the supporting pin is resulting.

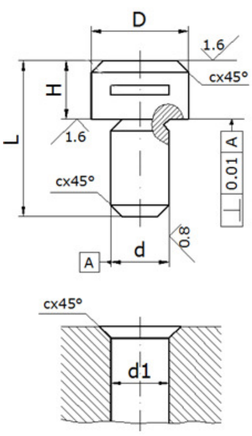

Fig. 11 Supporting pin with plate cylindrical head - surface C.

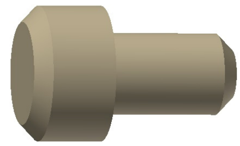

Fig. 12 Virtual model of the supporting pin.

Table 5

Dimensions of the supporting pin.

D	d (n6)	c	L	H
10	6	1,2	16	6

3.4 Corner support

The dimensions of the corner support are presented in Figure 13, respectively table 6.

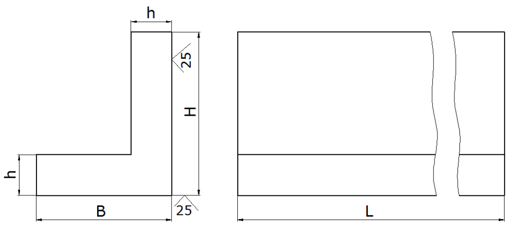

Fig. 13 Corner support.

Table 6

Dimensions of the corner support.

H	B	h	L
81	70	20	68

The corner support presented in Figure 13 was drawn in *Sketch* module, using *Rectangle* function and 3D version was generated using *Extrude* function.

3.5 Two-direction fixing clamp

The dimensions of two-direction fixing clamp, Figure 14, is recommended by [10] and [11], and its dimensions are presented in table 7.

The virtual model of this clamp was drawn by generating a sketch in *XY* plane using functions as *Line*, *Arc*.

After that the 3D model of the solid was generated using *Extrude* function with 25 mm.

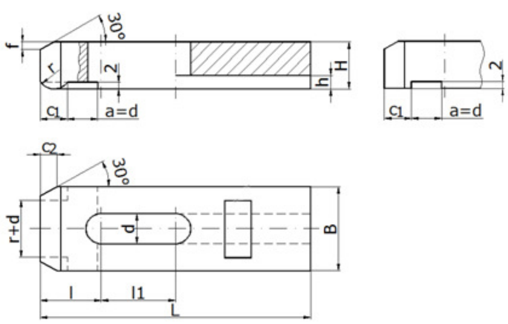

Fig. 14 Mobile clamp for fixing on surface D.

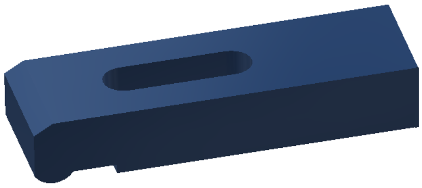

Fig. 15 Virtual model of the clamp.

Table 7

Dimensions of the mobile clamp used for fixing.

d	9	**L**	80
l	18	$\mathbf{l_1}$	22
B	25	**H**	14
$\mathbf{c_1}$	8	$\mathbf{c_2}$	5
f	4	**r**	8
h	4	**Fixing screw**	M8

3.6 Hexagon nut with collar and spherical setting surface

The hexagon nut with collar and spherical setting surface, Figure 16, is recommended by [10] and [11] and its dimensions are presented in table 8.

Figure 17 presents the 3D model of the hexagon nut with collar and spherical setting surface drawn using *Line*, *Circle and Extrude* functions with 12 mm.

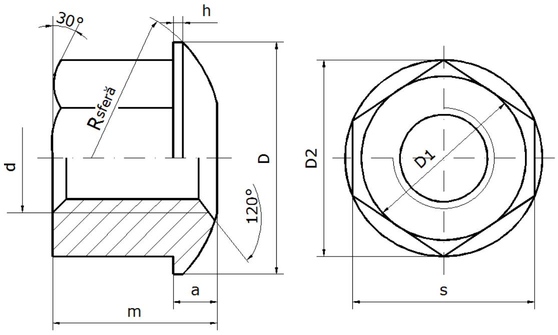

Fig. 16 Hexagon nut with collar and spherical setting surface.

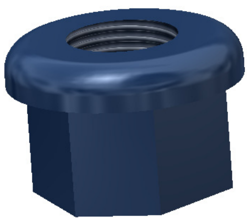

Fig. 17 Hexagon nut (3D).

Table 8

Dimensions of the hexagon nut with collar and spherical setting surface.

Filet d	M8	**S**	13
D	17	**M**	12
$\mathbf{D_2}$	14,38	**a**	3,2
R	12	**h**	0,7
TPC	0,54		

3.7 Conical hole plate

The dimensions and shape of the plate are recommended by [10], respectively [11]. A plate with conical hole is selected, Figure 18 and table 9.

The hexagon nut is supported by the conical hole plate with spherical collar. The plate is modeled using *Line* and *Revolve* functions and is presented in Figure 19.

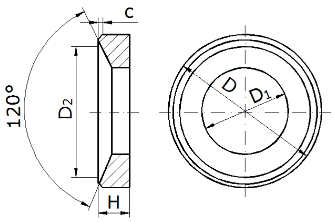

Fig. 18 Conical plate hole.

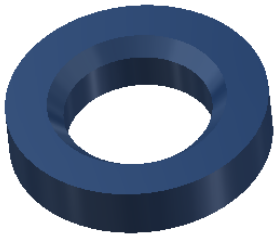

Fig. 19 Virtual model of the conical hole plate.

Table 9

Dimensions of the conical hole plate.

Screw	$\mathbf{D_1}$	$\mathbf{D_2}$	**H**	**D**	**c**
M8	9,6	14,5	3,5	17	0,5

3.8 Screwed bolt

The dimensions and shape of the screwed bolt are recommended by [10] and [11]. An A-shape screwed bolt is selected as the one presented in Figure 20 and table 10.

Figure 21 presents the 3D model of the bolt, drawn using *Line* and *Revolve* functions, and *Thread* function is used for generating the two threads of the bolt.

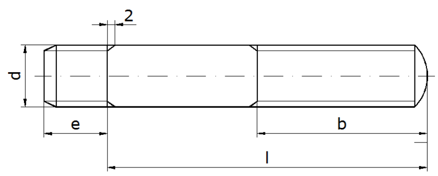

Fig. 20 Screwed bolt – A-shape.

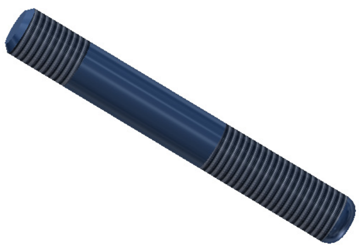

Fig. 21 3D model of the screwed bolt.

Table 10

Dimensions of the screwed bolt.

d	e	b	l
8	10	22	68

3.9 Thick hexagon nut

Thick hexagon nut (Figure 22) is recommended by [10] and [11] and its dimensions are presented in table 11. The 3D model of the thick hexagon nut was drawn using functions as *Line*, *Circle* and *Extrude* with 12 mm.

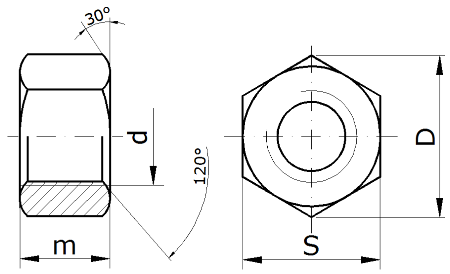

Fig. 22 Thick hexagon nut.

Table 11

Dimensions of thick hexagon nut.

d	S	D_{min}	m
M8x1	13	14.38	12

3.10 Variable supporting pin with curved hexagon head

The dimensions and shape of the variable supporting pin with curved hexagon head, Figure 23, are recommended by [10], respectively [11] and its dimensions are presented in table 12.

The supported pin presented in Figure 24 was drawn using a sketch created in *Sketch* module, similar to the one presented in Figure 24. After that, the 3D solid was generated using *Revolve* function. The thread of the supporting pin was generated using *Thread* function.

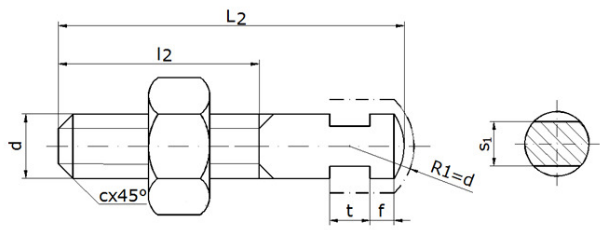

Fig. 23 Variable supporting pin with curved hexagon head.

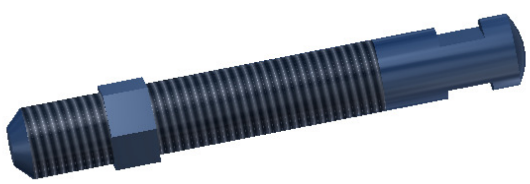

Fig. 24 Variable supporting pin with hexagon head (3D).

Table 12

Dimensions of the variable supporting pin with curved hexagon head.

d	R_1	S_1	t	f	c	l_2	L_2
8	8	5,5	5	3	1,8	25	40

3.11 Collar bush for fixturing devices

The collar bush, Figure 25, is recommended by [10] and [11] and its dimensions are presented in table 13.

The Collar bush is used for centering and guiding the tool while part drilling.

The virtual model presented in Figure 26 was drawn using *Line, Circle, Chamfer* functions, in *XY* plane, respectively *Revolve* and *Extrude*, in 3D editing plane.

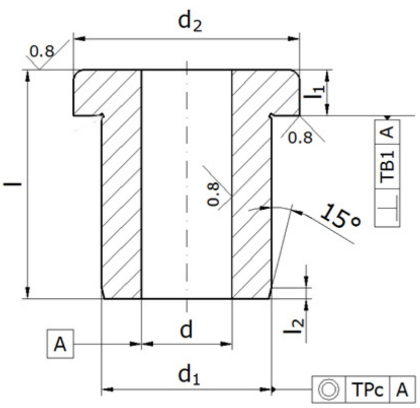

Fig. 25 Collar bush.

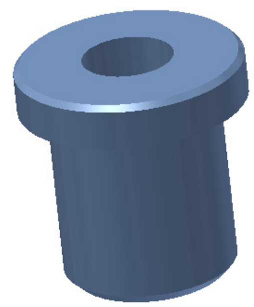

Fig. 26 Virtual model of the collar bush.

Table 13

Dimensions of the collar bush.

d	d_1	d_2	l	l_1	l_2	r	r_1	TBf	TPc
8	15	20	20	4	1	2	1	0,03	0,02

3.12 Rectangle base plate

The base plate of the fixturing device, Figure 27, with rectangular shape, is recommended by [10], [11] respectively [12] and its dimensions are presented in table 14.

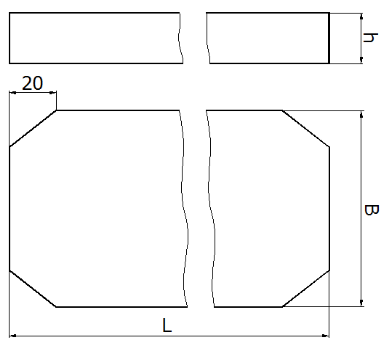

Fig. 27 Rectangle base plate.

Table 14

Dimensions of the base plate.

h	**B**	**L**
20	130	307

The base plate is drawn by choosing a projection plan, in this case *XZ* plane, in *Sketch* module, in which a rectangle of 307x130 mm is drawn, using *Rectangle* function.

Using *Circle* function, the holes and cavities of the base plate are edited. The virtual model of the plate is drawn by *Extrude* function at 20 mm height.

3.13 Fixing hangers

The fixing hangers, Figure 28, are recommended by [10], respectively [11] and their dimensions are presented in table 15. The fixing hangers presented in Figure 29 were drawn by generating some sketches, in the base plate plane, using *Line* and *Arc* functions and by generating these sketches in 3D designing mode through *Extrude* function.

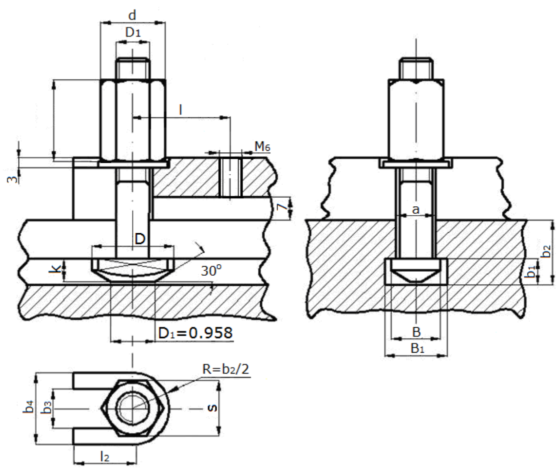

Fig. 28 Fixing hangers.

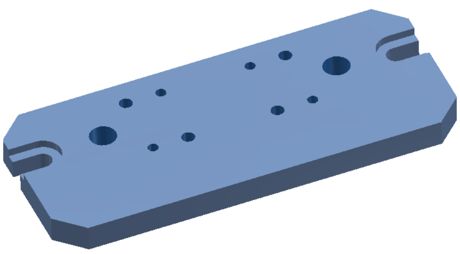

Fig. 29 Virtual model of fixing hangers.

Table 15

Dimensions of fixing hangers.

a		14	**B$_1$**	**min**	23
b$_1$	**min**	9		**max**	25
	max	11	**b$_2$**	**min**	23
d (M)		12		**max**	28
D		30	**K**		8
D$_2$		21,9			

4. FIXING SCHEME OF THE SHAFT

Figure 30 presents the scheme for applying the cutting-fixing-actioning forces.

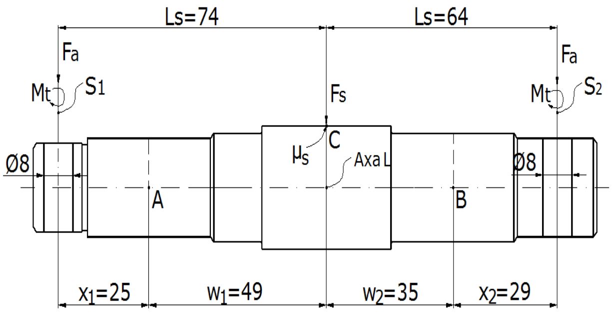

Fig. 30 Scheme for applying the cutting-fixing-actioning forces.

Calculation of fixing and actioning forces

The necessary fixing force 1 is given by equation:

$$x_1 \cdot F_a = F_s \cdot w_1 \Rightarrow F_{s\,nececar_1} = F_a \cdot \frac{x_1}{w_1} \cdot K_s \,[\mathrm{N}], \qquad (1)$$

where:
- x_1=25 mm;
- F_a is cutting force, F_a= 1664,729 N;
- K_s – safety coefficient, which is calculated by equation:

$$K_s = K_1 \cdot K_2 \cdot K_3 \cdot K_4, \qquad (2)$$

where:
- K_1 – coefficient that considers uniformity of the cutting allowance, K_1=1.8;
- K_2 – influence coefficient of the supporting surfaces dimensions, K_2=1;
- K_3 – coefficient that considers the continuity of the cutting process, K_3=1;
- K_4 – coefficient that considers the increasing of the exterior forces which are determined by cutting tools tear and wear, K_4=1.15.

$K_s = 1.8 \cdot 1 \cdot 1 \cdot 1.8 = 2.07.$

Using the values of these coefficients in equation (1), the following necessary fixing force 1 is resulting:

$$F_{s\,nececar_1} = 1\,664{,}729 \cdot \frac{25}{49} \cdot 2{,}07 = 1\,758{,}157 \text{ N}.$$

The necessary fixing force 2 is given by equation:

$$F_{s\,nececar_2} = \frac{M_t \cdot K_s}{\mu_s \cdot L_s} \,[\mathrm{N}], \qquad (3)$$

where:
- M_t is the torque, M_t=6061 N·mm;
- μ_s – friction coefficient, μ_s=0,2÷0,35;
- L_s – fixing point position; L_s=74 mm.

$$F_{s\,nececar_2} = \frac{6\,061 \cdot 2.07}{0.2 \cdot 74} = 847.72 \text{ N}.$$

$$F_{s\,necesar} = F_{s\,necesar_1} + F_{s\,necesar\,2}$$
$$= 1\,758{,}157 + 847{,}72 = 2\,605{,}877 \text{ N}.$$

Figure 32 presents the fixing scheme of the shaft.

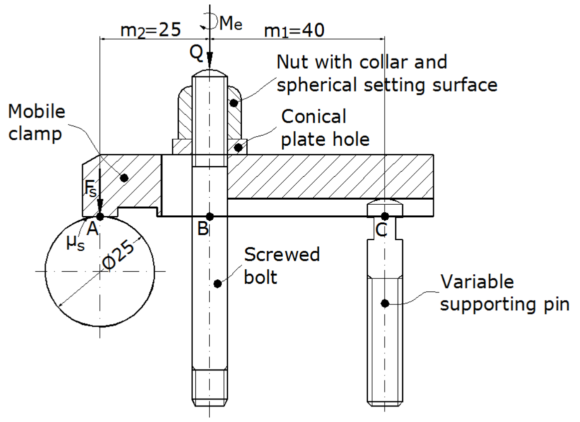

Fig. 31 Fixing scheme with mobile clamp of the shaft.

The fixing force, F_s, developed by the fixture device, is given by equation:

$$F_s = Q \cdot \frac{m_1}{L} \cdot \eta \, [\mathrm{N}], \tag{4}$$

where:

- Q is the thread mechanism force, which is calculated with equation:

$$Q = \frac{F_m \cdot L_c}{\frac{d}{2} \cdot tg(\alpha + \varphi) + \frac{\mu_s}{3} \cdot D_e} [\mathrm{N}], \tag{5}$$

where:

- F_m is manual actioning force, F_m=100÷150 N;
- L_c – key tool lenght; for simple fixing key tool, with dimension S=13 mm, L_c=140 mm.
- d – diameter; d=8 mm;
- α – thread screw angle, which is calculated with equation:

$$\alpha = arctg\left(\frac{p}{\pi \cdot D}\right)\left[^\circ\right], \tag{6}$$

where:

- p is screw step, p=1 mm;
- D – diameter; D=8 mm.

$$\alpha = arctg\left(\frac{1}{\pi \cdot 8}\right) = 2,279^\circ.$$

- φ – friction angle between nut and screw thread spires, which is calculated with equation:

$$\varphi = arctg \, \mu_f \left[^\circ\right], \tag{7}$$

where μ_f friction coefficient of the thread; μ_f=0,25÷0,35.

$\varphi = arctg 0,35 = 19,29^\circ$.

- μ_s – friction coefficient, μ_s=0,2÷0,35;
- D_e – equivalent diameter of the fixing/contact surface; it is calculated with equation:

$$D_e = 2 \cdot R \cdot \cos\beta \, [\mathrm{mm}], \tag{8}$$

where:

- R is radius of collar hexagon nut and spherical setting surface; R=12 mm;
- 2·β – centering cone angle of the plate; 2·β=120°.

$D_e = 2 \cdot 12 \cdot \cos 60^\circ = 12$ mm.

Therefore, by replacing in equation (5), the value of Q force is obtained:

$$Q = \frac{150 \cdot 140}{\frac{8}{2} \cdot tg(2,279 + 19,29) + \frac{0,2}{3} \cdot 12} = 8\,823,529 \text{ N}.$$

- m_1=L – (l_1–l) [mm], where: L=80 mm, l_1=22 mm şi l=18 mm;

m_1=80 – (22+18)=40 mm.

- m_2=25 mm.
- η – efficiency, η=0,8÷0,95.

Therefore, by replacing in equation (4), the value of fixing force F_s of the mechanism is obtained:

$$F_s = 8\,823,529 \cdot \frac{40}{80} \cdot 0,95 = 4\,191,176 \text{ N}.$$

The mechanism checking:

$$\left.\begin{array}{l} F_s \geq F_{s\,necesar} \\ 4\,191,176 \text{ N} \geq 2\,605,877 \text{ N} \end{array}\right\}$$ results that the structure and elements of the fixing mechanism were correct selected or predimensioning.

5. THE DESCRIPTION OF THE FIXTURING DEVICE

Figures 32 and 33 present the sketches, respectively the 3D model of the fixturing device.

Constructiv-functional description

The straight shaft (blank) 7 is put in the fixturing device having its surface in contact with the two supporting 8, mounted on rectangular base plate 2 of the fixturing device. In order to fix the prisms on the base plate, two cylindrical head screws with hexagon hole 3 M8x1 and two B-type cylindrical pins 16 are used.

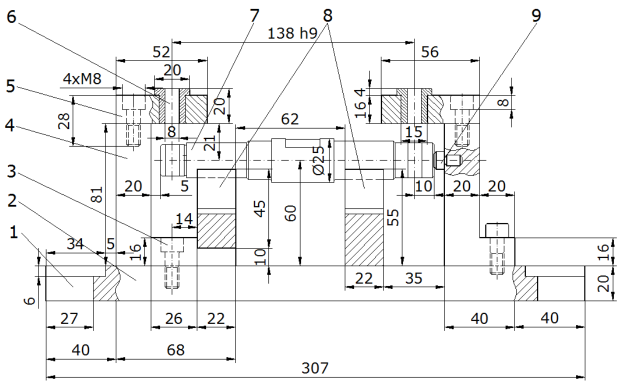

Fig. 32 The scheme of the fixturing: 1 – fixing hangers; 2 – rectangular base plate; 3 - screw M8x1; 4 – corner support; 5 – guiding plate for bushes; 6 – guiding bushes; 7 – straight shaft; 8 – supporting prisms; 9 - supporting pin with plate cylindrical head.

The supporting pin 9 is mounting on the corner support 4, in order to be oriented on horizontal position. The pin is mounted in the fixturinrg device body by pressing with tight fit.

The fixing of the corner support on the base plate is made by 2 M8 screws and two cylindrical pins.

The blank is fixed for machining using the two-direction fixing clamp 10.

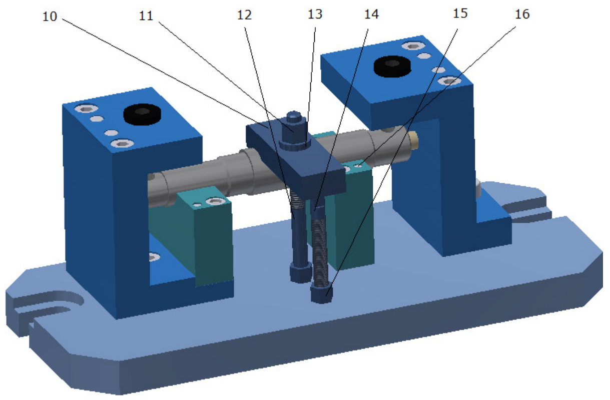

Fig. 33 3D model of the fixturing device: 10 – fixing clamp; 11 – hexagon nut with collar; 12 – screwed bolt; 13 – conical hole plate; 14 – variable supporting pin; 15 – thick hexagon nut; 16 – B-type cylindrical pin.

The clamp is fixed with screwed bolt 12 and hexagon nut with collar 11 supported by the conical hole plate 13 and variable supporting pin 14.

Both supporting pin and screwed bolt are mounted on the base plate of the fixturing device with the thick hexagon nuts 15. In order to mount the fixturing device on the cutting machine table (drilling machine G25), the fixing hangers 1 are used.

The guiding bushes 6 of the cutting tools are mounted on the guiding plate 5 for cutting the holes. After machining the final part is removed from the fixturing device.

ACKNOWLEDGEMENTS

This work was supported by a grant of the Romanian National Authority for Scientific Research and Innovation, CNCS – UEFISCDI, project number PN-II-RU-TE-2014-4-0031.

6. CONCLUSIONS

The designing software as AutoCAD and Autodesk Inventor are reliable tools for designing complex fixturing devices used for cutting on CNC machines.

This paper presents the steps for designing a cutting fixturing device for drilling a straight shaft on EMCO CONCEPT TURN 55. The 3D model of the drilling fixturing device was made. This model can be used for carrying out numerical simulations for determining the stresses during shaft machining.

The necessary fixing force of the shaft on the fixturing device was calculated so that the device should withstand the dynamic stresses which occur during drills machining. The calculated fixing force, based on the fixturing device elements which were selected or dimensioned, is 4191.176 N. This value is higher than the necessary force, meaning that the elements fixturing device were correct dimensioned. The designing tools presented in this paper can be used for modeling other fixturing devices for other type of cutting processes.

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