

## THE GRAPHIC MODEL AND THE CONSTRUCTIVE-FUNCTIONAL ANALYSIS OF A NORMALLY OPEN DIRECT-ACTING VALVE

**Abstract:** The valves are elements which provide the opening of a hydraulic circuit when the flow in one direction exceeds a certain value. This paper presents the basic concepts about valves, in general, and also the 3D graphic model of a normally open direct-acting valve in the Autodesk Inventor design environment, respectively, an analysis of such a valve, both functionally and constructively, as well as from the point of view of a calculation of forces acting on some elements of the valve. At the same time, carry out the CAM simulation in the manufacturing process of the mark "Screw".

**Key words:** valve, direct-acting, spring, flow, screw, opening force.

### 1. INTRODUCTION

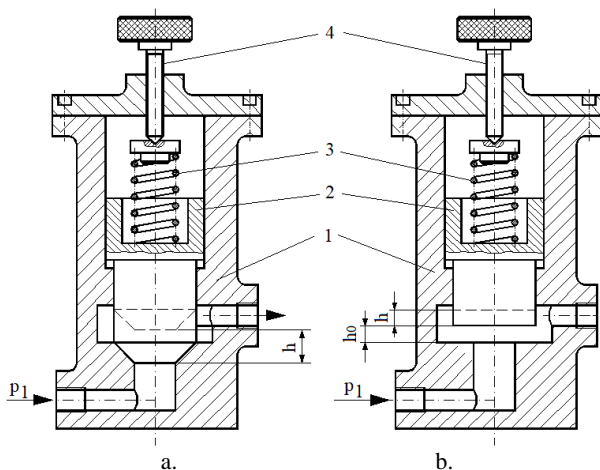
Valves feature among the top places, in order of importance, in a hydrostatic actuation system, due to the fact that the pressure, along with the flow, is one of the two parameters by which the hydraulic power transmission is quantitatively expressed [1], [2].

As a rule, the diversity of constructive solutions of the valves derive from the concern of producers to achieve the most advantageous variants on ensuring functions, operational safety, easy steerability and the improvement of joining techniques [3].

Valves, in accordance with their function under hydrostatic actuation systems, can be grouped into two broad categories: pressure control valves and check valves [2].

*Pressure control valves* are designed to ensure the desired pressure in certain hydraulic circuits [1], [4]. From a functional point of view, they can be divided into: expansion valves, check valves and pressure limiting valves.

Check valves ensure the blocking for one sense of direction for the oil flow along a route of the hydraulic system. They fall into two categories: simple check valve (or directional control valves), check valves with hydraulic unlock control, double check valves [1].



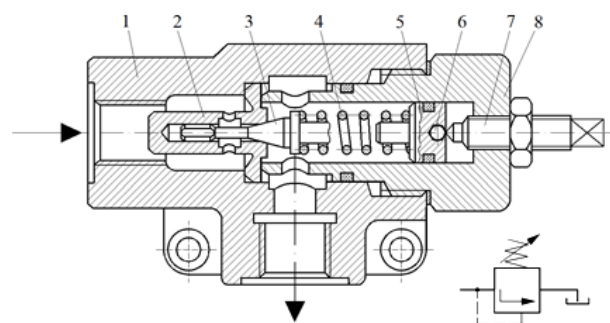
**Fig. 1** Pressure control valve: a – normal closed valve; b – normal open valve [1].

Constructively, pressure valves contain three important elements: the valve body (1), the seal element (2), which can be plunger valve, plate valve, ball valve etc. and the elastic element (3), whether or not equipped with force control unit (4).

In normal check valves (Figure 1a), the shut-off element first fully clogs the transition from one orifice to another, the poppet inside the body being pressed by the elastic element (3). They are opened through the slot  $h$ , allowing the full passage of the flow from the circuit which controls. This occurs when pressure level  $p_1$  performs a motive power on the plunger (2) larger than the force in the spring (3). At this point  $p_1 = 0$ .

In *normal check valves* (Figure 1.b) first there is the slot  $h_0$  which allows leaking of a certain part of the flow from an orifice of the valve to the other one, even in a situation where  $p_1$  has very low values (close to zero). The size of this slot changes to the value  $h$ , depending on the level of pressure controlled by the valve, value which seeks to be constant.

Figure 2 presents a normally open direct-acting valve.

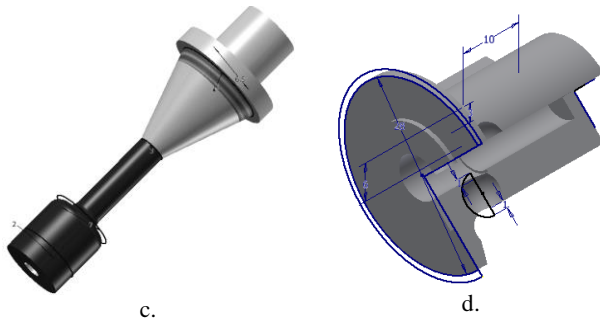


**Fig. 2** Normally open direct-acting valve:

1 - body; 2 - poppet; 3 - seal element; 4 - spring;  
5 - port-spring bushing; 6 - ball; 7 - levelling screw;  
8 - element for setting the poppet [1].

The cone (3) represents the closure element of the valve, and the flow acts directly on it. The control element, as an extension of the cone, has both the role of positioning the closure element and ensuring the truth of the conic surface with the corresponding surface of the poppet (2). The static element (4) ensures the pressing force of the cone on the poppet (2), force which can be regulated with the screw (7).

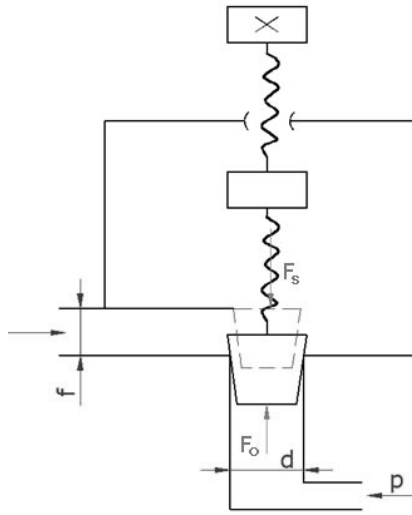




**Fig. 7** Pinning-setting-controlling elements of the normally open valve: *a* - levelling screw; *b* - pressing plate; *c* - plate (tapered plug); *d* - poppet of the valve.

### 3. CALCULUS OF THE VALVES WITH TAPERED POPPET

In valve dimensioning there shall be taken into account the passage of the flow to the opening of the valve, Figure 8.



**Fig. 8** Simplified model of the valves with tapered poppet: *f* - slot; *p* - valve entrance pressure; *d* - diameter of the valve's orifice.

The spring will take hold on the poppet of the valve allowing the flow in one sense of direction. The force of the fluid opposes this force, generically known as the opening force of the valve,  $F_o$ .

For an optimal operation of the valve it is necessary that the opening force of the valve,  $F_o$ , have a smaller value than the force of the spring,  $F_s$ , according to the relation (1):

$$F_s > F_o \text{ [daN]}, \quad (1)$$

If the opening force is stronger than the force of the spring, the tapered plate is pushed off the poppet of the valve, so the fluid is moving in the opposite direction, as the valve overflows to the bowl

The opening force of the valve  $F_o$  is determined using the relation (2):

$$F_o = p \cdot A \cdot 10^{-2} \text{ [daN]}, \quad (2)$$

where:

- $p$  – entrance pressure in the valve, measured in bars;
- $A$  – area of the orifice,

$$A = \frac{\pi \cdot d^2}{4} \text{ [mm]}. \quad (3)$$

Therefore,

$$F_o = p \cdot \frac{\pi \cdot d^2}{4} \cdot 10^{-2} \text{ [daN]}. \quad (4)$$

This paper presents a hypothetical situation where the flow may have different values of pressure ( $p_1, p_2, p_3, p_4$ ), in correlation with the dimensional values of different flow areas.

The goal is to determine, out of the combinations with values from Table 1, in which of the circumstances the opening force,  $F_o$ , is stronger than the force of the spring,  $F_s$ .

*Table 1*  
**Admeasurements for calculating the opening force of the valve**

$d_1$ [mm]	$d_2$ [mm]	$d_3$ [mm]	$d_4$ [mm]	$F_s$ [daN]
5	6	8	10	118
$p_1$ [bar]	$p_2$ [bar]	$p_3$ [bar]	$p_4$ [bar]	
81	104	149	261	

$$F_o < 118 \text{ daN}. \quad (5)$$

$$F_{o_1} = p_1 \cdot \frac{\pi \cdot d_1^2}{4} \cdot 10^{-2} = 81 \cdot \frac{\pi \cdot 5^2}{4} \cdot 10^{-2} = 15.896 \text{ daN}$$

$$F_{o_2} = p_1 \cdot \frac{\pi \cdot d_2^2}{4} \cdot 10^{-2} = 81 \cdot \frac{\pi \cdot 6^2}{4} \cdot 10^{-2} = 22.890 \text{ daN}$$

$$F_{o_3} = p_1 \cdot \frac{\pi \cdot d_3^2}{4} \cdot 10^{-2} = 81 \cdot \frac{\pi \cdot 8^2}{4} \cdot 10^{-2} = 40.694 \text{ daN}$$

$$F_{o_4} = p_1 \cdot \frac{\pi \cdot d_4^2}{4} \cdot 10^{-2} = 81 \cdot \frac{\pi \cdot 10^2}{4} \cdot 10^{-2} = 63.585 \text{ daN}$$

$$F_{o_5} = p_2 \cdot \frac{\pi \cdot d_1^2}{4} \cdot 10^{-2} = 104 \cdot \frac{\pi \cdot 5^2}{4} \cdot 10^{-2} = 20.410 \text{ daN}$$

$$F_{o_6} = p_2 \cdot \frac{\pi \cdot d_2^2}{4} \cdot 10^{-2} = 104 \cdot \frac{\pi \cdot 6^2}{4} \cdot 10^{-2} = 29.390 \text{ daN}$$

$$F_{o_7} = p_2 \cdot \frac{\pi \cdot d_3^2}{4} \cdot 10^{-2} = 104 \cdot \frac{\pi \cdot 8^2}{4} \cdot 10^{-2} = 52.249 \text{ daN}$$

$$F_{o_8} = p_2 \cdot \frac{\pi \cdot d_4^2}{4} \cdot 10^{-2} = 104 \cdot \frac{\pi \cdot 10^2}{4} \cdot 10^{-2} = 81.640 \text{ daN}$$

$$F_{o_9} = p_3 \cdot \frac{\pi \cdot d_1^2}{4} \cdot 10^{-2} = 149 \cdot \frac{\pi \cdot 5^2}{4} \cdot 10^{-2} = 29.341 \text{ daN}$$

$$F_{o_{10}} = p_3 \cdot \frac{\pi \cdot d_2^2}{4} \cdot 10^{-2} = 149 \cdot \frac{\pi \cdot 6^2}{4} \cdot 10^{-2} = 40.107 \text{ daN}$$

$$F_{o_{11}} = p_3 \cdot \frac{\pi \cdot d_3^2}{4} \cdot 10^{-2} = 149 \cdot \frac{\pi \cdot 8^2}{4} \cdot 10^{-2} = 74.857 \text{ daN}$$

$$F_{o_{12}} = p_3 \cdot \frac{\pi \cdot d_4^2}{4} \cdot 10^{-2} = 149 \cdot \frac{\pi \cdot 10^2}{4} \cdot 10^{-2} = 116.965 \text{ daN}$$

$$F_{o_{13}} = p_4 \cdot \frac{\pi \cdot d_1^2}{4} \cdot 10^{-2} = 261 \cdot \frac{\pi \cdot 5^2}{4} \cdot 10^{-2} = 51.221 \text{ daN}$$

$$F_{o_{14}} = p_4 \cdot \frac{\pi \cdot d_2^2}{4} \cdot 10^{-2} = 261 \cdot \frac{\pi \cdot 6^2}{4} \cdot 10^{-2} = 73.758 \text{ daN}$$

$$F_{o_{15}} = p_4 \cdot \frac{\pi \cdot d_3^2}{4} \cdot 10^{-2} = 261 \cdot \frac{\pi \cdot 8^2}{4} \cdot 10^{-2} = 131.126 \text{ daN}$$

$$F_{o_{16}} = p_4 \cdot \frac{\pi \cdot d_4^2}{4} \cdot 10^{-2} = 261 \cdot \frac{\pi \cdot 10^2}{4} \cdot 10^{-2} = 204.885 \text{ daN}$$

As a result of the calculations, it is noticed that  $F_{o_{15}}$  and  $F_{o_{16}}$  have higher values than  $F_s$ . In this case, there may be multiple ways of reducing the opening force, considering that the spring force is already at a maximum value: for instance, whether reduce the value of  $d_3$  and  $d_4$ , situation which would basically imply replacing the valve, or reduce the pressure  $p_4$ .

There is the matter of knowing the value to which the pressure can be reduced, so as to preserve the optimal operating condition of the valve. Reducing those two parameters shall be recalculated as follows:

- for  $F_{o_{15}}$  :

$$F_s = p'_4 \cdot \frac{\pi \cdot d_3^2}{4} \cdot 10^{-2} [\text{daN}] \Rightarrow p'_4 = \frac{4 \cdot F_s}{\pi \cdot d_3^2 \cdot 10^{-2}} [\text{bar}];$$

$$(11)$$

$$p'_4 = \frac{4 \cdot 118}{\pi \cdot 8^2 \cdot 10^{-2}} = 234.872 \text{ bar.}$$

Thus,

$$F'_{o_{15}} = 234.872 \cdot \frac{\pi \cdot 8^2}{4} \cdot 10^{-2} = 117.999 \text{ daN} < F_s = 118 \text{ daN.}$$

- for  $F_{o_{16}}$  :

$$F_s = p'_4 \cdot \frac{\pi \cdot d_4^2}{4} \cdot 10^{-2} [\text{daN}] \Rightarrow p'_4 = \frac{4 \cdot F_s}{\pi \cdot d_4^2 \cdot 10^{-2}} [\text{bar}];$$

$$(12)$$

$$p'_4 = \frac{4 \cdot 118}{\pi \cdot 10^2 \cdot 10^{-2}} = 150.318 \text{ bar.}$$

Thus,

$$F'_{o_{16}} = 150.318 \cdot \frac{\pi \cdot 10^2}{4} \cdot 10^{-2} = 117.999 \text{ daN} < F_s = 118 \text{ daN.}$$

#### 4. CAM SIMULATION OF THE MANUFACTURING PROCESS OF THE MARK „SCREW”

CAM simulation of the manufacturing process for the marker "Screw" is built in *CATIA*, being necessary to establish and schedule the technological stages starting from the admeasurements of the semi-product, in order to reach to the desired deliverable.

Therefore, the opting is choosing a round bar-type semi-product, with a diameter of  $\varnothing 12$  mm and the length  $l = 35$  mm.

The technological stages for processing the *M10x1,5* mm levelling screw, are:

- rough turning and abut finishing  $\varnothing 12$  mm;
- rough milling  $\varnothing 10,5$  mm;  $L=10$  mm;
- finish milling  $\varnothing 10$  mm;  $L=10$  mm;
- longitudinal rough turning  $\varnothing 11 \times 23$  mm;
- longitudinal turn finishing  $\varnothing 10 \times 23$  mm;
- tapping, *M10x1,5* mm.

Figure 9 presents the work drawing of the levelling screw.

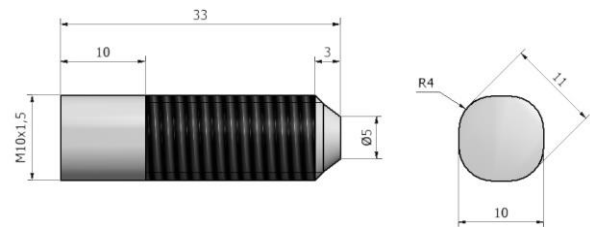


Fig. 9 Sketch of the levelling screw.

Thus, *Catia Software* will be opened from the *Machining* menu, choosing the *Machining Prismatic* module. Specification menu is displayed, containing a default set of operations (*Part-Operation.1*), which is also a processing program (*Manufacturing Program.1*).

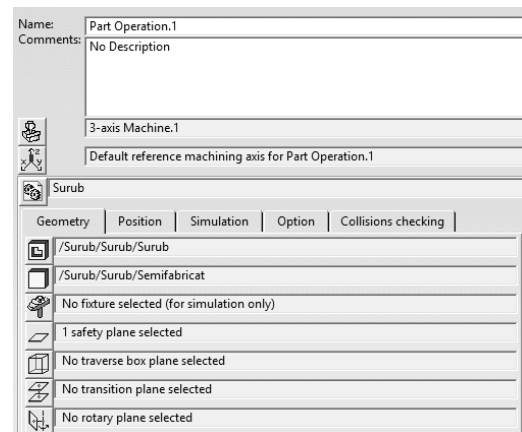


Fig. 10 Selection window *Part Operation*.

To define the type of the machine-tools, its axes system which is numerically ordered, the parts that will be processed etc., will be made by double-clicking on the item *Part Operation.1* from the menu, with the selection window with the same name, Figure 10. Thus, there shall be established and selected a *CNC* milling machine with 3 axes (*x*, *X* and *Y*) called *3-axis Machine 1*.

There should be chosen a system of orthogonal axes belonging to the semi-product. The *Z*-axis is vertical, with the positive direction upward, parallel to the axis of the main shaft, and the *X* and *Y* axes in the plane of the upper face of the semi-product. The axes system must be positioned on the model of the semi-product in a given orientation. The correct orientation of the system leads to changing the colour of its components in its green symbol (see Figure 11).

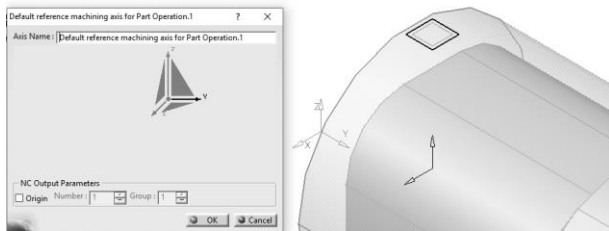


Fig. 11 Choosing the coordinates system.

In the next stage, a safety plane positioned above the semi-product, *Safety Plane*, will be indicated. The plane is symbolised by a green square, above the semi-product, at a distance from the positive direction of the *Z* axis e.g. 20 mm, Figure 12.

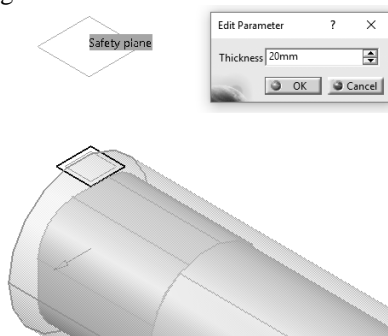


Fig. 12 Establishing the safety plane.

In order to achieve the operation of  $\varnothing 12$  mm facing, the command *Facing* will be used. The first step consists in choosing the cutting tool (cutter block with P-type carbide plates). The name of the tool will be chosen *T1 Face Mill D 12*, having the geometry and the admeasurements as shown in Figure 13.

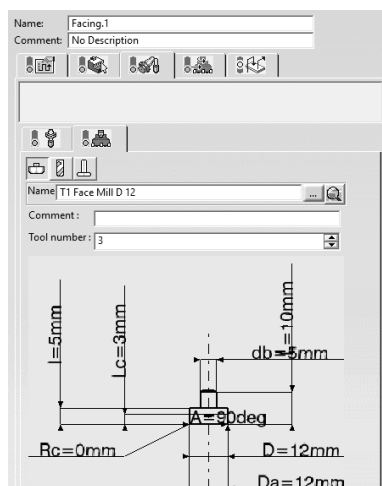


Fig. 13 Choosing the cutting tool.

To select the flat surface to be processed, access the *Geometry* tab, as shown in Figure 14.

On the suggestive image from the figure, the main geometrical elements which can be selected are marked. Therefore, the *Top* area determines the surface from where the workpiece processing operation begins (choose the front of the semi-product), and the *Bottom* area represents the area to which the processing ends (the front will be chosen).

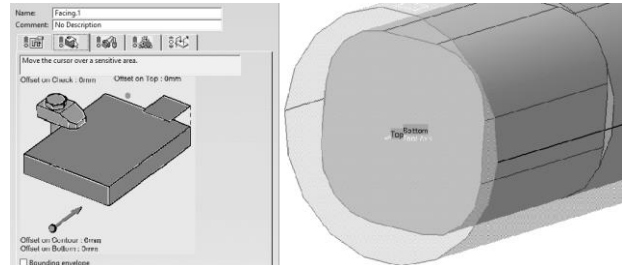


Fig. 14 The Geometry tab.

From the scrolled list of the *Tool Path Style* field, one of three types of trajectories of the tool's passages shall be chosen (path), in this case *Back and forth* (Figure 15).

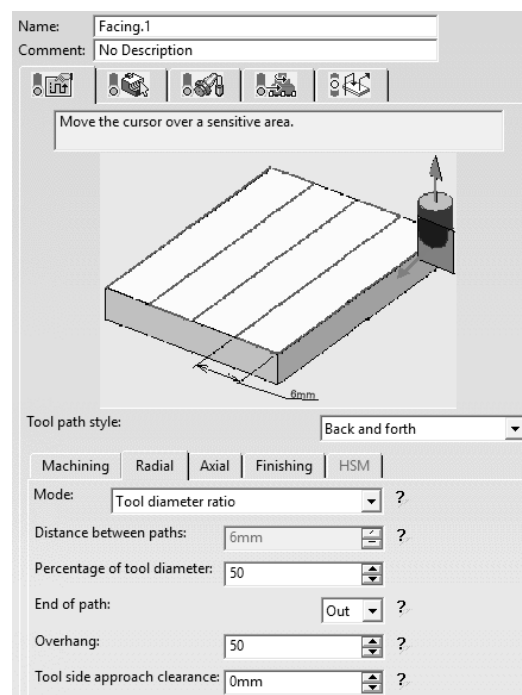


Fig. 15 Choosing the tool's trajectory and the processing steps.

The option *Tool diameter ratio* will be chosen, then in the fields *Percentage of tool diameter* and *Overhang*, the value of 50% will be inserted.

Thus, only about half of the tool diameter (milling machine) splits off in a passage.

Also, the tool's trajectory begins and ends outside the workpiece (the option *Out* in the *End of the path* field). The number of passages shall be chosen, respectively, 1 roughing pass from the tab *Axial* and 1 finishing pass, from the *Finishing* tab.

In the end, auxiliary approach and back movements of the tool onto the workpiece will be activated, Figure 16.

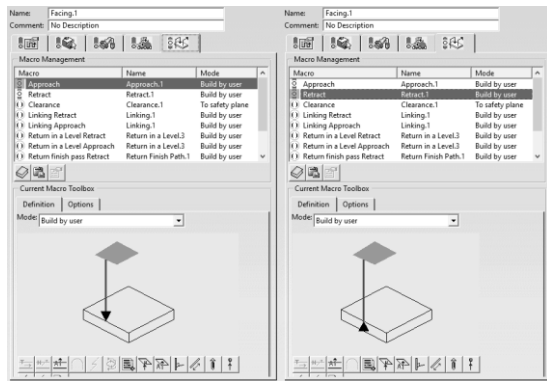


Fig. 16 Defining approach and back movements of the tool onto the workpiece.

Therefore, after defining all parameters necessary for the facing operation, the simulation of the process will be visualised, Figure 17.

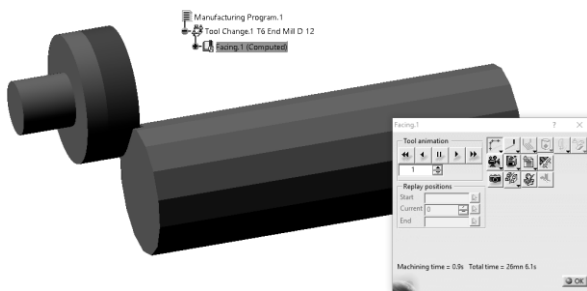


Fig. 17 Simulation of the facing operation.

Milling and turning operations are carried out in the *Lathe Machining* module, using the commands *Rough Turning*, for roughing and *Profile Finish Turning*, for finishing. The steps required to define work parameters used in the building process are similar with the parameters defined in the *Prismatic Machining* module, Figure 18 and Figure 19.

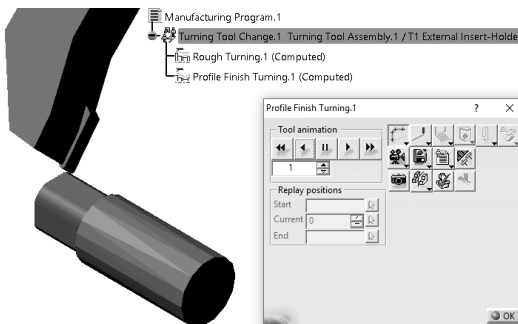


Fig. 18 Simulating the milling and finishing operations.

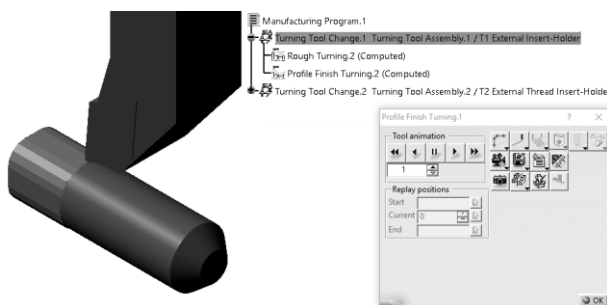


Fig. 19 Simulating the milling and longitudinal finishing.

For the  $M10 \times 1$ , 5 mm tapping operation, made in the *Lathe Machining* module, the *Thread Turning* command will be used, indicating the pitch of the thread,  $p = 1.5$  mm, its length,  $l = 20$  mm, and the *T2 Insert External Thread Holder* cutting tool, with the geometry and the corresponding admeasurements, Figure 20.

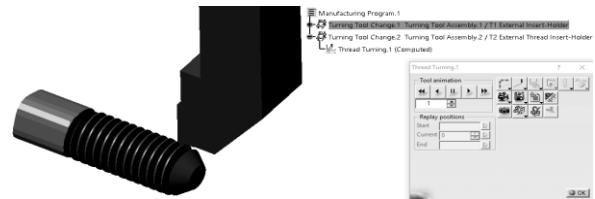


Fig. 20 Simulation of the tapping operation.

## 5. CONCLUSIONS

The components for pressure regulation play an extremely important role. The industrial practice of the last decades noted the introduction of automated hydraulic equipment to regulate processes of various industries. Currently, components have developed with mobile parts in the form of modules to work with standard signals with continuous or discrete action. These are used to adjust some parameters or technological machine-tools with sequential order.

Taking into account a valve to which the orifice diameter of its poppet may have different values, determining minimum opening forces  $F_o$  was possible, knowing the maximum force in the spring,  $F_s$ , based on some normalised pressure values.

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