Theoretical Aspects regarding the Pressure Safety Valves Operation within a Hydraulic Circuit

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Abstract: *Construction and agricultural machinery and equipment drives are currently accomplished by means of high-performance hydraulic and pneumatic systems through which difficult workloads are easily performed. Such systems have evolved over time, being indispensable from the basic functional machinery aggregate. In research-driven development there is a continuous increase in working power based on the increase of working pressure values inside the hydrostatic circuits used. Primary components represented by pumps, motors, distributors need protection during the circuit operation at medium and high pressure values. This overpressure protection is carried out by means of safety valves or pressure valves that are able to send part of the working fluid flow rate to the plant tank adjusting the pressure to a value at which the plant components are able to operate safely. A pressure valve assembly model is shown in this paper with spherical and tapered locking elements which have the possibility to perform translational movement inside the valve body in this way achieving the valve opening when the pressure values in the circuit exceed a certain set value. A numerical analysis of the working fluid flow through the valve body is made and the results are presented in terms of pressure and velocity of the working fluid, depending on the position of the spherical locking element.*

Keywords*: Pressure valve, hydraulic device, fluid flow, three dimensional model, computational fluid dynamics*

1. Introduction

Today, there are many possibilities for machinery and equipments to achieve multiple workloads with high degrees of difficulty. These skills are possible through the intake of hydrostatic drive systems that fit into these machines. Hydraulics and pneumatics are present in most industrial branches with optimal results that have been continuously improved due to the constant upgrading of materials and components used in work circuits.
In hydraulics the working fluids used are greatly improved in terms of viscosity properties providing the moving parts lubrication which reduce the components wear and extend their service life.
Regarding the hydraulic plant primary components quality, improved designs have been acquired in order to ensure optimal operational results within the working circuit (silent operation in the case of pumps and motors, firm commands in the case of distribution and control elements).
The working pressure values have been steadily increased while reaching higher values of hundreds of bars, which means high values of the hydrostatic forces acting on the installation components used in the equipping of machines and equipment.

2. Constructive and functional details for a safety valve model

The construction model corresponding to a pressure valve device is constituted by a body with inward orifices necessary for the circulation of the working fluid between the active branches of the plant and a valve closing/opening element maintained in the closed state by means of a compression spring which ensures the blocking of the circulation fluid flow to the tank if the pressure value is within the parameters for which the system is operating safely. At the moment when the pressure value rises above the value set on the valve (spring elastic force value), the locking piece is moved from the initial locking position by means of the action of hydrostatic forces, at which point the fluid is able to circulate behind the enclosure being directed to the system tank, reducing the momentary pressure value in the system to the initial value.
Once the pressure value has been lowered, the closure element is again moved to the initial position, ensuring the closure of the fluid drainage orifices, which is maintained until a further increase in the system pressure value when the recovery cycle is achieved.

During the operation of the pressure valve inside the hydraulic circuit the hydrostatic pressure forces are considered (F_h), which acts directly on the blocking element part determining a displacement and the discharge opening surface (*A*), enabling the working fluid circulation to the reservoir.
The mechanical work (L_h) performed to move the closure element of a pressure valve is dependent of force and displacement values of the blocking element, for which a fluid volume (*V*) is circulated, which also enters in calculating the amount of energy required along with the momentary pressure value. [1][2]

$$F_h = p \cdot A \tag{1}$$

$$L_h = p \cdot A \cdot s_a \# \tag{2}$$

$$V = A \cdot s_a \# \tag{3}$$

$$E = V \cdot p \# \tag{4}$$

On the other hand the closing piece movement resistances are given by the compression spring elastic force acting directly on the pressure valve locking element keeping it pressed on the seat practiced in the valve body alignment.
The spring force (F_a) is given by the compression spring constant (c_a) and the amount of displacement (s_a) carried out in the event of spring compression due to the action of the hydrostatic forces acting directly on the closure element: [4]

$$F_a = s_a \cdot c_a \tag{5}$$

$$F_a = \frac{G \cdot d_w^4 \cdot s_a}{8 \cdot D_a \cdot n} \# \tag{6}$$

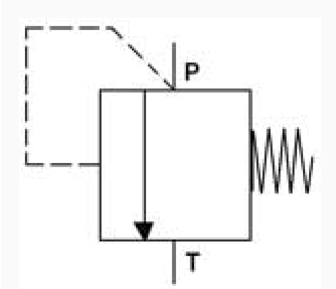
$$s_a = \frac{8 \cdot D^3 \cdot F_a \cdot n}{d^4 \cdot G} \# \tag{7}$$

where:
D_a - spring average diameter;
d_w - spring wire diameter;
G – shear modulus;
n - spiral number.

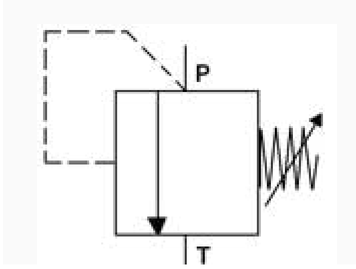
Possible cases for the functioning of pressure control valves are determined by the values of the involved forces. Thus, when the hydrostatic pressure forces are lower than the spring force value the valve remains closed and when the value of the hydrostatic pressure exceeds the value of the spring elastic force, the valve opens and sends a part of the working fluid to the tank, while the momentary pressure peak value of the system is discharged.

$$\begin{cases} F_h < F_a & - \Pr essure\ Valve\ Closed \\ F_h > F_a & - \Pr essure\ Valve\ Open \end{cases}$$

The pressure valves used in hydraulic circuits are driven by means of compression arcs and the value of the spring force can be constant or adjustable. The symbolic mode of these valves is shown in Figure 1.



a) pressure valve symbol



b) adjustable pressure valve

Fig. 1. Pressure valve symbolization

Such pressure valve models are normally closed, being activated only at system high pressure values. If the system does not have such a component mounted, the pressure will greatly increase up to the energy limit of the pumping group and ultimately produce damage to one of the system components (breakdown of the hydraulic ducts, destruction of the distributor, etc).

3. Pressure valve assembly model

An assembly pattern for a pressure safety valve must include the specific elements necessary for operation inside the hydraulic circuit. These components are represented by device body with orifices made for fluid access, the locking spherical or conical piece and the element which achieve and maintain the closed position of the locking piece, which is a compression spring.
A three-dimensional overall model for a pressure valve was made using the Solid Edge V20 program (Figure 2).

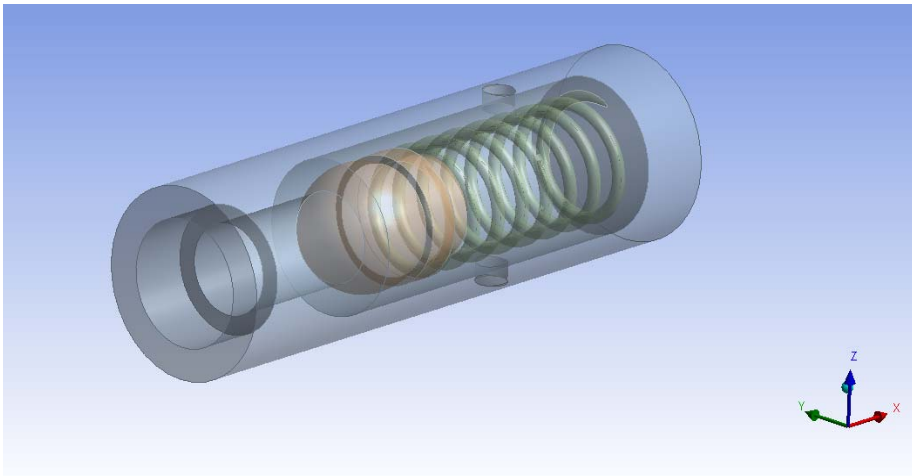


Fig. 2. Pressure valve assembly model

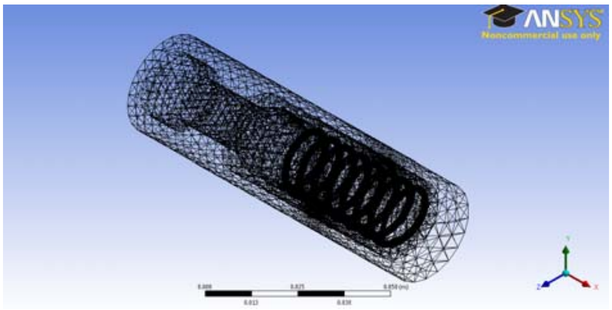
The shown assembly model has the outer dimensions of 30 mm in diameter and 100 mm in height, a main axial orifice for allowing access of working fluid inside the device body of 20 mm diameter, as well as two 5 mm diameter orifices necessary for the working fluid outlet when circulating to the reservoir.
The locking piece is positioned inside the body being connected to the spring that keeps it in contact with the seat (an inner edge of the body). The seating edge of the closure piece has a diameter of 14 mm and the arc contains 8 spirals with a 3 mm diameter.
During operation of the hydraulic system, the pressure valve receives a pressure signal from the circuit branch in which it is mounted. The pressure valve is normally closed and this state depends on the value of the hydrostatic forces acting directly on the spherical part wall, while the possible situations can be presented as follows:

1) Case 1 - when the hydrostatic forces are lower than the elastic spring force the valve remains closed;

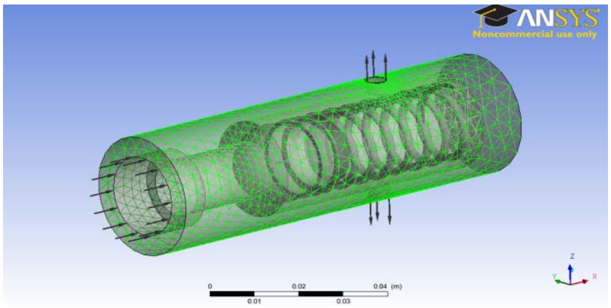
2) Case 2 - when the hydrostatic pressure forces exceed the value of the elastic force in the spring the valve opens by moving the spherical piece in the axial direction.

4. Fluid flow analysis on the pressure valve assembly virtual model

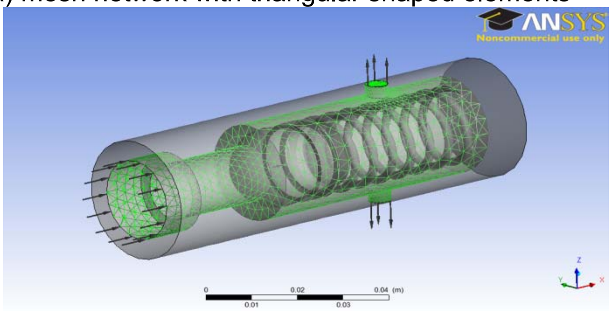
Having pressure valve three-dimensional assembly model available, an analysis of the working fluid flow through the valve body is carried out corresponding to the moment in which the spherical piece is displaced on the axial direction, which allows the fluid access in the chamber behind the spherical piece and the circulation to the two outlet circular openings. This displacement corresponds to the moment when the valve is opened by the pressure forces acting directly on the spherical part wall and compression force on the spring.
Flow analysis is performed using the ANSYS CFX program, a fluid analysis dedicated program. The working fluid is a mineral oil with a density of 900 kg/m^3, and a kinematic viscosity of 33.4 cSt at $40^O C$.



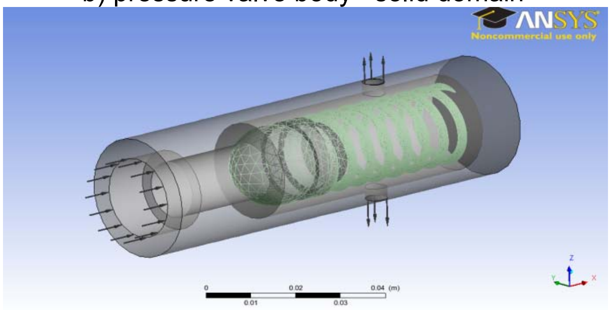
a) mesh network with triangular shaped elements



b) pressure valve body– solid domain



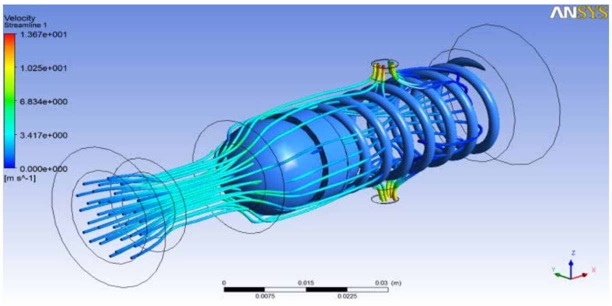
c) fluid domain



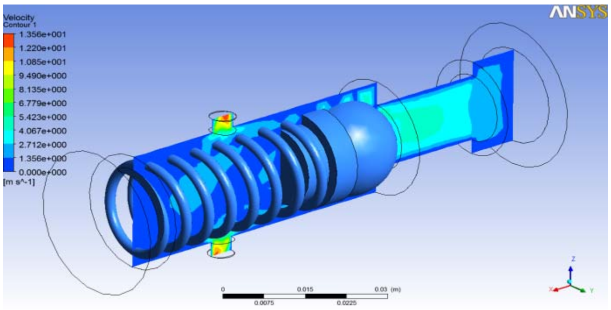
d) blocking element (spherical piece with compression spring) – immersed solid

Fig. 3. Fluid flow analysis domain details

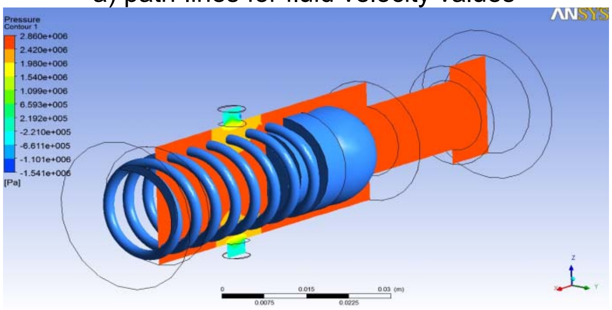
The fluid flow analysis domains represented by the valve body assembly are established, the solid range being steel, valve fluid domain positioned inside the body and the closure element with spring form together a solid domain (steel material) submerged in the volume of the fluid, as shown in Figure 3.
The fluid flow analysis is of transient type which describes better the pressure valve assembly operation on a finite period of 1 second operation time in 0.2 seconds steps. Thus, on the fluid domain having a reference pressure value of 150 bar, the three orifices ports as one inlet (20 mm diameter) and two outlets (diameter 5 mm each) are defined. At the inlet the fluid has the possibility of movement with a velocity of up to 8 m/sec. For the spherical blocking piece has been declared an axial directional movement with a translational velocity of 5 mm/sec.
The results are presented in terms of pressure and velocity of the working fluid calculated at the analyzed fluid region (Figure 4).



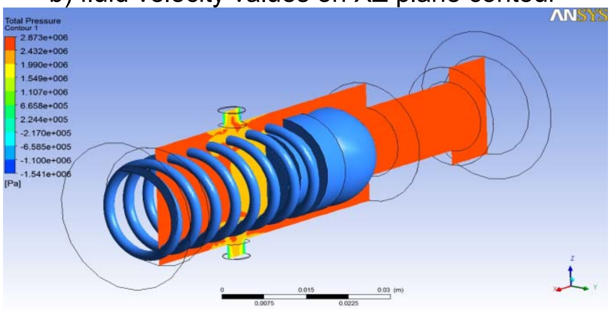
a) path-lines for fluid velocity values



b) fluid velocity values on XZ plane contour



c) static pressure values on XZ plane contour



d) total pressure values on XZ plane contour

Fig. 4. Fluid flow analysis results

Based on the results shown in Figure 4, it can be observed the working fluid flow model inside the pressure valve body when axial movement of the locking element is performed. The values for the fluid circulation velocity are appropriate for the analyzed fluid areas, with large values being recorded at the pressure valve exit ports. The static and total pressure values are comparable, with higher general values recorded for the main fluid region and lower values recorded on small regions at the outlet openings.

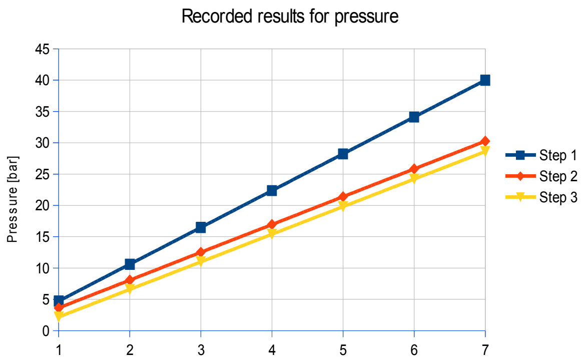
The fluid flow analysis was performed taking into account the total working time divided by several working steps.

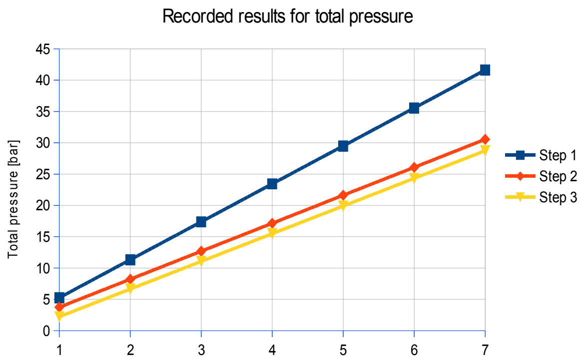
In order to highlight the results for the working fluid circulation velocity and pressure are presented three representative analysis steps that coincide with the start of the locking device movement from the initial position to the maximum stroke.

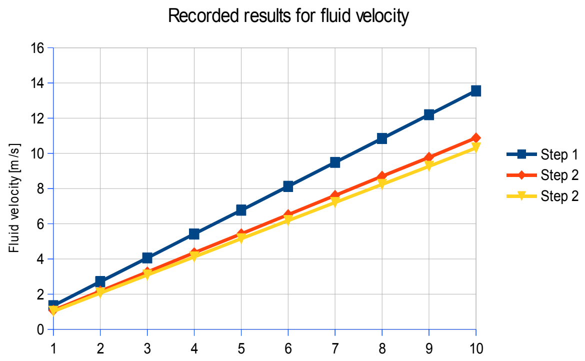
The results obtained on the analysis work steps reveals the higher pressure values when the locking piece is in the closed position and gradually according with the axial displacement lower values are recorded. Circulation velocity are rising towards the exit ports where the maximum values are recorded as the working fluid flow through reduced outlet orifices in this fluid region.

The diagrams corresponding to the values obtained from the analysis for the three steps are shown in Table 1.

Table 1: Result diagrams for fluid velocity and pressure







The pressure signal that performs the displacement of the locking piece, initially in a closed position, is taken from the main circuit powered by the plant pump. It is the compression spring constant that determines the adjusted value of the pressure required to open the pressure valve. Also, such pressure valves models benefit from the adjusting system, needed for adjusting the pressure value at which the valve can be opened and for higher circulation fluid flow rates, constructive models with pilot are used.
The pressure valves are used in circuits at pressure values in the range of 315-630 bar and fluid flow rates of 80-330 l/min but piloted constructions are capable to circulate higher flow rates values of up to 650 l/min.

5. Conclusions

A direct-operated pressure valve model has been presented in this paper, highlighting the constructive and functional principle.
The assembly model was analyzed with the Ansys CFX program in order to highlight the fluid flow dynamics through the valve body.
The results are presented in terms of velocity and pressure of the working fluid, taking into account the total movement of the locking piece over the total analysis time.
Specific velocity and pressure values are recorded corresponding to the relative positions between the locking piece and the valve body, depending on the surface area created between the locking member and the valve body as a result of the gradual displacement.

References

[1] Axinti, Adrian Sorin and Fănel Dorel Șcheaua. *Introduction to Industrial Hydraulics/Introducere în hidraulica industrială*. Galati, Galati University Press, 2015, ISBN 978-606-696-032-8.
[2] Axinti, Gavril and Adrian Sorin Axinti. *Fluid Power Systems/Acţionări hidraulice şi pneumatice*, Vol I-V. Chişinău, Tehnica-Info Publishing House, 2008-2012.
[3] Șcheaua, Fănel Dorel. „Functional description of a hydraulic throttle valve operating inside a hydraulic circuit." *Hidraulica - Magazine of Hydraulics, Pneumatics, Tribology, Ecology, Sensorics, Mechatronics*, ISSN 1453 – 7303, no. 1 (March 2016): 47-50.
[4] https://www.hennlich.ro/fileadmin/_migrated/ro_arc_compresiune.pdf.