# Increasing the Operating Safety of the Machine-Tools by Using Hydro-pneumatic Accumulators. Modeling - Simulation

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**Abstract.** This paperwork presents the results of the theoretical and experimental research that has had as object of study the hydraulic installations with hydro-pneumatic accumulators. It presents simulations for determining the performance of some hydraulic safety systems designed for actuating brakes, for ensuring bearings lubrication when the circuit incorporating the pump fails and for lifting loads in emergency situation. A hydraulic installation designed for a grinding machine is presented at the end.

**Keywords:** machine-tools, accumulator, safe operation.

## 1. Calculation of Safe Systems Incorporating Accumulators

The accumulators are hydraulic components that allow the receiving, storage and transmission of the hydrostatic power as volumes of pressured liquid. The reduced compressibility factor of the liquids makes difficult the storage of power in small volumes, but allows the transmission of high efforts. Unlike liquids, gas has higher possibility regarding the compressibility and that allows storing higher energy in smaller volumes. Associating liquids and gas in special construction has led to the manufacturing of the hydro-pneumatic accumulators [1].

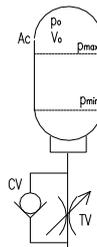It is given the operation scheme in Figure 1 [2].



Fig. 1: The operation scheme of a hydro-pneumatic accumulators

The accumulator Ac operates within pressures $p_{min}$ and $p_{max}$. Its useful volume is $V_0$, and its initial charging with nitrogen is made at the pressure $p_0$. Usually, this pressure verifies the following relations:

$$p_0 = k \cdot p_{\min} \qquad k \in [0.6 \div 0.9] \tag{1}$$

The charging of the accumulators with oil is made through the check valve Cv, in the transitory phase $p_{min} \rightarrow p_{max}$. The discharge is made through the throttle Tv during the phases corresponding to the pressure lowering, $p_{max} \rightarrow p_{min}$.

If considerring the charging and the discharging of the accumulator with oil are made under isothermal condition ($T$=ct.), then:

$$p_0 \cdot V_0 = p_{\max} \cdot V_{\min} = p_{\min} \cdot V_{\max} \tag{2}$$

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where: $V_{min}$ – minimum volume occupied by nitrogen, $V_{max}$ – maximum volume occupied by nitrogen.

In the discharging phase of the accumulator, the maximum volume of the available oil is:

$$\Delta V = V_{max} - V_{min} = p_o \cdot V_0 \cdot \left( \frac{1}{p_{min}} - \frac{1}{p_{max}} \right) \tag{3}$$

This volume is discharged through the throttle Tv. The throttle characteristic is considered as being:

$$Q_{Dr} = C_{Dr} \cdot S_{Dr} \cdot \sqrt{\frac{2}{\rho} \cdot \Delta p} \tag{4}$$

where: $Q_{Dr}$ – throttle flow, $C_{Dr}$ – throttle constant, $S_{Dr}$ – useful surface of the throttle, $\rho$ – density of the oil, $\Delta p$ – pressure drop on the throttle.

If considering the accumulator as being in the phase of discharge, as in Figure 2, then two situations can be distinguished:

  a.  the discharge towards a negligible pressure circuit, $p_s = 0$;
  b.  the discharge towards a system with pressure $p_s$, negligible value



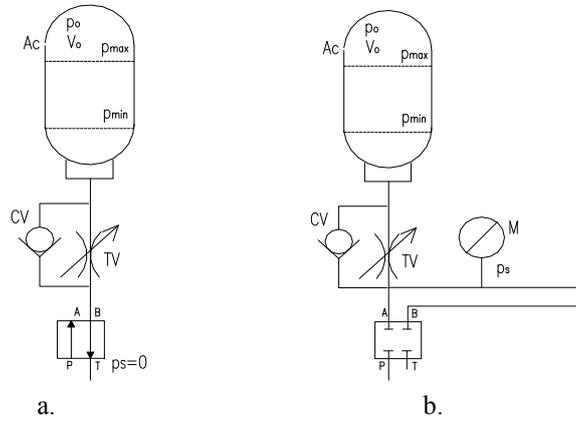a.                                                                b.

Fig. 2: The phases of discharge of the accumulator

From the relations above it results:

$$\frac{dV}{dt} = -\frac{p_0 \cdot V_0}{p^2} \cdot \frac{dp}{dt} = Q_{Dr} = C_{Dr} \cdot S_{Dr} \cdot \sqrt{\frac{2}{\rho} \cdot (p - p_S)} \tag{5}$$

If considering the discharge diagram in Figure 2 a, by integrating the relation above it is obtained:

$$\int_{p_{max}}^{p_{min}} \frac{-dp}{p^2 \cdot \sqrt{p}} = \frac{C_{Dr} \cdot S_{Dr}}{p_0 \cdot V_0} \cdot \sqrt{\frac{2}{\rho}} \cdot \int_0^{t_u} dt \tag{6}$$

For the charging diagram in Figure 2 b, by integrating the relation (5) it results:

$$\int_{p_{max}}^{p_{min}} \frac{-dp}{p^2 \cdot \sqrt{p - p_S}} = \frac{C_{Dr} \cdot S_{Dr}}{p_0 \cdot V_0} \cdot \sqrt{\frac{2}{\rho}} \cdot \int_0^{t_u} dt \tag{7}$$

For determining the time the accumulator can act as a source of energy for the system, it is necessary to calculate the integrals of the relations above.

When $p_s = 0$ – for example the safety systems of the hydrostatic lubrication installations – it is obtained:

$$t_{u0} = \frac{2}{3} \cdot \frac{p_0 \cdot V_0}{C_{Dr} \cdot S_{Dr} \cdot \sqrt{\frac{2}{\rho}}} \left( \frac{1}{p_{min} \cdot \sqrt{p_{min}}} - \frac{1}{p_{max} \cdot \sqrt{p_{max}}} \right) \tag{8}$$

If the accumulator serves a circuit with the pressure $p_s$, which has a value that cannot be neglected – for example the locking and clamping systems - it is obtained:

$$t_{us} = \frac{p_0 \cdot V_0}{C_{Dr} \cdot S_{Dr} \cdot p_s \cdot \sqrt{\dfrac{2}{\rho}}} \cdot \left( \frac{\sqrt{p_{max} - p_s}}{p_{max}} - \frac{\sqrt{p_{min} - p_s}}{p_{min}} + \frac{1}{\sqrt{p_s}} \cdot \left( arctg\sqrt{\frac{p_{max}}{p_s}} - arctg\sqrt{\frac{p_{min}}{p_s}} \right) \right) \quad (9)$$

As a practical example: given the values $V_0 = 4$ l, $p_{max} = 80$ bar, $p_{min} = 40$ bar, $p_0 = 30$ bar, $p_s = 25$ bar, then $t_{u0} = 46$ s and $t_{us} = 65$ s are obtained.

For both cases, the time can be determined by using simulation software [3].

## 2.   Simulation of Braking System Incorporating an Accumulator

The simulation takes into consideration the diagram in Figure 3 [4]. The pump P driven by the electric motor EM sucks up the oil from the tank through the absorption filter SF. The pressure valve PV allows the adjustment of the maximum pressure. The directional control valve D1(S1) ensures the charge of the circuit, specific to the pre-controlled installations [2]. The pressure filter F filters the oil. The circuit provided exclusively for braking in emergency situation contains: the accumulator Ac, the directional control valve D2(S2), the check valve CV. The pressure switch PS confirms the pressure required for brake actuation.
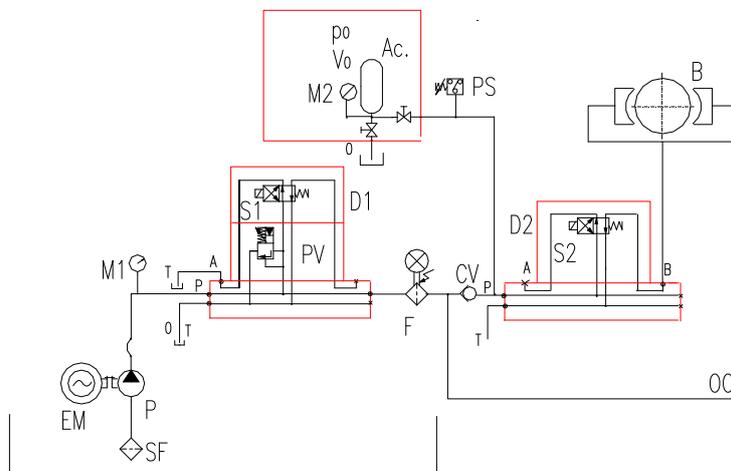


Fig. 3: SF – absorption filter , EM - electric motor, P - pump, M1, M2 – manometer, PV – pressure valve, D1, D2 – directional control valves, F - filter, S1,S2 - electromagnets, CV – check valve, Ac - accumulator, PS – pressure switch, B – hydraulic brake, OC – other hydraulic circuits.

The manometers M1 and M2 display the pressure in the general circuit and the pressure in the brake circuit. Normally, the installation also serves other circuits OC, not shown in the diagram. In case of emergency – pump failure, mains power failure, pipe break, etc. – the directional control valve D2(S2) is actuated. The accumulator, which has been charged until that moment, discharges and actuates the brake B. After dimensioning the required accumulator, a simulation is recommended for checking the operating mode of the brake B. Figure 4 presents the result of the simulation for the evolution of the pressure when activating (S2+) and deactivating (S2-) the brake.
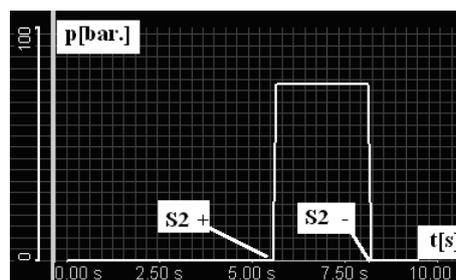


Fig. 4: The result of the simulation

When activating the brake the pressure rises to 75-80 bar in 0.2s approximately, this corresponds to a braking force Ff over 5800 daN. The deactivation of the brake is accomplished as fast as the activation. For higher forces, the pressure or the braking surface should be increased.

## 3.    Simulation of Safety Systems Incorporating an Accumulator [4], [5]

It is considered the diagram of the actuation of a cylinder on vertical direction, as given in Figure 5. The installation is made based on the three hydraulic modules: MOD1 – pre-control module, MOD2 – up and down actuation module and MOD3 – safety module used for the lifting up of the load without requiring the operation of the pump. The pilot operated valve is provided to prevent accidental failure of the load [6]. The pump driven by the electric motor EM, sucks up the oil from the tank through the absorption filter SF. The pressure valve PV allows the adjustment of the maximum pressure. The pressure filter F filters the oil. The circuit intended exclusively for emergency cases contains: the accumulator Ac, the directional control valve D2(S2) and the check valves CV1 and CV2. The pressure switch PS confirms the pressure required for the actuation. The manometers M1 and M2 display the pressure in the general circuit and the accumulator circuit. Normally, the installation serves the lifting and descending circuit – module MOD2.
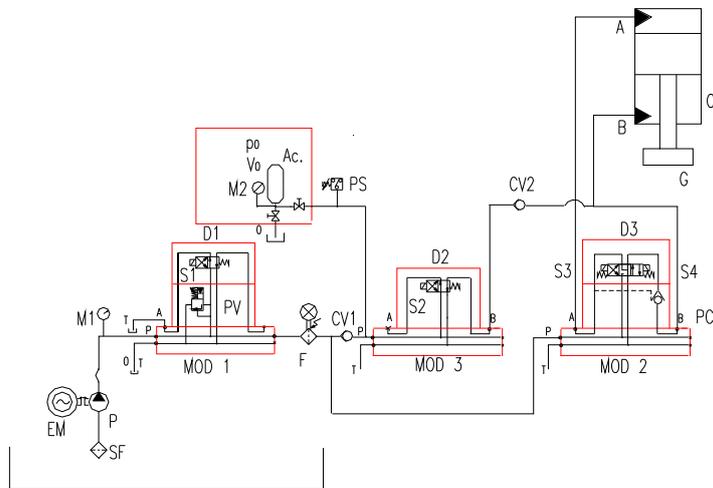


Fig. 5: SF – absorption filter, EM – electric motor, P - pump, M1, M2 - manometers, PV – pressure valve, D1, D2, D3 – directional control valves, F - filter, S1, S2, S3, S4 - electromagnets, CV1, CV2 – check valves, Ac - accumulator, PS – pressure switch, C – hydraulic cylinder, M – mobile mass, PCV – pilot controlled valve, MOD1, MOD2, MOD3 – hydraulic motors.

In case of emergency – pump failure, mains power failure, pipe break, etc. – the directional control valve D2(S2) is actuated. The accumulator that has been charged until that moment discharges and actuates the piston cylinder C on the lower surface. The oil accumulated in the accumulator gets relaxed and lifts up the load M. Figure 6 presents the evolution of the pressure on the lower surface of the piston and the position of the rod (its withdrawal) from the moment the commend of emergency lifting up is given (S2+).
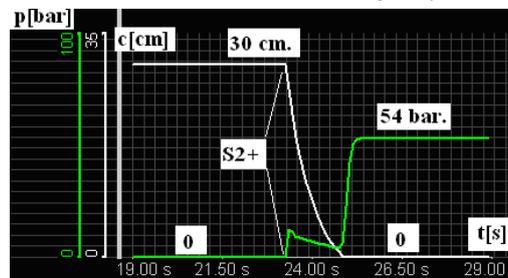


Fig. 6: The evolution of the pressure

It is noticed that the lifting up of the mobile assembly is accomplished in less than 3 seconds. Actually, it can last longer, depending on several factors that have not taken into consideration: tightening type of the cylinder, friction forces on the guideways or on the piston rod, etc. However, some of modifications usually made after building up a prototype can be avoided by simulation and that means saving time and money.

## 4. Experimental Researches Carried out

For the straight cup wheel grinding machines, in case of accidental stoppage of the magnetic table supply, the workpieces can be thrown away. That leads to workpiece damage and represents a serious threat for the operational safety [6]. The solution presented further (Figure 7) allows lifting up the grinding wheel – almost instantaneously, so as the workpieces are no longer driven when the power supply of the magnetic table is interrupted. If the power supply of the magnetic table fails, the circuit incorporating the accumulator actuates two linear hydraulic motors that lift up the wheel.



Fig. 7

For simulation, it has been considered the usage of an accumulator with V0 = 2.5 l, loaded to p0 = 80 bar. The working head with the holding devices and the wheel weighs 2000 kg. In accordance with the catalogues of hydraulic equipment manufacturers, the time required to switch on the directional control valve is 10 - 25 ms, for D.C. driving. When simulating, it is noticed that after 0.08s the head lifts up by 7 mm, which is a dimension sufficient for the protection of the workpieces on the magnetic table. The directional control valve switching time is added. Therefore, it can be considered the time of 0.1 s is sufficient for a lifting up higher than 5 mm. After building-up the real installation, during tests, it has been noticed the lifting up is done in a time short enough to eliminate the risk of throwing away the workpieces from the magnetic table.

## 5. Conclusions

The hydro-pneumatic accumulators can be used to increase the operational safety of various hydraulic installations of the machine-tools. The selection of the accumulator should be done for each case by taking into consideration the real working conditions.

The modeling represents a series of equations or systems of equations, algebraic or differential, linear or not, describing the operation of the studied element or system. The input parameters supposed to be known and the output parameters to be determined should be clearly defined for these models. Defining those parameters is sometime difficult for the hydraulic installation of the machine-tools. A subjective factor intervenes: the expertise of the hydraulic designer. Computer-aided Design cannot be done just using the software and the computer. A series of factors and coefficients is necesary and neither the manufacturer of the hydraulic componets nor the specialised books provide them. They have to be experimentally determined in laboratories endowed with special equipment.

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