Energy Loss Reduction in Hydraulic Installations of the Machine Tools Served by Constant Flow Pumps

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Abstract: *In this paper, the authors present an analysis of the adjustment systems related to the flow-pressure type operating parameters in the hydraulic installations of the machine-tools which enable energy consumption to be reduced. Some of the most common basic schemes in the hydraulic installations of the machine-tools are presented, analyzing technically but also economically the opportunity to use them. In order to support possible options, the authors also present the results of the simulations carried out.*

Keywords: *Machine-tools, hydraulic installations, energy loss reduction, simulations*

1. Introduction

The transfer of power in any hydraulic installation is carried out as shown in the diagram in Figure 1 [1].

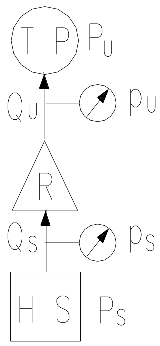

Fig. 1. Transfer of power in a hydraulic installation

The power of the P_S source is developed at the HS hydraulic source. The components are: Q_S flow rate and p_S source working pressure. Among these sizes, we have the relation:

$$P_S = p_S Q_S \tag{1}$$

The flow rate and pressure can be adjusted, as necessary, by means of the adjustment equipment R. Finally, the technology process served by TP includes: the effective flow Q_U, the effective pressure P_U and the effective power P_U:

$$P_U = p_U Q_U \tag{2}$$

The efficiency of the installations of the type shown in Figure 1 is:

$$\eta = \frac{P_U}{P_S} \tag{3}$$

The value of the required power results from the specific process. In this case, to increase the efficiency value, the only solution is to reduce the power of the source. However, the actual operating conditions must also be taken into account in the presence of local losses and on hydraulic flow and/or pressure routing [2, 3, 4]:

$$Q_U < Q_S \quad (4)$$

$$p_U < p_S \quad (5)$$

If the process requires multiple flow rates and/or working pressures, then the hydraulic system may provide much higher powers than the effective one in some phases. In addition to the low efficiency of the installation, there is another drawback: the lost power is converted into heat which can lead to the installation malfunctioning or even to its destruction [2, 3]. The difference between the OABC and OXYZ triangle areas, shown in Figure 2, is the power lost in any operation phase of the installation.

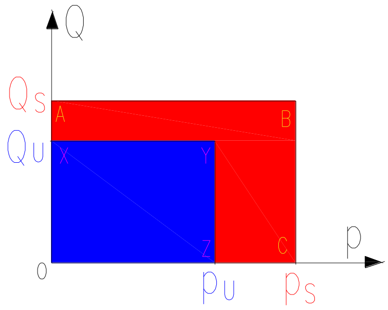

Fig. 2. Effective power and lost power

The hydraulic source (HS) is usually made up of [1]: the electric drive motor of the pump(s), the pump(s) and the pressure regulation system p_S. Under these conditions, the flow Q_S with a certain characteristic represented by the closed curve C_1 in Figure 3 shall be provided.

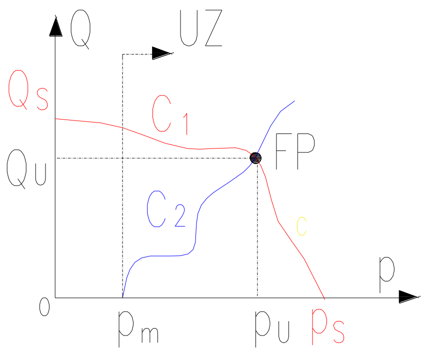

Fig. 3. Establishing the operating point

At the level of the technological process (TP), a minimum p_m pressure and flow rate are required represented by the open curve C_2. The intersection of the two curves represents the “operating point” of the FP installation [1]. This is where the Q_U effective flow and the p_U pressure get. Any adjustments may only be carried out in the feature’s useful area (UZ), as shown in Figure 3.

2. Hydraulic Sources

The simplest hydraulic source is shown in Figure 4 and includes: the EM electric motor, the PC constant flow pump which sucks oil from the T tank and the PV pressure regulating valve. The source pressure is displayed on the M_1 pressure gauge.

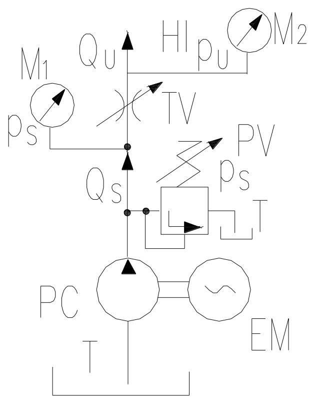

Fig. 4. The source with a constant flow pump

The hydraulic installation (HI) served is supplied by the Q_U flow-rate source regulated by the hydraulic installation represented by the TV hydraulic throttle. Under these conditions, an instantaneous p_U pressure develops in the installation and can be seen on the M_2 pressure gauge. Such pressure must check the relation:

$$p_m \leq p_U \leq p_S \tag{6}$$

If the pressure valve is considered to open instantaneously, the characteristic of this source and the method of determining the operating point in this case are shown in Figure 5.

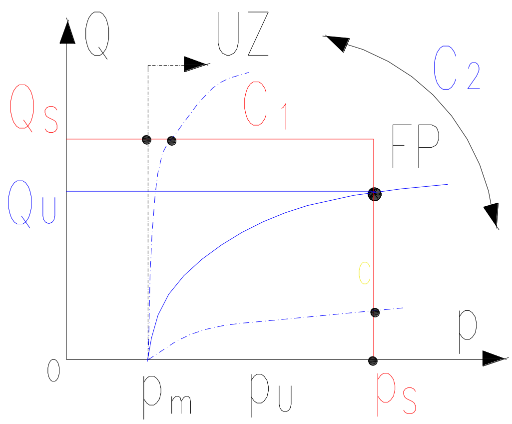

Fig. 5. The characteristic of the hydraulic source with a pump

According to the characteristic in Figure 5, the Q_U effective flow is:

$$Q_U = \begin{bmatrix} 0, p \leq p_m \\ Q_S, p_m < p < p_S \\ \in (0, Q_S), p = p_S \\ 0, p \geq p_S \end{bmatrix} \tag{7}$$

In this case, if the installation works with significantly different flow rates and in a restricted pressure range close to the p_S value, the source sizing shall be carried out for the maximum flow required and p_S pressure.
Let us assume that the served installation works in two phases:
Phase1: Q_{U1} = 30 l/min, p_{U1} = 15 bar, p_m = 10 bar;
Phase2: Q_{U2} = 3 l/min, p_{U2} = 70 bar, p_m = 10 bar.
Under these conditions, a pump with a flow rate of 30 l/min has been selected and the pressure valve will be adjusted to 70 bar.

The source power shall be, in this case, $P_S = 3.5$ KW. The effective power in the first phase is $P_{U1} = 0.75$ KW and, in the second phase, $P_{U2} = 0.35$ KW. The outputs in these two cases shall be: $\eta_1 = 21.5\%$ and $\eta_2 = 10\%$.
The operating characteristics for the two phases are shown in Figure 6.

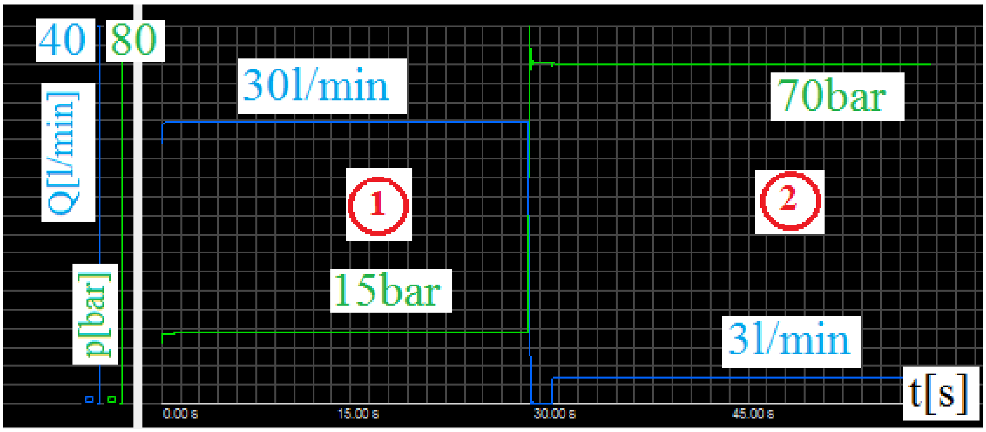

Fig. 6. Operating characteristics

This solution, with a single pump and a single pressure valve, is characterized by the fact that the outputs in both working phases are low, but also by the fact that it is the cheapest solution.
A solution which even exceeds twice the previous price is the one which uses two pumps and two pressure valves, as shown in Figure 7.

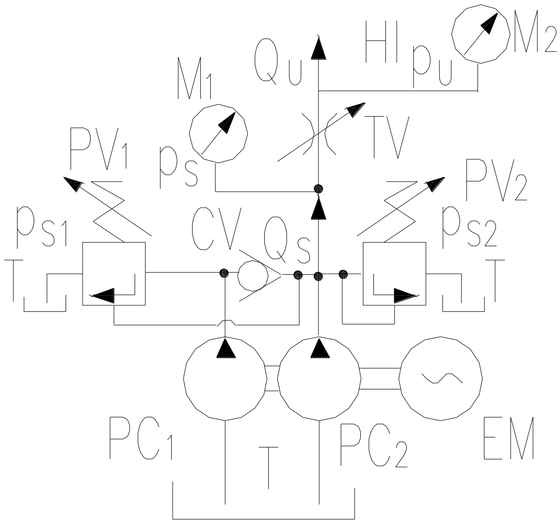

Fig. 7. The hydraulic source with two pumps

In this case, the EM electric motor drives two constant flow pumps PC_1 and PC_2. Their flows are $Q_{S1} = 24$ l/min and $Q_{S2} = 6$ l/min. The two pumps are coupled in the installation via the CV non-return valve. The PV_1 and PV_2 pressure valves are adjusted at pressures $p_{S1} = 20$ bar and $p_{S2} = 70$ bar. The same working conditions as in the previous case are considered.
If the pressure valves are considered to open instantaneously, the characteristic of this source and the method of determining the operating point in this case are shown in Figure 8.

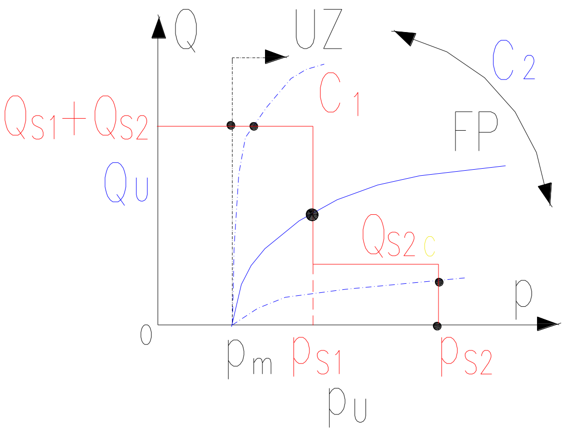

Fig. 8. The characteristic of the source with two pumps

According to the characteristic in Figure 8, the Q_U effective flow is:

$$Q_U = \begin{cases} 0, p \le p_m \\ Q_{S1} + Q_{S2}, p_m < p < p_{S1} \\ \in (Q_{S2}, Q_{S1} + Q_{S2}), p = p_{S1} \\ Q_{S2}, p_{S1} < p < p_{S2} \\ \in (0, Q_{S2}), p = p_{S2} \\ 0, p \ge p_{S2} \end{cases} \quad (8)$$

The source power shall be, in this case for the first phase P_{S1} = 1 kW, and on phase two it becomes P_{S2} = 0.7 KW. The effective power in the first phase is P_{U1} = 0.75 KW, and in the second phase P_{U2} = 0.35 KW. The outputs in these two cases shall be: η_1 = 75% and η_2 = 50%. There is a significant increase in outputs for each phase.
Even if the solution seems to be more complicated and expensive, cost reductions are being made for other reasons. In the first case, an electric drive motor was required with the power P_{EM} = 4 KW. For the second option, a motor having the power P_{EM} = 1.5 KW is sufficient.
In the second case, for the two phases the operating characteristics are as shown in Figure 6. The difference is that, at a pressure of 70 bar, the flow rate of the PC1 pump is fully discharged through the pressure valve PV1 at a pressure of 20 bar.
In fact, in the case of machine tools, type 2 phases (chipping processes) take much longer than type 1 phases (positioning, approach phases etc.) [5]. This meant an even greater energy saving.
Apart from the work phases, hydraulic installations actually have phases in which they do not work. In this case, the oil is discharged through the pressure valves.
In the first case, the 30 l/min flow rate is discharged through the pressure valve PV at a pressure of 70 bar. In the second case, the 24 l/min discharge shall be carried through the pressure valve PV_1 at a pressure of 20 bar and the remaining 6 l/min shall be discharged through valve PV_2 at a pressure of 70 bar.
For such cases, considerable energy savings are achieved without stopping the pump(s) by using pre-control type solutions [1, 6].

3. Pre-control Hydraulic Installations

Pre-control valves require a pressure valve bypass system so that, when the installation is not required, the pumps discharge freely to the tank.
The diagram shown in Figure 4 was supplemented by a pre-control system as shown in Figure 9.
As long as the DV distributor is not driven and is in position 0, the pump will discharge directly to the tank. If coil E is powered, the distributor switches to position 1, which engages the system for the desired phases.

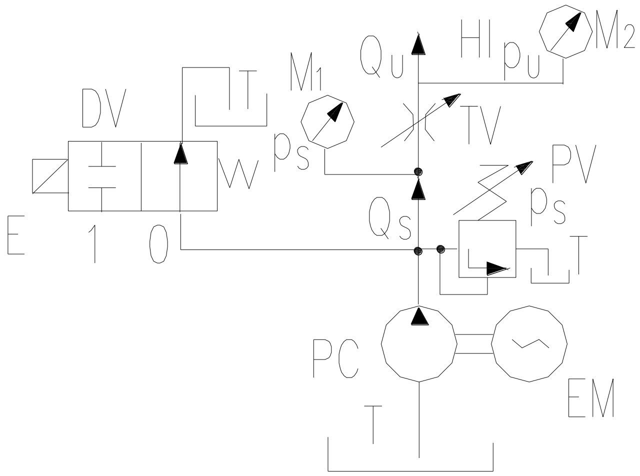

Fig. 9. Pre-control hydraulic source

Figure 10 shows the three operating phases in case there is pre-control.

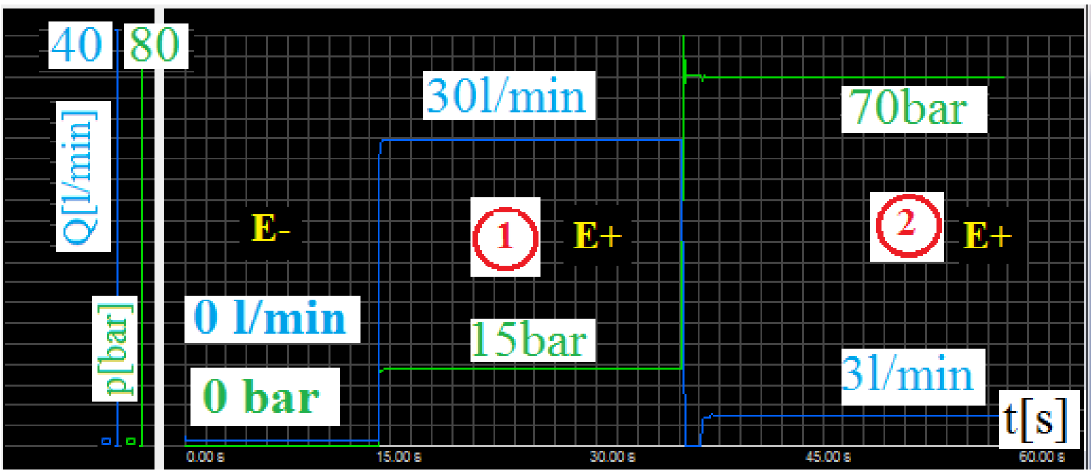

Fig. 10. Operating characteristics

The Q_U effective flow shall be:

$$Q_U = \left[\begin{array}{c} if\ E- \\ 0 \\ if\ E+ \\ 0, p \leq p_m \\ Q_S, p_m < p < p_S \\ (0, Q_S), p = p_S \\ 0, p \geq p_S \end{array} \right. \tag{9}$$

Theoretically, when the distributor is not driven, the source power is P_S = 0 KW because the pressure is zero (p_S = 0) because the PV pressure valve is closed. In fact, the system must cover the inherent pressure and flow losses.
In the case of machine-tools, there are installations where the pre-control systems are accompanied by hydro pneumatic accumulators [2, 5, 7, 8].

4. Conclusions

Due to multiple power conversions, electrical to mechanical, mechanical to hydraulic and, finally, hydraulic to mechanical, the hydraulic installations are characterized by low outputs. Constant flow or variable flow pumps shall be used as hydraulic power generators. Due to the low price, constant flow pumps (usually gear pumps) are the most commonly used. The design of the hydraulic system when these pumps are used has a particular effect on the efficiency of these installations. The use of two or even three pumps, with or without different flow rates, which together provide the maximum required, can increase the efficiency of these plants. The characteristics of the pumps and of the equipment used must be selected according to the phases and work procedure.
Pre-control systems can bring significant energy savings, especially for high-power installations, if there are working phases where the hydroelectric installation is not required. In this case, it is not recommended to switch electric pump drive motors on/off, the only option being to use the pre-control whether or not the batteries are present.

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