Optimization of Manufacturing Processes by Reducing the Costs of Tools and Equipment on Hydraulically Operated High-Pressure Technological Lines

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Abstract. Most technological manufacturing lines include hydraulically operated stationary tools, devices and equipment. During a manufacturing cycle, there are phases, usually short, in which part of the hydraulic cylinders of the drive systems concerned, with small gauges and displacement speeds, have to generate / maintain high clamping or pressing forces, which implies functioning at high working pressures.

The solution for such cylinders is to use modular hydraulic pumping units comprising: oil tank; low-pressure electric pump; hydraulic directional valve for starting, stopping and changing the direction of displacement of the cylinder; electric pump pressure control valve; pressure filter; return filter; oscillating hydraulic pressure intensifier (minibooster mounted directly on the cylinder).

Such pumping units, which consume low pressure (in the primary side of the minibooster) to generate high pressure (in the secondary side of the minibooster), are cost-effective when it comes to the procurement of components, installing them, the space required for installation, and their maintenance, too.

The classic applications of using them are for achieving and maintaining high pressure values, either in volumes of closed spaces (endurance tests on pipes and tanks), or at the active stroke end of hydraulic cylinders (hydraulic presses).

The authors demonstrate, on a laboratory test bench, the following:

- The range of applications of such pumping units can be extended in a third direction, namely for actuation of hydraulic cylinders with low gauge / speeds and constant high load (high working pressure) over the entire stroke;

- The uniformity of displacement of these cylinders with load over the entire stroke, fed and actuated by such pumping units, is weakly affected by the pulsating mode of operation of the hydraulic pressure intensifier.

Keywords: Low Pressure, Pumping Unit, Oscillating Hydraulic Pressure Intensifier, High Pressure, Hydraulic Cylinder.

1 Introduction

There are known two solutions for generating high pressure in hydraulic drive systems: an expensive one, based on pumps and equipment for adjusting / controlling high-pressure hydraulic parameters, and a cheaper one, based on pumps and equipment for adjusting / controlling low-pressure hydraulic parameters, plus hydraulic pressure intensifiers. For example, Fig. 1 shows the two drive solutions for a hydraulic cylinder with a load of 700 bar.

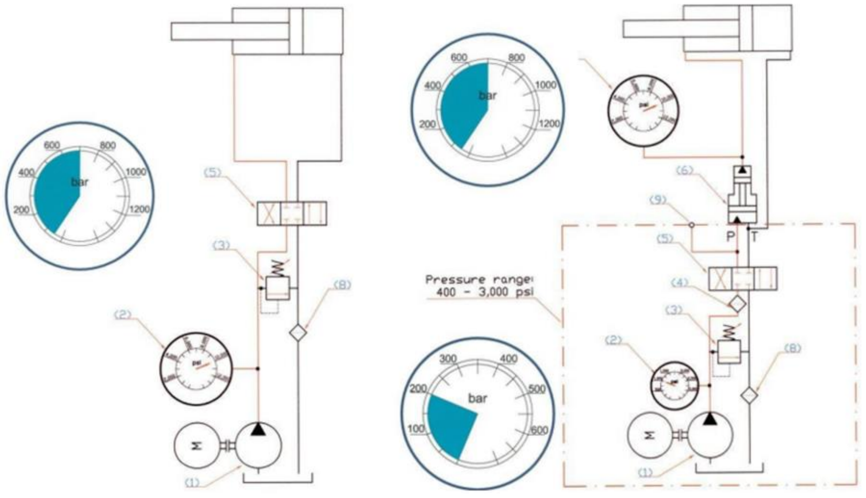


Fig. 1. Generating a pressure of 700 bar for actuating a hydraulic cylinder: left - with high-pressure pump; right - with low-pressure pump and hydraulic intensifier.

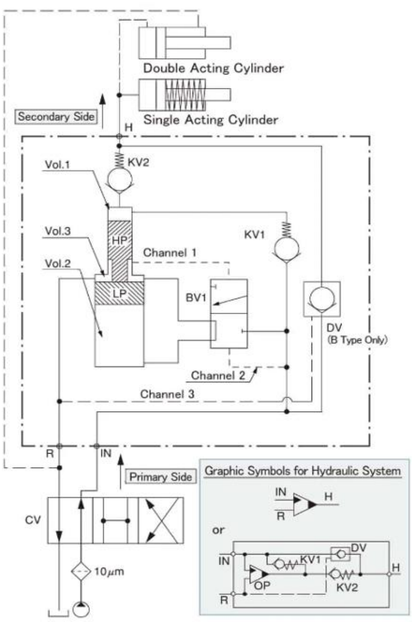
In the hydraulic drive diagram [1] shown in Fig. 1-left, motor **M** drives **high-pressure pump (1)**, to direct hydraulic oil, at a pressure of 700 bar, indicated on pressure gauge **(2)**, limited by valve **(3)**, via directional control valve **(5)**, switched to the field of parallel arrows, to the cylinder rod chamber. The cylinder piston chamber discharges into the tank via return filter **(8)**, and the hydraulic cylinder moves to the right with a load of 700 bar.

One can move the same hydraulic cylinder to the right, with a load of 700 bar, according to the hydraulic drive diagram [1] shown in Fig. 1-right, where **low-pressure pump (1)**, pressure relief valve **(3)** and directional control valve **(5)** operate at 200 bar, indicated on pressure gauge **(2)**. Return filter **(8)** remains, while additional low-pressure filter **(4)** and **pressure intensifier (6)** appear; the latter is fed via connecting fitting **P**, from the primary side, by pump **(1)**, and on the outlet of the secondary side, it delivers hydraulic oil at 700 bar in the cylinder rod chamber. Due to the pulsating mode of operation of the pressure intensifier, one uses this drive diagram for **short displacements under load** of the hydraulic cylinders or with the purpose of **achieving and maintaining the load at the stroke end**.

2 Testing of pumping units equipped with minibooster

2.1 Structure and operation of an oscillating hydraulic pressure intensifier

An oscillating hydraulic pressure intensifier (minibooster) is connected in the primary side to a low-pressure pumping unit [2]: port **IN** connects to the pump outlet; port **R** connects to the tank. It consumes low pressure (at high flow rate) in the primary side, which it converts at port **H**, in the secondary side, to high pressure (at low flow rate) for a double or single acting hydraulic cylinder, Fig. 2.



Double acting cylinder;
Single acting cylinder;
Minibooster:
H = high-pressure port;
LP = low-pressure piston;
HP = high-pressure piston;
BV1 = 3/2 bistable directional control valve;
Channel 1 and **channel 2** = hydraulic control of BV1;
KV1, **KV2** = check valves for oil intake / discharge in / from the HP piston chamber;
DV = pilot-operated check valve;
Channel 3 = hydraulic control for piloting the DV valve;
IN = inlet port for oil from the pump;
R = return port for oil to the tank;
OP = **LP+HP+BV1** = pressure oscillator.
Low-pressure pumping unit:
Low-pressure **pump**;
Pump drive **motor** (not shown);
Pump discharge **filter**;
Pressure control **valve** (not shown);
CV = 4/3 hydraulic directional control valve.

Fig. 2. The basic hydraulic diagram of a minibooster.

There are four phases in the operation of a minibooster:

1. The oil enters port **IN** and passes through valves **KV1**, **KV2**, **DV** directly to port **H**. Pump flow bypasses pistons **LP**+**HP**; a hydraulic cylinder connected to port **H** moves fast forward;
2. When the cylinder encounters resistance, valves **KV2** and **DV** close. The pump pressurizes **Vol. 1**, the pistons move downwards, valve **BV1** discharges **Vol. 2** to the tank, via **Vol. 3** (oil suction in the secondary side of the minibooster);
3. When the pistons have moved fully downwards, hydraulic pilot **channel 1** is pressurized, and bistable directional control valve **BV1** changes its position. Pump flow is driven to **Vol. 2**, the pistons move upwards, delivering a low flow rate to the cylinder at high pressure (oil discharge from the secondary side of the minibooster);

4. When high-pressure piston **HP** has been moved fully upwards, hydraulic pilot **channel 1** connects to the tank, and valve **BV1** switches to its start position. The cycle is repeated until the required high pressure is set at port **H**. Switching 4/3 directional control valve **CV** on the hydraulic connection field on the right (**R** to the pump and **IN** to the tank), **channel 3** for hydraulic control of valve **DV** is pressurized and the high-pressure circuit connected to port **H** is discharged to the tank.

2.2 Test bench for the pumping unit equipped with minibooster

To demonstrate that high-pressure pumping units, consisting of low-pressure pumping modules and oscillating hydraulic pressure intensifier [3], can also be used for displacement of a hydraulic cylinder with constant load over the entire stroke, the authors have built the experimental bench [4] shown in Fig. 3.

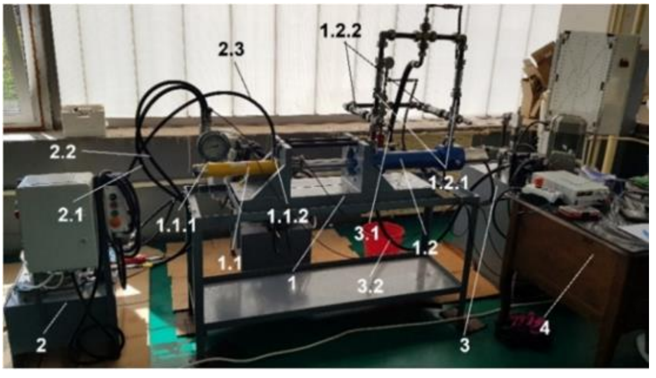


Fig. 3. Experimental test bench for the pumping unit equipped with minibooster.

The structure of the bench and the pumping unit in the figure above is as follows:

- **1**: **Module for clamping the hydraulic cylinders**; **1.1**: test cylinder - piston Ø= 38.1 mm, rod Ø= 25 mm, stroke= 257 mm, pmax= 700 bar; **1.1.1**: fitting connecting cylinder piston chamber with secondary side of the minibooster; **1.1.2**: connecting fitting and hose for cylinder rod chamber; **1.2**: load cylinder with built-in stroke transducer and piston Ø= 80 mm, rod Ø= 45 mm, stroke= 300 mm, p_{max}= 300 bar; **1.2.1**: cylinder chambers inlet check valves; **1.2.2**: cylinder chambers outlet check valves;
- **2**: **Low-pressure pumping unit** equipped with: electric pump of 4 kW, 200 bar, 10.5 l/min; oil tank with V= 38 l; fill and vent filter, and return filter; hydraulic block with pressure filter, pressure control valve, 4/3 directional control valve; HC7 minibooster with 5:1 amplification ratio, 0...1000 bar outlet pressure, 10.5...1.2 l / min outlet flow rate; electric panel; **2.1**, **2.2**= minibooster primary side connection hoses;
- **3: Pumping station for filling the load cylinder** equipped with: electric pump of 2 kW, 10 bar, 90l/min; oil tank with V= 180 l; filling pressure control valve; proportional load control valve; fill and vent filter; return filter; **3.1**= cylinder chambers fill connecting fitting; **3.2**= cylinder chambers drain connecting fitting;

- **4: Control and data acquisition unit**, acquiring data from the transducers for: acceleration measured in the direction of displacement of the minibooster pistons (**Acc1**); acceleration measured in the direction of displacement of hydraulic cylinders (**Acc2**); minibooster primary side pump pressure (**p1**); load cylinder pressure (**p2**); filling pump pressure (**p3**); minibooster primary side input flow rate (**Q1**); load cylinder flow rate (**Q2**); **stroke** (incorporated into the load cylinder).

2.3 Excerpt from the nomenclature of experimental tests

The results of the tests carried out for two values of the load of the test cylinder are presented, namely: for **800 bar**, equivalent to a resistive force of the load cylinder of **91x103N**, and for **700 bar**, equivalent to a resistive force of **80x103N**.

Experimental tests [5,6] have been performed in the following conditions: on the test bench shown in Fig. 3 the opening pressure of the normally closed valve, which the low-pressure pumping unit is equipped with, has been set to **160 bar**; the opening pressure of the safety valve of the load cylinder filling pump has been set to **19 bar**; the experimental tests have been performed on the advance stroke of the test cylinder; the data acquisition has been done as follows: with a speed of **200 samples / s** and a duration of **44 s**, for the 800 bar test - a duration of **20 s**, for the 700 bar test; on a segment of **27.6 mm**, for the 800 bar test – a segment of **169.6 mm**, for the 700 bar test, out of the total **257 mm** stroke of the test cylinder.

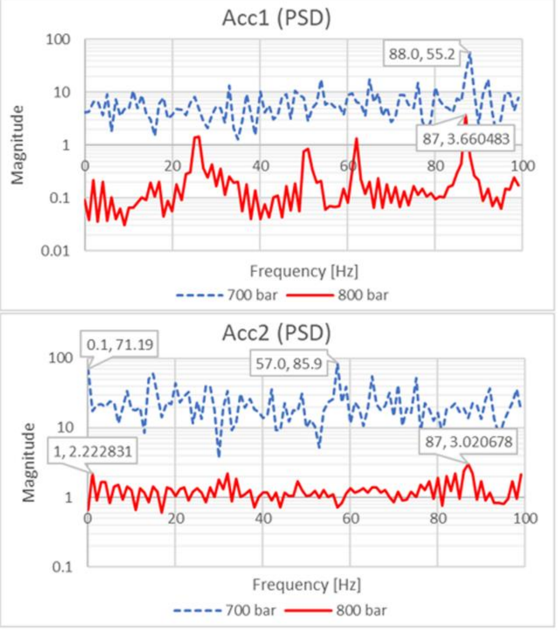


Fig. 4. Power spectral density measured with Acc1 (top) and Acc2 (bottom).

The power spectral density (PSD) of vibration highlights the variation of the magnitude (ratio between maximum and minimum amplitude) of acceleration in the frequency domain, measured • in **the direction of displacement of the minibooster pistons**, Fig. 4-top, with peak values of 3.66 (at 87.3 Hz) for a load of 800 bar, and 55.2 (at 88 Hz) for a load of 700 bar; • in **the direction of displacement of hydraulic cylinders**, Fig. 4-bottom, with peak values of 2.22 (at 1 Hz) and 3.02 (at 87 Hz) for a load of 800 bar, and 71.19 (at 0.1 Hz) and 85.9 (at 57 Hz), for a load of 700 bar. On the graphs in Fig. 4 and Fig. 5, one can notice: the magnitude of vibration decreases with increasing the load of the hydraulic cylinder; the magnitude of vibration of the hydraulic cylinder increases compared to that of the minibooster.

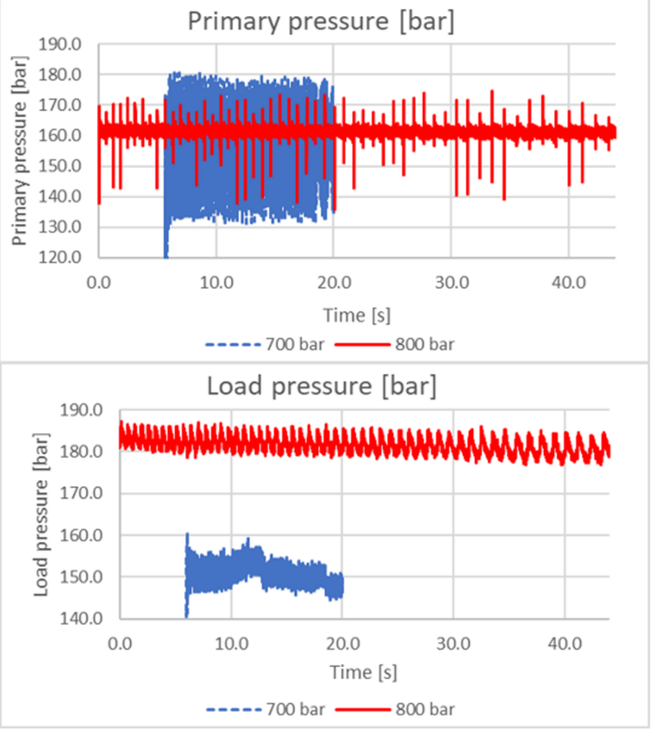


Fig. 5. Time variation of pressure measured with: p1 (top); p2 (bottom).

Fig. 5-top shows the time variation of the pressure in the minibooster primary side, around the average values of 160 bar and 140 bar for a load of 800 bar and 700 bar, respectively. At higher loads, there is a smaller variation in pressure, because the pump pressure valve in the minibooster primary side, set to 160 bar, opens when in its secondary side a pressure of 160x5=800 bar is achieved.

In Fig. 5-bottom one can notice that the time variation of the pressure in the load cylinder is less at the load of 800 bar compared to the one at the load of 700 bar, for the same reason: the pumping unit pressure regulating valve has been set to 160 bar for both sets of measurements (800 bar load and 700 bar load).

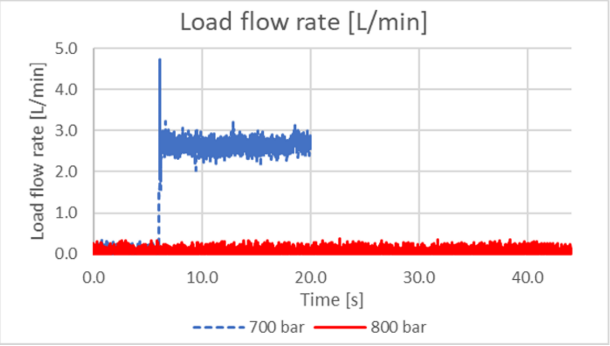


Fig. 6. Time variation of the flow rate in the load cylinder (Q2).

The time variation of the flow rate in the load cylinder, fig.6, takes place around the average values of 2.5 l / min and 0.1 l/min for the loads of 700 bar and 800 bar, respectively (the test cylinder working pressure has been limited to 800 bar).

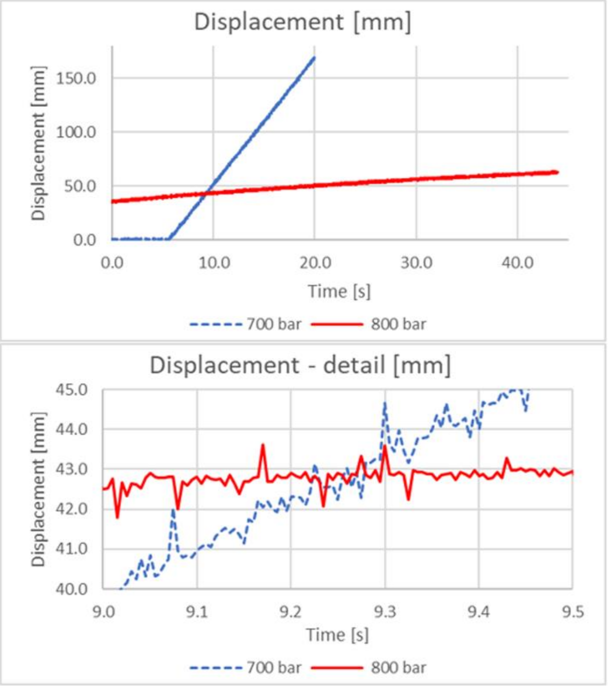


Fig. 7. Time variation of the displacement of hydraulic cylinders (stroke transducer).

Due to the low flow rate of the test cylinder at a load of 800 bar, its displacement, Fig. 7-top, has a small slope compared to that for a load of 700 bar. In the detail of Fig. 7-bottom one can notice the deviations from the linearity of the displacement of hydraulic cylinders.

3 Conclusions

It has been shown experimentally that the displacement of a high-pressure hydraulic cylinder with a small size and constant load over the entire stroke can be done safely by resorting to a cheaper solution: cylinder supply with low-pressure pumping unit, equipped with oscillating hydraulic pressure intensifier (minibooster).

The pulsating mode of operation of the minibooster, caused by the alternating symmetrical displacement of the pistons and the spool of the bistable directional control valve, with a frequency of 0.01 ... 20 Hz, does not induce dangerous shocks that would affect the mechanical strength of the hydraulic cylinder and its drive system.

The deviations from linearity of the displacement are small, and the speed of displacement at high loads increases if the normally closed valve of the pumping unit is set to an opening pressure higher than that corresponding to the load.

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