Aspects Regarding Methods for Hydraulic Cylinders Synchronization

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Abstract: *To address the issue of synchronization of the hydraulic cylinders, that can lead to safety hazards for the operators, this study develops a hydraulic circuit intended for vehicles service lifting. The study covered two variants that were compared through Fluid SIM design and simulation while monitoring important parameters, demonstrating the main differences between electrical and proportional controlled transmissions. Testing highlighted a better precision regarding the proportional transmission, but at a higher cost while it also requires specialized personnel to handle due to its complex design.*

Keywords: *Hydraulic cylinder, proportional control, flow divider, hydraulic system*

1. Introduction

Hydraulic systems are indispensable in many industrial fields [1] due to their ability to develop large forces and moments. These forces, which they develop, allow the lifting, supporting, blocking and transportation of very large installations, equipment, etc., which cannot be moved or handled otherwise than with high-power systems.
One solution for the synchronization of hydraulic cylinders can be the use of an external controller to synchronize the movement of the cylinders and a non-linear internal control system for the cylinders [2]. Nowadays hydraulic press plays a role in the heavy industry to which synchronized hydraulic cylinder is the key component, therefore a thorough investigation is needed through simulation and testing [3].
In industrial manufacturing systems, it is often needed to synchronize two, three or more hydraulic cylinders to assure a better control of an automatic and synchronized system [4]. Advanced research on multi-cylinder synchronization confirms this requirement, especially in forging hydraulic presses [5]. Thus, to assure it, the cylinders are going to be accompanied by position sensors.
Several methods of cylinder synchronization can be identified in the specialized literature [6]:

- flow divider;
- rigid cylinder coupling mechanism;
- pumps with equal flow rates for individual supply of each cylinder;
- proportional directional control valves.

The flow divider is the most frequently used method of synchronization of hydraulic cylinders, due to its constructive simplicity and the results obtained. It prevents kinematic discrepancy and improves vehicle mobility; the most important types of flow dividers are spool type and gear type. Each type has its own characteristics as accuracy, pressure drop and application parameters [7].
Coupling the cylinders by a rigid mechanism is another method used for their simultaneous movement. This solution assumes that one of the cylinders is forced to move at the same speed as the other, even if there is a difference in flow rate between the branches. Although in the short term it ensures good positioning accuracy, over time, due to repeated forcing, premature mechanical wear occurs, which affects the operation of the entire system.
Using two pumps with equal flow rates can ensure an identical fluid flow rate for both cylinders and, implicitly, synchronized operation. However, this solution cannot be applied in any type of system, but only where the configuration allows the integration of two hydraulic pumps. Doubling the equipment in the system leads to an increase in size, maintenance costs and circuit complexity.
The use of proportional directional control valves for position control allows for high precision, thanks to position sensors that provide a quick response to the movement of the directional control valve spool. Although the precision is very good, the cost of acquiring the equipment can be

disproportionate to the workload of the system. In this case, a rigorous assessment of the possibility of recovering the initial investment is necessary.
For the proposed model, the use of a flow divider was chosen as the method of synchronization of the movement. This equipment consists of two throttles, which allow the adjustment of the fluid flow entering the cylinder feed holes. Depending on the application, the two throttles can have identical or different flow sections.

2. Modelling and simulation of the hydraulic circuit intended for servicing vehicle lifting installations

The proposed transmission model, which will serve a vehicle lifting platform with energy, was designed so that the hydraulic energy produced no longer has a carbon footprint, due to the way it is generated. Thus, using the wind engine as an energy source, hydraulic energy has a minimal impact on the environment.
To model a circuit that allows a vehicle to be lifted with a platform, the literature [6] was consulted, which indicates that the use of a flow divider allows the synchronization of the hydraulic cylinders. Their synchronized movement is a common problem in hydraulic drive systems that use linear motors.
Two variants of the transmission model serving the vehicle lifting platform are analysed:

- Electrically controlled;
- Proportional controlled.

The first variant is based on the use of electrically controlled equipment. This is a more affordable technical solution in terms of costs. A main disadvantage, observed during the simulation, was the delay that occurred when switching between one state and another of the circuit. Considering the scope of application, such delays can be acceptable. The lowering or raising of the vehicle is performed relatively slowly, to avoid instability that may occur due to the mass that the platform must lift.
The second proposed variant uses proportional hydraulic equipment, with closed-loop control. Proportional control equipment makes precise adjustments, positioning the cylinders exactly at the desired height. This solution requires solid knowledge in the use of proportional equipment and its control, knowledge that those who use the platform may lack. Compared to classic technology, with manual or electric control, proportional technology is much more sensitive to environmental conditions. External factors can influence the proper functioning of the circuit. This type of equipment has high acquisition costs and requires dedicated electronics, as well as specialized personnel for installation and commissioning. Maintenance costs could reduce the profitability of the solution.

2.1 Electrically controlled lifting platform

Vehicle lifting systems are manually operated by the people who carry out technical checks on cars. As a rule, there are two hydraulic cylinders mounted on either side of the platform on which the vehicle is placed. After placing it on the platform, depending on the technical problems it has or the necessary checks, it is raised to a certain height, which allows easy access for the mechanic under the vehicle, to make an assessment of the actual situation of the vehicle.
The manual operation of this platform allows employees who do not have technical training to operate the system easily. Both manual and electric operation can be used for such simple systems, but essential for carrying out technical checks on vehicles. One advantage of these is the low cost of the hydraulic components used. Having a simple to use operating principle and a not very advanced technological level, the cost of acquisition, maintenance and replacement of equipment is low.
Considering that this system works against quite large forces, generated by the weight distribution on the platform, an emergency stop system is necessary. This prevents the sudden lowering of the platform if, for various reasons, the hydraulic circuit fails and one of the directional control valves does not maintain its position. An emergency system is proposed that is triggered to protect the personnel performing the checks, by blocking the cylinders in the extended position.

This is achieved using a series of accumulators, which release the fluid stored on the circuit that allows the cylinders to be extended. Simultaneously, two auxiliary directional control valves, which under normal operating conditions are in the preferential "open" position, close, blocking the fluid in the first chamber of the cylinder.
Testing of the proposed hydraulic circuit does not include the safety system, since the purpose of the simulation is to observe the behaviour of the system and its degree of controllability, as well as to identify technical obstacles, but also those related to costs, in relation to the degree of innovation brought by each proposed model.
Thus, an electric drive system for the advance and retraction of the cylinders was designed and built, corresponding to the lifting and lowering movement of the platform. The user has two buttons that activate the electromagnets of the 4/3 directional control valves, responsible for switching the spool to the position through which the chambers that allow the cylinders to advance are supplied, but also for their retraction. Each button activates an electromagnet of each directional control valve, corresponding to the advance and retraction command of the cylinder. Speed adjustment is achieved using track throttles, mounted on both the advance and return circuits.

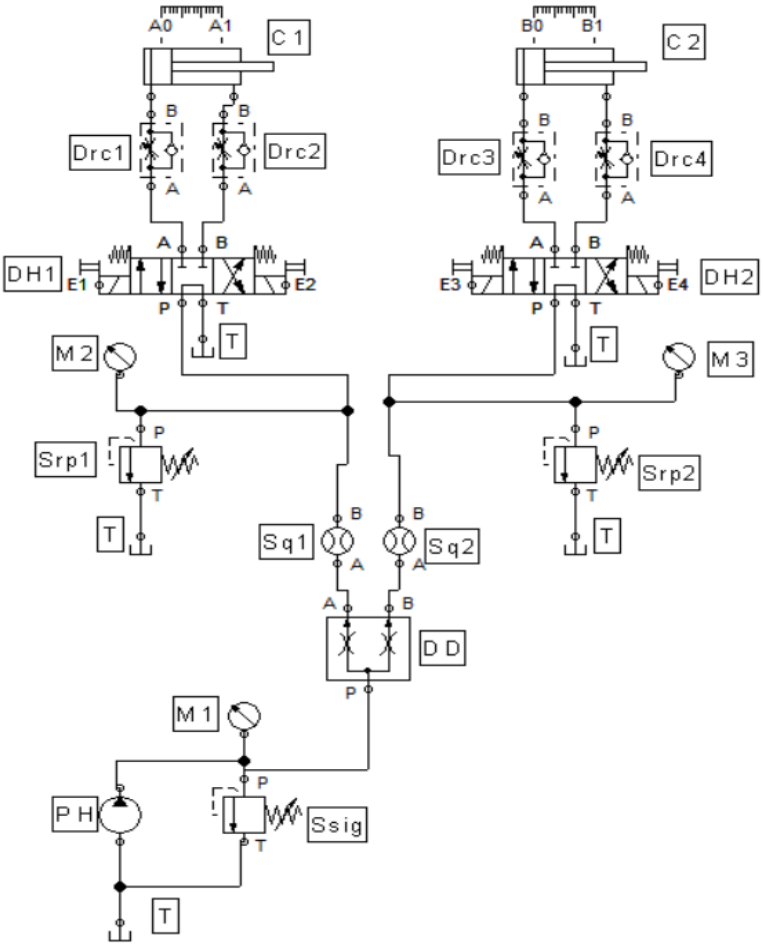

Fig. 1. Hydraulic circuit for supplying and operating a platform for lifting vehicles

Fig.1 shows the hydraulic power supply and drive circuit of a vehicle lifting system. The hydraulic power supply system consists of: PH – hydraulic pump, which ensures a constant fluid flow; M1 – pressure gauge, for checking and monitoring the pressure on the pump discharge; Ssig – safety valve, ensures circuit protection and allows the flow to be diverted to the tank when the set working pressure is exceeded; T – hydraulic fluid tank.
The hydraulic circuit is completed by the cylinder drive system, which consists of the following equipment: DD – flow divider, which ensures equal distribution of the flow on the two branches of the drive circuit; Sq1 and Sq2 – flow sensors, through which the flow values obtained after the

divider are monitored; Spr1 and Spr2 – pressure valves, which have the role of reducing the pressure that is created on the supply branch due to the configuration of the circuit, but also of the directional control valve, which does not allow, in the central position, the sending of the fluid flow to the tank. Thus, as a safety measure, the two pressure valves were installed, which send the fluid flow to the tank. The pressure at the connection points is measured with two pressure gauges, M2 and M3. Two 4/3 bistable directional control valves are also installed in the circuit, with electrical control, but also manual, with spring return. In the preferential position, these have the P, T, A, B ports blocked. When the electromagnet E1, respectively E3, are powered, the directional control valves switch the spool to the position that connects P-A and B-T. When the electromagnet E2, respectively E4, are powered, the directional control valves switch the spool to the position that allows communication between the P-B and A-T ports. The hydraulic circuit for driving the hydraulic cylinders, which are part of the vehicle lifting system, has been completed and improved by integrating track throttles, Drc1, Drc2, Drc3, Drc4, on the circuit branches that advance and retract them, respectively. Double-acting hydraulic cylinders, C1 and C2, were chosen for this application.
Fig. 2 shows the electrical diagram of the circuit for driving the vehicle lifting platform. This electrical circuit activates the electromagnets that control the advance of the cylinders, as well as the electromagnets that control their retraction. The electrical circuit has been designed to operate manually, by pressing two buttons. The user sets the required height at which the vehicle should be positioned, depending on its height and the required technical intervention.
To verify the functionality of this drive system, a series of important parameters were monitored, such as: flow and pressure variation, pump speed, cylinder advance.

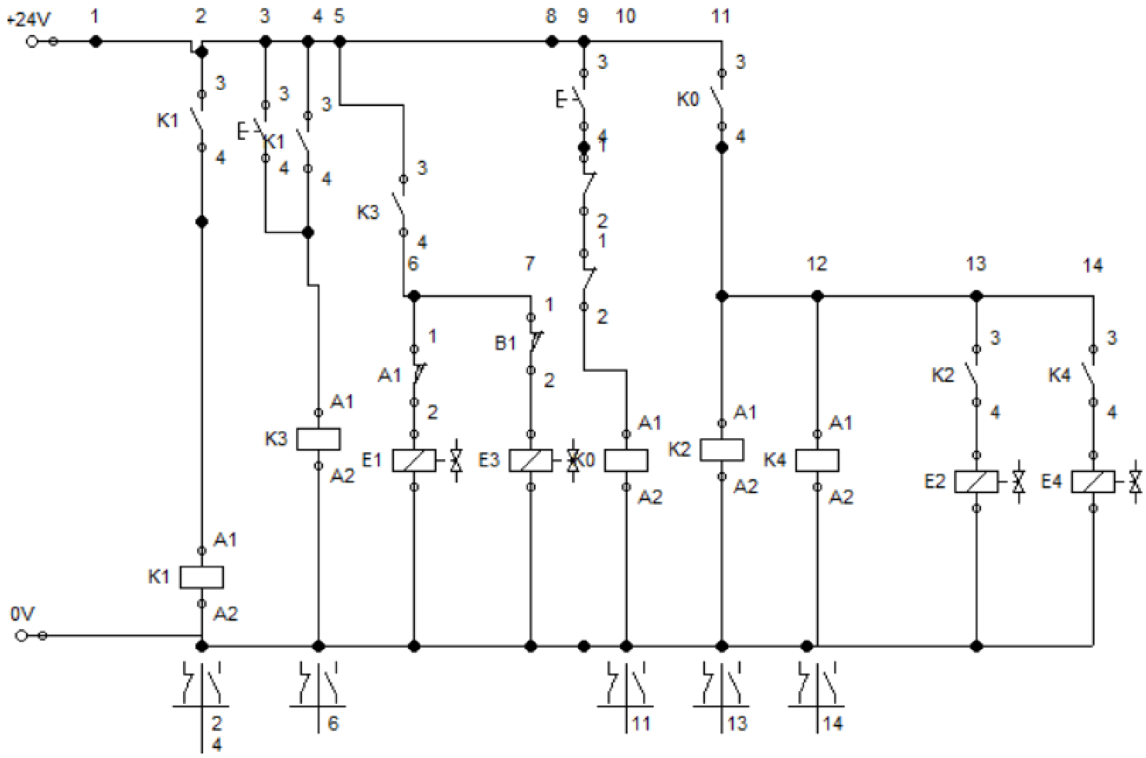

Fig. 2. Electrical diagram of the vehicle lift platform drive circuit

2.2. Proportional controlled lifting platform

During the testing of the functionality of the simulation scheme, an oscillatory movement of the hydraulic cylinders that raise the platform was observed. This oscillatory movement is determined by the variation of the flow section of the directional control valve, which occurs during positioning.
Although the flow section is also implicitly regulated by the proportional directional control valve, the flow speed varies uncontrollably, so the cylinders move either too fast or too slow. To regulate the speed at which the two cylinders raise the platform, it was necessary to improve the drive

circuit scheme by adding on each branch of the circuit a track throttle and an accumulator. Considering the simulation carried out for variant 1, it was possible to deduce that the use of accumulators with a larger capacity could have prevented the flow and pressure drops during the switching of the two buttons.
For this simulation, hydraulic accumulators were chosen, with a pre-charge pressure of 10 bar and a volume of 3 l. To simplify the electrical control scheme and reduce the electronic components, it was decided to use two monostable proportional directional control valves, 4/3. The position adjustment of the hydraulic cylinders is performed in a closed loop, by using a position transducer on each cylinder.
Fig. 3 shows the hydraulic diagram of the circuit for lifting vehicles, variant 2, which includes proportional control of the movement of the two cylinders by means of two directional control valves. The simulation of the circuit operation was performed without considering human presence. Sensor systems for user protection will be considered if, following the analysis of the results obtained, it is decided to implement this technical solution.

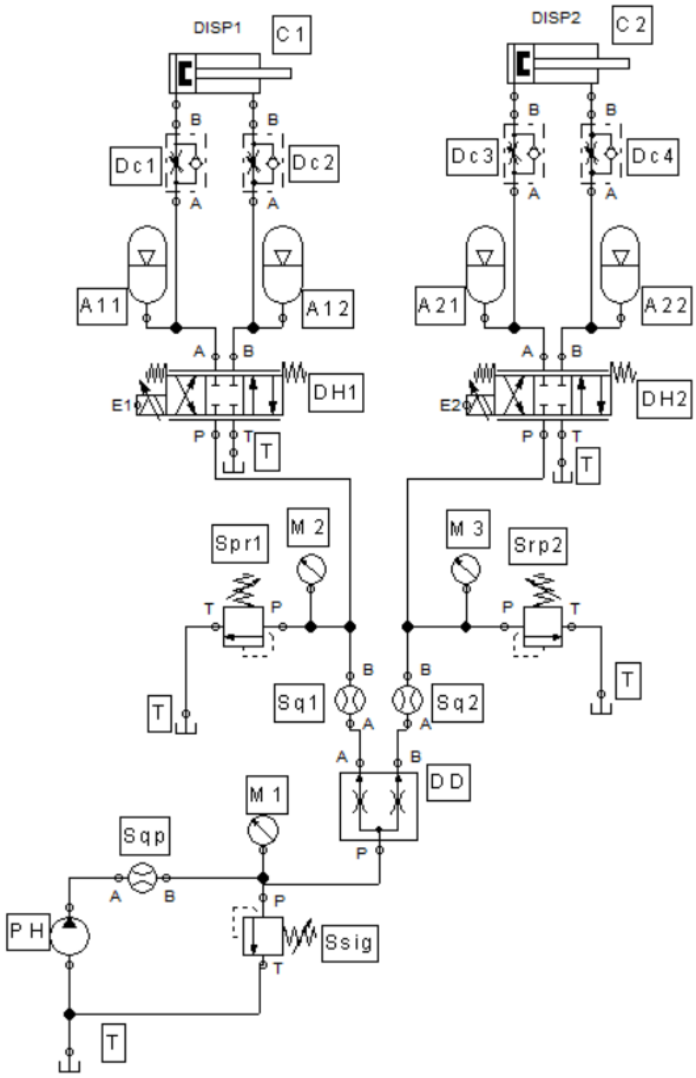

Fig. 3. Hydraulic circuit diagram for vehicle lifting with proportional control

The hydraulic diagram of the tested circuit includes the following equipment:
• PH – fixed-flow hydraulic pump, similar to variant 1;
• Sqp – flow sensor, introduced because of the results obtained from the simulation of the first variant, to avoid possible phenomena that may go unnoticed in the hydraulic energy supply system;
• Ssis – safety valve, adjusted to the system's working pressure;

• T – hydraulic fluid tank;
• DD – flow divider;
• Sq1, Sq2 – flow sensors, which monitor both the flow and the proper functioning of the divider. At small flow sections, the flow divider may suffer blockages, which would lead to the supply of only one circuit branch with a much too large volume of fluid, generating a malfunction;
• Spr1, Spr2 – pressure valves, which protect the system from backpressure;
• M2, M3 – pressure gauges, allow for quick verification of the pressure values on the two branches of the hydraulic circuit;
• DH1, DH2 – monostable hydraulic directional control valve, 4/3, with proportional control;
• A11, A12, A21, A22 – hydraulic accumulators, which store and release energy when needed;
• Dc1, Dc2, Dc3, Dc4 – track throttle, allows precise adjustment of the piston speed, both on advance and on retraction;
• DISP1, DISP2 – position transducers;
• C1, C2 – hydraulic cylinders.

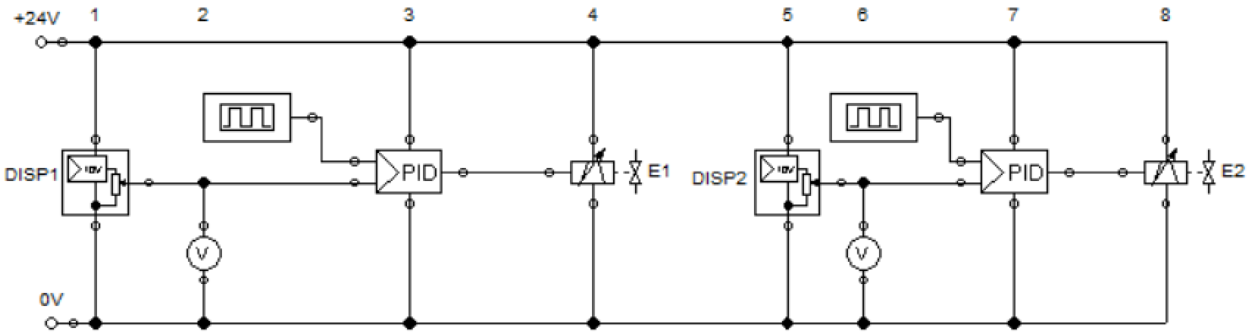

Fig. 4. Electrical and control diagram of the hydraulic circuit

Fig. 4 shows the electrical control diagram of the drive circuit. The following notations can be seen: DISP1 and DISP2 – are the position transducers, which operate on a principle similar to that of a potentiometer; the reading of the voltage drop corresponding to the position of the cylinder rod is carried out by a voltmeter, symbolized by V, positioned between the central pin of the sensor and GND.
A P-type (proportional) controller was used for each controlled electromagnet. The sensor signal pin and an output signal from a function generator are connected to the controller inputs.
A rectangular signal was chosen for the electromagnet control, with a variation range of 0–10 V, at a frequency of 0.1 Hz. Regarding the adjustment range of the P-controller, a range between -10 and 10 V was chosen, specific to hydraulic equipment with proportional control. This range covers the three states that the proportional valve can have: -10 V – the valve is switched to the P-B, A-T position; 0 V – central position, locked; 10 V – the valve connects P-A, B-T.

3. Conclusions

Both transmission model variants have their advantages and disadvantages; an electrically controlled transmission is easier to command and cheaper to maintain, but it presents a delay between the raising and the lowering of the platform. As for the proportional controlled transmission, it has a better precision, it can be commanded to lift or lower to a certain height, but it needs specialized personnel and represents a higher cost. Therefore, for a vehicle lifting platform used by mechanics to service cars, the electrically controlled transmission might be advantageous, but overall the proportional controlled transmission represents a better and more reliable option, especially for advanced projects or automatic lifting use.

References

[1] Li, Ruichuan, Wentao Yuan, Xinkai Ding, Jikang Xu, Qiyou Sun, and Yisheng Zhang. “Review of Research and Development of Hydraulic Synchronous Control System.” *Processes* 11, no. 4 (2023): 981. https://doi.org/10.3390/pr11040981.

[2] Woś, Piotr, and Ryszard Dindorf. “Synchronization of the Movement for Multi-Cylinder Electrohydraulic Servo Driver.” Paper presented at the 14th International Conference “Experimental Fluid Mechanics 2019” - EFM19, Františkovy Lázně, Czech Republic, November 19-22, 2019. *EPJ Web of Conferences* 269 (2022): 01069. https://doi.org/10.1051/epjconf/202226901069.

[3] Yu, Jin, Ming Zhen Fan, Guo Qin Huang, and Min Yu. “Simulation and Analysis on Main Synchronized Hydraulic Cylinder of Huge Hydraulic Press.” *Applied Mechanics and Materials* 233 (2012): 150-153. https://doi.org/10.4028/www.scientific.net/amm.233.150.

[4] Adenuga, Olukorede Tijani, and Khumbulani Mpofu. “Control System for Electro-hydraulic Synchronization on RBPT.” *Procedia CIRP* 17 (2014): 835–840. https://doi.org/10.1016/j.procir.2014.01.135.

[5] Xu, Cong, Xiao Xu, Zhao Liu, and Xin Wang. “Research on multi-cylinder synchronous control system of multi-directional forging hydraulic press.” Paper presented at the 8th International Conference on Applied Materials and Manufacturing Technology (ICAMMT 2022), Hangzhou, China, April 15-17, 2022. *Journal of Physics: Conference Series* 2338, no. 1 (2022): 012081. https://doi.org/10.1088/1742-6596/2338/1/012081.

[6] Avram, Mihai. *Fluid Power / Actionari Hidraulice și Pneumatice*. Bucharest, University Publishing House, 2005.

[7] Przybysz, Mirosław, Marian Janusz Łopatka, Marcin Małek, and Arkadiusz Rubiec. “Influence of Flow Divider on Overall Efficiency of a Hydrostatic Drivetrain of a Skid-Steer All-Wheel Drive Multiple-Axle Vehicle.” *Energies* 14, no. 12 (2021): 3560. https://doi.org/10.3390/en14123560.