Small-Scale Hydraulic Excavation System for Educational Purposes

Assoc. Prof. PhD. Eng. **Ionel Laurențiu ALBOTEANU**[1,*]

[1] 1 University of Craiova, Faculty of Electrical Engineering

* lalboteanu@em.ucv.ro

Abstract: *The paper presents the development of a scaled-down excavation installation model, designed to highlight the operation of the hydraulic system and the electromechanical actuation system. The project aims to replicate the fundamental principles of force transmission through miniaturized hydraulic cylinders, as well as their interaction with the mechanical structure to ensure the characteristic movements of the excavation process. Furthermore, the electromechanical subsystem integrates motors, sensors, and control elements, providing both the actual actuation of the system and the sequential control of operations. This combination enables a small-scale simulation of real working conditions and offers a clear perspective on the interdependence between the mechanical, hydraulic, and electrical subsystems. The model thus serves as a valuable demonstrative and educational tool, contributing to a deeper understanding of the fundamental principles of hydraulic and electromechanical actuations employed in modern excavation installations.*

Keywords: *Hydraulic drive, excavation system, didactic model*

1. Introduction

Hydraulic systems employed in excavation equipment represent a key component in the field of mechanical engineering and modern construction, ensuring the efficient conversion of mechanical energy into controlled, high-force motion. These systems operate on the principle of transmitting energy through an incompressible fluid—typically hydraulic oil—for the actuation of the machine's working elements. Owing to their ability to generate substantial forces at controllable speeds, hydraulic installations constitute the preferred solution in lifting, digging, loading, and handling mechanisms for heavy materials [1, 2].

In excavators, the hydraulic system is responsible for operating the boom, stick, and bucket, as well as the rotation mechanisms of the superstructure and the movement of tracks or wheels. The optimal configuration of circuits, accurate component sizing, and the selection of the appropriate pump, valve, and cylinders determine both the performance and reliability of the equipment. The integration of modern technologies, such as proportional electro-hydraulic control and digital monitoring systems, has significantly enhanced energy efficiency while reducing component wear [3, 4].

Therefore, the study of hydraulic excavation systems extends beyond constructive aspects, encompassing a thorough understanding of fluid mechanics phenomena, subsystem interactions, and preventive maintenance strategies. Such analysis is essential for optimizing on-site productivity and ensuring an extended service life of the machinery [5, 6, 7]. In this paper, a small-scale excavation installation model is presented, designed for educational use by students in electrical and mechanical engineering programs.

2. Structure of the Hydraulic System of the Excavation Installation

The main components and the corresponding workflow of an excavation installation are outlined below and schematically represented in Figure 1:

- Hydraulic oil reservoir – stores the working fluid, ensuring continuous supply and partial heat dissipation.
- Hydraulic pump – driven by the excavator's internal combustion engine (typically diesel), it converts mechanical energy into hydraulic energy by increasing the fluid pressure.
- Suction and return filters – retain impurities to prevent wear and potential component failure.

- Hydraulic distributors (control valves) – direct the oil flow to the different circuits (boom, stick, bucket, rotation, tracks).
- Hydraulic cylinders – transform hydraulic energy into linear motion for actuating the working elements.
- Hydraulic motors – in certain applications (superstructure rotation, travel), convert hydraulic energy into rotary motion.
- Pipes and high-pressure hoses – ensure fluid transfer between components.
- Safety and control valves – protect the system against overpressure and regulate flow rate and direction.
- Hydraulic oil cooler – maintains the fluid at an optimal temperature for performance and durability.

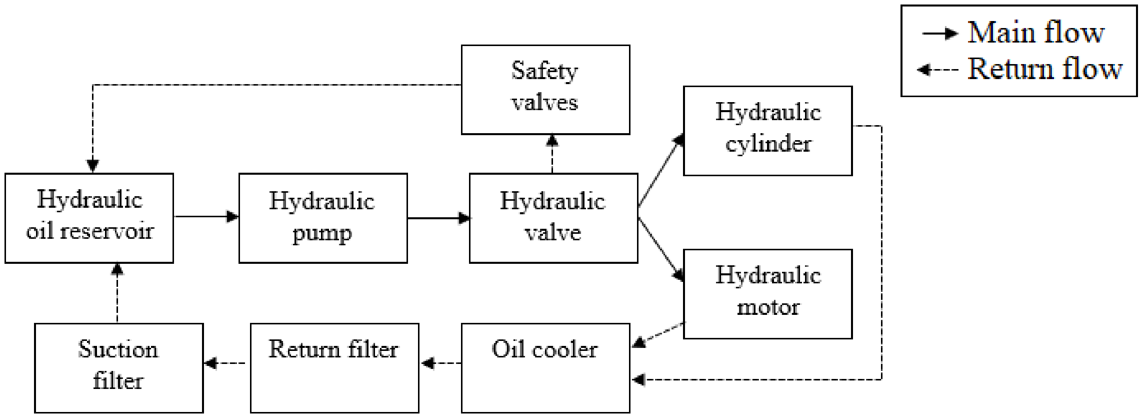

Fig. 1. Block diagram of hydraulic system

For the didactic model, a modular structure of the hydraulic system for the excavation installation was proposed [8]. The scaled-down model comprises the mechanical, hydraulic, electrical, and control subsystems, without including the propulsion system. The proposed structure is illustrated in Figure 2.

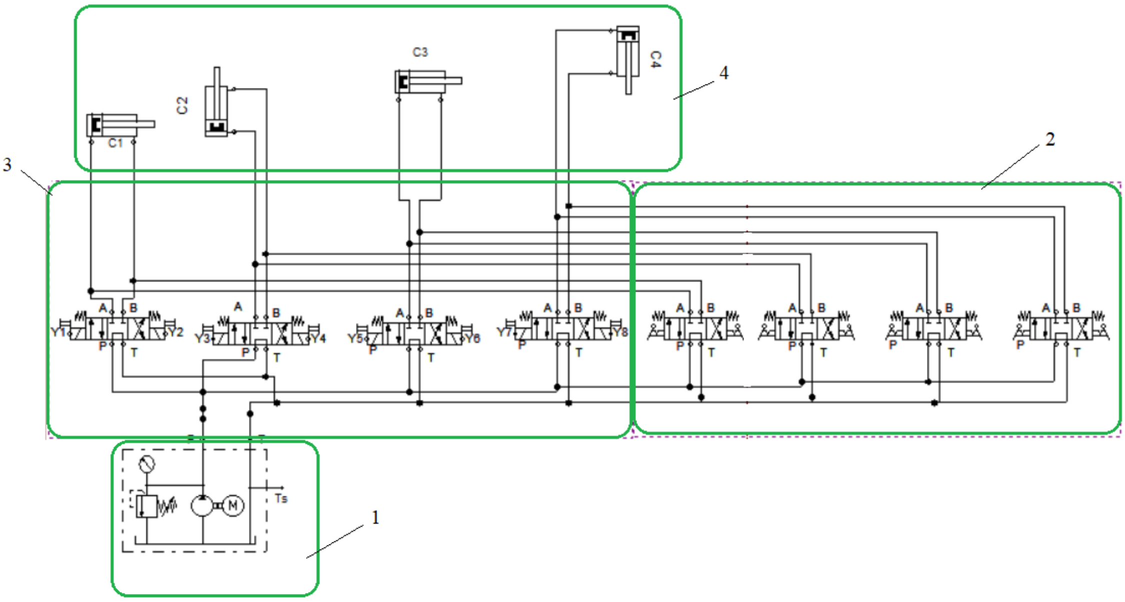

Fig. 2. Structure of the proposed hydraulic system for the excavation installation

The hydraulic system is organized into four modules, as represented in Figure 2:

1- Pumping system module
2- Mechanically actuated distributor module
3- Electrically actuated distributor module
4- Hydraulic cylinder module

The hydraulic cylinders shown in the figure have the following designations:

C1 – hydraulic cylinder for boom rotation
C2 – hydraulic cylinder for actuating joint 1 of the boom
C3 – hydraulic cylinder for actuating joint 2 of the boom
C4 – hydraulic cylinder for actuating the excavator bucket

Since the model was designed for educational purposes, two different types of distributor modules were used in parallel.

3. Excavation System Simulation

For simulating the proposed hydraulic installation, the dedicated FluidSIM software was employed. Simulation with FluidSIM enables a clear and interactive visualization of hydraulic actuation processes, thus facilitating the learning of component operating principles (cylinders, valves, pumps, etc.) and their interactions [9, 10, 11, 12].
Through simulation, complex hydraulic circuits can be tested and validated without physical risks or material costs, while also eliminating design errors prior to practical implementation. Figure 3 illustrates the program window during the simulation of the C1 cylinder movement.

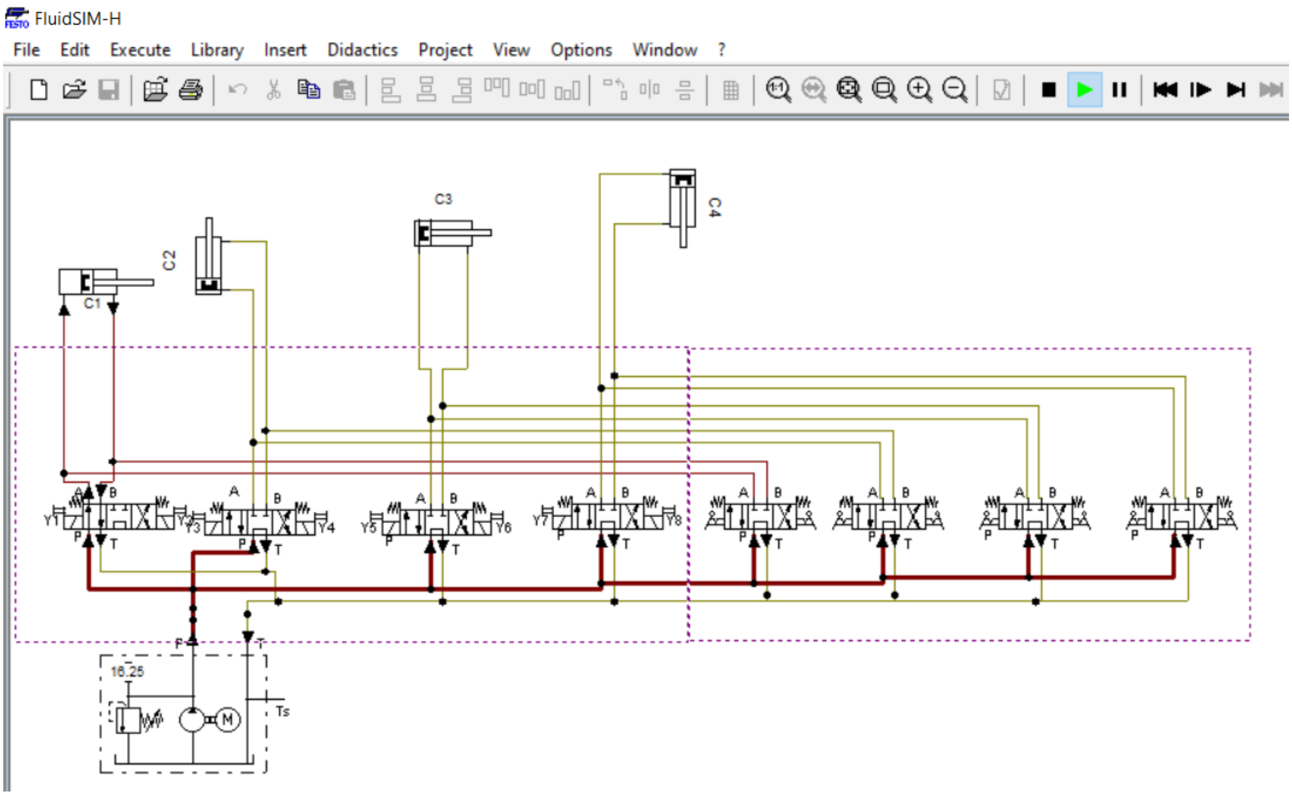

Fig. 3. FluidSim simulation of hydraulic system

For the control of the electrically actuated valves, a command circuit based on contacts and relays was designed (Fig. 4). Figure 4 illustrates the activation of the control sequence for executing the forward stroke of cylinder C1.

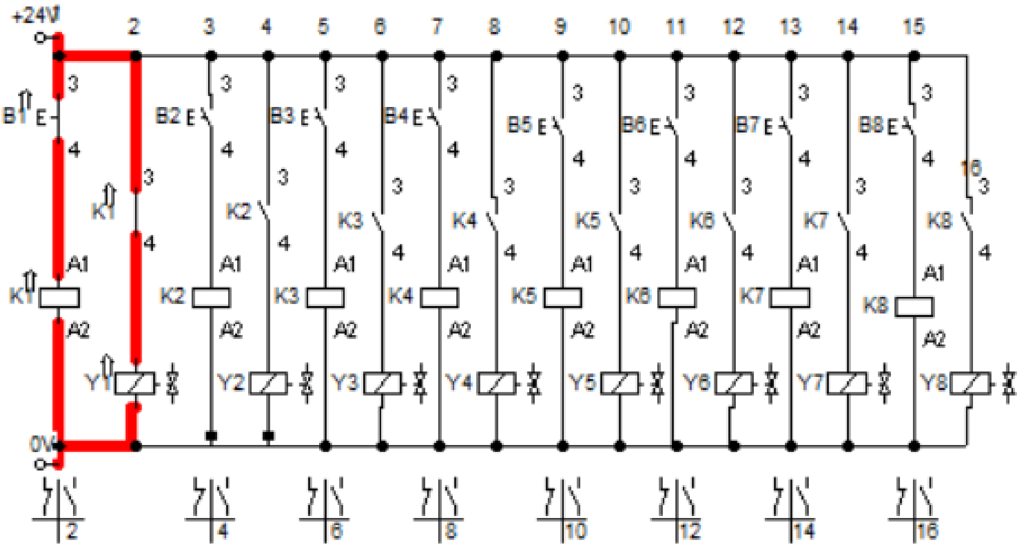

Fig. 4. Control circuit with contacts and relays for operating the electrically actuated valves

The notations used in the diagram have the following meanings:

B1...B8- control push button;

K1...K8- intermediate relay;

Y1...Y8- valves coils.

The FluidSIM software enables the display of a state diagram for the elements within the hydraulic actuation system. Figure 5 presents the state diagram of the hydraulic cylinders of the excavation installation during the execution of a work cycle.

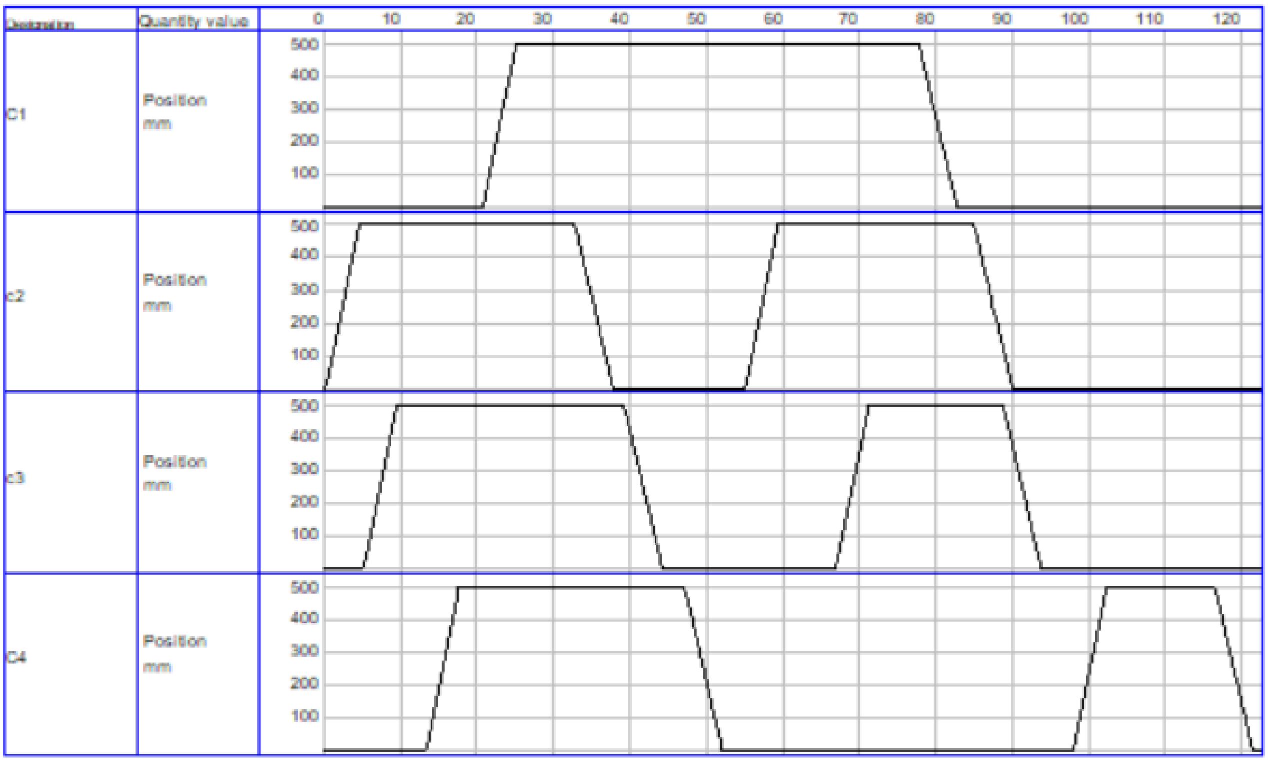

Fig. 5. State diagram of the cylinders during a work cycle

4. Description of the Educational Model

After completing the simulation using the FluidSIM software, the scaled-down excavation installation model was built (Fig. 6).

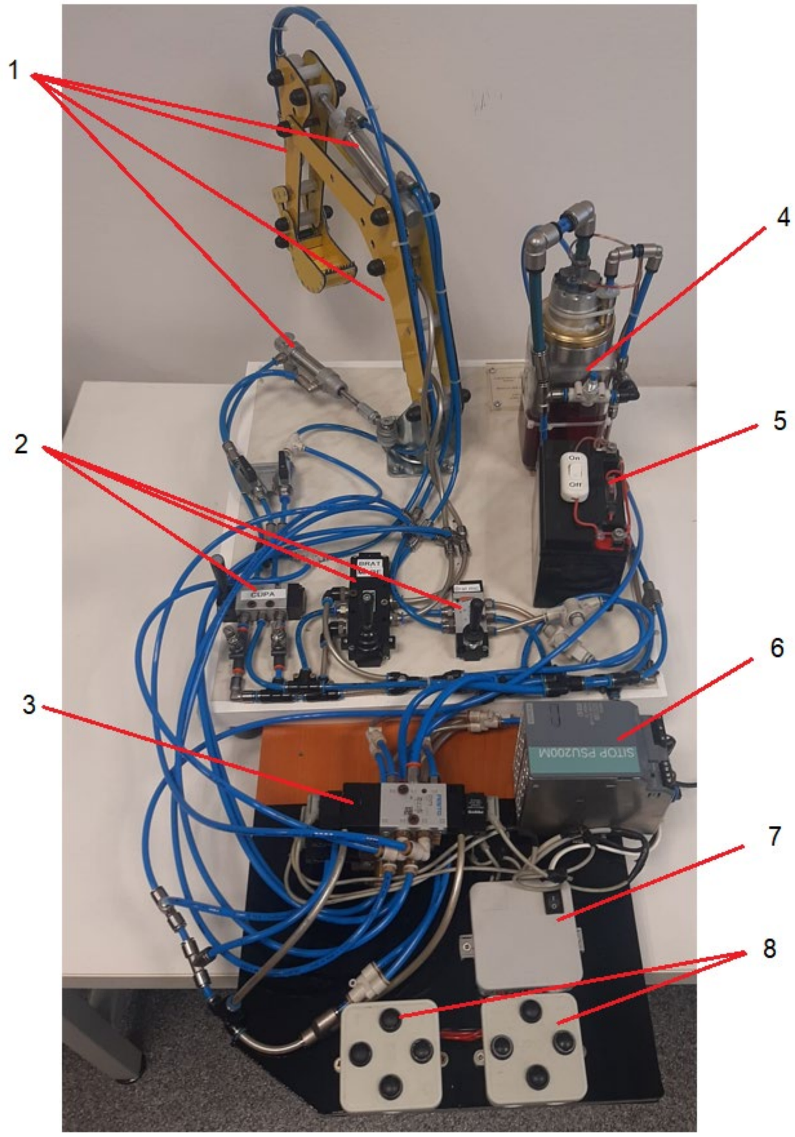

Fig. 6. Constructed model of the excavation installation

The components of the educational model are as follows:

1- Hydraulic cylinders
2- Mechanically actuated valves group
3- Electrically actuated valves group
4- Pumping system
5- 12 V DC battery for pump power supply
6- 24 V DC power supply for valves coil activation
7- Switch for activating the electric control of the valves
8- Push buttons for the electrical control of the valves

The inclusion of two types of valves in the model was implemented for educational purposes. Mechanical control is suitable for simple, robust applications where automation is not required. Electrical control is preferred in modern, automated applications that require precision, remote control, and integration into complex systems.

The choice of control method should consider the desired level of automation, system complexity, cost, and operating conditions. In the future, it is planned to complete the model with an automation subsystem (sensors, PLC, display, etc.).

5. Conclusions

The hydraulic system realized in the form of a model is capable of performing all the intended functions, with operating parameters consistent with the objectives pursued during its development process.
The model successfully reproduces the fundamental principles of an excavation installation, illustrating the operational workflow and the sequence of technological stages. At a reduced scale, the main mechanisms can be more easily observed and analysed.
The model serves as a valuable tool for presenting the technological process, facilitating the understanding of its operating principles. It is suitable for educational activities, exhibitions, or demonstrations of basic excavation mechanization concepts.
The excavation installation can be further enhanced by integrating automated control systems or simulating real working conditions. It can serve as a foundation for designing more complex experimental models.

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