Development of a Hydraulic Press Machine for Laboratory Applications

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Abstract

This paper presents the design and development of a hydraulic press machine intended for laboratory-scale applications. The system is designed to manufacture standardized rock specimens by compressing powdered materials. To enhance operational efficiency, the machine incorporates three independent working stations. The development process includes mechanical configuration, electrical system design, and implementation of control using a Programmable Logic Controller (PLC) and Human Machine Interface (HMI). A dedicated proportional control module is developed to regulate the pressure relief valve. Due to the nonlinear characteristics of the hydraulic system, experimental analysis is conducted and integrated into the PLC program for accurate control. Key operational parameters such as pressure and hysteresis limits can be adjusted within predefined ranges.

1. Introduction

Automation has become a fundamental component in modern engineering systems, significantly improving productivity and reducing dependency on manual labor. With the advancement of control technologies such as PLCs, complex industrial and laboratory processes can be efficiently automated. Hydraulic press machines are widely used in applications requiring high force, including forming operations like bending, punching, and stamping.

Some manufacturing processes use hydraulic press machine to perform forming operation with large forces. These operations can be, e.g., punching, bending, stamping. In a design process of a manually operated hydraulic press is introduced, which is capable to perform various press works [1]. Control systems are essential to solve various automation problems. Design and implementation of a control system for a mechatronic hydraulic press machine is detailed in [2]. The control system is based on PLC and sensors. A 100 kN hydraulic actuated press machine is designed and controlled for stamping operations in [3].

The main purpose of the research and develop task is to build a new hydraulic press machine, which can be suitable for production of standard rock cores from rock powder and adhesive materials. The rock powder is obtained by grinding and classifying rock materials brought to the surface in the course of exploratory drilling operations. The design of the device is modular therefore, it can perform several functions, thus the design and pressure range of the device can be flexibly modified within certain limits, in accordance with the requirements. The primary objective of this work is to develop a modular hydraulic press system capable of producing standard rock cores from powdered materials.

2. Materials and Methods

The system consists of three independent stations designed to produce cylindrical samples with a diameter of 38.5 mm and lengths ranging from 50 mm to 150 mm. Each station can generate a maximum force of 60 kN. Hydraulic cylinders are selected based on force balance equations, considering efficiency and frictional losses. The system operates within a maximum pressure of 250 bar and includes components such as pumps, valves, and sensors for safe operation.

The hydraulic circuit of the rock press machine for one station is shown in Figure 1. The common elements of the three stations are the following: pump, relief valve (RELIEF), the proportional pressure relief valve (PROP_VALVE), and the speed selection valves (VEL1, VEL2, VEL3).

During operation, only one pressing process can be started at a time, once one of the stations has been started, the next station can be prepared until the desired pressure is reached. The process begins with the start of the pump and then the relief valve (RELIEF) must be switched. The selection of the run-out velocity is performed with the actuation of the appropriate 2/2-way hydraulic valve. Thereafter the actuation of the 4/3-way main valve (MV_1a) results that the cylinder (CYL_1) runs out of its upper end position. When the inductive sensor (IND1) is reached, the changeover to the creep velocity takes place. Upon reaching the rock core, the pressure will start to build up gradually, which will be measured by the pressure transmitter (TRM_1) [4]. If the pressure set on the proportional pressure relief valve (PROP_VALVE) is reached, the system switches off the pump and waits for the rock core at the next station to be inserted and then the next pressing process can be started. There may be cases where pressure drop is taking place in the chamber of each cylinder, then the actuation of the pump is required. A hysteresis range can be defined, which is ± 5 bar.

In the event of an increased chamber pressure caused by heated oil must be returned to the tank via a valve equipped with a choke valve (OP_1). A hydraulic accumulator (ACC_1) is placed into the system to supply oil to the chamber of the piston if leakage takes place. If the accumulator is empty, the reduced oil pressure results to switch the pump back on and switching the main valve (MV_1a). At the end of the pressing process, the load can be removed from the rock core using the control panel. Then the proportional pressure relief valve (PROP_VALVE) is actuated with preset pressure by the user. Thereafter the pump will turn on, then the relief valve (RELIEF) will be operated, and finally the main valve (MV_1b) and the drain valve (DRAIN_V1) must be actuated to return the oil to the tank. A pressure relief valve (P_RELIEF_1) can be found at each station can be set manually, and it serves safety purposes, i.e., preventing the overpressure. The built system can be seen in Figure 1.

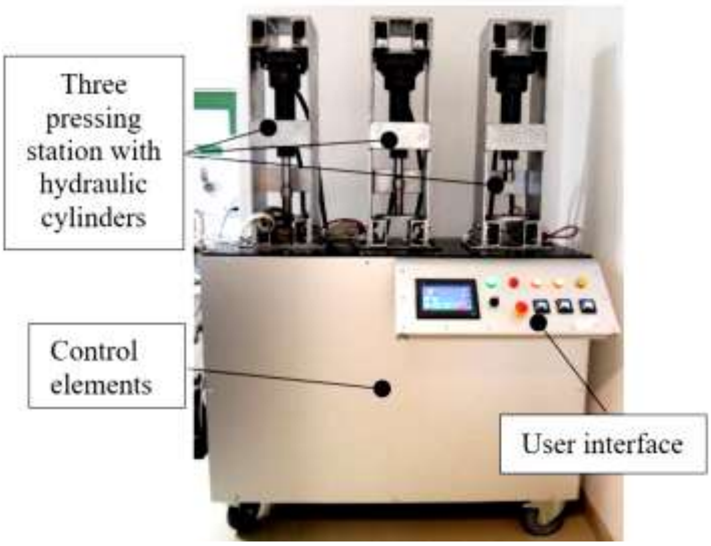

Fig.-1 Hydraulic Press Machine

3. Electrical System Design

The electrical system includes a PLC, relays, solenoid valves, power supply units, and an HMI. A custom proportional controller is developed to convert voltage signals from the PLC into current signals required for valve operation. The controller ensures stable and accurate pressure control, though nonlinear system behavior is compensated using software.

The mechanical and electrical design of the equipment are modular therefore, it can perform several functions, thus the design and pressure range of the device can be flexibly modified within certain limits, in accordance with the requirements. A special purpose controller circuit is developed to provide adequate current input for the main proportional pressure control valve. The whole electrical system consists of the following modules: power supply unit, PLC, switching relays, proportional valve controllers, solenoid valves, measurement unit, temperature controllers, HMI, and a 3-Phase AC motor with 250 bar oil pump.

The power supply unit provides electrical energy to the entire system. It is divided into two subsystems: electrical mains voltage unit and DC power supplies. The electrical mains voltage unit receives the electrical energy from the main network, and it switches the electrical three-phase power to the power rail. The power rail includes high voltage terminal blocks, circuit breakers and contactors [5]. There are three DC power supplies for the control subsystem two of them are 24V DC power supply, the smaller one with 2.5 A maximum output current is to power the PLC, and the larger one with 40 A output drives the solenoid valves. The third DC power supply had to be 12 VDC/10 A output since the special solenoid requires 12 VDC/22 W power to drive the proportional valve shaft. All DC power supplies have common ground (GND), which is the common reference for the PLC also (AGND, SGND). The electrical mounting plate can be seen in Figure 2.

Originally three pieces of proportional valves were included in the plan, but during the preliminary tests two of them were replaced with two manually operated valves. Only one proportional pressure control valve remained in the main circuit, however, all three controllers remained on the mounting plate for later use. This equipment can be relatively flexible and can be reconfigured if required. Standby items will be turned on when they are needed.

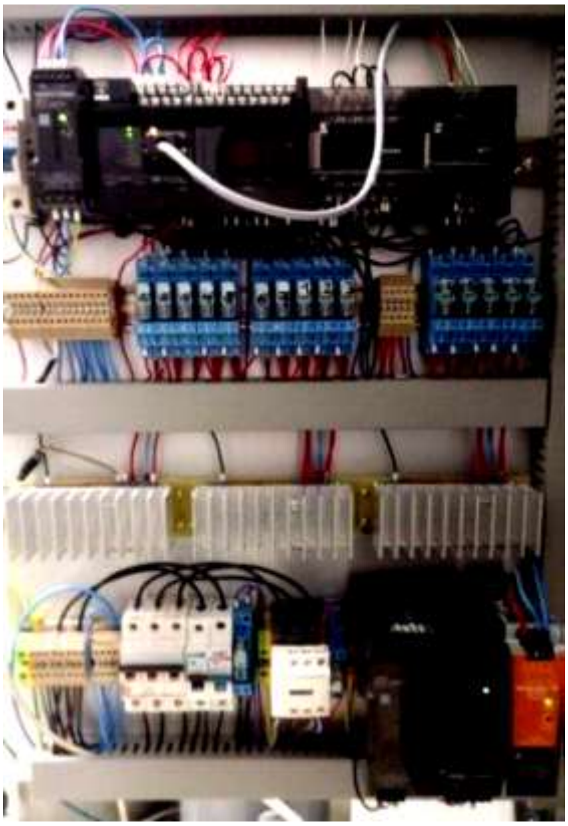

Fig. 2 Electrical Mounting Plate

4. PLC Programming and HMI Implementation

4.1 PLC Programming

The PLC is programmed using ladder logic and operates in automatic, manual, and diagnostic modes. Correction algorithms are implemented to compensate for nonlinear system behavior. A ramp-up function ensures gradual pressure increase, and priority control is used to manage multiple stations.

An OMRON CP2E-N compact PLC extended with analogue module is used to control the rock press process.

There are different programing languages according to IEC 61131-3 standard to program a PLC. The program of the PLC is developed under CXDeveloper software in Ladder Diagram (LD) programing language. Five subprograms are placed for the sake of transparency. There are three modes of the hydraulic press machine: automatic, manual, and diagnostic modes. In manual mode the user can change the position of each cylinder, in automatic mode the system is performing the press operation until a stop signal by user is not arriving. The diagnostic mode serves testing purposes of each element of the system [6].

The first subprogram contains the setup of analogue input/output modules, the storing process of default values, and variable conversations. All modules are set to 0-10 V mode to receive the data of the three pressure transmitters and to send voltage output to the module of the main pressure relief valve.

A default hysteresis values related to the pressures to be set are defined to ± 5 bar. The scaling process of the analogue inputs, i.e., values from the pressure transmitters are also performed in this section. *SCL* block is used with knowledge of the limit values, in this case the maximum incoming raw value is 12000, the minimum value is 0, and it will be scaled to 250 and 0, respectively.

The pilot-operated, normally-open, proportional relief valve (Comatrol, 2015) was used with 12 VDC coil to set the required pressures of the cells. The valve can operate up to 250 bar pressure. In order to make the ability of controlling the pressures of the cells, measurements are essential. The self-devised proportional controller card of the proportional pressure relief valve has voltage input and current output. The pressure-voltage-current values are determined for the range of 5-200 bar.

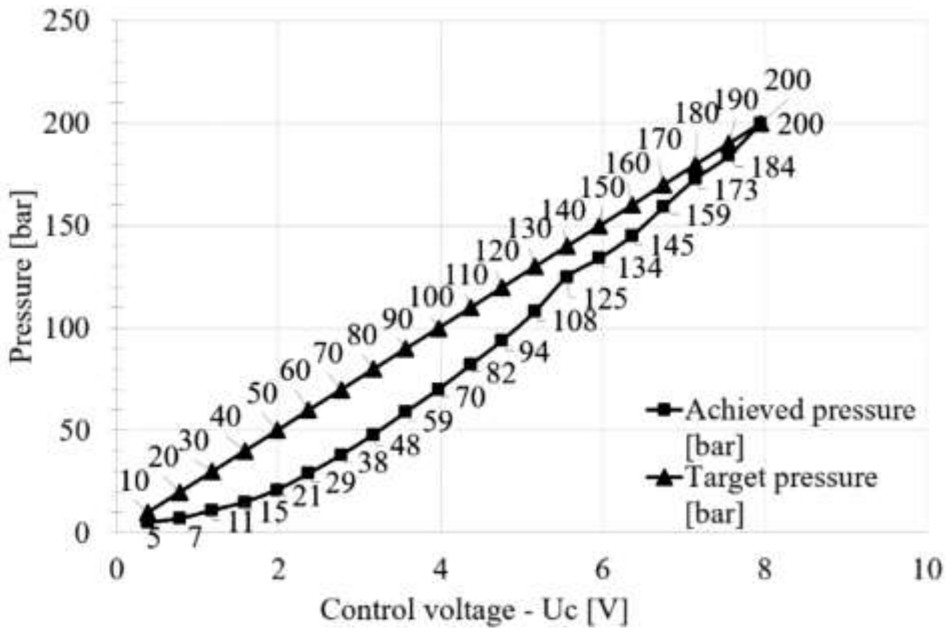

Fig. 3 **The pressure versus the control voltage of the controller module**

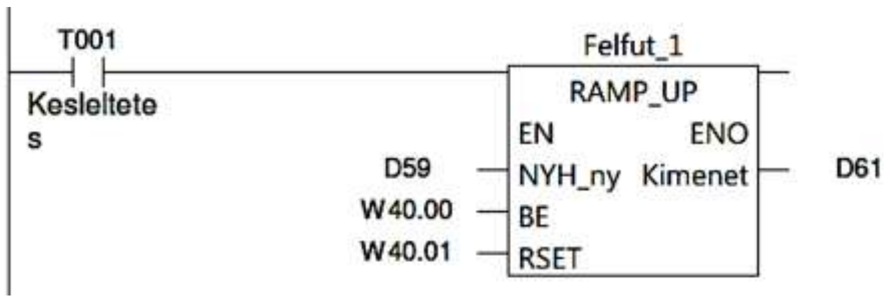

Fig. 4 **The RAMP UP function block**

4.2 HMI Design

The HMI provides a user-friendly interface for monitoring and control. It includes safety features, real-time parameter display, and data logging capabilities for further analysis. The use of an HMI is essential for process monitoring [7]. The user interface of the system (see Figure 10) should be designed to be safe, convenient, and clear. A traditional button-lamp control panel would have too many controls, therefore an Omron HMI unit is installed.

The control panel is divided into 3 sections, where the 3 press units can be operated. There are common controls that affect the whole system, e.g., pump operation, system diagnostics and setting of internal parameters.

The HMI unit is not a simple set of buttons and displays but also implements safety functions, as most of the controls are only allowed to be operated if the appropriate safety conditions are met. The rock press machine can be dangerous; therefore, it is important to eliminate the possibility of faults occurring during operation. In order to prevent the operator from a potentially dangerous condition, conditions are added to the HMI. For example, moving the press units or starting an automatic cycle is only possible if the pump is running and the correct oil pressure is available.

In addition to system management, another important function of the HMI unit is data logging, which is performed independently of the PLC. It saves the measured data (e.g., current pressure of each unit, set pressure, etc.) to a USB Host socket on the back of the HMI panel for further analysis. This function can be enabled or disabled by a virtual switch on the control panel. If the unit detects the corresponding data logger, it will enable logging, which will save the system data to a CSV file.

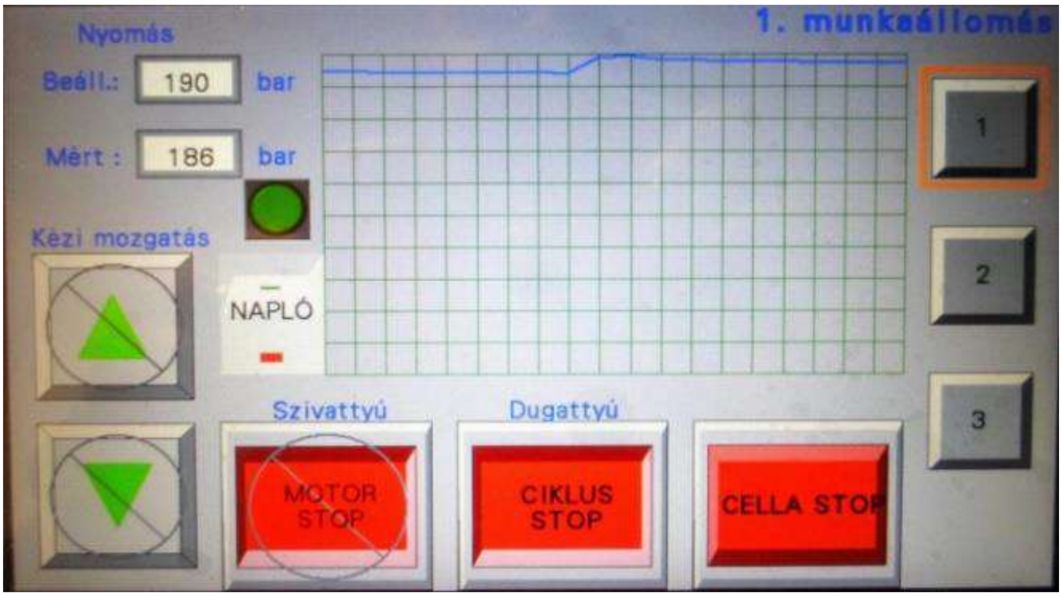

Fig. 5 User interface of the system

5. Conclusion

The developed hydraulic press machine integrates mechanical, electrical, and control systems into a unified solution. The system demonstrates reliable performance and flexibility, making it suitable for laboratory and research applications. This paper was dealt with the development of a hydraulic press machine with three independent stations to press rock cores form rock powders. The mechanical, electrical designs, PLC programing were performed to create the mechatronic system. A self-devised controller card was designed to control the proportional valve.

The nonlinearity of the system was determined by measurements, and it was considered in the PLC program. Test measurements were performed to check the system during pressing process. The system parameters of the machine can be adjusted depending on the task.

In the future the device will serve research purposes, which will be used at the Research Institute of Applied Earth Sciences in the University of Miskolc.

7. References

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