ELECTRICAL DESIGN OF A PRESS SYSTEM

József Subert
research fellow, Research Institute of Applied Earth Sciences, University of Miskolc
3515 Miskolc, Miskolc-Egyetemváros, e-mail: subert@uni-miskolc.hu

László Rónai
senior lecturer, Institute of Machine Tools and Mechatronics, University of Miskolc
3515 Miskolc, Miskolc-Egyetemváros, e-mail: ronai.laszlo@uni-miskolc.hu

József Lénárt
assistant lecturer, Institute of Machine Tools and Mechatronics, University of Miskolc
3515 Miskolc, Miskolc-Egyetemváros, e-mail: lenart.jozsef@uni-miskolc.hu

Abstract
The paper deals with an electrical design of an electrohydraulic system, which is capable to use for rock pressing. The system has three stations, which controlled by programmable logic controller. The electrical design contains the wiring, and the development of a valve controller card, which provides adequate current to a pressure relief valve.

Keywords: *press machine, proportional control, electrohydraulic system*

1. Introduction

Hydraulic systems are widely used not only in industries, but also for research purposes. Design of hydraulic press machines are detailed in publications, e.g., (Adam 2004; Ferreira et al., 2006).

The article introduces electrical design of an electrohydraulic rock press machine. The presented system is suitable for preforming experiments on different type of rock cores. Artificially produced rocks are cheaper than rock cores extracted from natural drilling and there is a large market for synthetically produced standard rock cores in the world.

In Section 2 the main parts of the unit will be introduced. Section 3 deals with the electrical designs, especially a self-developed proportional card. The module can provide adequate current for a pressure relief valve, which is responsible for the setting of the system's pressure. The programing and the human machine interface (HMI) design is discussed briefly in Section 4. Section 5 presents a calibration process, which means measuring and software tuning of the system. The results are summarized in the Section of Conclusions.

2. The main parts of the system

The device has a modular design. It consists of six larger units, as it is shown in Figure 1. The modules are the following:

- **Compression Modules (CM-1, CM-2, CM-3):** allows the installation of a negative template (cell) to produce a standard rock core and its modified versions in the compression frame. This unit is responsible for transferring the appropriate load to the rock.

- **Hydraulic Power Supply Unit (HPSU):** the unit supplies hydraulic power to the press module.
- **Other hydraulic elements:** the piping system contains the elements used to store, control and switch the pressure carried by the hydraulic fluid (e.g., pressure relief valve, diverter switches, hydraulic accumulators).
- **Control Module (CTRL):** includes electrical power supply and additional electrical components.
- **Data Acquisition Module (DAQ):** Part of the Control Module. Contains programmable logic controller (PLC) I/O cards, and connected to pressure and temperature transmitters for measuring, calculating, displaying, and recording process characteristics (pressure, temperature, load force, etc.).
- **Operator module (HMI-1, HMI-2):** the human-machine interface module, which contains input and output elements (switches, indicators, touch screen) essential for operating the device are integrated in this module.

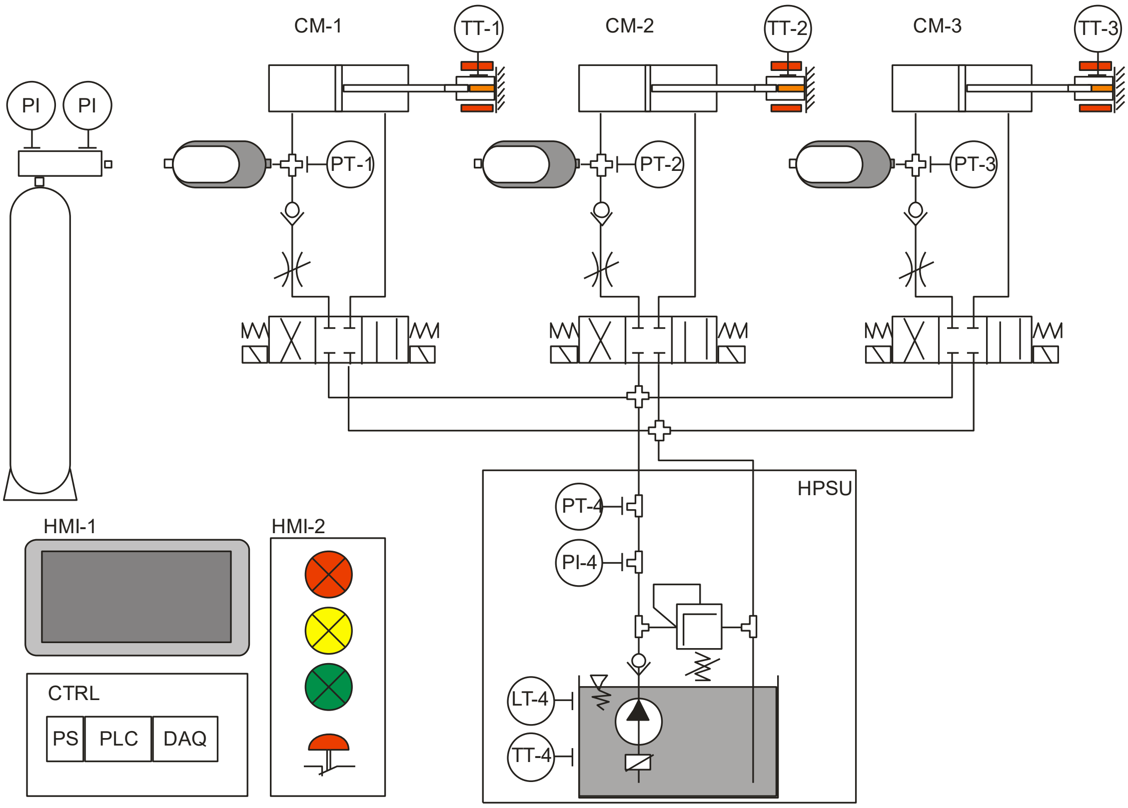

Figure 1. *Simplified structure of the entire hydraulic and control system*

There are three gas-filled hydraulic accumulators in the system to continuously replace leaks that occur during operation. To serve this, a separate nitrogen tank is required, with the help of which the hydraulic accumulators must be refilled with gas at intervals. The assembled equipment can be seen in Figure 2.

Figure 2. *The picture of the electrohydraulic press machine*

3. Electrical design

The principle of the development was to design and build a modular device with settings that can be changed flexibly within certain limits depending on the task to be performed. The pressure range of certain station can be set between the range of 0 – 250 bar. A controller card is developed to operate the central pressure relief valve, which is proportional. The electrical system is built from the following units:

- Power supply unit (PSU)
- Programmable Logic Controller (PLC)
- Relays
- Self-devised controller card
- Electrohydraulic valves
- Measurement unit
- Temperature controllers
- Human Machine Interface
- Oil pump equipped with 3-Phase AC motor

The electrical PSU serves the adequate voltage levels for the developed device. It consists of two subsystems: high voltage and DC PSUs. The main voltage level is 230 V AC. The power input subcircuit receives the electrical energy from the main network, and switches the three-phase electrical power to the terminal blocks. The power rail contains terminal blocks, circuit breakers and high current contactors.

Three DC power supplies with common ground had to be installed into the equipment. First of them has a 24 V and 40 A current in order to actuate the solenoid valves of the system, while the second one can deliver 2.5 A maximum current output for PLC driving. Third DC PSU module has 12 V DC and 10 A, which is used to power on the proportional pressure relief valve.

According to the original concept, three proportional pressure control valves would have been added to the system to set the pressure levels for each station. However, as the result of the preliminary tests, only one proportional pressure relief valve is applied, which serves the ability to set the pressure level of the three stations separately. Naturally manually operated relief valves are used for the cylinders to limit the maximum pressure of each cylinder.

Besides the proportional pressure relief, which is a Comatrol XMP 06-250-12D (Comatrol 2015) valve the other solenoid valves are traditional types, i.e., they have two states.

The function of the proportional pressure control valve is to ensure the load pressure value set by the operator during pressing. The value entered using the touch screen is converted by the PLC into a voltage in 0-10 V range and transferred to the control circuit. The control circuit then supplies the solenoid coil connected to its output with a constant, stable current proportional to the received voltage in order to set the requested pressure level.

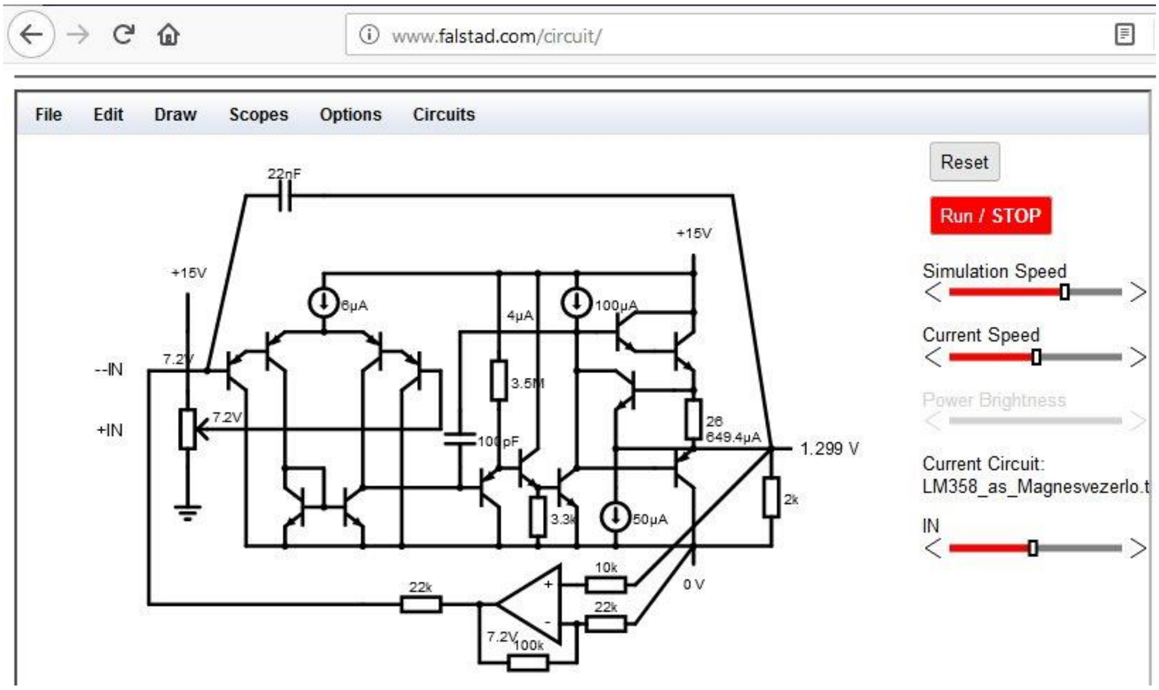

Figure 3. *Testing the preliminary circuit design in the simulator*

During the planning procedure preliminary circuit layout was checked (see Figure 3) in an online available simulator (falstad.com).

Although this control circuit is specifically optimized for the Comatrol XMP 06-250-12D solenoid coil and its 1.8 A maximum load current, the settings can be easily changed for any hardware changes within certain limits.

The control unit delivers 0-10 V output control signal for the proportional valve controller input terminal, which produces 0-1.8 A current range at the output side to create the opportunity of the 0-250 bar pressure range.

Controllers for various solenoid valves are commercially available but their price can sometimes be 15-20 times higher than the controller presented here. These proportional control cards are individually developed and built from discrete electrical components. To ensure quick replaceability simple and cheap dual in-line packaged integrated circuits are applied. All integrated circuits are general purpose operational amplifiers that are operated from a single power supply. Negative supply voltage is not required in the electric system. The proportional valve controller under lab test is shown in Figure 4.

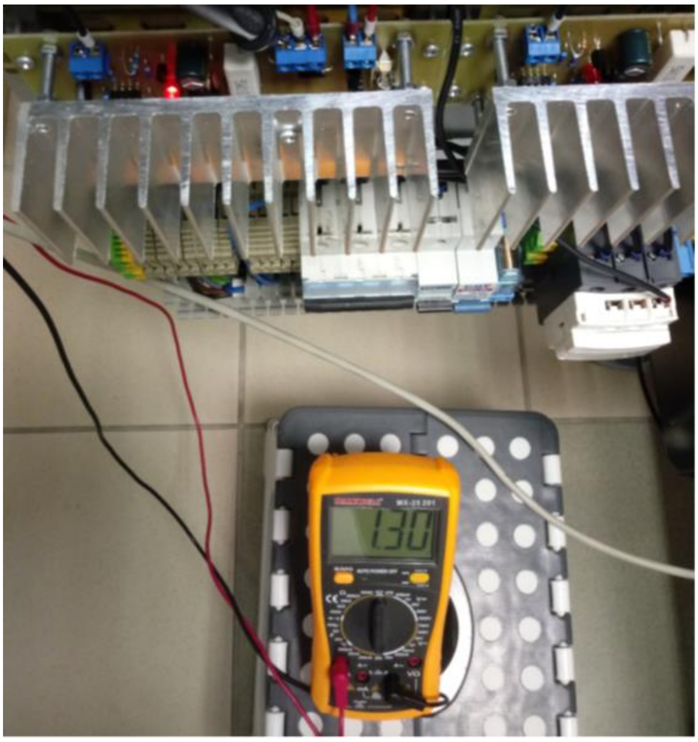

Figure 4. *Proportional valve controller unit under lab test*

The main concept of the design of the control electronics is simplicity, which guarantees reliability and robustness. There are significant reserves in the hardware of the device: a single TO-220 bipolar junction transistor or a combination of smaller, general transistors with TO-126 casing can be installed onto the control card created in the final stage in the event of any failure. During calibration operation of the controller, it contained trimmers and other temporary parts, which were removed after the tuning process. The heatsink was dimensioned with a double safety factor, which results in the fact that the output drive elements will not heat up more than 75 °C degrees even in an extremely hot environment (45 °C air temperature) at full load, compared to the junction temperature of 150 °C which generally allowed for semiconductor cores on their datasheets.

The output current reserve is also significant: with appropriate settings, the device can supply a load current 3-4 times higher than the actual 1.8 A output current (up to 8 A).

In the course of tests, linearity of the controller and the power dissipation of the switching elements were measured. The controller has good linearity according to the result of the tests. The maximum dissipation of the output elements is at 2/3 of the range. This last statement is very important because the nominal working point of the equipment usually will be in this range during pressing, therefore the heat load will be constantly close to the maximum value.

4. Programing and HMI design

OMRON CP2E-N PLC is applied with analogue extension module in order to control the pressing operations. The control program of the system is developed in Ladder Diagram language. The environment of the CX Developer software can be seen in Figure 5 with the part of the program.

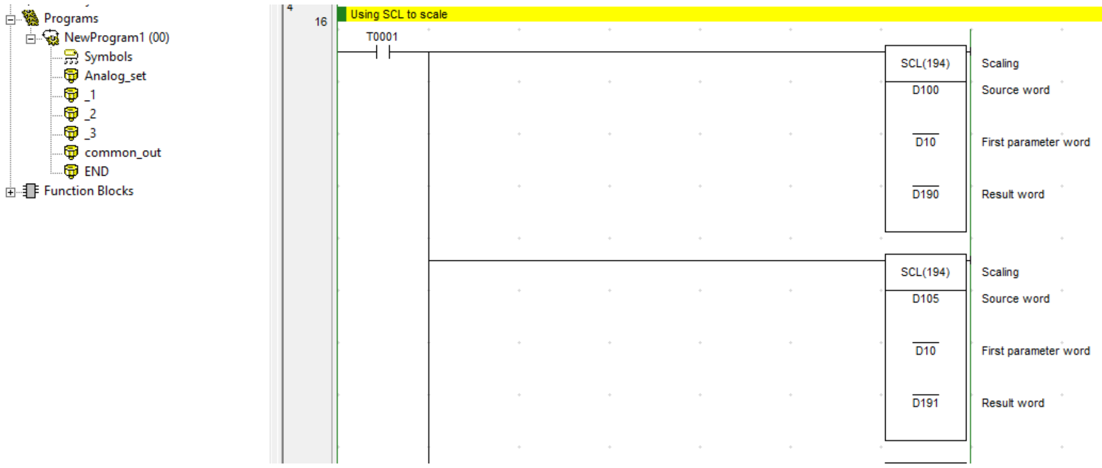

Figure 5. *The analogue set part of the program*

An OMRON NB7W-TW01B touch screen (see Figure 6) is used to establish a connection between the user and the system.

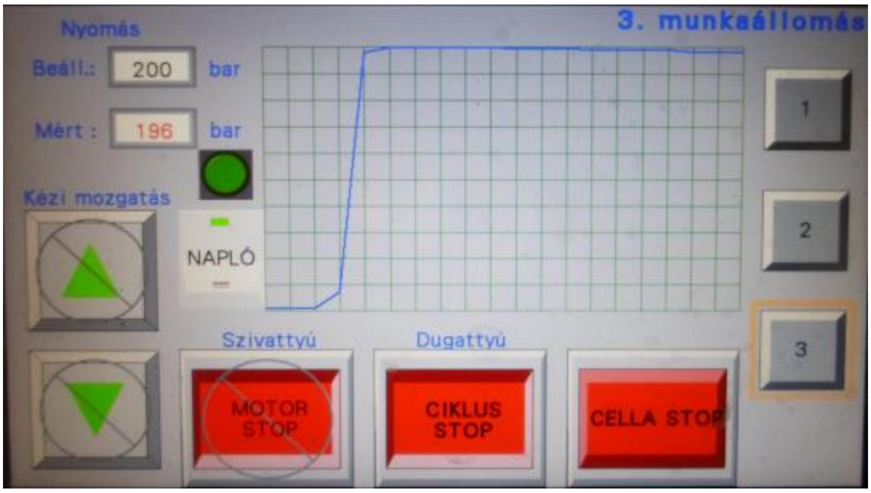

Figure 6. *HMI interface during test procedure*

The HMI module has three functions, i.e., automatic operation of stations based on given parameters by user, manual operation of the cylinders, diagnostics screen, where the parameters of the system can be set.

5. Calibration of the system

In order to get valuable information about the correctness of the system, measurements are essential. In the following a measurement is presented to determine the necessary control voltage of the proportional card to ensure proper current of the output of the card to the proportional pressure relief valve, which main task is to set the system pressure of the stations.

The measurement showed that there is difference between the target- and achieved pressure therefore, software correction is needed. The characteristic of the measurement is divided to two segments. In order to determine the necessary control voltage of the desired system pressure, two linear trend line equations (see Figure 7) are used, which is implemented in the program of the system.

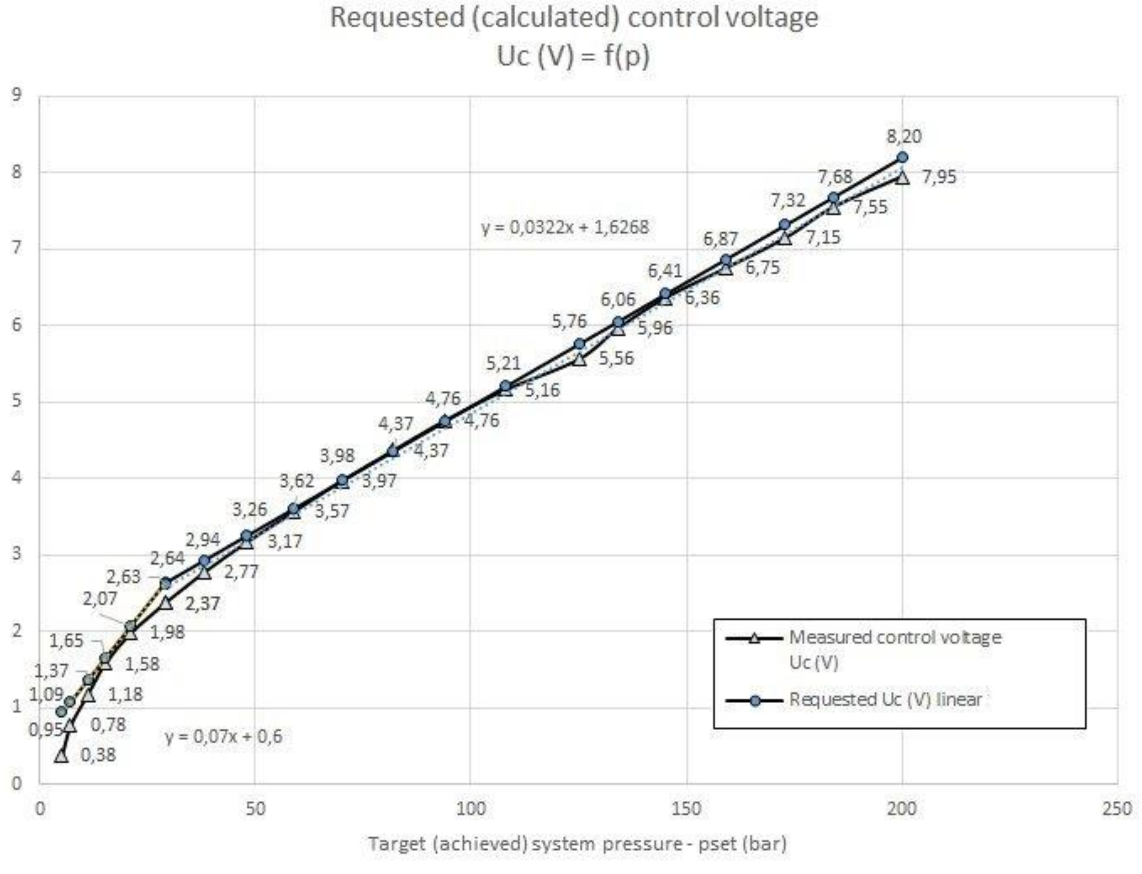

Figure 7. *Calculation of the requested control voltage (U_c)*

After calibration, test operations are performed to check the correctness of the system. The test runs were completed successfully. One of the manufactured rock cores with use of the developed press can be seen in Figure 8.

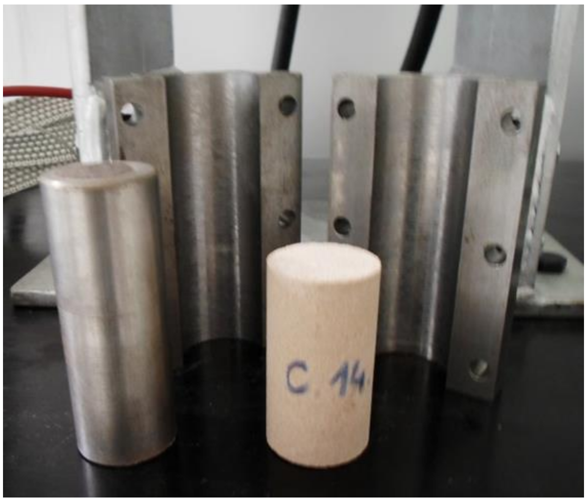

Figure 8. *Synthetic rock cores manufactured by press*

6. Summary

This paper was dealt with the electrical development of a hydraulic system in order to perform pressing process of different rock cores. Calibration measurements were performed to determine the adequate control currents of the proportional card of the pressure relief valve. The problem of the nonlinearity of the entire system has been successfully solved.

The article focused on only the electrical development of the unit, the programing and HMI design in more detail will be published in another journal paper.

7. Acknowledgements

The research was carried out in the framework of the GINOP-2.3.2-15-2016- 00010 "Development of enhanced engineering methods with the aim at utilization of subterranean energy resources" project of the Research Institute of Applied Earth Sciences of the University of Miskolc in the framework of the Széchenyi 2020 Plan, funded by the European Union, co-financed by the European Structural and Investment Funds.

References

[1] Adam, G. K. (2004). Design and control of a mechatronic hydraulic press system. *Proceedings of the IEEE International Conference on Mechatronics*, Istanbul, Turkey, pp. 311-315. **https://doi.org/10.1109/ICMECH.2004.1364457**

[2] Ferreira, J. A., Sun, P., Gracio, J. J. (2006). Design and control of a hydraulic press, *Proceedings of the 2006 IEEE Conference on Computer Aided Control Systems Design*, Munich, Germany, pp. 814-819. **https://doi.org/10.1109/CACSD-CCA-ISIC.2006.4776750**

[3] Comatrol (2015). Proportional Valves Catalog, *datasheet*, 11141718, Rev CA, pp. 1-64.

[4] Online circuit simulator: www.falstad.com/circuit