Computer simulation of a laboratory hydraulic system with ITI-SIM simulation software

G. Gregov[1], T. Marohnić[2], S. Žic[3]

[1] University of Rijeka, Faculty of Engineering,
Department of Mechanical Engineering Design, Vukovarska 58, 51000 Rijeka, Croatia

[2] University of Rijeka, Faculty of Engineering,
Department of Mechanical Engineering Design, Vukovarska 58, 51000 Rijeka, Croatia

[3] University of Rijeka, Faculty of Engineering,
Department of Industrial Engineering and Management, Vukovarska 58, 51000 Rijeka, Croatia

Keywords: hydraulic systems, differential cylinder, ITI-SIM, computer simulation

This paper presents a computer simulation of a laboratory hydraulic system consisting of a power unit and a differential cylinder. Simulation has been executed with ITI-SIM software, and the achieved results have been compared with the laboratory measurements of pressure in the two chambers of differential cylinder. Laboratory measurements have been executed in Laboratory for hydraulics and pneumatics at Faculty of Engineering, University of Rijeka.

Introduction

Modern design and optimisation of hydraulic systems involves detailed knowledge of phenomena that may take places in static and dynamic states of real systems. Here, especially important are simulation tests for being appreciably cheaper and more rapid than experimental ones. The principles of simulation tests are often simplified and do not take exact mathematical models into consideration. Simulation tests are particularly useful if model creation of real system is complicated and time-consuming. This is particularly evident in a case of mining machines and equipment [1].

There are quite a number of simulation packages for hydraulic systems, which can be used for design and analysis of the dynamic characteristic of hydraulic circuits. Some of the most commonly used simulation packages for hydraulic systems are DSH or DSHplus (Fluidon), Hydraulic Blockset (The MathWorks), Hylib (Dynasim), HOSPAN, Hydro Analyst (Flotron) and ITI-SIM.

In this paper, the operation of the laboratory hydraulic system (power unit and differential cylinder) was simulated by the simulation package ITI-SIM [2]. The aim of the performed simulation is to compare obtained results with the results of laboratory measured pressure in the two chambers of differential cylinder. By comparing both results, their differences and the advantages and disadvantages of using the simulation package ITI-SIM while designing hydraulic systems are to be determined.

Description of the laboratory hydraulic system

The laboratory hydraulic system consists of a power unit with direction control valves, differential hydraulic cylinder, PLC unit, measuring sensors and measuring instrument, as represented in Figure 1.

The working principle of the hydraulic system is based on supplying the differential cylinder with working fluid (hydraulic oil) using a power unit whereby the energy pressure of the working fluid converts into mechanical energy of the piston cylinder motion. Maximum working pressure of the fluid is defined with the pressure relief valve. Directional control valve is used to define the direction of working fluid flow towards hydraulic cylinder, which results in cylinder piston motion.

Technical characteristics of power unit [3] and directional control valves [4] are as follows: electromotor power P = 5,5 kW, electromotor speed n = 1460 rpm, pump displacement Q_1 = 10,8 cm^3, maximal pressure of system p_{max} = 210 bar.

Power unit pump is connected with the directional control valve through the switchboard which results in cylinder piston motion. Solenoid valves are used. Upon cessation of current flow, the valve piston returns to neutral position due to spring. Directional control valves with three positions require two solenoids, one for shifting left, and one for shifting right. Determination of duration of the current flow is achieved by using Programmable Logic Controller (PLC). This way the dynamics of the directional control valve within the specific time can easily be arranged.

PLC programming is accomplished by entering values of the duration of control signal and pauses between two signals, and the number of repetitions of those two, via PLC interface. Figure 2 presents a sketch of control signals used in laboratory measurements. Only piston extraction is considered.

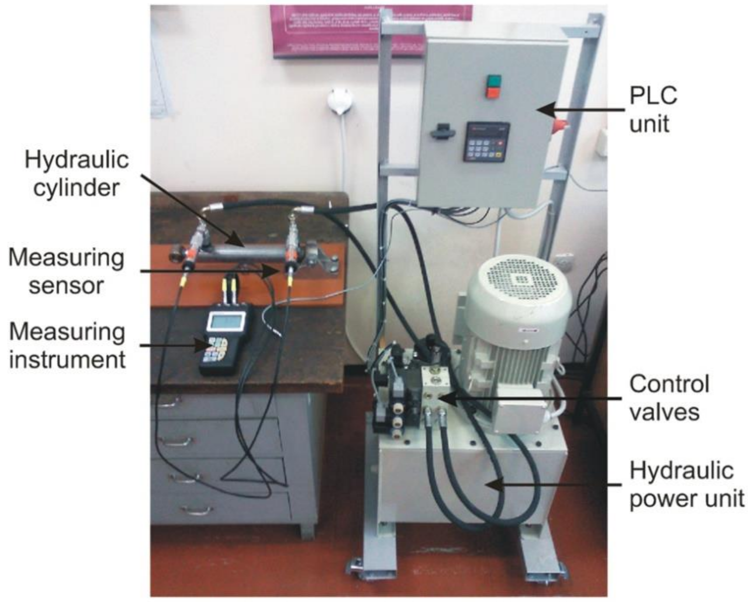

Figure 1. Laboratory hydraulic system

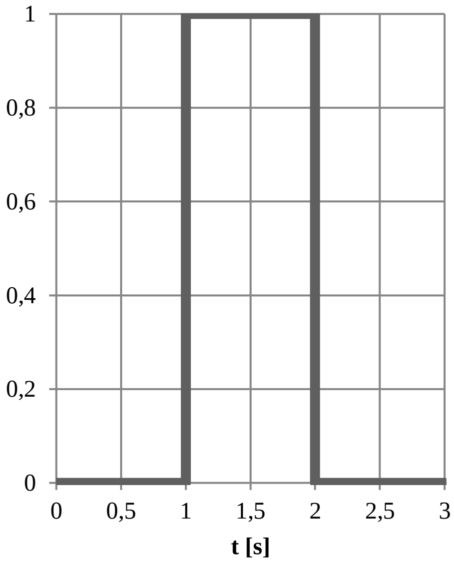

Figure 2. Control signal

Differential hydraulic cylinder has the ability to perform useful work in both directions, and due to its compact dimensions is often used in practice. Preformed work is different depending on direction of motion; the piston rod reduces the area of the piston on one side. Technical characteristics of laboratory differential piston are: piston diameter D = 40 mm, piston rod diameter d = 25 mm, maximal piston position x_{pmax} = 200 mm, continues ratio of ring side area to piston side area α = 0,625.

Measuring equipment consists of a measuring instruments and measuring sensors [5]. Measuring sensors measure pressure and temperature changes of the working fluid, which are then shown on the measuring instrument. Laboratory measurements were performed on a differential cylinder, the aforementioned characteristics, where p_A denotes measured values of the cylinder pressure in the chamber on the piston side, and p_B denotes measured values of the cylinder pressure in the chamber on the piston rod side.

Measurements were performed for control signal consisting of three segments, from t=0 to 1 and from 2 to 3 s where no electric current flows ie. valve is closed, while from t=1 to 2 s electric current acts on the solenoid and working fluid flows through the valve.

Measurements were performed for the case without loading the cylinder with external force and without adding additional weight, which means that the cylinder load is presented only with mass of piston and the piston rod (about 2 kg). The obtained measurement results are recorded in a measuring instrument, which can be connected with a computer.

Measurement results of pressure in cylinder chambers (p_A i p_B) are shown in Figure 3, from the initial moment to the third second. Figure 4 shows the change of the pressure in cylinder chambers in the directional control valve opening time (t=0,9 s to t=1,2 s) and the affect of the hydraulic fluid to the cylinder piston. From the given results it can be concluded that the acting of the hydraulic fluid to the piston makes the pressure increase rapidly until the force on the piston becomes sufficient to overcome the mass of the piston and the piston rod plus the friction force. Friction force is one of the major factors that cause nonlinearity of hydraulic systems, it's determined as a function of velocity and presented as Stribeck's curve. Stribeck's friction force can be divided into static friction, Coulomb's friction and viscous friction [6]. Values of the friction force are unknown, and must be predicted while performing computer simulation with ITI-SIM.

After achieving the necessary force on the piston, piston moves and the pressure in chambers of the cylinder is almost constant ($p_A \approx 4$ bar and $p_B \approx 6{,}5$ bar). From these results it can be concluded that during the piston movement, pressure on the piston rod side (p_B) is higher than on the piston side (p_A). This pressure behaviour can easily be explained by observing the equilibrium equation on the piston (external load and the friction force are not taken into account): $p_A A_P = p_B \alpha A_P \rightarrow p_B = p_A / \alpha$.

Looking at pressures in Figure 3, a sudden increase of pressure p_A and pressure drop p_B can be seen. This occurs due to stroke of the piston (maximum piston movement) to the cylinder wall while the directional control valve is still open and the working fluid is entering the cylinder. Closing the directional control valve after 2 seconds, pressure in the chamber on the piston side suddenly decreases in the start and then gradually decreases.

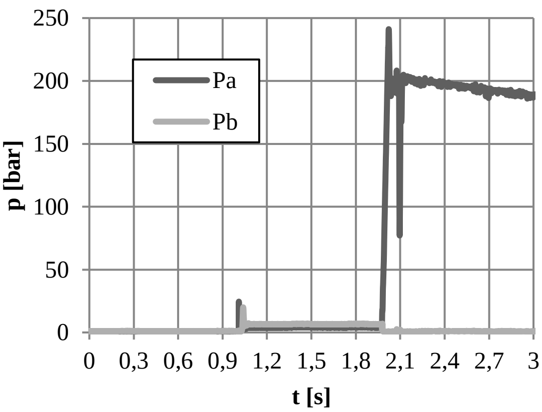

Figure 3. Measured values of the cylinder chambers pressure p_A i p_B

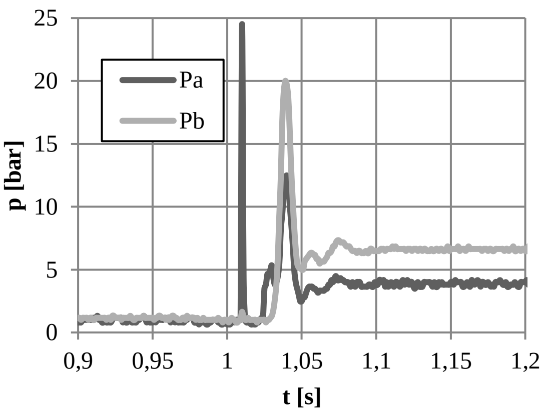

Figure 4. Detail of the cylinder chambers pressure p_A i p_B during cylinder extraction

Modelling the laboratory hydraulic system with the ITI-SIM simulation package

ITI-SIM is a computer simulation program designed for engineers and scientists to solve practical problems of modelling, simulation and optimization. It is applied for simulation of technical problems in mechanics, hydraulic and pneumatic systems and electronics. The structure of simulation models is based on a graphical interaction with real components of the model taken from the program library. Each component is schematically shown and stored in the library as a symbol. Using the symbols of actual components, scheme of the system is being modelled and by changing the parameters of each component, the required system performance is obtained.

Laboratory hydraulic system is modelled by connecting hydraulic components taken from the program library, according to actual laboratory system scheme. Figure 5 represents the simulation scheme of hydraulic power unit that consists of hydraulic pump with displacement Q_P=10,8 cm^3, connected to a constant speed component, which represents the electromotor. The pump draws the working fluid from the tank at atmospheric pressure, and pushes it to directional control valve.

Pressure relief valve that opens at pressure of 210 bar is connected parallel with the pump. Directional control valve is chosen from the library, and is connected with the component that represents control signal as represented on Figure 2. Directional control valve is connected with differential cylinder. Components for measuring pressure and flow are connected to components that represent pipes. Dimension of differential cylinder are taken according to laboratory cylinder, and the mass load is 2 kg (equivalent to mass of piston and the piston rod). Stribeck's friction force is chosen as friction force, and the parameters were taken by default program settings, due to the lack of actual parameters that are unknown or couldn't be measured what affects the simulation's results.

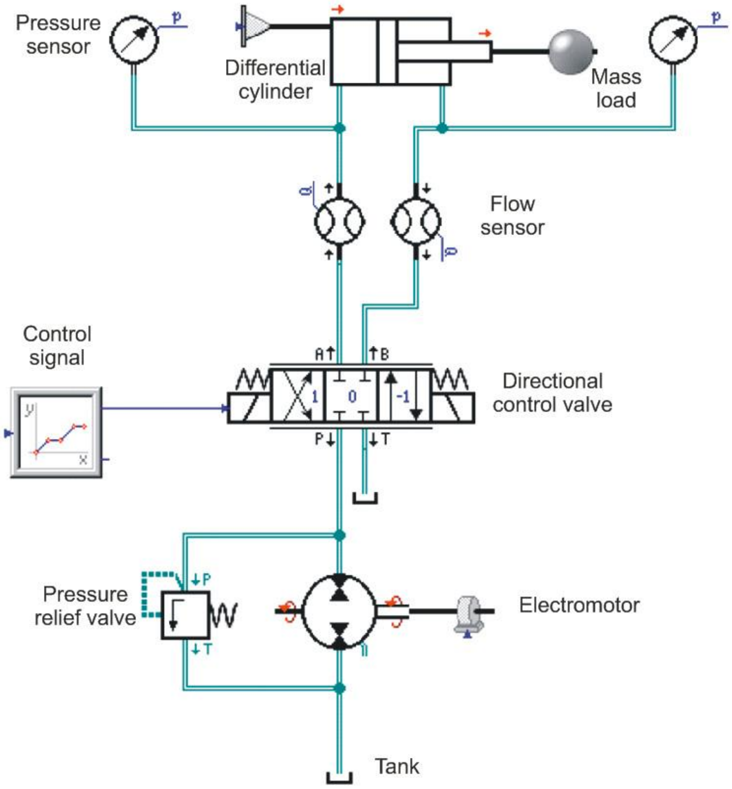

Figure 5. Simulation scheme of hydraulic system

Results of ITI-SIM simulation of the laboratory hydraulic system

After the simulation has been performed, following results have been observed:

- the flow of the hydraulic fluid towards the cylinder is shown on Figure 6 and Figure 7
- pressure in cylinder chambers *(*p_A and p_B) are represented by Figure 8 and Figure 9, which are compared to laboratory pressure measurements
- piston velocity is shown on Figure 10 and piston movement on Figure 11.

Piston velocity and movement are very important to hydraulic system because they represent the output values (signal) of hydraulic system.

Comparison of the results

Comparing the results obtained by laboratory measurements of cylinder pressure and the results obtained by simulation in ITI-SIM, it can be concluded that the pressure behaviour is similar, but not the same. Pressure in chamber on the piston side (p_A) in laboratory measurements at the beginning rapidly increases, and immediately falls, while the simulation doesn't show such behaviour.

This effect can be ascribed to stick-slip effect which isn't taken into account in the simulation. Comparing the value of increasing pressure at the beginning, shows a difference of approximately 5% ie. 0,5 bar as it can be seen on Figure 12. The initial pressure in the simulation is less what can be explained by incomplete knowledge of the friction parameters of laboratory hydraulic cylinder. Observing the pressure during the motion of the piston, the pressure is identical, which proves the correctness of the simulation.

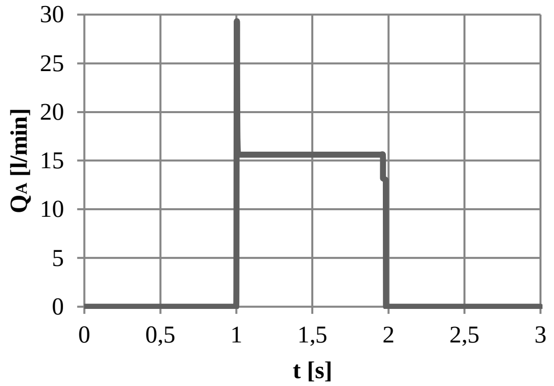

Figure 6. The flow of the working fluid through the valve Q_A

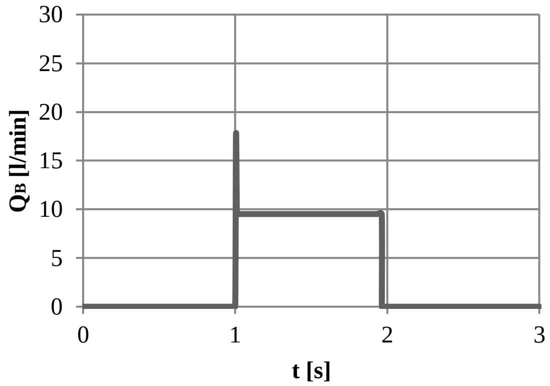

Figure 7. The flow of the working fluid through the valve Q_B

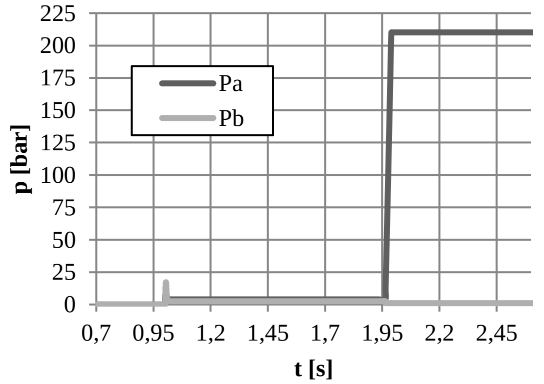

Figure 8. Cylinder chambers pressures p_A and p_B in a period t=0,7 to 2,45 s

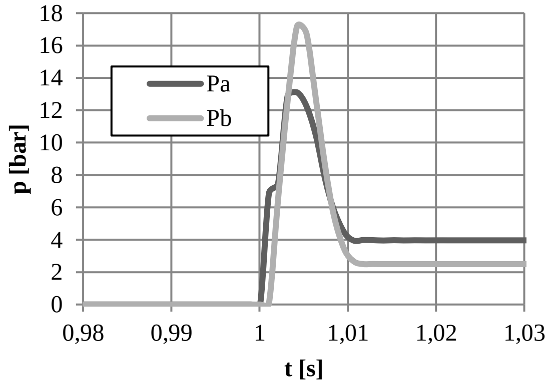

Figure 9. Cylinder chambers pressures p_A and p_B in a period of t=0,98 to 1,03 s

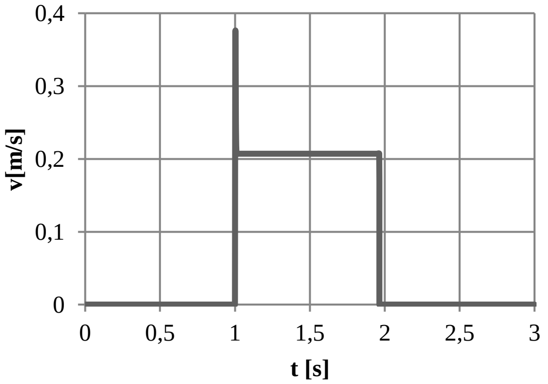

Figure 10. Cylinder piston velocity

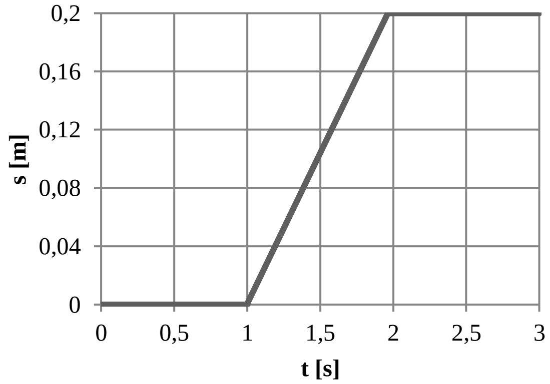

Figure 11. Cylinder piston movement

Much greater differences appear when comparing the pressure in chamber on the piston rod side (p_B), where the pressure obtained by simulation is lower for approximately 20% ie. 3 bar at the initial increase of pressure, and during further piston movement it has a value of approximately 2,5 bar and in laboratory measurements approximately 6,5 bar as it can be seen on Figure 13. Difference of approximately 4 bar can be explained by insufficient knowledge of the friction force and the manner in which ITI-SIM calculated the pressure when the friction force is expressed as a function of velocity.

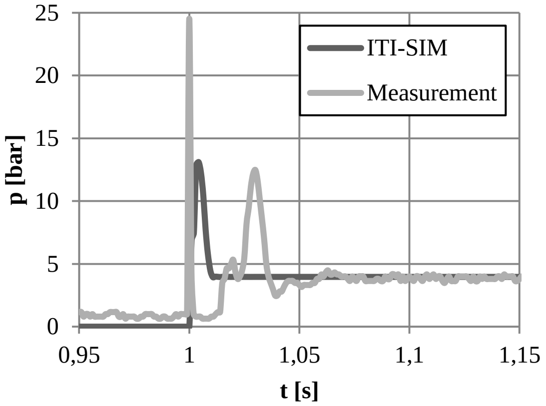

Figure 12. Comparison of pressure p_A

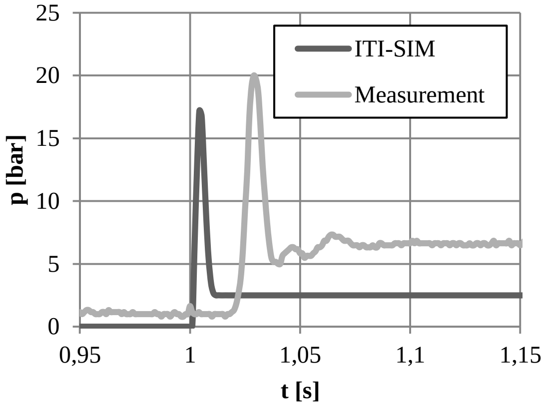

Figure 13. Comparison of pressure p_B

Conclusion

Using computer programs in designing the hydraulic system greatly facilitates and speeds up the process of design, and doesn't require production of expensive prototype. Regardless given advantages of computer simulation programs such as ITI-SIM, they are not almighty. To achieve quality simulation, one must possess a good knowledge of hydraulic systems, effect of particular parameters to system (i.e. friction force, temperature change, flow valve coefficient etc.). Also, the user should have experience of working in the program and application of results obtained in practice. It can be concluded that people should strive for greater use of computer programs when designing hydraulic systems, but the results obtained by computer simulation should not be taken for granted.

Literature

1. Jędrzykiewicz Z., Pluta J., Stojek J.: Application of the MATLAB – Simulink package in the simulation tests on hydrostatic systems, Acta Montanistica Slovaca, Ročnik 3 (1998), 1, 29-36
2. ITI-Sim, URL: http://www.iti.de/en/home.html, (01.07.2010.)
3. Hansa Flex, URL: http://cat.hansa-flex.com/hr/cat/1, (01.07.2010.)
4. ATOS, URL:http://www.atos.com/english/technical_tables/english/E010.pdf, (01.07.2010.)
5. Parker, Senso Control, URL:http://www.parker.com/, (01.07.2010.)
6. Jelali M., Kroll A.: Hydraulic Servo-systems, Modelling, Identification and Control, Springer, London, 2003.