# Simulation of the Working Cycle for a Hydraulic Press Equipped with a Flow Regulator Mounted in Graetz System

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***Abstract:*** *The paper focuses on mathematic modelling of the working operation with the press unit, with hydraulic acting, where flow regulation in load is carried out with a flow regulator mounted in Graetz system. A non-linear simulation model has been developed in Matlab/SimHydraulics environment for highlighting the dynamic behaviour of the main parameters of working regime of hydraulic press unit.*

***Keywords:*** *Hydraulic press, Graetz system, dynamic working regime, Matlab/SimHydraulics, simulation*

## 1. Introduction

Generally, the hydraulic system was gradually developed from the hydrostatic transmission theory (initiated by Pascal) until today when the control of these systems can respond to complex demands posed by actual technology. For example, a hydraulic press is a mechanical device using a hydraulic cylinder to generate a compressive force, to shape, deform, and configure various types of materials (e.g. metals, plastics, etc.). The basic working principle of the hydraulic press are simple. For better understanding of the working cycle of the press equipment, three phases are presented in schematization in figure 1.

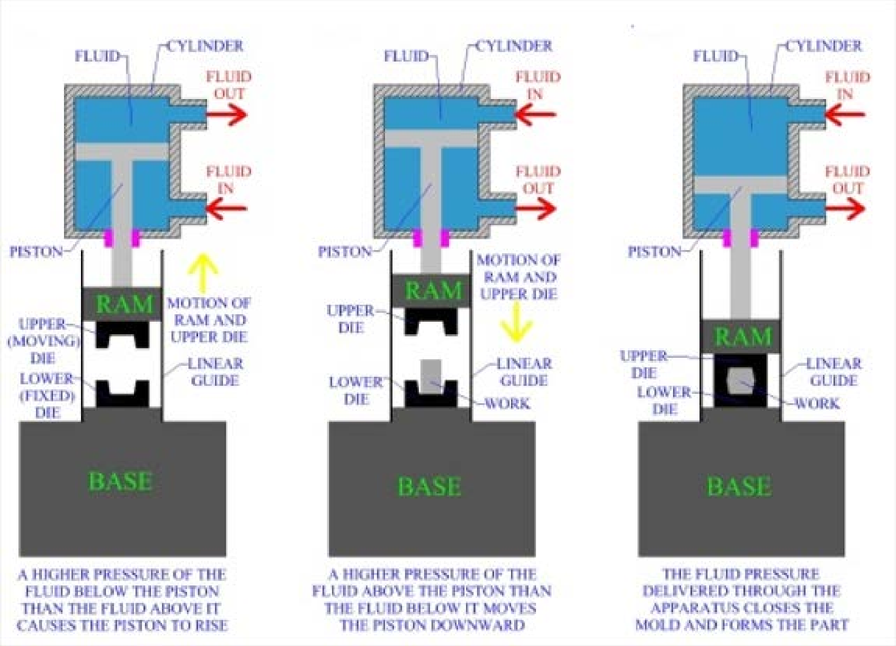


**Fig. 1.** Principle of operation of the hydraulic press [1]

The hydraulic press is a major part of a variety of manufacturing and production processes. Their main parts consist of a mainframe, power system, and control devices (fig. 2). The hydraulic presses in figure 2 use a single rod piston so the hydraulic pressure is applied over the entire diameter of the piston that drives the ram press.

**Fig. 2.** Examples of press equipment

The performances of hydraulic presses required for proper operation of the technological process consist on ability of force control or positioning control systems that follow-up varying reference signals [2-4].

## 2. Problem statement

The study carried out in this work proposes an analysis of the hydraulic cylinder from the component of a hydraulic press, where the flow control in the load is ensured with a Graetz system. This system consists of four directional valves placed so as to form a bridge (Fig.3). The scheme demonstrates how a bridge circuit works to ensure that fluid can only flow one way through a pressure-compensated flow-control.

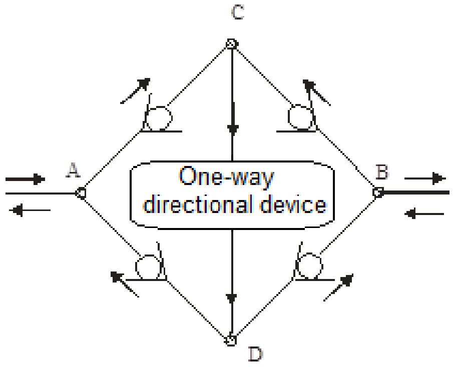
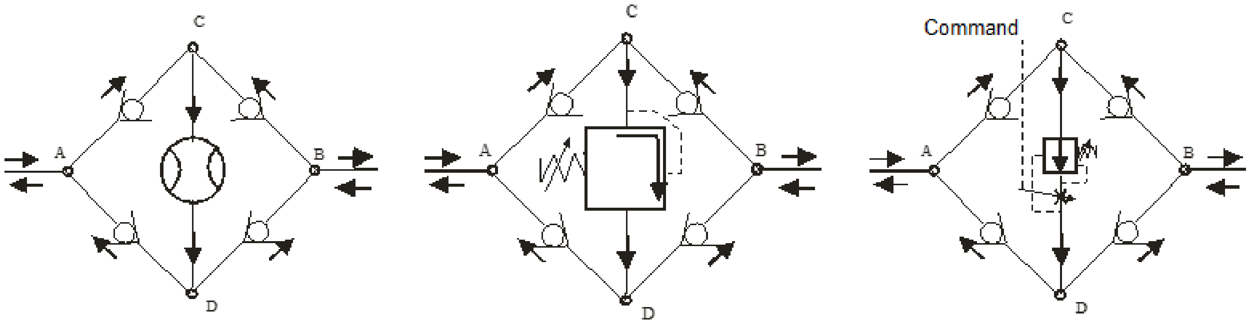


**Fig. 3.** Principle of operation of Graetz circuit diagram

Thus, the inlet and outlet of the system are placed in the corners of the bridge, and the regulating or measuring device is located on the other diagonal. However, the central component does not have to be a flow control (fig. 4). It could just as well be a filter or any other component that requires unidirectional flow (e.g. flow meter, pressure regulator, flow regulator, etc.).



a) b) c)

**Fig. 4.** Positioning of the bridge devices:
a) flow meter; b) pressure valve; c) flow regulator.

Into the hydraulic scheme for press acting with Graetz rectifier circuit, the four non-return valves are combined to assure a unitary functioning. The circuit diagram in figure 4c shows how this operates in conjunction with a flow control valve: flow passes through this valve from left to right during both the advance and return strokes of the cylinder (in the case of press equipment). The situation during the advance stroke is shown. It is observed that regardless of the direction of entry into bridge A or B, the circulation of the hydraulic agent on the diagonal CD is carried out only in the direction from C to D, a fact that leads to a unique adjustment of the parameters of the hydraulic system, whatever the direction of flow might be.

In the following, the diagram of the hydraulic circuit of a press unit will be equipped, for comparison, with the Graetz system and, respectively, with four directional valves, for adjusting the velocity of displacement of the working tool (press ram), regardless of the load on the piston active area.

## 3. Analysis and simulation of working regimes of hydraulic press equipment

The analysis of the behavior of the hydraulic system to the variation of the load on the press piston (corresponding to working operation) is based on a mathematical model for mechanical-hydraulic co-simulation of the driving unit of press [5-6], taking into account by flow rate and motion equations available for [7-8]:

- mathematical model of pump with constant flow;
- mathematical model of discrete hydraulic directional valve;
- mathematical model of flow regulator with pressure balance (Graetz bridge);
- mathematical model of linear hydraulic cylinder.

To simulate the behavior of the hydrostatic driven of press equipment, a scheme has been performed using the Matlab/SimHydraulics environment (Figure 5), usually used for a lot of virtual scenarios [9-11]. It was implemented a simplified model of an open circuit for ram piston acting from a simple acting cylinder. The global scheme contains the following blocks, namely: the driving unit of the circuit, the auxiliary equipment (directional valves, protection valves, pipelines), the regulated blocks of the flow rate into circuit (with throttles and Graetz bridge), and the sensor blocks for instantaneous monitoring of the hydraulic parameters (e.g. input and output pressures, fluid rate flow, piston force, kinematics parameters of the piston motion). Visual representation of the main blocks has been marked separately, in different colors, for better understanding of functional components of the hydraulic scheme.

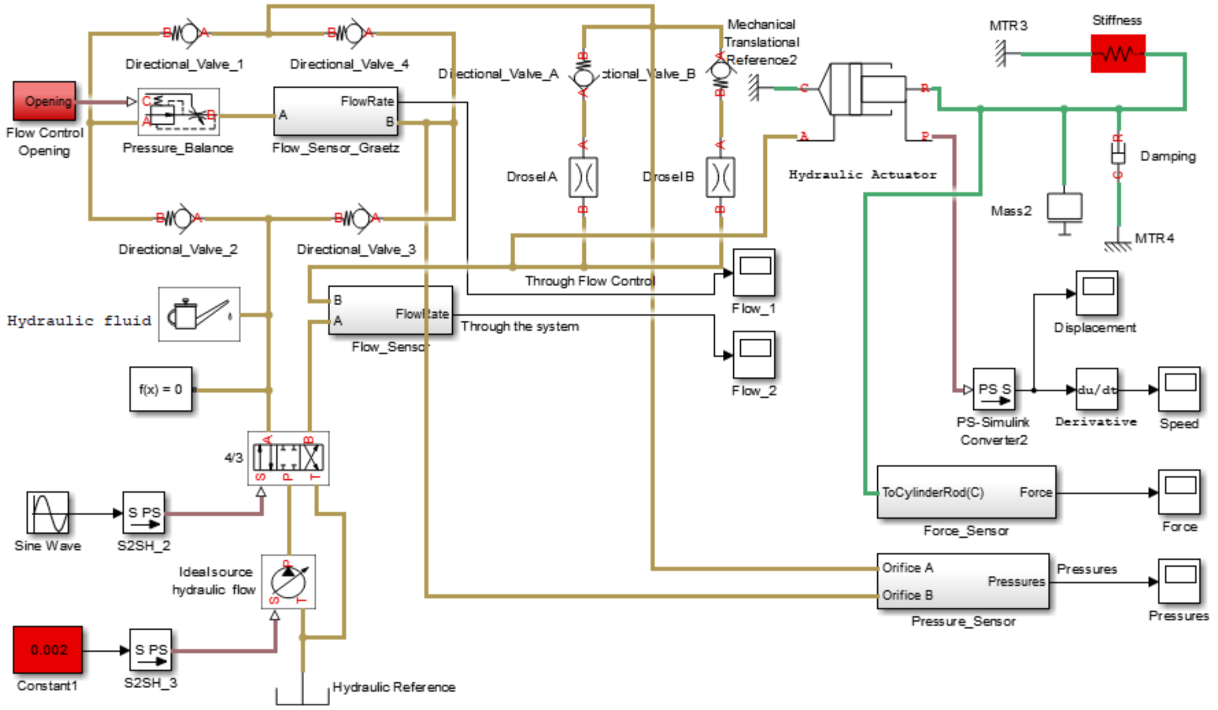


**Fig. 5.** Schematic of hydraulic circuit implemented in Matlab/SimHydraulics environment

The parameters that customize main blocks of the scheme in figure 5 are centralized in tables 1-4.

**Table 1:** Block parameters: Hydraulic fluid

| Parameter | Value |
|---|---|
| Type | MIL-F-5606 |
| Density | 847.4 kg/m$^3$ |
| Viscosity | 12.15 cSt |
| Flow discharge coefficient | 0.7 |

**Table 2:** Block Parameters: Pressure – Balance

| Parameters | Value |
|---|---|
| Orifice maximum area | 5x10$^{-4}$ m$^2$ |
| Orifice maximum opening | 0.016 m |
| Pressure differential across the orifice | 6x10$^5$ Pa |
| Pressure reducing valve regulation range | 5x10$^4$ Pa |
| Flow discharge coefficient | 0.7 |
| Critical Reynolds number | 12 m |
| Leakage area | 10$^{-12}$ m$^2$ |

**Table 3:** Block Parameters: 4/3-Way directional valve

| Parameters | Value |
|---|---|
| Valve passage maximum area | 5x10$^{-4}$ m$^2$ |
| Valve maximum opening | 0.01 m |
| Flow discharge coefficient | 0.7 |
| Critical Reynolds number | 12 m |
| Leakage area | 10$^{-6}$ m$^2$ |

**Table 4:** Block Parameters: Single-acting hydraulic cylinder

| Parameters | Value |
|---|---|
| Piston area | 0.035 m$^2$ |
| Piston stroke | 0.08 m |
| Piston initial position | 0 |
| Dead volume | 10$^{-4}$ m$^3$ |
| Specific heat ratio | 1.4 |
| Contact stiffness | 10$^6$ N/m |
| Contact damping | 150 Ns/m |

## 4. Results

The response of the actuation system, simulated for 5 seconds, starting from the moment of initialization of the movement, is presented in figure 6. The dynamic performance of the linear hydraulic actuator (in the case of Graetz system acting) is represented as piston displacement-time, piston speed-time and flow rate-time (controlling by Graetz bridge comparatively by resistive circuit).

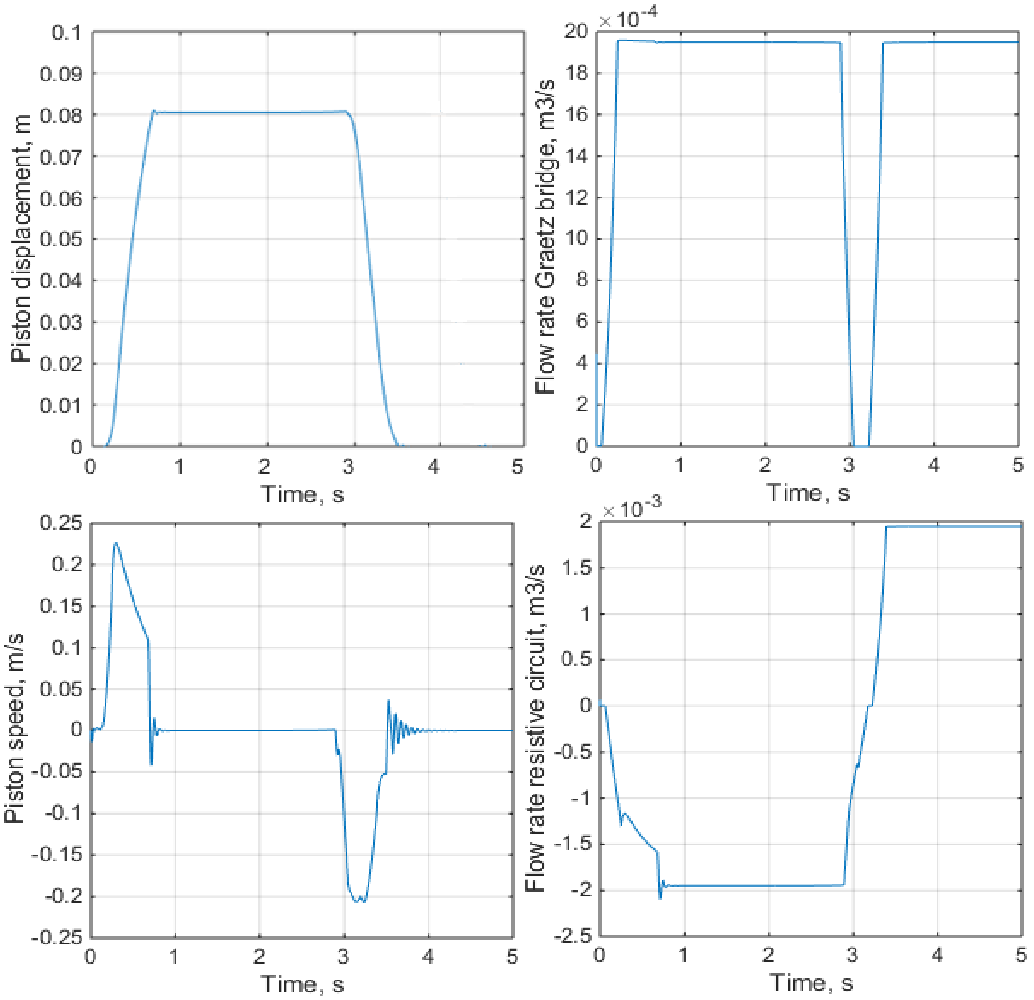


**Fig. 6.** Simulation results

Thus, these dynamic characteristic curves were simulated in one work cycle and one can see that they are characterized by intensive temporal variation of analysed parameters. In the flow control system (and implicitly in the piston force control), it is required that maximum overshoot must not be excessive. With Graetz bridge the control of flow rate is maintained around 2x10$^{-3}$ m$^3$/s, curve different from the one through the resistive circuit. This aspect assures a maximum value of flow rate regardless of load at working tool. In addition, for simulating various loads acting at the piston rod, a subsystem that can vary working scenarios was implemented in the scheme. With help of the SimHydraulics module, it is easier to carry out sensitive analyses regarding the influence of some parameters on the performances of the press actuation system (e.g. pressures, impact force, acceleration piston, energy consumption, etc.).

## 5. Conclusions

This paper highlights the functioning of the Graetz bridge (known as a unit pressure balance), consisting of four direction valves and a flow regulator, embedded into a concrete engineering application (e.g. hydraulic press equipment).

Due to the constructive layout, this assembly determines the flow of hydraulic agent always in the same direction through the flow regulator. In this way, the flow of hydraulic agent with a constant and continuous value determines the stability and precision of the actuation system, which is simulated and shown on the response diagrams of the actuator.

The use of the Matlab/SimHydraulics analysis environment allows the direct modelling of the blocks that define the mathematical model of the hydraulic actuation system. The modelling results highlight the interdependence of the process parameters, and the dimensional ones can be modified individually, for a qualitative refinement of the response of the press actuator.

Finally, the control of flow rate can be performed even with a Graetz system as alternative solution for resistive adjustment of the hydraulic agent speed by means of throttle devices.

**References**

[1] Kabra, Nilesh. "Forging & Press Working." *Slideshare*, October 23, 2015. Accessed July 20, 2022. https://www.slideshare.net/NileshKabra1/forging-press-working-54292765.

[2] Chen, Hong-Ming, Guo-Wei Yang, and Chong-Cyuan Liao. "Precision Force Control for an Electro-Hydraulic Press Machine." *Smart Science* 2, no. 3, (2014): 132-138.

[3] Rodriguez-Guerra, Jose, Carlos Calleja, A. Pujana, Iker Elorza, and Igor Azurmendi. "Real-time HiL for hydraulic press control validation." Paper presented at the 7th International Conference on Simulation and Modeling Methodologies, Technologies and Applications SIMULTECH 2017, Madrid, Spain, July 26-28, 2017.

[4] Šitum, Željko, Tihomir Žilić, and Vladimir Milić. "Improving performance of a hydraulic press with real-time nonlinear control". Paper presented at the 9th International Fluid Power Conference (9th IFK), Aachen, Germany, March 24-26, 2014.

[5] Curduman, Laurentiu, Silviu Nastac, Carmen Debeleac, and Mircea Modiga. "Computational dynamics of the rotational heavy loads mastered by hydrostatical driving systems." *Procedia Engineering* 181 (2017): 509–517.

[6] Curduman, Laurentiu, Carmen Debeleac, and Silviu Nastac. "On path oscillations analysis of mechanical multi-body and hydrostatical driving units coupled system." *Procedia Engineering* 181 (2017): 518–525.

[7] Axinti, Gavril, and Adrian-Sorin Axinti. *Fluid Power Systems – Components and systems, functions and characteristics. Vol. I / Acţionări hidraulice şi pneumatice – Componente şi sisteme, funcţii şi caracteristici. Vol. I*. Chişinău, Tehnica-Info Publishing House, 2008.

[8] Axinti, Gavril, and Adrian-Sorin Axinti. *Fluid Power Systems – Equipment and systems dynamics. Vol. II / Acţionări hidraulice şi pneumatice – Dinamica echipamentelor şi sistemelor. Vol. II*. Chişinău, Tehnica-Info Publishing House, 2008.

[9] Zheng, HongBo, MingJun Li, and ZhouLin Wang. "Simulation and optimization for pressing system of hydraulic brick press based on AMESim." *Journal of Physics: Conference Series* 2187 (2022): 012026.

[10] Debeleac, Carmen. "Dynamic Modeling and Simulation of Working Regime of the Hydraulic Driven of Auger Bucket for Loader Using Matlab/SimHydraulics ". *Hidraulica Magazine*, no. 4 (December 2021): 7-16.

[11] Eltantawie, Manar Abd Elhakim. "Design, manufacture and simulate a hydraulic bending press." *International Journal of Mechanical Engineering and Robotics Research* 2, no. 1 (January 2013): 1-9.