ISSN 2176-5480

22nd International Congress of Mechanical Engineering (COBEM 2013)
November 3-7, 2013, Ribeirão Preto, SP, Brazil

VALIDATION OF COMPUTATIONAL MODEL VALVE HYDRAULIC PROPORTIONAL

Denilson Mauri,
IFSP-Campus São Paulo. Rua Pedro Vicente, 625. Canindé, São Paulo, SP.
denilsonmauri@gmail.com
Alexandre Simião Caporali,
IFSP-Campus São Paulo. Rua Pedro Vicente, 625. Canindé, São Paulo, SP.
caporali@gmail.com
Eduardo Bock,
IFSP-Campus São Paulo. Rua Pedro Vicente, 625. Canindé, São Paulo, SP.
eduardo_bock@yahoo.com.br
Alexandre Brincalepe Campo,
IFSP-Campus São Paulo. Rua Pedro Vicente, 625. Canindé, São Paulo, SP.
brincalepe@gmail.com

Abstract. This work proposes a validation of a nonlinear mathematical model of a hydraulic proportional valve. In hydraulic systems that use hydraulic proportional valves inexpensive, comes from the nonlinearities geometries and and imperfections of the spool. A model that represents the actual system allows the control to be developed in virtual environment, and variations in size and geometry of the proportional valve can be changed to control test without the costs of various prototypes. Linear equations were developed for a generic model, where simplifying assumptions and boundary conditions used are generally accepted. Are equations that relate physical and geometrical characteristics of the spool with the data constructive, in order to facilitate interaction with the designer. A comparison between the experimental data and the results of the computer simulation showed the overall quality of the model and the constructive aspects that may improve the quality of the model. The validation had to overcome difficulties of using two separate programs, as a simulation was performed in Matlab ® and Data Acquisition LabView ® program.

Keywords: *hydraulic control, proportional valve, computational simulation, hydraulic circuits, cfd.*

1. INTRODUCTION

In general terms the whole project in the area of industry is subject collections for better quality and lower costs (Schlueter, 1999). Changes or quality improvements commonly add cost to the project, to solve this problem it is necessary for the designer to find a more economical way equating the problem cost-effectiveness (Gouvinhas & Cobert, 1999).

The inherent quality of hydraulic systems causes them to be applied in different solution, but the cost of the project does not allow mistakes. For this reason a study was conducted at the Federal Institute of Education, Science and Technology of São Paulo - São Paulo campus focused on the research of hydraulic systems and their application in automation and industrial process control (Mauri, 2010).

The objective of this work was to create a simple computational simulation process for the use of designers, getting the response characteristics of a hydraulic proportional valve. To achieve this goal, it was determined that the physical parameters of the valve construction would be input to the simulation, so the simulation result can be used to optimize the design of the valve. The designer can simulate all conditions, determining with greater accuracy and confidence the project, avoiding future problems that will lead to higher costs as they need to be solved with the mounted equipment and field.

The project was based on the choice of a proportional hydraulic valve, because this element allows you to control the flow rate of the system. Comparing hydraulic proportional valves with servo valves, proportional valves are more tolerant to contamination of hydraulic oil, coupled with the fact the project is simpler, resulting in lower cost and higher robustness of the design (Parker 1999) (Eaton 2006).

2. HYDRAULIC PROPORTIONAL VALVE

To validate the computational model was chosen a valve in hydraulic proporcinal existing hydraulics laboratory IFSP - São Paulo, which has a configuration of three positions with four-way center closed, self centering spring (Figure 1). Mounted on a bench with two pumping systems with two gear pumps 6 liters per minute each, the total capacity of 12 liters per minute. This bench is possible hydraulic circuit simulations, allowing testing of individual components or together. To research the bench received modifications to the measurement and research.

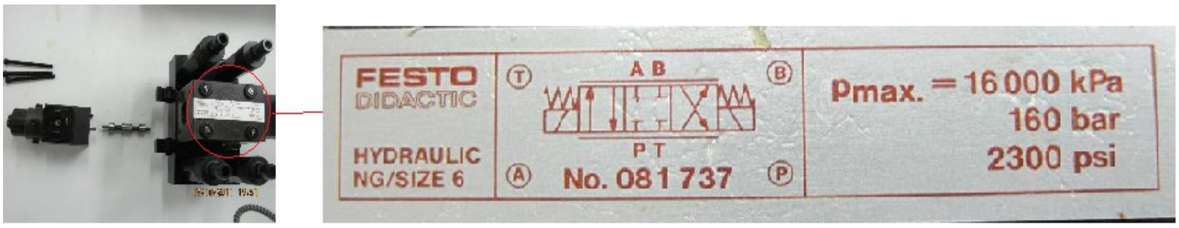

Figure 1: Hydraulic Proportional Valve.

The assembly chosen for the test uses only the proportional hydraulic valve individually fed by pump set maximum flow rate of the hydraulic system. The measurement of flow was obtained by connecting the valve outlet to a graduated container for volume measurement. With the data of the measured time for filling the reservoir graduate, was possible to measure different flows for different levels of voltages applied in your solenoid valve.

3. SIMULATION

A simulation is to describe the physical model of a system with aspects relevant to the study and consider their desired simplifying hypothesis. For the description of the hydraulic proportional valve were used and described seven equations with nonlinearities and multiple variables corresponding to the operation of the mechanical and electrical parts of the valve (Borghi, 2000). The electro-electronic and mechanical parts can be seen in Figure 2.

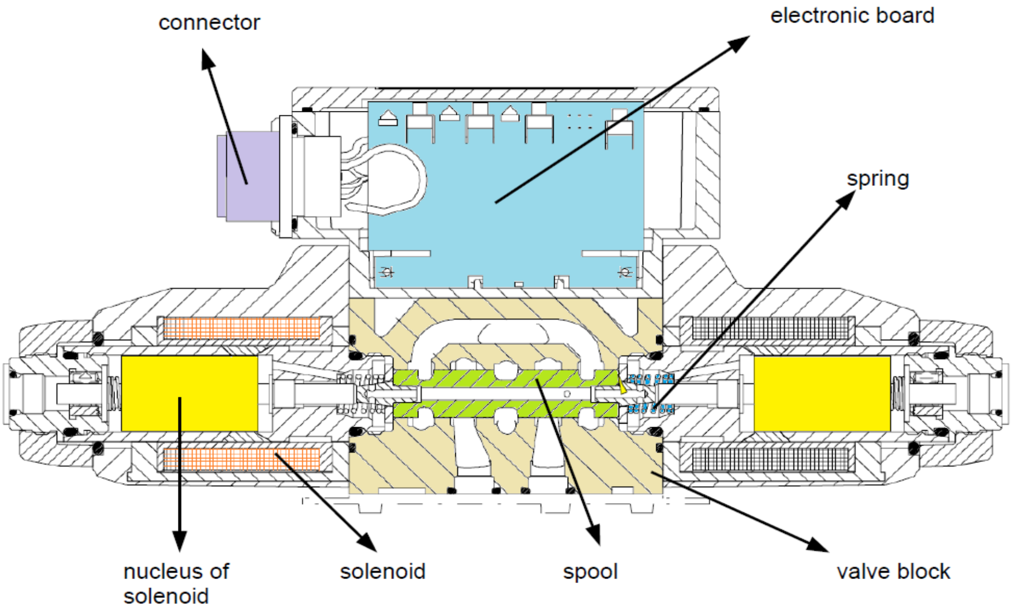

Figure 2: Valve Eaton Vickers® (Vickers, 2012).

The Eq.1 represents the flow of fluid through an orifice restriction (Merritt, 1967) (Koskinen, 2000) (Linsingen, 2006), the gradient area is given by Eq.2 (Gieck, 1979) and the force acting on the spool is given by Eq.3. The latter was obtained by applying the Newton Law of F = MA plus a portion of viscous damping of the fluid surrounding the reel and elastic part by the spring.

$$Q = Cd \, . \, A \, . \sqrt{2 \, . \, g \, \frac{\Delta P}{\gamma}} \qquad (1)$$

$$A = \frac{h^2 \, . \, (32 \, . \, r - 13 \, . \, h)}{12 \, . \, \sqrt{2 \, . \, r \, . \, h - h^2}} \qquad (2)$$

$$F = M_{tcarr} . \frac{d^{2x}}{dt^2} + Bc . \frac{dx}{dt} + K_x . X \quad (3)$$

The electrical hydraulic proportional valve corresponding to the electromechanical converter (solenoid), was represented by four other equations where Eq. 4 regarding the strength of the solenoid, Eq.5 relating to winding resistance, Eq.6 referring to the magnetic field, Eq.7 regarding the inductance of the solenoid (Vaughan, 1996) (Hallen, 1962).

$$F_{sol} = I \, . \, C_{sol} . \, B_{sol} \, . \, Sen\theta \quad (4)$$

$$R = kr \, . \, Lfio \quad (5)$$

$$B_{sol} = \mu_0 \, . \, \frac{I \, . \, N}{C_{sol}} \quad (6)$$

$$L = \mu \, . \, \mu_o \, . \, \frac{N^2 \, . \, S}{C_{sol}} \quad (7)$$

Description	Value
Permeability constant in vacuum (μ_0)	$4*\pi*(10^{-7})$ [$N*A^{-2}$]
Permeability constant of the material (μ)	800 [$N*A^{-2}$]
Number of turns of the coil winding (N)	1800 [adim]
Coil length (C_{sol})	0,05 [metro]
Elastic constant of the spring (K_x)	2000 N/m
Radius of the valve cavity (r)	0,0025 m
Number of cavities reel	3 [adim]
Fluid density (γ)	860 g/m^3
Discharge coefficient (Cd)	0,6 [adim]
Inlet pressure in the valve (P_{in})	$10*10^6$ [Pascal]
Outlet pressure valve (P_{out})	$6,5*10^6$ [Pascal]
Input voltage valve (Vin)	24 [Volts]
Diameter of coil (D_{fio})	0,01 m
Constant resistive wire (kr)	$36*(10^{-3})$ ohms/m
Number of coils (n_{coil})	1[adim]
Number of coil layers (n_{camada})	$(n_{voltas}*NB) / (n_{comp}/D_{fio})$
Mass reel (M_{tcarr})	$1,5*10^2$ [gramas]
Outer radius of the coil (R_{coil})	$D_{nucleo}/2 + (n_{camada}*D_{fio})$
Maximum current Wire (I_{max})	3,5 A
Average radius of coil (C_{med})	$D_{nucleo}/2 + n_{camada}*D_{fio}$
Resistivity coil (R)	$K_{fio}*(2*\pi*R_{aiomedio}*n_{voltas})/NB$

4. RESULTS

The simulation and solution of the equations representing the program were conducted MATLAB ®, Simulink ® using the tool. For the results obtained from the simulation could be compared to a real model, variables constructive hydraulic proportional valve available were measured and entered values the computational model.

4.1 GRAPH VOLTAGE FLOW

Implementing the equations using MATLAB ® was possible to generate a graph of time flow for each applied voltage and the result is shown in Figure 3.

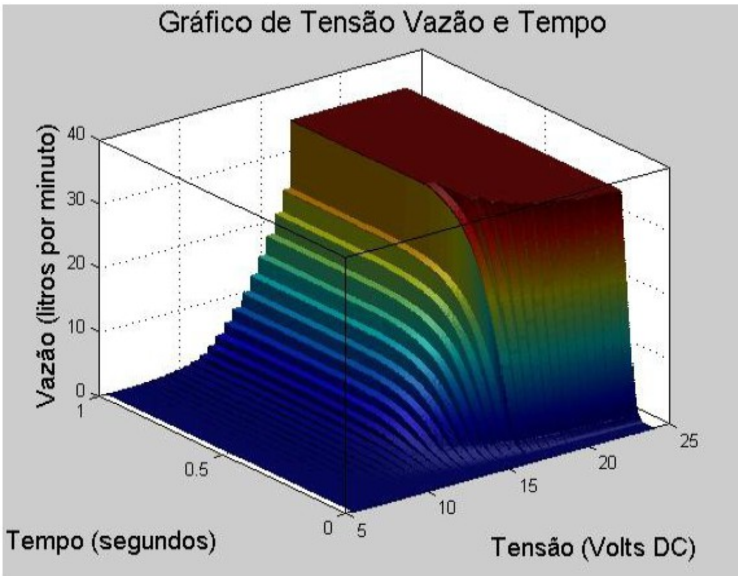

Figure 3. Flow chart as a function of time.

For each applied voltage proportional hydraulic valve spool takes some time to move into position and allow the passage of fluid corresponding the tension applied. Thus 16Vdc voltage hydraulic valve reaches its maximum flow of 36 liters per minute it is not necessary to apply 24 volts available from the power supply.

The program features allow the individual analysis of each part of the valve showing data as current in solenoid (Figure 4) for all possible voltages. In the case of electronic parts with the anticipation of behavior is possible to project the control circuit before building.

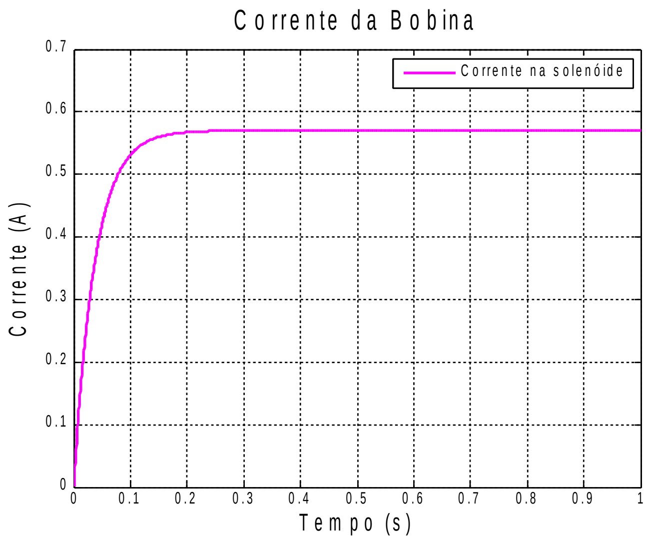

Figure 4. Figure current circulating in the coil by applying DC 15volts.

The analysis allows to know in advance what the response of the system with this information control systems can be developed. Comparing Figure 4 with Figure 5 you can see the difference in speed of response of the electrical and mechanical system and apply a new control based on this information.

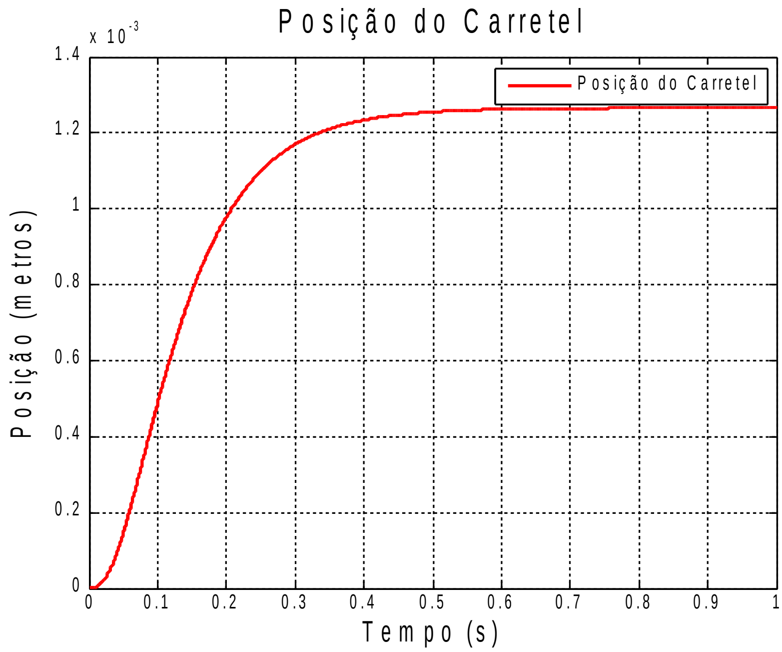

Figure 5. Graph position of the spool with the application of DC 15volts.

Since the objective of this work is to propose a methodology of mathematical modeling to assist the design of hydraulic proportional valves. The interaction of the program can be made constructive changes in the geometry and dimensions of the spool and the dimensions of the coil and its winding, materials and mechanical clearances of the set in order to adjust or customize the performance of the hydraulic valve.

5. VALIDATION OF THE MODEL

With the collection of data on proportional hydraulic valve hydraulic bench IFSP. During the simulation program MATLAB ® demonstrated the potential flow valve exceeding 30 liters per minute, this potential was confirmed by comparing the data with the manufacturer catalogs Parker and Eaton. In these catalogs hydraulic proportional valves of the same size (NG06) present maximum throughput from 30 to 80 liters per minute, consistent with the simulation and the valve from the bench.

The hydraulic bench has maximum flow of 12 liters per minute when the two pumps connected in parallel from the bench, which was done for the test. In this way it was possible to compare the experimental data with flow rate of 12 liters per minute from the countertop hydraulic simulated data of 35 liters per minute valve (Figure 6).

Within the flow rate of 12 liters per minute model was adequate with a maximum deviation of 4%, using the formula (Eq.8) below:

$$Desvio=\sqrt{\left(\frac{Valorteórico-Valormedido}{Valorteórico}\right)^2}.100 \qquad (8)$$

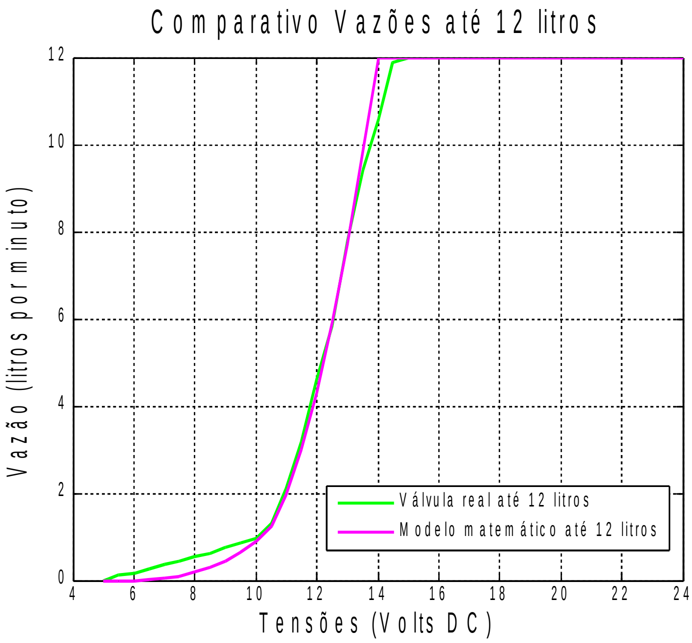

Figure 6: Comparison of mathematical simulation of flow proportional valve with the hydraulic bench.

The flow rate used to compare the simulated data with real data is shown in the graph below that analyzes the pressure drop during the measurement on the bench. The conditions for maintaining the pressure load (60 kgf / cm ²) in the valve remains around 10 Vdc applied to the valve, above this value the pumping system can not maintain the pressure load.

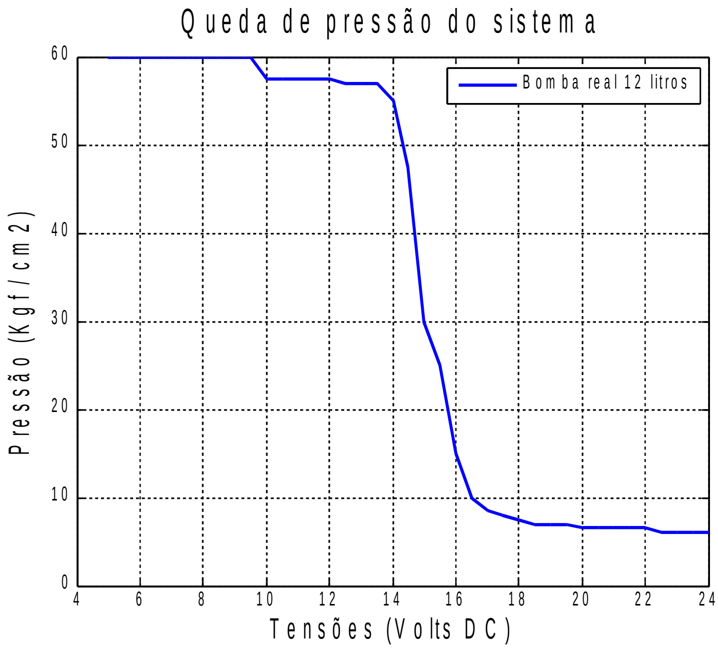

Figure 7: Pressure drop in hydraulic power test bench

6. CONCLUSION

The objective of this work was to develop a mathematical model that can help the designer to prepare a draft of a hydraulic proportional valve. Thus the focus was to create a model of interaction where rapid filling a table with values promote the physical valve design change according to the command of the designer. Obtaining the anticipated response of the valve behavior changes may be made reducing the cost, since it is not necessary to construct and test one or more prototypes.

Although the hydraulic bench has not provided all the required flow for testing across the operating range of the valve, the result can be compared and used showed great accuracy of the mathematical model, proving the quality of the method used.

Finally the program brings besides the data fluid mechanical valve information about the electronics. With this information it is possible to use the model to design an electronic control circuit and also a control program for the hydraulic system. Being able to integrate a larger model simulation of a hydraulic circuit complete.

7. ACKNOWLEDGEMENTS

I thank the friends and teachers for effective collaboration and contribution. Support of the Federal Institute of Education, Science and Technology of São Paulo - São Paulo campus, my family and friends from the area of Mechanical IFSP.

8. REFERENCES

EATON Fabricante. (2006). "*Proportional Directional and Throttle Valves - Solenoid Operated KDG4V".*

GIECK, K. (1979) . "Manual de Fórmulas Técnicas. Hemus" livraria editora limitada.

GOUVINHAS, R. P.; COBERT, J. A (1999) "*Discussion On Why Design Methods Have Not Been* Widely Used Wuthin Industry. International Conference on Engineering Design Munich" .

HALLÉN, E. (1962) . *"Electromagnetic Theory." London: Chapman & Hall, ltda .*

KOSKINEN, Kari T &. M. (2000) março. "Steady State and Dynamic Characteristics of Water Hydraulic proportional Ceramic Spool Valve." *International Jornal of Fluid Power* , volume 1 - 5 a 15.

LINSINGEN, I.(2003) "*Fundamentos de Sistemas Hidráulicos"* (segunda ed.). Florianópolis, Santa catarina, Brasil: UFSC. .

BORGHI, M. (2000). *"Stacionary Axial Flow Force Analysis on Compenseted Spool Valves." International Jornal of Fluid Power , volume 1 numero1 17 a 29.*

MAURI, D. (2010) Simulação Computacional de uma Válvula Hidráulica Proporcional (monografia). Instituto Federal de Educação Ciência e Tecnologia de São Paulo.

MERRITT, H. E. (1967). " *Hydraulic Control Sistems"*. New York/USA: John Wiley & Sons.

PARKER Fabricante (1999). Apostila M2001-1 BR . Tecnologia Hidráulica Industrial. www.parker.com .

SCHLUETER, A. (1999). " *Requirements on the use of Methods in Industry*." *International Conference on Engineering Design Munich* .

VAUGHAN, N. D.; GAMBLE, J. B. (1996). *The Modeling and Simulation of a Proportional Solenoid Valve*. *Journal of Dynamic Systems, Measurement and Control*, Volume 118- março.

9. RESPONSIBILITY NOTICE

The authors are solely responsible for the content of this article.