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CONTROL METHODS OF HYDRAULIC POSITIONING SYSTEMS AND A PROMISING SIMULATION FRICTION MODEL

M. Papoutsidakis*, **A. Chatzopoulos**

Department of Industrial Design and Production Engineering, University of West Attica, Athens, Greece

Abstract. The subject of this research work deals with the hydraulic systems such as pistons and motors. Initially, it analyzes how these and other components are necessary for the hydraulic circuits, such as control valves and regulating valves, as well as motion sensors. It also refers to the production automation, the industrial use, the advantages it provides, the disadvantages it may have, but also the part of the damages that is often presented, how they are caused, how we can predict them and how they are repaired. Finally, it presents the automatic control of hydraulic systems through P.I.D type controllers as well as through a programmable logical controller PLC. Moreover, the well-known LuGre friction model is introduced and the way it will be adopted for use in simulation environment, will be described in the paper.

Keywords: hydraulic systems, fluid power, PLC for hydraulic control, linear positioning actuators.
Corresponding author: Michail, Papoutsidakis, Department of Industrial Design and Production Engineering, University of West Attica, Athens, Greece, Phone:+302105381483, e-mail: *mipapou@uniwa.gr*
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1 Introduction

Automated control systems or automation systems are concepts that we currently use on a daily basis. It is a sector that has as main objective the facilitation of human life. Automation, in essence, is a sequence of steps that takes place when there is some excitation in a particular system and is intended to offer a certain result without human interference. This is also the main reason why automation systems are necessary in today's industry. In the modern industry, four basic automation systems are used. Hydraulics, pneumatics, electric and electronics. In order to solve today's very demanding and complicated problems, it is usually necessary to combine more than one type of automation, which is called a mixed type automation (Pantazis, 2006; Kissell, 2005; Merrit et al., 1967; Costopoulos, 1992; Pantazis, 2008). Hydraulic automation systems consist of hydraulic pipes, pumps, hydraulic motors, pistons and valves and use fluids with the most common of them the oil. Their key features are the great forces they exert, the high positioning accuracy and the sensitivity they have to temperature alteration.

The main parts that a hydraulic positioning system consists of are typically listed below:

- Hydraulic Pumps
  Hydraulic pumps are necessary for a hydraulic circuit because it is the component that propel the fluid used in the system. Single-directional or bi-directional pumps are available. Bidirectional pumps are rotated clockwise as well as counter-clockwise, so they can propel the fluid in whatever direction the engineer wants. There are also steady flow and variable flow pumps, where the flow rate can be adjusted.

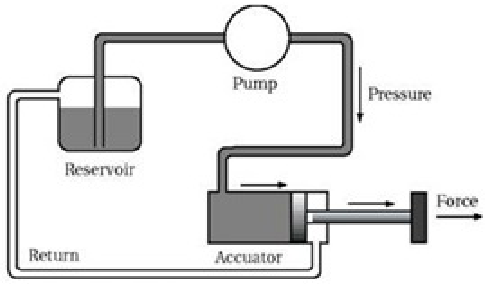

Figure 1: A simple hydraulic system

- Hydraulic Valves
  These are another highlight in hydraulic systems as hydraulic valves are the ones that control the movement of the fluid in the circuit. Because of the many functions they perform, the hydraulic valves are divided into the following categories:
  (a) Direction control valves
  (b)Non-return valves
  (c)Pressure regulating valves
  (d)Flow control valves

- Hydraulic Pistons
  Hydraulic pistons or hydraulic cylinders, are the mechanical hydraulic components used to make linear movement in the circuit. The requirements of the hydraulic system in which we want to use the hydraulic pistons (speed, power, pressure) indicate the proper choice of the cylinder. Depending on their operation, the hydraulic pistons are divided into two main categories: Single acting hydraulic pistons and double acting hydraulic pistons.

- Hydraulic Motors
  The logic of the construction of the hydraulic motors is the same as the logic of the construction of the hydraulic pumps. However, the operating logic of these two hydraulic components is exactly the opposite. The purpose of a pump is to get mechanical energy and convert it into hydraulic energy while the hydraulic motor receives hydraulic energy by offering mechanical energy. The torque a hydraulic motor offers depends on the system pressure and the surface of the liquid moving parts. However, the torque required to start the engine is greater than that needed when the engine reaches the maximum speed due to friction, inertia of components and resistances. Therefore, the choice of the engine must be based on its ability to start the load. When the maximum engine velocity has been reached, system pressure must be reduced.

- Other Components
  In addition to the above basic components of a hydraulic system, there are also some other elements that may not perform some basic operation, however, their existence is necessary for completing a hydraulic system, such as the reservoir in which the fluid is stored, the piping through which the fluid is transported, and various filters and control instruments, such as the manometer to control the system pressure.

2 Industrial automation applications of hydraulics

Hydraulic automations are hydraulic systems that are designed and built to perform a particular desired process. By "automation" is meant that the system should perform the process itself without any human intervention. Many times, even the startup of the system process is automatic. This is achieved by the use of special actuators (sensors), whose function focuses on giving the start signal to the system at the right time. Moreover, the correct design of the system - that is to say, the hydraulic circuit that will take the signal from the sensor - is necessary to perform and produce the desired result. Hydraulic circuits are the basic and most important part of a hydraulic system. These are the right combination of the hydraulic components - are mentioned previously - which create the circuit that provide the desired process. For example, supposing that there is a conveyor belt on which an object is to be diverted from transporting it, we have to place a piston and when the object passes from that point, it subsequently pushes it out of the conveyor belt., However, to do this, is necessary to create a circuit comprising a constant flow pump, a direction control valve, a relief valve and a double acting piston, in order to return to its original position, which convert the hydraulic power to kinetic power.

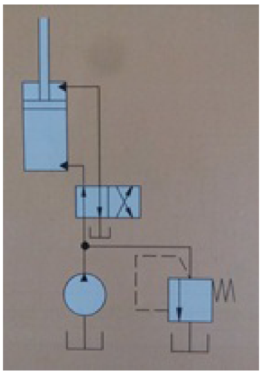

Figure 2: A typical hydraulic circuit

As it is aforementioned, in order for a hydraulic system to start automatically or to take some initiative without human interference, the use of sensors is required. Sensors are components that are capable of detecting physical magnitudes such as motion, velocity, power, temperature and so on. When they detect the desired information, they trigger the system to initiate or affect the process that is being executed. Many times, a controller is used simultaneously to determine the value at which the sensor will respond or to receive information that the sensor returns from the circuit, such as the position of a piston. Significant elements for selecting a sensor are the range of values it can detect, the accuracy it offers in relation to the actual value, the error it may have, the response speed from the time of the detection of the information and the operating time it has.

Hydraulic systems today are so widespread that we come in contact with them almost daily, even in cases we may not know. The hydraulic systems are used not only in very simple and everyday situations but in very complex and demanding conditions as well. Their advantages are such that for specific applications the hydraulic systems are the only reliable choice. A simple and everyday example of this sector is the hydraulic brakes of cars. However, the usefulness of

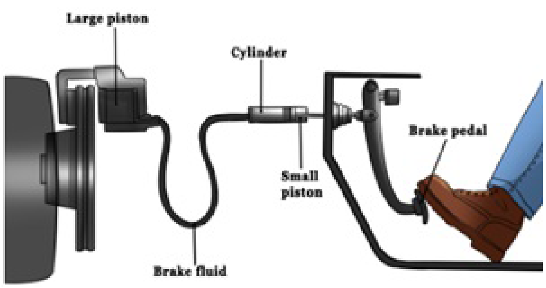

Figure 3: Hydraulic brakes

hydraulic systems is more easily understood in more demanding applications where the use of other automatic systems seems inadequate or inconvenient. For example, the use of hydraulic systems in construction industry vehicles is almost exclusive. Vehicles such as cranes, bulldozers, excavators or tipper trucks use hydraulic systems. During one flight, the forces created and

Figure 4: A tipper truck

exercised in the airplane are enormous. Hydraulic systems are essential and an important part of aircraft systems. Hydraulic systems are an integral part of robotics. Hydraulic power can give

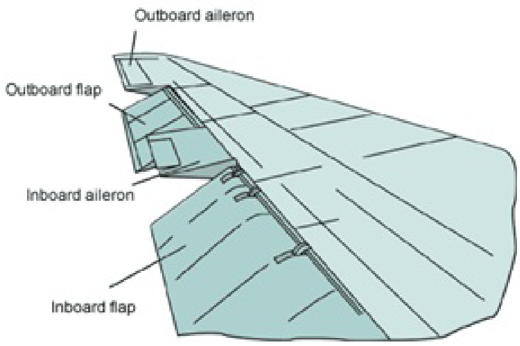

Figure 5: Hydraulic aircraft systems

much greater force to a robotic joint than an electric motor. The requirements of industry and

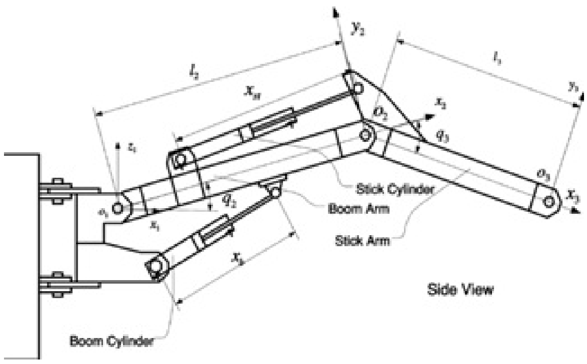

Figure 6: Drawing of a hydraulic robotic arm

production lines are high. In order to reduce production costs, the use of the most appropriate systems is required. For this reason, automation in industries is often of a mixed type to exploit the advantages of all types. Hydraulic systems have an important place in automated production lines as they offer velocity, linear motion and power.

3 Automation methods and control of hydraulics

In order to control any hydraulic positioning system over many years of hydraulic system applications in industrial processes, many methods have been applied. The most typical, common

Figure 7: Modern industry

and low cost are presented below and include the classical PID controllers and PLC control methodology (Stavros, 2010; Olsson et al.,1998) A simple but almost everywhere applied controller is the PID control method. During the construction of a hydraulic system, the response of the system is not always desirable. For this reason, we use a P.I.D. controller in order to minimize the error. The controller monitors the system and tries to control its behavior., However, to do this, the controller and the hydraulic system whose response we want to control, must be in a closed loop system. The existence of feedback is necessary.

The Ziegler - Nichols method is usually used to calculate the three Kp, Ki and Kd parameters

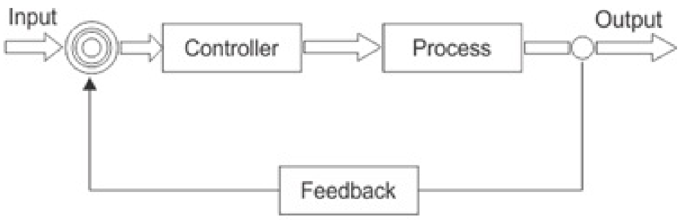

Figure 8: Closed loop system

while the Matlab computational program is an excellent tool for simulating a system, calculating parameters and displaying graphs in order to achieve the desired response. As approximately 90% of industrial loops make use of PID controllers they are considered to be the most frequently used in industry. A PID controller provides a control signal that depends on three terms and is given by the following equation where $U(t)$ is the control signal and $e(t)$ is the error signal which is the difference between the reference signal r(t) and the system output $y(t)$. K_p, K_i and K_d are the proportional gain, the integral gain and the derivative gain respectively, like Loukianov et al., (2009), Rozali et al., (2010) and Minav et al., (2010):

$$U(t) = K_p^* e(t) + K_i^* \int_0^t e(t)dt + K_d \frac{de(t)}{dt}$$

K_p, K_i and K_d are these parameters that have to be tuned and were experimentally defined at first. Proper modelling of the system to be controlled is a defining step in the design of the controller. The environment chosen to create the system model, which consists of a hydraulic and a mechanical part as well as the controller, is Matlab / Simulink using Sim Hydraulics. Most of industrial processes implement a wide, non-linear setup PID controller algorithm turning, in several cases, the classic PID controller to be less effective even though its conventional algorithm offers simplicity, stability, easy adjustment and high reliability, as in Bahita et al., (2011) and Aly, (2012).

PLCs are modern programmable logical controllers that are nowadays extensively used in automation systems and in the global industry. This is a digital device that has a microprocessor and a programmable memory. It also has digital and analogue inputs and outputs, and controls an automated system through digital logic, Boolean logic, timing, numerical operations and enumeration. Key advantages of a PLC are:

- Versatility in initial circuit conversions
- Fast fault detection
- Adequacy of contacts, relays and timing
- Excellent operation in a difficult industrial environment
- Ability to connect to external units and control the system over long distances

PLCs are programmed in the Ladder, STL and FDB languages, which are languages close to the machine language and easily understood by all automation installers. Automatic control of

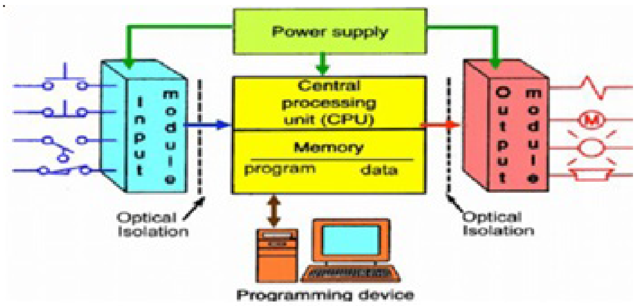

Figure 9: PLC Structure

a hydraulic system requires the design and construction of the hydraulic circuit, its connection to the PLC and PLC programming so that it leads the hydraulic circuit to the realization of the desired scenario. The function of the PLC is to receive signals at its inputs, to do the necessary processes required by the code, and to display the results at its outputs. Signals at its inputs are either analogue or digital type and come from components such as switches, pushbuttons, sensors and so on. For example, in order to control a double acting hydraulic piston, at least one input is required, the connection of the module to the PLC, the programming of PLC, the connection of the PLC outputs to a direction control valve for controlling the piston and the connection of the valve to the piston.

4 The LuGre friction model

Friction is perhaps the most important nonlinearity that is found in any mechanical system with moving parts. For the system considered in this research project, friction, which arises in the contacts of the piston with the cylinder walls as well as the linear slide-way and other minor rubbing elements, has a direct impact on the dynamics of the system in all regimes of operation. All classical friction models do not consider the presliding region; the system does not move as long as the applied force is smaller than the maximum static force so, in order accurately to design compensation, friction has to be identified in both the sliding and presliding regions. To construct a general friction model from physical first principles is simply not possible.

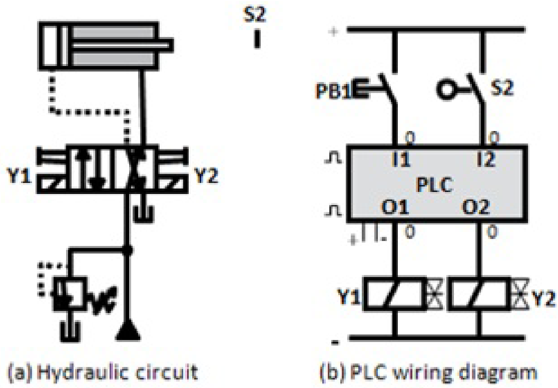

Figure 10: Hydraulic circuit and PLC diagram

What researchers look for instead is a general friction model for control applications, including friction phenomena observed in those systems. This task is by no means a simple one since no universal friction model exists, on the one hand, and the practical measurement of friction is not straightforward on the other. A good model structure for the identification of friction would ease the desired task. The LuGre model is a dynamic friction model introduced in De Wit et al., (1995). The same researchers developed extensive analysis of the model and its application two years later Olsson et al., (1998). The model is related to the bristle interpretation of friction. The deformation of the bristles is presented in the next layout: Friction is modelled as the

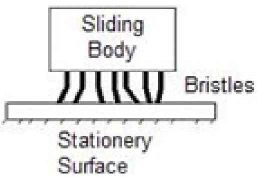

Figure 11: Bristle deformation of LuGre model

average deflection force of elastic springs. When a tangential force is applied the bristles will deflect like springs. If the deflection is sufficiently large the bristles start to slip. The velocity determines the average bristle deflection for a steady state motion. It is lower at low velocities, which implies that the steady state deflection decreases with increasing velocity. The LuGre friction model is illustrated in the following Fig.12. This models the phenomenon that the

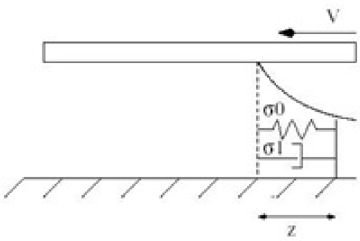

Figure 12: The LuGre friction model

surfaces are pushed apart by the lubricant, which is between the cylinder body and the piston rubber. The model is widely used in modern pneumatic research projects but not in hydraulics yet and it is considered the most appropriate for control tasks, like reference (Ganseman et al., 1997). The LuGre friction model has the general form:

$$F_f = s_0 z + s_1 \frac{dz}{dt} + s_2 v$$

Where z is friction internal state that describes the average elastic deflection of the contact surfaces during the stiction phases, the parameter σ_0 is the stiffness coefficient of the microscopic deformations z of the bristles during the presliding displacement, σ_1 is a damping coefficient associated with dz/dt and σ_2 represents the viscous friction, whereas v is the current velocity of the piston. The dynamic of the internal state z is expressed by:

$$\frac{dz}{dt} = v - \frac{s_0\,|v|}{g(v)}z$$

Where $g(v)$ is a positive function that describes part of the steady state characteristics of the model for constant velocity motions and it is given by:

$$g(v) = Fst + (Fv - Fst)e^{-(v)^2}$$

Where F_s, F_v are the static and viscous friction. From the control point of view the simplest yet most effective approach to counteract the friction phenomenon appears to be the use of sliding mode control; in fact, one of the main characteristics of this control technique is its robustness against bounded uncertainties and disturbances. Friction is regarded as a bounded disturbance of unpredictable sign and therefore counteracted by choosing suitable control amplitude. The LuGre friction model turned out to be robust under the influence of all the parameters of the control methods applied to the simulation model.

In the aggregate and as a summary, the friction model will be designed and adopted in the integrated model that will be used for the simulation process that will follow this preliminary study. An overview of the simulation system can be seen in the following figure:

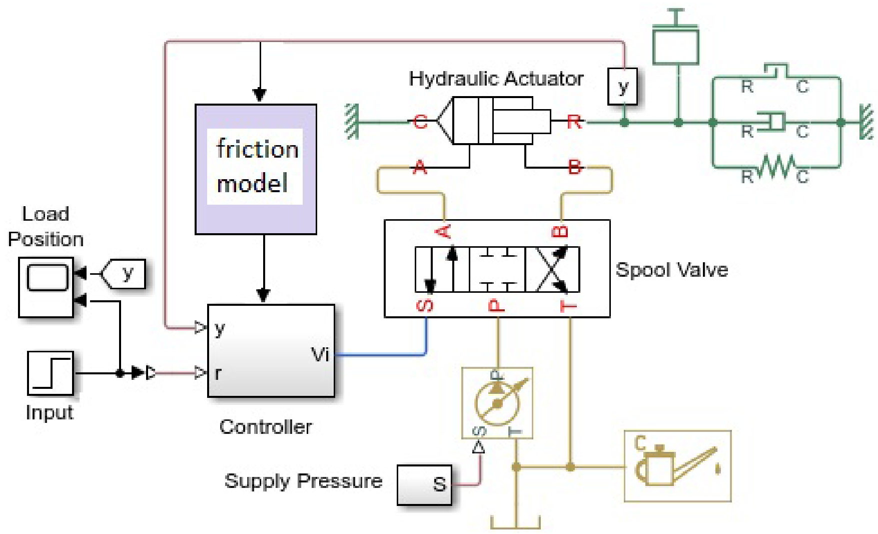

Figure 13: The LuGre friction model

5 Conclusions and further research

In this research work, the fundamental characteristics of use and the main advantages of hydraulic fluid power applications have been addressed. In terms of extensive force usage and 100% precision in position accuracy, hydraulics are the only way of solving problems not only in industrial environments but almost anywhere. Given the fact that they are mechanical systems with often impacts and wear, they occasionally develop unwanted situations that can negatively affect their performance, corrode the components, and even damage the environment outside the system. Possible damages to a hydraulic system could be fluid leakage, noise in the system, vibrations, overheating, hydraulic fluid pollution, cavitation's phenomenon and air in the fluid. To predict and cope with problematic situations, specific methods are made for each problem individually. Some of these are the temperature-tracking method for temperature monitoring, vibration monitoring method, auditory audit method and other specialized tools for maintenance of the systems.

In the close future, authors will present the simulation results of the system, which is a process that already is in progress. The specific friction model's dynamics will affect the system behavior in simulation in a beneficiary and unique way that cannot be found in bibliography up to day.

References

Aly, A.A. (2012). Model reference PID control of an electro-hydraulic drive. *International Journal of Intelligent Systems and Applications*, *4*(11), 24.

Bahita, M., Belarbi, K., Prakash, R., Anita, R., Jolevski, D., Bego, O., ... & Anderson, G. O. (2011). Fuzzy feedback linearization adaptive control for nonlinear systems via a NN-based approach. *International Review of Automatic Control*, *4*(2), 144-152.

Costopoulos, T.N. (1992). Hydraulic and Pneumatic Systems, Symeon Publishing Co, Athens, Greece.

De Wit, C.C., Olsson, H., Astrom, K.J. & Lischinsky, P. (1995). A new model for control of systems with friction. *IEEE Transactions on automatic control*, *40*(3), 419-425.

Ganseman, C., Swevers, J., Prajogo, T., Al-Bender, F. (1997). An integraded friction model with improved presliding behaviour. *IFAC Symposium on Robot Control*, France.

Kissell, T.E. (1990). *Modern industrial/electrical motor controls: operation, installation, and troubleshooting.* Prentice Hall.

Kissell, T. E. (1999). *Electricity, Fluid Power, and Mechanical Systems for Industrial Maintenance.* Prentice Hall.

Loukianov, A.G., Rivera, J., Orlov, Y.V. & Teraoka, E.Y.M. (2009). Robust trajectory tracking for an electrohydraulic actuator. *IEEE Transactions on Industrial Electronics*, *56*(9), 3523-3531.

Merritt, H., Merritt, H.E., & Merritt, H.E. (1967). Hydraulic control systems, John Wiley & Sons.

Minav, T.A., Laurila, L.I., & Pyrhönen, J. J. (2012). Self-Tuning-Parameter Fuzzy PID Speed Controller Performance in an Electro-Hydraulic Forklift with Different Rule Sets. *International Review of Automatic Control* (I.RE.A.CO.), 5(5).

Olsson, H., Åström, K.J., De Wit, C.C., Gäfvert, M. & Lischinsky, P. (1998). Friction models and friction compensation. *Eur. J. Control*, *4*(3), 176-195.

Pantazis, N. (2008). Automatic Control and Automation, Publisher Stamouli.

Pantazis, N. (2006). Hydraulic automatic control systems, Publisher ION.

Rozali, S.M., Rahmat, M.F., Wahab, N.A. & Ghazali, R. (2010, December). PID controller design for an industrial hydraulic actuator with servo system. *In Research and Development (SCOReD), 2010 IEEE Student Conference on* (pp. 218-223). IEEE.

Stavros, R. (2010). Automation programmable controllers, Publisher Simeon.