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# CONSIDERATIONS ABOUT DIGITAL PID CONTROL OF ELECTRO-HYDRAULICS EQUIPMENT

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***Abstract:*** *Classic hydraulic systems offer a sum of advantages such as robustness and easy adaptability to some variations of the working environment, being capable of realizing high force and torque values at relatively low costs of implementation and maintenance. The global evolution of electronics and informatics fields had influenced positively hydraulic researches on developing new types of equipment, tending to facilitate an easy integration with digital controllers of computer controlled systems. It has been imposed the concept of intelligent hydraulic equipment, which include in their structure digital electronic modules (with self-diagnosis, auto-adjustment and bus communication features) and specific transducers. These improvements had a positive effect on the dynamic characteristics of electro-hydraulic equipment, some of them being known in technical literature as intelligent electro-hydraulic equipment.*

Keywords: electro-hydraulics, digital PID, driving systems

## 1. Introduction

Electro-hydraulic systems are widely used nowadays, being the most suitable solution for power transmission over a certain distance, control and flexibility because of the technological developments in high precision industrial systems such as robotics, multi-axis control and 3D positioning applications. Classical approaches to a certain problem are still used in industry, but there are some applications that need digital electronics control along with IT solutions. Mainly, the architecture of electro-hydraulic driving systems include software components and IT technologies, digital and analog electronic modules and, of course, the electro-hydraulic equipment themselves. This kind of approach facilitates the measurement and acquisition of system's working parameters, trying to correlate the output control signal with program reference signal and environmental factors (such as temperature, vibrations, perturbations and so on) thus obtaining a low error and high positioning accuracy. Also, the flexibility of the electro-hydraulic drive is one important factor because the control system itself can adapt to new requirements not needing, in most cases, a hardware reconfiguration – which is expensive.

## 2. Why choosing electro-hydraulic systems

Choosing the best drive system for an industrial application is not an easy task - the system's engineer must take into consideration various technical, functional, environmental or reliability criteria [1]. Basically, hydraulic drives can be classified into two major categories: hydrostatic and hydrodynamic power systems.

Hydrodynamic systems' functioning is based on increasing the kinetic energy of the working fluid, usually mineral oil, having a high power-weight ratio, improved controllability but there are mostly limited to rotary motion.
Hydrostatic systems transmit power by increasing the pressure of the working fluid, being the most used type of drive system in industry, aviation equipment or heavy machinery control. Main benefits of hydrostatic drive systems are protection against overloading, energy storage capabilities (accumulators), high power/weight ratio, increased stiffness of cylinders and lubrication through working fluid.
The need for accurate positioning systems based on electronics and hydraulics equipment/modules, leaded to the establishment of electro-hydraulics field using proportional and servo devices. These kinds of systems put together the advantages of hydraulic drive systems and electronic modules: accuracy, precision, controllability, high power/weight ratio and stiffness. Mainly, electro-hydraulic equipment is dived into: digital valves, servovalves, proportional valves and ON/OFF valves. Electro-hydraulic equipment has high static and dynamic performances, thus offering optimal solutions for certain industrial applications and sometimes being the only available solution for complex drive and control issues[5]. Current trends in improvement of electro-hydraulic equipment imply continuous increasing of static and dynamic performances along with lowering manufacturing and running costs. These all can be realized by putting together various technical fields such as mechanics, electronics, control engineering and IT. Various manufacturers of electro-hydraulic equipment tend to offer fully integrated solutions made of transducers, controllers, displays and the electro-hydraulic equipment itself.

## 3. A few considerations on digital PID controllers

Electro-hydraulic drives can be regarded as mechanical transmission systems from a power source towards actuators, using a pressurized fluid as transmission mean, and can be classified into three major categories, as follows:

- electro-hydraulic control systems;
- command systems for external high power equipment;
- driving system, having the sole role to transmit mechanical energy without having control over the quantity and parameters of working fluid.

By including electro-hydraulic equipment into a drive, the system's engineer obtains high static and dynamic performances using only an electrical control current that ranges between 200…800 [mA] for proportional equipment and between -80…80 [mA] for servovalves[4]. Widespread of computer technologies and digital electronic control systems along with high-integration of electronic components, allowed the manufacturers to develop new types of electronic modules that can be included into the structure of electro-hydraulic equipment.
PID (Proportional-Integrative-Derivative) control algorithm [2,3] has the following analog mathematical expression:

$$p(t) = \overline{p} + K_c\left[e(t) + \frac{1}{\tau_I}\int_0^t e(t')dt' + \tau_D\frac{de(t)}{dt}\right] \qquad (1)$$

Using the finite difference approximations on the PID equation given above (1), we will obtain the digital equivalent:

$$\int_0^t e(t')dt' \approx \sum_{k-1}^{n} e_k \Delta t \qquad (2)$$

$$\frac{de}{dt} \approx \frac{e_n - e_{n-1}}{\Delta t} \qquad (3)$$

The equations given above in (2) and (3) can be used for obtaining the positioning form of digital PID control by substituting equations (2) and (3) into equation (1), thus obtaining:

$$p_n = \bar{p} + K_c\left[e_n + \frac{\Delta t}{\tau_I}\sum_{k=1}^{n} e_k + \frac{\tau_D}{\Delta t}(e_n - e_{n-1})\right] \quad (4)$$

Next, equation (4) can be written as Z-transform and let $p_n'$ be defined as deviation variable (5).

$$p_n' = p_n - \bar{p} \quad (5)$$

The Z-transform translation theorem:

$$Z(e_n) = E(z) \quad (6)$$

$$Z(e_{n-1}) = z^{-1}E(z) \quad (7)$$

$$Z(e_1) = z^{-n+1}E(z) \quad (8)$$

Considering the above, the Z-transform of equation (4) is written as:

$$P'(z) = K_c\left[E(z) + \frac{\Delta t}{\tau_I}(z^{-n+1} + z^{-n+2} + \cdots + z^{-1} + 1)E(z) + \frac{\tau_D}{\Delta t}(1 - z^{-1})E(z)\right] \quad (9)$$

Equation (9) can be simplified because the integral term given for large values of n approaches a limit of $\frac{1}{(1-z^{-1})}$ and therefore the equation (9) can be written as:

$$P'(z) = K_c\left[1 + \frac{\Delta t}{\tau_I}\left(\frac{1}{1-z^{-1}}\right) + \frac{\tau_D}{\Delta t}(1 - z^{-1})\right]E(z) \quad (10)$$

Considering the above, digital PID transfer function is given by equation (11), also referred as the positional form al the digital PID algorithm because it gives directly the output of the controller:

$$D(z) = \frac{P'(z)}{E(z)} = K_c\left[1 + \frac{\Delta t}{\tau_I}\left(\frac{1}{1-z^{-1}}\right) + \frac{\tau_D}{\Delta t}(1 - z^{-1})\right] \quad (11)$$

The digital PID algorithm can be implemented on 8-bit and 16-bit microcontrollers because of its reduced number of operations per every sample of one acquired signal and low RAM requirements for storing variables.

## 4. Open loop vs. closed loop

Electro-hydraulic drive systems allow control of mechanical parameters such as speed or force through hydraulic parameters: pressure and flow. Mainly, the operator must define a setpoint for each interest parameter and depending of the type of control selected – open or closed loop – the digital controller will correct the errors [6]. When choosing open loop (Figure 1) the interest parameter has a start value that can be modified manually by the operator if there are signaled errors, during the functioning or stationary phases of the electro-hydraulic system. When dealing with open loop systems the operator must have solid previous experience or good calculus methodology for determining the necessary value of the command current in order to obtain certain hydraulic parameters.

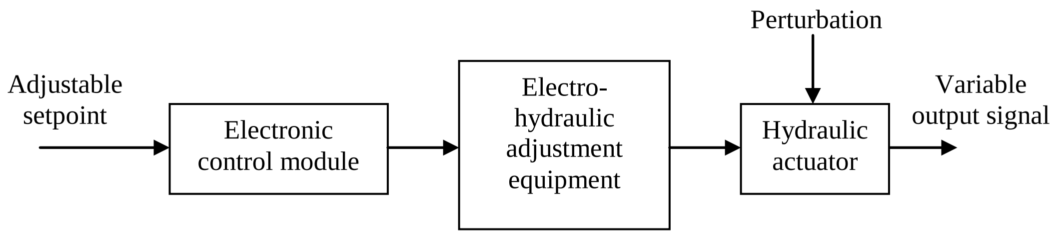


Figure 1 – Open loop electro-hydraulic system (example)

Closed loop control (Figure 2) represents a system where the interest parameter is measured permanently by using a transducer and automatically adjusted by the electronic controller in order to equal the output and setpoint signals. The transducer's signal is usually called feedback, allowing permanent automatic adjustment of the output signal in order to obtain prescribed hydraulic parameters.
Main elements of modernization were made combining electronic digital modules and hydraulics, allowing varying mechanical parameters such as speed, force or torque through electronic control of hydraulic parameters in the electro-hydraulic system. Hydraulic control through electronic modules has changed ON/OFF electro-hydraulic valves into proportional and servo equipment. Furthermore, by combining hydraulics, electronics, sensors and informatics it was obtained new and more accurate driving systems based on mechatronics concepts.

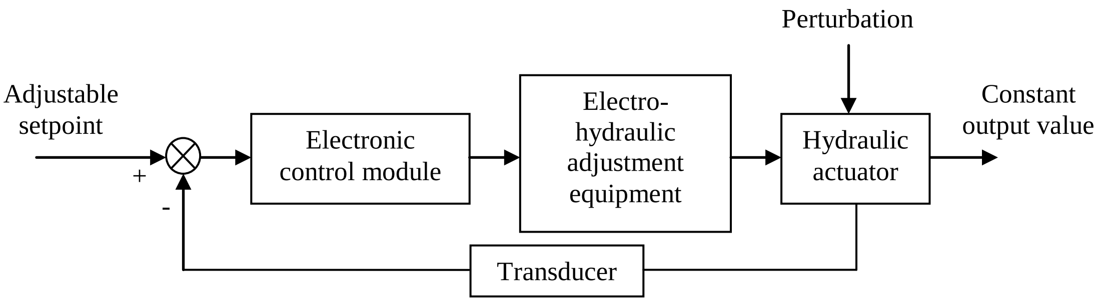


Figure 2 – Closed loop electro-hydraulic system (example)

Main components of any closed loop hydraulic control system are the electronic controller and electro-hydraulic adjustment equipments that have improved over time having two structural and functional directions: servo and proportional equipment. In servos the electro-mechanic convertor is generally a torque motor, capable to work at relatively high frequency. In proportional equipment, the electro-mechanic convertor is a proportional electromagnet capable to work at medium frequencies. These differences in functional performances have an influence on purchase and maintenance costs.
Usually, automated electro-hydraulic control systems are based on translation unit architecture using an electric signal as command input. Their controller uses the difference –usually called error - between the setpoint and feedback signals, the structure being represented by a block diagram resulted from a set of differential equations or from the transfer function equation (when it is needed to perform the transient and stationary analysis of the output signal for small variations of the setpoint).

## 5. Conclusions

Digital control of electro-hydraulic equipment is considered to be a complex technical field, which involves mechanics, hydraulics, electronics and informatics. When choosing a digital control system for a specific industrial application, system's engineer must analyze thoroughly existing solutions and define correctly interest parameters and their way of variation and must take into consideration practical aspects along with manufacturing and maintenance costs.
Digital electronics and informatics technologies combined simplify implementation and reconfiguration of industrial electro-hydraulic systems, by using specific sensors and transducers, data acquisition boards, virtual instrumentation and so on.
Future developments on digital electro-hydraulic field include an even more miniaturization of equipments, due to advanced researches on materials and electronics fields (such as using high integration SMD components).

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