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A STUDY OF HYDRAULIC ACTUATOR CONTROL METHODS IN SIMULATION

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Abstract— In this paper we deal with the issue of controlling the position of a hydraulic piston, with the help of Matlab and Simulink in particular, where we designed the system to be tested. We want to check the position of the piston with a PID controller or its combinations (Plain P or PI). In the first chapter there is a historical retrograde to the automatic systems from antiquity and slowly, we come in later times, going through the industrial revolution and reaching today with the evolution of automation in general being soaring. Moving to the second chapter refers to hydraulic systems, hydraulic engineering and hydromechanics with definitions and reports of early tests of hydraulics in Greece-Persia and Rome. We continue to refer to hydraulic systems with advantages and disadvantages but also with examples of their application, such as excavators, loaders, elevators, etc. At the end of this chapter, the system of work is given along with some typical hydraulic components. In the third and final chapter of the work, tests are carried out to find the best controller (P-PI-PID) based on system characteristics and comparison of results for each control method, in order to better control the piston.

Keywords— PID controller, hydraulic actuator, position accuracy

I. CHAPTER I

[1] A brief historical review of the automated control systems: At first, it starts from the ancient years when man was occupied with automatic systems and in general with automation. There are many references to people who have made machines capable of moving on their own or even more complicated, that could even make calculations of hours, days and months with the most well-known of them, to be the Antikythera mechanism. This machine is a complicated mechanism, made of copper, located within a wooden frame. It was discovered in 1900 AD. where it was found by locals in a wreck near Antikythera, along with other historical finds. The Antikythera mechanism is considered one of the first computing systems. It is a clock mechanism with dozens of precision gears, revolving around many axes, like mechanical

watches. It is claimed to have been an analog computer, designed to calculate the motions of the planets. It is estimated that it was built around 87 BC. by Geminus an astronomer of that time. The archaeologists who studied the mechanism noticed that one of its stone blocks had a built-in rack. Thus, it is considered the oldest saved gear with gears. Our reference in Ancient Greece stops at Heron, who studies the properties of liquids and gases and devises the precursor of the steam engine. Heron exploited the capacity of expanding the heated air to build temple gates that open and close automatically. The temple was constructed so that once the fire is lit on an altar at its entrance, the door of the temple will open automatically and once the fire is turned off. When the fire is lit on the altar, the heated air expands to the container beneath it, presses the water in a leaky and stable container below and transports it to a movable container, connected by pulleys and counterweights to the gates of the temple. Heron, being an engineer and geometer of the time, constructed several "automatic machines" such as a self-propelled tricycle, an automatic rotating statue, and a fountain operated with compressed air.

Continued, in the following years, specifically in the Byzantium-Medieval-Renaissance. The tradition that had been created by Greece was preserved in Byzantium, with the well-known hydraulic watch of Ktissios, with Hercules striking the hours with his bat, while well known as well was the golden throne of Emperor Theophilus, which was based on mechanical lions who were roaming. At the same time, Heron's works were translated into Arabic and spread to the Indies. Here it is good to mention the significant contribution of the Arabs who perfected the rafts of the ancient Greeks in the Middle Ages. Since the 8th century, the pioneers in the design of advanced technology machines, have been made by the Arabs who created automatic systems of all kinds such as hydraulic watches, mechanical birds, and even models of anthropomorphic machines. Between the 15th and 16th centuries, Leonardo da Vinci's series came to the fore, and he made a whole series of inventions, some of which are listed below.



Self-propelled carriage:

Da Vinci designed a self-propelled carriage that moved without the need for human intervention. This inventor's feat was considered by many to be the first robot in the world. The carriage was powered by the power of rolled-on springs, with both navigation and brakes. When the brake was released the carriage started and through a programmed rudder proceeded either straight or to predetermined corners.

Flying Machines:

For much of his life, Leonardo has dealt with the phenomenon of flying, making many studies on bird flight. He also made a raft for several flying machines, such as a bird's eye and a propeller. Some of his rafts, such as parachutes, were interpreted, constructed and tested years later, some of them successfully, while others had no practical application.

Beyond Da Vinci was James Watt. James Watt was a Scottish engineer and inventor and was named, "father of the steam engine". From an early age he was interested in mathematics and engineering. He was named "father of the steam engine" for the way he used steam to heat the cylinder, and for the invention of a steam engine that could be used in several applications. He also built a pressure screw as well as mercury manometers. With his inventions, he led the world a step closer to the Industrial Revolution.

[2] Continuing the historical retrospection and we are going to the Industrial Revolution. The Industrial Revolution is a historical period during which rapid changes in the arts, economy, culture and society in general, which led to the industrialization of society in Great Britain during the years 1760 – 1860.

There was also a great deal of influence from France and the US, in proportion to the operation and development of both the economy and the structure of society.

Typical robot applications in the industry include product loading- unloading, dyeing, etc. The greatest achievements of the industrial revolution are the invention of the steam engine and the railroad in Great Britain. The first train started operating in 1830 in Great Britain, and in the following years a railway network was built in Great Britain and France. Essentially, the railroad has revolutionized transport.

Thanks to the Industrial Revolution, devices have also begun to optimize energy production. For the steam engine, the regulator was built, in which when a load was applied and slowed it down, it caused an increase in steam supply to the engine, and on the contrary, when the load was reduced, it restricted it.

With the internal combustion engine of the 19th century, the innovation of recycling was introduced, in the form of pistons that took their initial position after each cycle of work.

In the late 19th and early 20th centuries there was a large increase in the number of motorized devices in industrial processes. These machines initially required a human presence, for the processing of objects and machine operation, later on, only in the processing of objects, and later, in the

middle of the 20th century, they did not even require the presence of man.

We end this chapter with the Post-industrial Society:

Reaching today, a characteristic of the industrial society is the entry of the machine into production. A central feature of post-industrial society is the use of computers and new technologies (automation, robotics, satellites) in production and services.

New-technologies (sophisticated computers, robotics, telecommunication satellites) are the achievements of post-industrial society. Below are some examples of modern technology.

Big Dog:

Big Dog is a robot designed by Boston Dynamics for the US Army, which can carry amunitions to soldiers in inaccessible areas where army trucks and cars cannot go. It has a height of 76cm, length 91cm, weighs 110kg and can carry weight of 150kg.

Artificial Leather:

Researchers at Berkeley and Stanford have managed to create an "e-skin" an electronic recyclable skin that can allow robots to use their hands as if they were human. This artificial skin can feel the smoothest touch. E-skin is made of flexible semiconductor materials that allow it to fold and contact curved surfaces, such as fingers, but it is not as elastic as human skin. Finally, what makes the skin remarkable is that it can heal itself by a strip that resembles a bandage in which chemical reactions occur between the compounds that make up it. In the future, this technology will find multiple applications, such as robot care (body temperature measurement, for example)

II. CHAPTER II

History of Hydraulic Systems: Since ancient times man has been troubled, but he has also been involved in hydraulic engineering. Early uses of water abstraction date back to Mesopotamia and ancient Egypt, where irrigation began in the 6th millennium BC. where watches from the early 2 nd millennium BC were used. Other early examples of water supply include the Qanat system in ancient Persia and the Turpan water system in ancient Central Asia.

The Greeks have developed sophisticated water and hydraulic power systems. An example is the construction by Eupalinos of a watering channel in Samos. Heron describes a series of work machines using hydraulic power, such as the power pump, which is known from many Roman locations that has been used for pumping water and fire engines. In Ancient Rome, many different hydraulic applications have been developed, including public plumbing, innumerable aqueducts, watermill power and hydraulic extraction. The Romans were among the first to use the siphon to transport the water into the valleys and they used the method of mute, (gold



mining method using the water flow) on a large scale to search for and then export minerals.

Hydraulic and Hydro Mechanics:

Hydraulic is called the applied hydromechanics. It is a technical science with the main object of exploiting fluids. Whilst hydro-mechanics (hydrostatic and hydrodynamic) deals with properties, laws governing fluids in general and water in particular, "on calm" and "on the move", hydraulics deal with ways of restraining, exploiting the water.

Hydraulics is the technology (and applied science) that uses engineering, chemistry and other sciences relating to mechanical properties and the use of liquids. Fluid mechanics provides the theoretical basis for the hydraulic system, which focuses on engineering using the properties of liquids. In liquid power applications, the hydraulic system is used to produce, control and transmit power using pressurized liquids.

Hydraulic systems:

By the term hydraulic systems, we mean power transmission systems consisting of pumps, piping, valves and hydraulic motors, rotary or reciprocating, which are used to create momentum or power. [3]

Hydraulic automation systems make use of hydraulic fluids to convey motion and power. Although they have the potential to develop large forces, they often have slow reactions. These systems are found in almost any system that needs powerful forces to be transmitted. In the industry, hydraulic systems typically come together as subsystems of other mixed-type automation systems that undertake the movement and transmission of forces.

The main units of each hydraulic system are: a) The hydraulic power supply unit. Includes oil tank, pump and electric motor for moving.

(b) Flow and pressure control valves; and (c) Linear or rotary actuators to convert hydraulic power to a payload.

Here it is good to mention the advantages and disadvantages of hydraulic systems.

Advantages: [4]

1. Hydraulic engines have a smaller volume and mass than electric motors.
2. It is quite stiff to stabilize the load with low energy consumption.
3. They have a fairly high reaction rate which is caused by high stiffness and small masses. Due to this, many times in some applications the use of a hydraulic system is exclusive.
4. They have mechanisms that are resistant to humidity and generally to corrosive environment, good water tightness to deal with high oil pressure inside the mechanisms.
5. They have the ability to easily change the speed of a shaft.
6. Finally, they can change the useful torque or force as desired by changing the operating pressure of the system. This maximum pressure is limited by safety valves.

A key advantage of the hydraulic systems is certainly the good power-to-weight ratio that makes them insurmountable in

high-load applications or applications requiring high accelerations.

Disadvantages: [4]

1. There is a risk of leakage of fluids which may create a dirty environment around the system.
2. They are sensitive to the contamination of the hydraulic fluid, particles or other fluid that may enter it. This is a major drawback whenever these systems require great cleanliness both in installation and maintenance.
3. Because of high stored energy, there is always a risk of system failure.
4. Their significant disadvantage is their high cost.

Applications of Hydraulic Systems:

The applications of the hydraulic systems are several and are summarized below in five main categories.

Industry:

Hydraulic systems are widely used in the industry through plastics processing, steel and primary metal mining applications, automated production lines, machine tools, paper industry, loaders, hydraulic crushers, textile machinery and, of course, robotic systems.

Kinematic Hydraulic:

Hydraulic systems are widely used in heavy-duty machine tools such as tractors, irrigation systems, earthmoving machines, material handling equipment (Clarks, Loaders), commercial vehicles, drills for tunnels, railway equipment, construction machinery (Excavators), drilling rings and finally lift systems.

Cars:

Hydraulics are also used in cars in the brake system, shock absorbers and the steering system.

Marine applications:

In marine applications, it covers mostly all ships, fishing vessels and naval equipment. For example, all seagoing vessels have a water purification system and a fishing hydraulic system for automatic nets.

Aerospace equipment:

Airplanes have equipment and hydraulic systems used to control the rudder, landing system, brakes and flight control. The same systems are also used in missiles and spacecraft.

Purpose Of Hydraulic Control:

A hydraulic system is a power transmission control system based on the use of a liquid. It converts a main engine's mechanical energy into fluid energy, controls energy in a fluid configuration, and converts it into a mechanical job at the selected position. As the fluid energy is transmitted and controlled, the power can be controlled by hydraulic valves driven by low electrical power and low hydraulic power. When connected to a computer, the power transmission system offers several desirable features such as high output power, continuous and precise control, high speed response etc.

Typical Hydraulic Phenomenon: [5]

The hydraulic press is a hydraulic mechanism that allows the application of a high lifting or compression force created by the British engineer Joseph Bramah. The hydraulic press is the most common type of press nowadays.

The way a hydraulic press works is related to the Pascal principle. The pressure, at all points, of a closed system is transmitted evenly. Regardless of the final design of a hydraulic press, the basic pattern is common: two pipes of different diameter (A1 and A2) are connected through a tank containing a fluid (eg. water, oil or gas). In each of the 2 tubes a piston is applied.

According to the Pascal principle, the pressure applied to the first piston is transmitted to the second piston. That is: $P_1 = P_2$ (1)

But the pressure is the quotient of the force applied (F), on a surface, for the area (A) of that surface: $P=F/A$ (2)

Therefore, the force exerted on the second piston (F2) will depend on the relationship between the two areas A1 and A2:

$$F_2 = F_1 \cdot A_2 / A_1 \quad (3)$$

For example, if $A_2 = 10 \times A_1$ then

$F_2 = 10 \times F_1$ therefore the second piston will receive 10 times the force of the first.

$$F_2 = F_1 (A_2 / A_1)$$

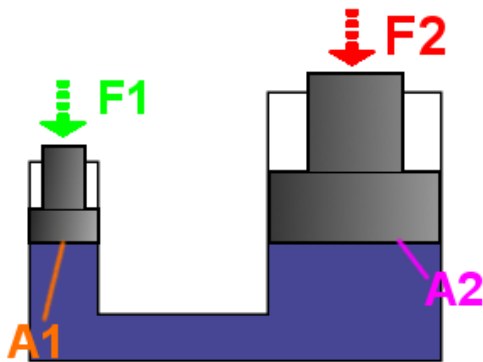


Fig. 1. Hydraulic press operation principle

https://upload.wikimedia.org/wikipedia/commons/7/7d/Hydraulic_Force%20C_language_neutral.png

It is therefore understandable that with the help of the hydraulic system we can perform tasks that would otherwise be impossible, such as the easy and safe lifting of a car.

III. CHAPTER III

Description Of The System:

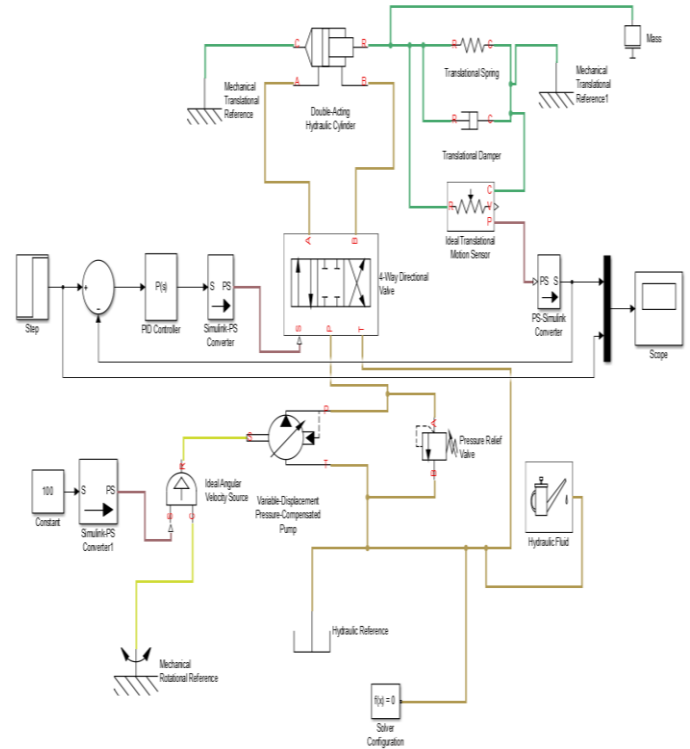


Fig 2. Simulink System for actuation control

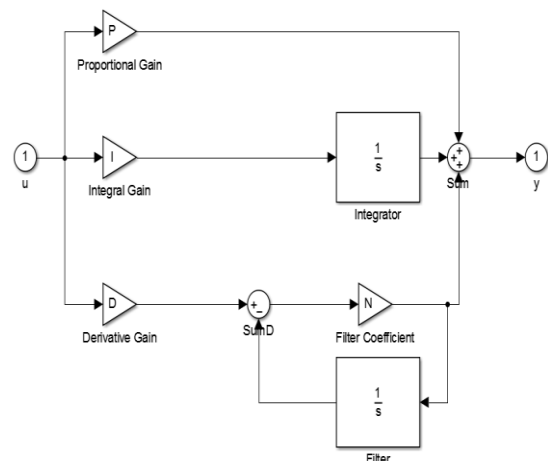


Fig 3. Analyzed PID Controller in Simulink

The controller which is used, is the PID (but also simple P and PI) and analyzed in Simulink has the above form. The control of the hydraulic actuator is based on this controller.

Step system specifications and response in the time domain:

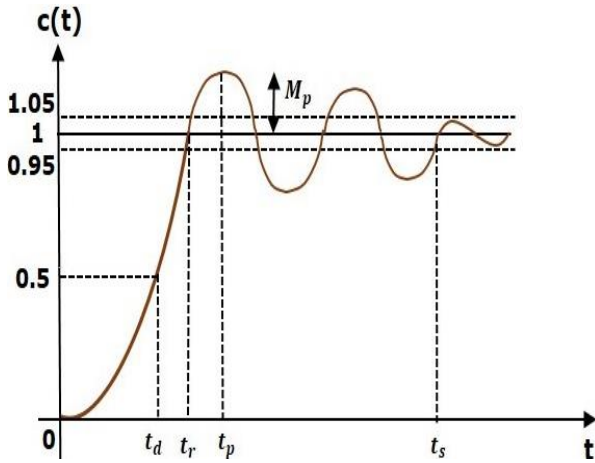


Fig 4.

The transitional response of an automated control system is important since it is desirable that the measure and its duration to be within tolerable limits.

Lifting time T_d : Lifting time is defined as the time required for the unitary step response to rise to 50% of its final value.

Rise Time T_r : The rise time is defined as the time required for the unitary step response to rise from 0% to 100% of its final value.

Maximum time T_p : Maximum time is the time required to have the maximum increment of the unitary step response.

Rehabilitation time T_s : Rehabilitation time is defined as the amount of time required for the system output to "calm" around a value, which varies by a certain amount of "d" in relation to the width of the input signal. A usual acceptable value for "d" is of the order of 5%.

Maximum overdraft M_p : Is the maximum value of the step response.

The controller P:

For input 0.5 and controller $P = 0.05$ we get the following response.

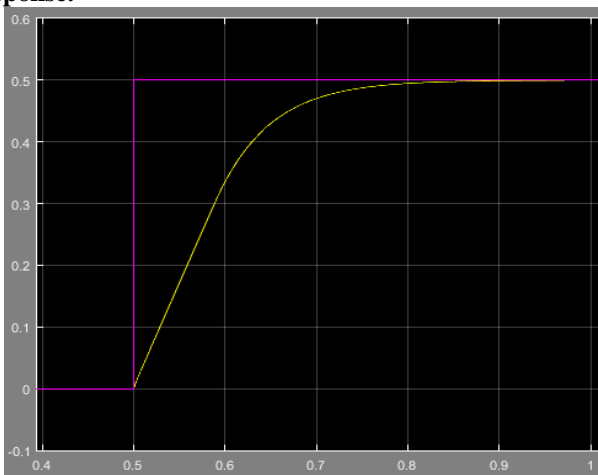


Fig 5.

Here the response is "smooth". Rise time is only 0.8sec There is no overdraft and the permanent error is zero. This response is quite good and acceptable for the control of the system.

For input 1 and controller $P = 0.02$.

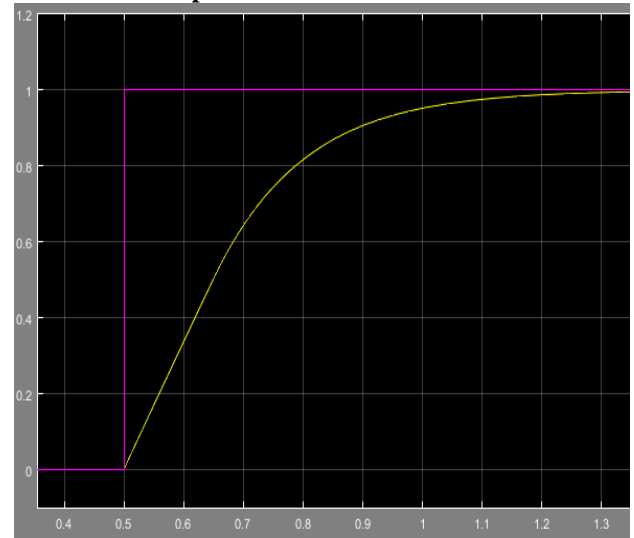


Fig 6.

Now, by changing the input to 1 and reducing the controller's price a bit, the system has the above response. We see that the rise time has increased to 1.2sec. There is no overdraft and the permanent error is zero as well. A general observation for the P controller is that we have only slightly better responses when our input is 0.5.

The PI controller:

For input 0.5 and controller $P = 0.01, I = 0.09$.

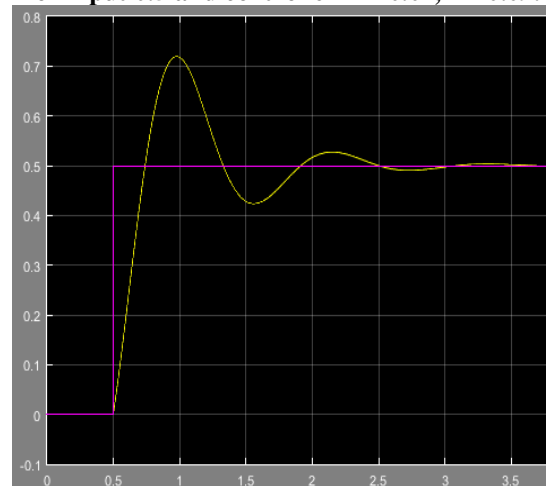


Fig 7.

Here the integral term has been introduced to create the PI controller.

It is immediately perceived that this response is worse than the previous ones, with the P controller. There is an elevation above the final value (0.5) of the order of 0.23. Then the system swings for 2.5 seconds (from the end of the highest value of the output) until it reaches (at 3.5sec) at rest but with a small permanent error. The response, although is not so bad, is certainly not optimal. The system is fast enough that oscillations are not so many and the permanent error is small but it differs from the previous cases.

For input 0.5 and controller P= 0.01, I=0.01.



Fig 8.

Keeping always the P term constant, by reducing 'I' the system has almost only one oscillation, but it never balances to the desired value and has here, too, a small permanent error. The elevation was further reduced and rehabilitation time remained almost the same at 3.5sec. This is the best response the system can give, with this controller for input at 0.5.

For input 1 and controller P=0.01, I=0.001.

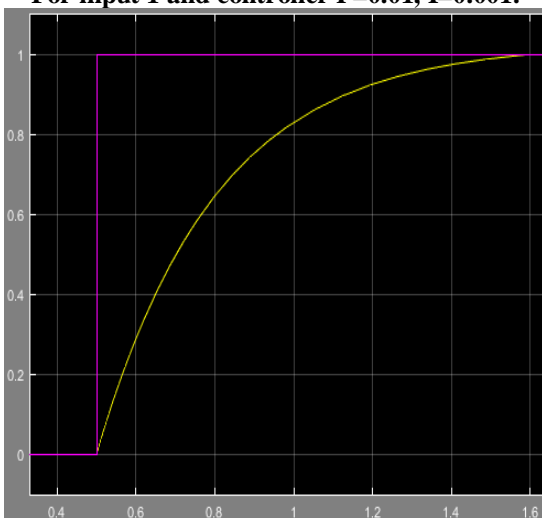


Fig 9.

By changing the input from 0.5 to 1 for the above values of the PI controller, the response initially seems to be very good,

but the term "I" has a very small value. The rise time is in 1.5sec and there is no overdraft. However, by enhancing our response to the point that joins the entrance (in 1.6sec) we get the following picture.

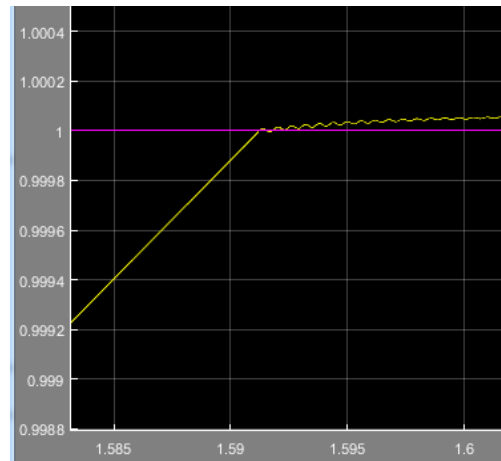


Fig 10.

It is obvious and although at first it did not seem, the system with these specs is not the best. There are several oscillations at the exit, so there is the 'noise' phenomenon, which is not allowed to exist in the system. Finally, there is a small, but a permanent error in the output, the output as it is overtakes the desired value.

Comparison of P and PI Controllers:

By comparing all the images from each controller (P and PI) it is obvious that for this construction (control of a hydraulic piston) the controller P is better. With this controller the system has better responses and remains stable without overdrafts, oscillations or permanent errors. It is good to mention the "problem" that the term I creates in our system. In a third-order non-linear system, the theoretical results that we expect, each term (P-I-D) to give us, are not working.

Results of the effects of each of the Kp, Ki and Kd controllers on a closed loop system:

The PID controller:

For input 0.5 and controller P = 0.09 I = 0.09 D = 0.009 we get the following response.

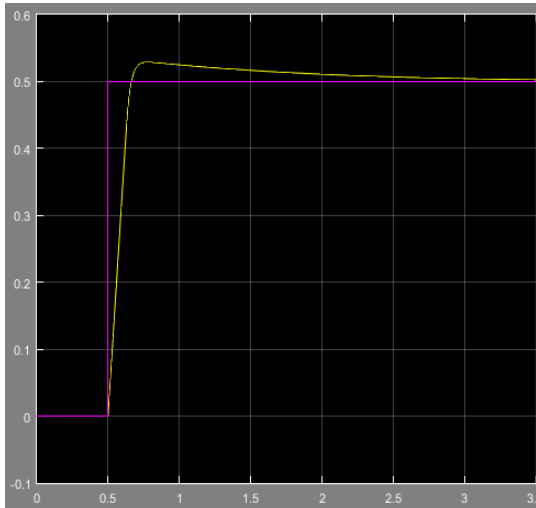


Fig 11.

Having introduced the derivative gain, we have the complete three-condition controller P-I-D. Seeing the response at the exit, there is a slight elevation above the desired value, which tends to drop and catch a fixed value at about 3.5sec. But it is perceived here that the response has a permanent error in exit. Also the response is somewhat "steep" and it must be as smooth as possible. It is worth mentioning here that the rise time has been significantly reduced in relation to the tests done with the other controllers and has reached 0.6sec.

For input 0.5 and controller $P = 0.01$ $I = 0.005$ $D = 0.001$ we get the following response.



Fig 12.

Changing only the term "I" it is observed a slight shift of the exit to the right. Rise time went up to 1.2sec, the overdrift has decreased a little and there was a greater distance from the exit and the entrance to the permanent error.

For input 1 and controller $P = 0.05$

$I = 0.002$ $D = 0.002$ we get the following response.

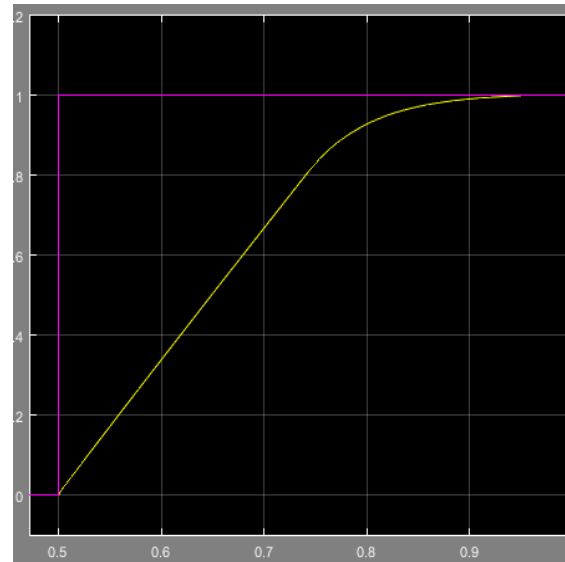


Fig 13.

By changing the step's input to 1 the system gives the above response. Initially it looks pretty good, it just seems to have a problem with, because, initially, the output is not so "smooth". The rise time is small enough at 0.9sec without oscillations and the curve reaches the desired value round at 0.95sec time fast enough. But that response has a slight permanent error, and that is not acceptable for our system.

Comparison of P-PI and PID Controllers:

By comparing the different control methods, first P, after PI and then PID, it becomes apparent that the best result, is given by the first case, where there is only the controller 'P'. The term 'I' is the one that disrupts the system and creates elevations, a small permanent error but also oscillations at the output of the system. The choice of the single term P is the best possible, for the proper operation of the system.

IV. ACKNOWLEDGMENTS

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