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Investigation and Enhancement Using Different Types of Pipelines for the Servo Hydraulic System with PID Controller Tuned Using Fuzzy Logic

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Abstract

This paper aims to investigate the effect of using different types of pipelines with the servo hydraulic system enhanced with PID controllers tuned by fuzzy logic. The mathematical models of several types of pipelines with different specifications (i.e. area variations in the pipe, disturbance source, etc.) are developed. The effect of the modified pipelines on the position control system at spool displacement is tested,since the servo hydraulic systems are difficult to control due to nonlinearity and complexity of their mathematical models. A PID controller tuned using fuzzy logic technique is used to improve the servo hydraulic system response.The results show that the mathematical models of the pipelines have a significant effect on the performance of the position control system at spool displacement according to the used pipeline type.Furthermore, a more desirable time response specifications and less steady state error are achieved after using the proposed controller.

Keywords: Servo Hydraulic System, Pipelines, PID controller and Fuzzy Logic Technique.

Introduction:

Many industrial plants are using servo hydraulic systems because they are able to achieve large forces and torques with high speeds. From several years ago, servo hydraulic systems have been commonly used in recent manufactures because of their strength, high power-to-weight ratio, reliability, precision, and controllability. They are oftentimes working in high-performance applications. These applications include the control of active suspension systems, power steering systems, material testing systems, earth-moving industries, load simulators, control of multi-axis robotic manipulators, pushing cheese production into large fiberglass trays, pack your bags for pack expo, and high-pressure hydraulic cylinders that provide muscle for pipe laying.

However, the rather complex structure of such drive systems makes it difficult to develop suitable, preferably low-order models of the dynamic of the plant. Because of its component nature, a number of nonlinearities have appeared with the hydraulic system; one such nonlinearity is the effect of pipeline types.

Different types of improving hydraulic systems, along with their nonlinearities,and useof automatic controller are cited in the literature. For example,M. Montanari, etal., 2004[1]analysed an actuated hydraulic clutch for commercial cars,also they presened a design ofa simplified system model forclosed-loop controller.Using the simulated model allows carrying out the performance directlyand avoiding expensive error design by fixing the system specifications before actual implementation.

M. A. M. Elbashir, 2007 [2],introduced the hydraulic transient for the different components using the graphical method and the method of characteristics to construct models (using the FORTRAN language) so as to calculate and simulate transients in a pipeline. The graphical solution was found to agree well with the computer solution.

Yousefi, et al [3], presented a promising unique evolutionary algorithms (the Differential Evolution (DE) algorithm) in order to handle the non-linear constraint functions as well as finding the best parameters for having a flexible load of the servo-hydraulic system.

T. M. Menshawy, et al. [4],built a model of the electrohydraulicsystem. It has been validated and used experimentally to investigate the performance of the system when working under several operating status, such as using different lengths of connecting hoses,after connecting hoses versus pump flow rate a hydraulic losses may be measured, while in the hydraulic cylinder chamber versus solenoid current, the developed transient pressure can be gauged. The resultant program was built with in Simulink program after taking the system’s elements mathematical modelling.

X. Jinghua et al., 2010 [5], modelled a beam of long straight pipe.After solving and analysing the pipe system effect using the sensitivity analysis method, the results showed that the most significant effective factor was that of the pipe system. The authors then built an optimised model of the system with the pipe system.

Yi Jiangang, et al., [6], proposed a control algorithm for digital PID controller with variable periods of the electric-hydraulic servo system position to be controlled. The results show the controller's ability to reduce the angle position time response, as well as reducing the system overshoot at the same time, meeting the requirements for the angle position control system.

Y. Efe [7] presented a manipulator robot model of a hydraulic servo system, accomplished by using a number of different methodologies.

Ayman A. Aly [8],developed and implementedthe self-tuning fuzzy PID controller in positioning fluctuation of an electrohydraulic servo system. The results showed that the self-tuning fuzzy PID control system can efficiently improve the dynamic characteristics.Several componentizes have conducted different research on pipelines. These researches provide an overview of a new pipeline hydraulics modelling capability that eliminates the need to employ separate third-party tools for pipeline hydraulics [9].

Zulfatman et al. [10], developed and improved the performance of the electro-hydraulic system usingthe self-tuning fuzzy PID controller, wherein the system performance has been improveas compared to classical PID controller.

This paper will focus on the pipelines' nonlinearity effect on the pressure transformation between the servo valve and the cylinder, considering the pressure transmission plays a very important role in the hydraulic system, such as the vehicle clutch performance.

It will be orderly in sections as below: Section 2 presents the open loop response ofa hydraulic system for different types of pipelines.An introduction and improvement using a PIDcontroller after tuning by the fuzzy logic technique will be discussed in Section 3.Finally section 4 describe the Conclusions.

1) Open loop servo-hydraulic system model

A hydraulic system is an arranging of interrelated components that uses a liquid under pressure to supply energy transmission and control.

The hydraulic systemis composed of six basic components: carrying the hydraulic oil with in a tank; forcing the oil with a certain flow rate by a pump through the system; controlling the oil direction, pressure, and flow rate with in the valves; transforming the pressure of the oil inside an actuator to mechanical force or torque to do a helpful work (theyare in the form of cylinders or motors); and a piping system, or transmission lines, which carry the oil from one location to another.

The servo hydraulic system modelling has been studied and improved in the earlier paper using the MATLAB\Simulink program [11]. In this study, the focus is on one of the neglected nonlinearities of the hydraulic system—the pipelining system type and its influence on the system which has a great effect according to the connecting of the pipeline as well as the pipe length and other problems, in this paper some of these will be shown and studied with in the system’s modelas illustrated in Figure 1.

The basic job of pipelines is to provide connection for pressure between the valve and the hydraulic cylinder. Since building cost is high as well as due to the safety factor and controllability, they are considered in the choosing of the suitable pipelines for any system according to their application compared to focusing on the production losses that may happen because of the incorrect system’s designs.

Transient operation—including changes in temperature, composition, and pressure inside oil and gas pipelines—is common, and must be taken into account. In addition, start-ups, shutdowns, and downstream production requirement changes to the steady-state conditions must be considered in a dynamic model.

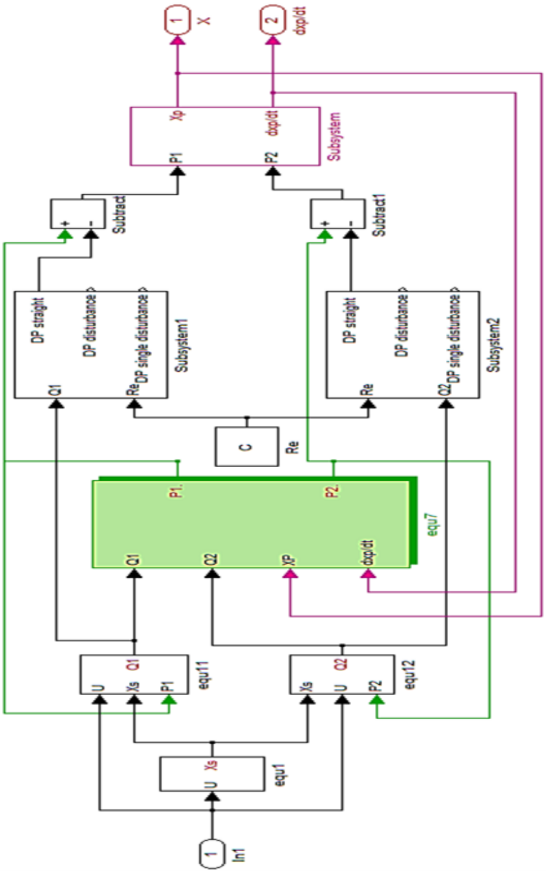


Figure 1: Modelling the servo hydraulic system with pipeline effect.

All of these requirements make pipeline hydraulics an extremely important step in field developmentplanning. Therefore, the accurate modelling of the pipeline and the connection between the pipelineand the equipment for midstream and upstream processing is fundamental in assuring optimised flow and production throughout the lifecycle of the field as well as safe operations of the entirenetwork. This model can be used to optimise new production, and revamp or add new assets to anexisting process [9].

In practice, it is set to evident losses in the pressure for all types of totally progressinginner flows (turbulent or laminar flows, smooth or rough surfaces, horizontal or inclined, circular or noncircularpipes) whether with fluids flowing in pipes, passages, ducts . . . etc.

Generally, the fluid flows in two types, laminar and turbulent flow, depending on important aspects of low Reynolds number flows. For instance, the most common form of pump, the heart, operates cyclically in the laminar to turbulent transition region, pumping a complex fluid with living cells and solids in suspension, whilst the flow of nutrients in plants occurs wholly in the laminar region [12].

A system loss factor can be define as the non-dimensional section in whole pressure between the extreme ends of two long straight pipes or passages as in equation (1) [12]. Laminar flow is linked by very viscous fluids or with lower velocities and smaller dimensions. We see that the turbulent flow is a flow thataltered static pressure and velocity distribution [12].

$$\Delta p_f = \begin{cases} \lambda \dfrac{l}{d}\dfrac{\rho v^2}{2} & at\ a\ striaght\ distance \\ \xi s\dfrac{\rho v^2}{2} & after\ a\ disturbance\ source \\ \xi\dfrac{\rho v^2}{2} & at\ a\ single\ disturbance\ source \end{cases} \quad \dots \ (1)$$

Where λ isthe loss coefficientat a straight distance, ζs is the loss coefficient after disturbances and ζ is the loss coefficient at a single disturbance source.

Assuming the hydraulic density ρ = 800 K kg/m and the flow velocity is constant throughout the pipes ($v = \frac{Q_1 + Q_2}{2}$) and d is the pipeline diameter, Figure 2 shows the input signal used for the servo hydraulic system, while Figure 3 shows the Simulink MATLAB representation for the types of pipelines suggested and used for the modelling in this paper with example for open loop response as follows:

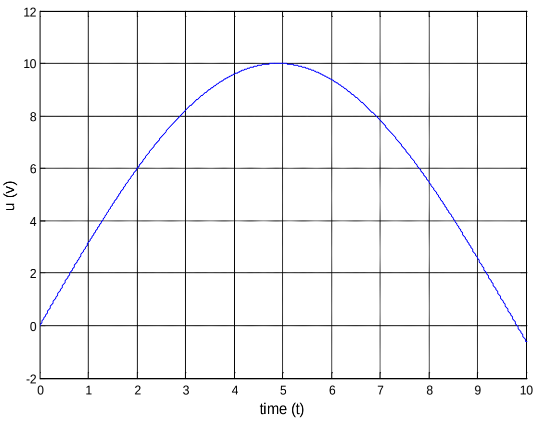


Figure 2 : The input voltage (u).

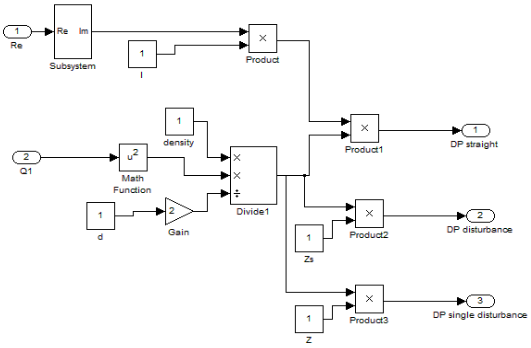


Figure 3 : Modelling of the suggested pipeline types.

1) At straight distance λ

Viscosity causes fluid particles immediately adjacent to rigid surface to be brought to rest. With increasing distance from a surface, fluid particles are less and less influenced by the surface, and so the velocity increases up to maximum, which is usually at the pipe or passage centre line. In pipes and passages, the flow is confident so that events in the boundary layer on one part of the perimeter are communicated indirectly to all flow.

The longpipe or passage before the component ensures a developed flow at inlet and the long pipe or passage at outlet from the component ensures that losses caused by the flow re-developed after the components are debited to the component.

Straight pipes and passages are considered first since they provide the inlet conditions for components as well as being of importance in their own right. Discussion of component flow starts with straight wall diffusers, which have single adverse pressure gradients. The friction gradients developed by the inlet and outlet are projected to the component and the difference between them is established. The loss coefficient, λ, is given by equation (2) [12].

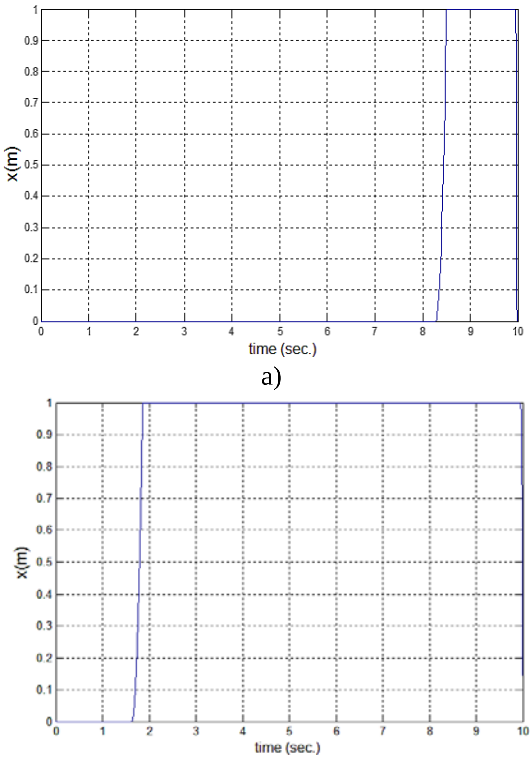
$$\lambda = \begin{cases} \frac{64}{Re} & Re < 2300 \\ & Laminar\ Flow \\ \frac{0.316}{\sqrt[4]{Re}} & 2300 < Re < 10^5 \\ Turbulent\ Flow\ in\ Smooth\ Pipes & \end{cases} \quad \dots (2)$$

where Re is Reynolds number.

It is convenient to nominate loss coefficients at a particular Reynolds number as being basic loss coefficients. To date, loss coefficients are only known over limited range of Reynolds numbers. Virtually, no data is available for loss coefficient above Reynolds number of 10^5 [12].

- **For laminar flow R_e = 2000(R_e< 2300)**

The first test example had the pipeline length L = 5 m and the pipeline diameter d = 0.5 and the Figure 4a illustrate the response of the system. Likewise, the second test example had the pipeline length L = 1 m and the pipeline diameter d = 0.85 and the Figure 4b. illustrate the response of the system.



a)

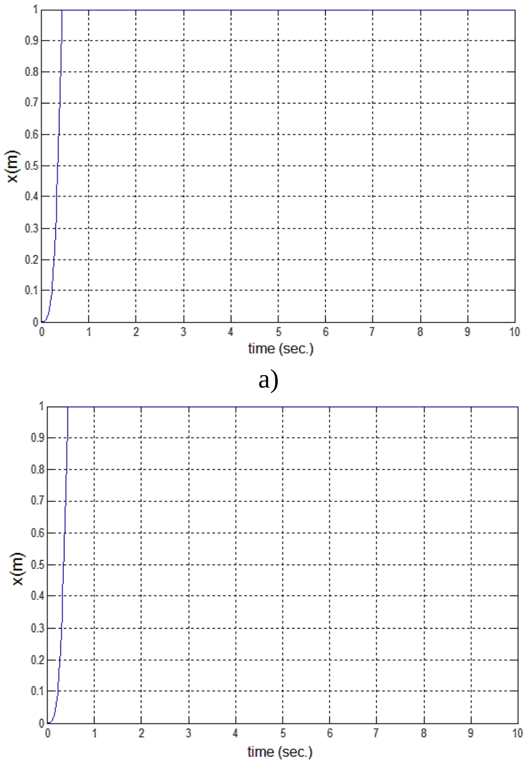
b)

Figure 4: Servo hydraulic system response with straight pipeline for laminar flowa) first example data b) second example data.

- **For turbulent flow R_e = 4000 (R_e> 2300)**

It was noted that turbulence generated locally did not immediately affect conditions across the whole cross-section, but as the flow proceeded downstream, the turbulence spread across the flow [12].

Accordingly, the first test example had the pipeline length L = 5 m and the pipeline diameter d = 0.5 and the Figure 5a. illustrate the response of the system. Similarly, the second test example had the pipeline length L = 1 m and the pipeline diameter d = 0.85 and the Figure 5b. illustrate the response of the system.



a)

b)

Figure 5: Servo hydraulic system response with straight pipeline for turbulent flow a) first example data b) second example data.

2. After disturbances ζ_s

- **For laminar flow R_e = 2000(R_e< 2300)**

It was noted that after a disturbance source, the laminar flow was completely developed after a distance and by tacking ξs ≈ 1.21, the system response is shown in Figure 6.

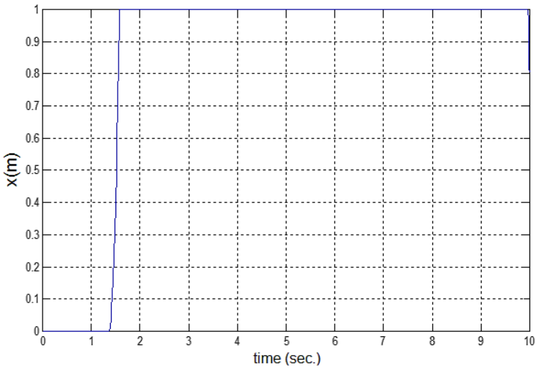


Figure 6: Servo hydraulic system response with pipeline of laminar flow after disturbances ζs.

- **For turbulent flow R_e = 4000 |(R_e> 2300)**

In particular, the turbulent flow was completely developed at a distance after a disturbance source and by tacking ξ_s = 0.09, the system response is shown in Figure 7.

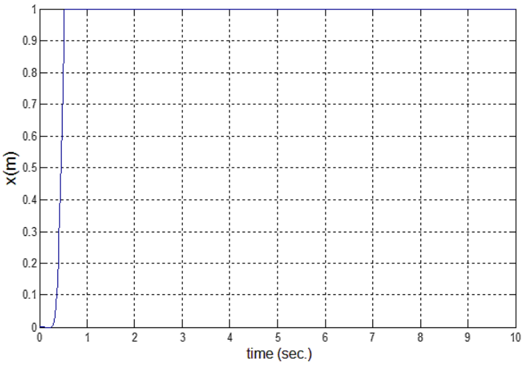


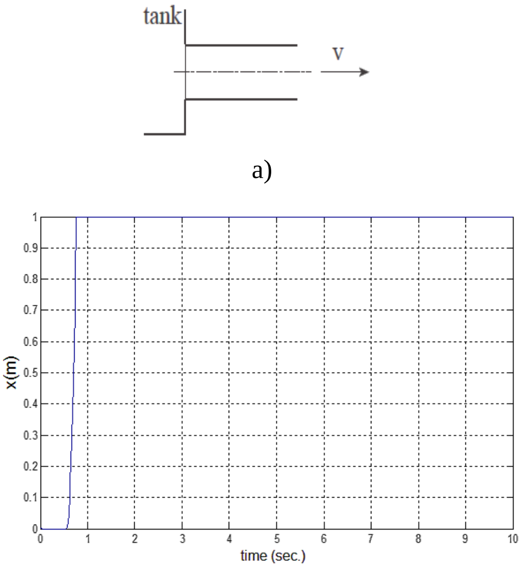
Figure 7: Servo hydraulic system response with pipeline of turbulent flow after disturbances ζs.

3. At a single disturbance source ζ

Specifically,the single disturbance source ζdepended on the pipe connections to reservoir:

3.1 Pipe connections to reservoir

Specifically, tacking ξ_s = 0.5, the system response is shown in Figure 8.



a)

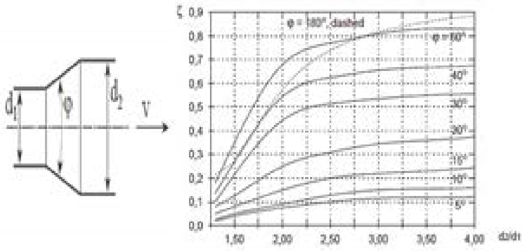
b)

Figure 8: a) Pipe connections to reservoir b)Servo hydraulic system response with the pipe connections to reservoir.

3.2 Area variations in the pipe having an:

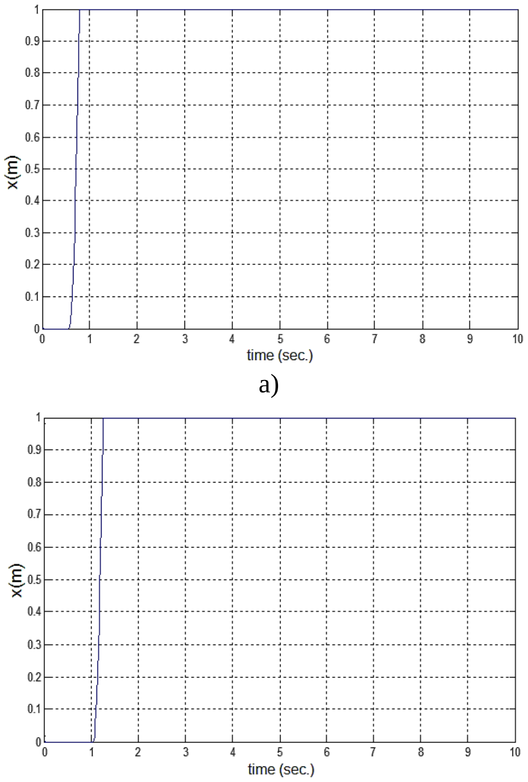
3.2.1 Increase of the accelerating area as shown in Figure 9.

Further assuming that the diameter of the pipe was increasing, where d1= 0.4 m, d2 = 1m, and with a specific angle as shown in Figure 9, the system response is shown in Figure 10a. Likewise, after assuming as example thatφ= 30, then ξ= 0.525; the response is shown in Figure 10b.Tacking further as example φ= 180, then ξ= 0.775.



a) b)

Figure 9: a) Increase of the accelerating area. b) The loss coefficient ☐ area relationship with the angle ☐ as parameter at increase of area.



a)

b)

Figure 10: The servo hydraulic system response with increase of the pipeline area a) first example data b) second example data.

3.2.2 Decrease of the area (diffusing)

Decrease of the area: The loss factor is described by $\boldsymbol{\zeta = \zeta_0 * \alpha}$, whereα was taken from Table (1) and ζ0 for different geometries was drawn from the previous section on Pipe Connections to Reservoir, as shown in Figure 11. Meanwhile, the uncompensated disturbance source factor ζs0 was taken from the section on Disturbance Source Factor, ζs. According to von

Mises, ζs applies in a similar way as in equation(3).

Table 1: The α factor according to the dimeters ratio

d_2 / d_1	0.9	0.8	0.7	0.5	0.3	0.1
α	0.19	0.37	0.51	0.76	0.91	0.99

$$\zeta s = \zeta_{s0}\left[1-\left(\frac{d_2}{d_1}\right)^3\right] \quad \text{... (3)}$$

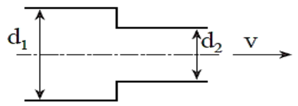
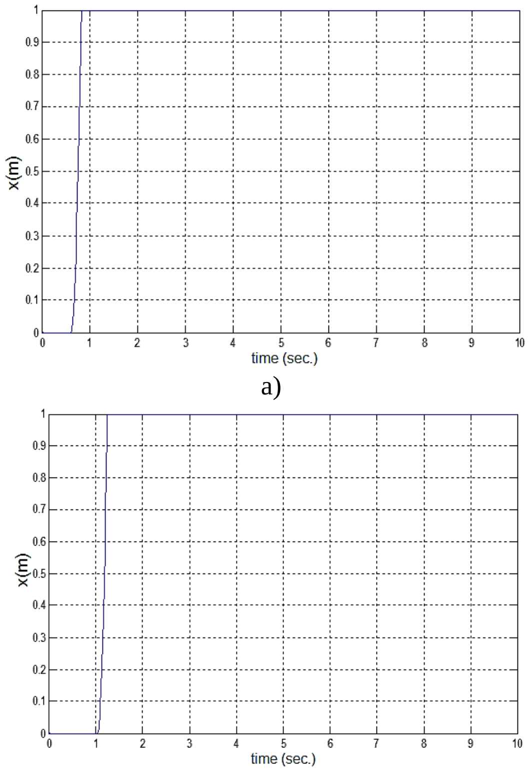


Figure 11: Schematic diagram for decrease of the area.

- **For laminar flow R_e = 2000(R_e< 2300)**

By tacking ξ0 = ξs = 1.12 and assuming d1=1m and d2= 0.5 as an example, then from Table (1),α is (0.51) and ζ = 0.6171, and the result is shown in Figure (12a). Likewise, as second example, assuming d1=0.75 m and d2= 0.2m then in Table (1) α is (0.91) & ζ = 1.1011 and the figure 12b illustrate the response of the system.



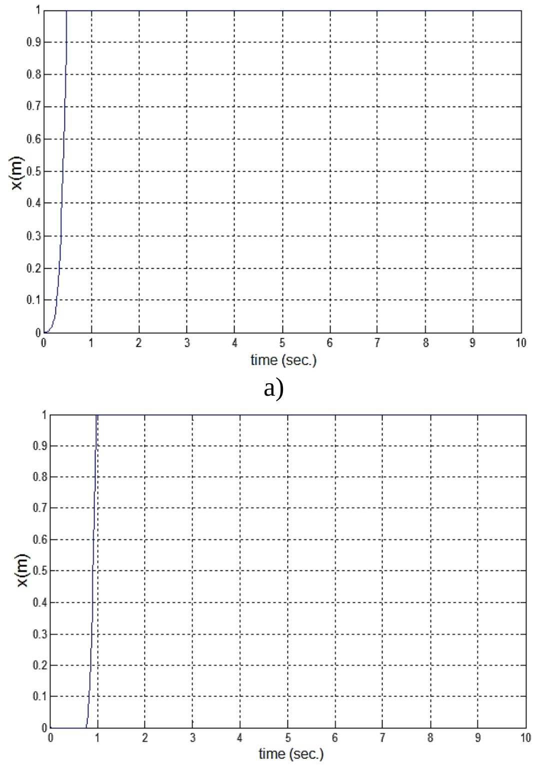
a)

b)

Figure 12 : Servo hydraulic system response for laminar flow decrease of the pipeline area a) first example data b) second example data.

- **For turbulent flow R_e = 4000 |(R_e> 2300)**

By tacking ξ_0 = ξ_s = 0.09 and assuming d1=1m and d2= 0.5 as an example, then in Table (1), α is (0.51)and ζ = 0.0459; the result is shown in Figure (13a) Similarly, using as second example by tacking d1=0.75m and d2= 0.2m, then in Table (1), α is (0.91) and ζ = 0.0819, andthe figure 13b illustrate the response of the system.



a)

b)

Figure 13 : Servo hydraulic system response turbulent flow decrease of the pipeline area a) first example data b) second example data.

3.3 Pipe bend

Assuming the pipe is bent into a specific angle, as shown in Figure 14a, and using as example φ= 40, then in the Table (2) and Table (3),ξ= 0.27 could be calculated from equation(4) and the system response is shown in Figure 14b.

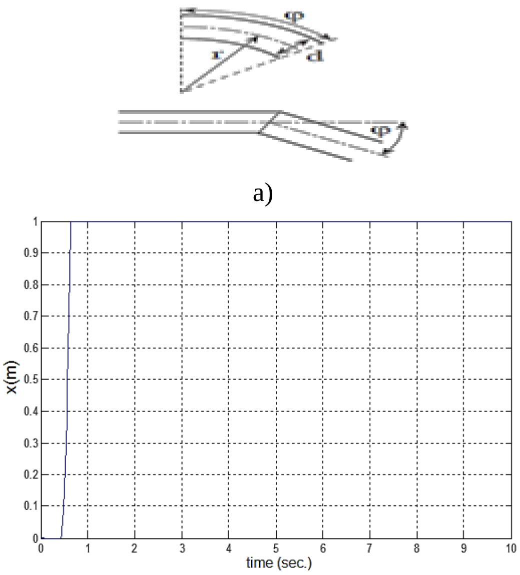
$$\xi = \xi_{90}\frac{\varphi}{90} \quad \text{… (4)}$$

Table 2: Pipe bend ratios

d/r	0.2	0.4	0.6	0.8	1
ξ_{90}	0.13	0.14	0.16	0.21	0.29

Table 3: Pipe bend with angle

φ	10	20	30	40	50	60	70	80	90
ξ	0.04	0.1	0.17	0.27	0.4	0.55	0.7	0.9	1.2



a)

b)

Figure 14: a) Shape of the bent pipe b) Servo hydraulic system response with the bent pipe.

2) Proportional integral derivative (PID) controller tuned by fuzzy logic technique

In order to have an excellent performance of a servo hydraulic system, a proper controller is required. PID controller is commonly used to improve the system response, mostly because it is easy to operate and very strenuous as well. Settling time, error steady state, rise time and overshoot are the system specifications needed to be enhanced by fine-tuning the value of the PID controller parameters K_p, K_i, and K_d, since each parameter has its own specificmission. It could be represented mathematically as in equation (5)

$$u(t) = K_p \,.\, e(t) + K_i \,.\int_0^t e(t)dt + K_d . \frac{de(t)}{dt} \quad \dots \ (5)$$

tacking e(t) is the error signale(t) = xd(t) – x(t).

Moreover, to ensure gratecontroller execution, an intelligent techniques used for tuning the parameters K_p, K_i and K_d, until reaching suitable values for the required response.

Hence, this study presented an execution of the suggested self-tuning fuzzy PID controller for the position controlling diversity of a servo hydraulic system. The self tuning fuzzy PID controller was a collection of a classical PID controller and fuzzy logic technique. It should be well-known that thetuning of K_p, K_i, and $K_d$which are the three parametersof the PID controller by fuzzy technique algorithm is aself-tuning fuzzy PID controller [10 13] as illustrated in Figure 15.

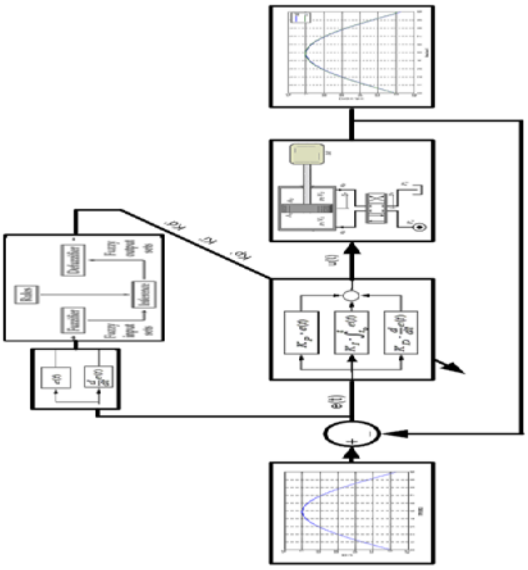


Figure 15: Structure of the servo hydraulic system with the self-tuning PID controller.

Previous literature stated that the three main parts of fuzzy inference are the construction under Mamdani model. First is the fuzzification of the input, in particular,the feedback error e(t) and the derivative of error de(t)/dt are two inputs to the fuzzy logic inference engine. Second is the rule base and third is the defuzzification with some adjustment to get the better value for K_p, K_i, and K_d , as in Figure 16 illustrated the fuzzy inference block.

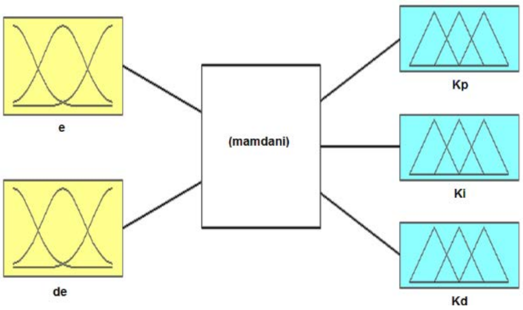


Figure 16 : Fuzzy inference block

The study assumed that the variable varieties of the PID controller parameters are K_p, K_i, and $K_d$as following:$[K_{pmin}, K_{pmax}]$, $[K_{imin}, K_{imax}]$ and $[K_{dmin}, K_{dmax}]$, respectively. The variety of calculating each parameter was established on high inference qualifications that based on getting a proper rule base from the PID controller simulated model. The sort of each parameter is as follows: $K_p \in [10\ 300]$, $K_i \in [5\ 20]$, and $K_d \in [0.5\ 0.8]$. Therefore, an adjustment over the interval [0, 1] can be made likewise as follows up:

$$K'_p = \frac{K_p - K_{p\,min}}{K_{p\,max} - K_{p\,min}} = \frac{K_p - 10}{300 - 10}$$

$$K'_i = \frac{K_i - K_{i\ min}}{K_{i\,max} - K_{i\,min}} = \frac{K_i - 5}{20 - 5}$$

$$K'_d = \frac{K_d - K_{d\,min}}{K_{d\,max} - K_{d\,min}} = \frac{K_d - 0.5}{0.8 - 0.3}$$

Hence, we obtain: $K_p = 290\,K_p' + 10$, $K_i = 15\,K_i' + 5$ and $K_d = 0.3\,K_d' + 0.5$

Accordingly, themembership functions for both inputs and outputs, as well as in the fuzzy rules are contingent on type of input-output signal consideration and the control aim. Founded on the membership function for thefuzzy rules was achieved as set in Table 4.The used linguistic variables for input were Negative (N), Zero (Z), and Positive (P), while the linguistic variables used for output were Small(S), Medium (M), and Big (B). Since the three linguistic variables that had been set, accordingly, nine (9) fuzzy rules. In addition, the certain values that were sent to PID controller parameters got from the defuzzification centroid method. Furthermore, the complete system was developed using Matlab Simulink environment.

It can be concluded from the results above-mentioned, that the PID controller parameter has enhanced the error of the response of the system as shown in Figure17. The error ratio is set to be 1%. The controller output is illustrated in Figure 18.

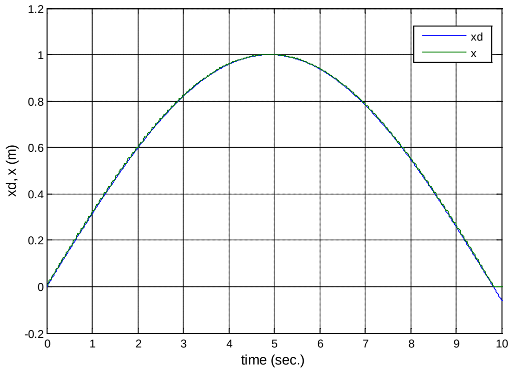


Figure 17: Simulation of the servo hydraulic system with PID controller.

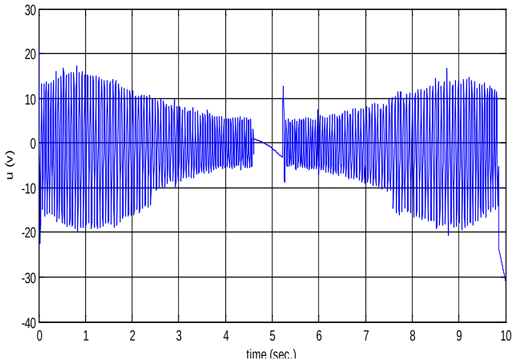


Figure 18: Output of the controller

3) Conclusion

This paper presents a nonlinear modelling for a servo hydraulic system. Largely, the focus is the effect of different types of pipelines connecting between the servo valve and the hydraulic cylinder. This is achieved by modelling the system using mathematical equations by usingthe MATLAB program and likewise by consideringthe hydraulic system nonlinearities. As a result, the open loop response showed a greater, although different,steady-state error for each pipeline type used. Accordingly, the steady-state error has been advance after using and tuning the PID controller using a fuzzy logic technique. The numerically simulated study shows that the suggested self-tuning PID controller get a significantly better performance in tracking accuracy of 1% for the steady-state error as compered by 6% classical PID controller.

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استقصاء وتعزيزاستخدام أنواع مختلفة من الأنابيب مع النظام الهيدروليكي باستخدام المسيطرالتناسبي- التكاملي- التفاضلي المٌنغم بالمنطق المُضبب

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الخلاصة :

يهدف هذا البحث الى عمل دراسة عن تأثير مجموعة مختلفه من الانابيب على النظام الهايدروليكي والذي سيتم تعزيزه بالمسيطر التناسبي -التكاملي –التفاضلي المُنغم بذكاء المنطق المُضبب. ويتم ذلك عن طريق دراسة موسعه للمعادلات الرياضيه ولعدة انواع من الانابيب مع اختلاف مواصفاتها كمـثال: (التغيير في اقطار الانابيب، وجود مصادر مسببه للاضطرابات، وهكذا). ان تأثير الانابيب المستخدمه على الازاحة الخطية للنظامتم اختبارها، وحيث ان النظام الهايدروليكي من الانظمه التي يصعبالسيطرة عليهابسبب التاثيرات اللاخطية والتعقيدات وذلك من خلال دراسة معادلات النظام الرياضيه فقد تم استخدام المسيطر التناسبي -التكاملي –التفاضلي المُنغم بذكاء المنطق المُضبب لتحسين نتائج النظام الهايدروليكي. اظهرت النتائج ان للنماذج الرياضيه المستخدمة للانابيب تأثير معتبر على اداء الازاحة الخطية للنظام وحسب نوع الانبوب المستخدم. علاوة على ذلك، اظهرت النتائج تحسن واضح في مواصفات زمن استجابة النظام وتقليل في الخطا بعد استخدام المسيطر المقترح.