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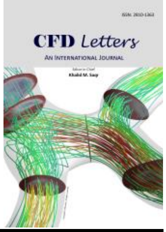

Experimental and Theoretical Investigation of the Response of the Liquid Level Controller

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ABSTRACT

This paper shows a mechanical manufactured design test for a water tank level control system. The purpose of this mechanical controller is to maintain the water level in the tank at the desired level as the process operator wish according to the manufacturing process requirements. That means the process operator as the observer have the ability to change the setting of input water level to control the actual output water level in the tank. The problem which is frequently encountered in manufacturing processes lines and even in nuclear power stations is to maintain the water level in the tanks at its desired level as the wish of human operator process. So, the purpose of this study is to submits a controller system to compensates and fill deficiency to the needs for a cheap, reliable, low maintenance controller. As a used method of this paper, an experimental results to control the system response had been tested. A proposed mathematical model had been derived, and simulated on a model using MATLAB/Simulink program. The experimented and the simulated results had been compared in different responses to give at the end a satisfactory level control results of the water tank. The major conclusions reached in this paper are a proposition of a simple automatic mechanical water level controller in a tank, which has the ability to accept manually step input changes of the water level, with a pressure sensor works as a system feedback. Being in mind that the manufacturing of the four sides of the water tank also all valves and pipes are taken as a plastic transparent made, to interact the students educational criteria with the main response controller of the system. Finally a comparison trend being set up between both results to show off the changing remarks happen to the system in both cases of operation.

1. Introduction

Water and its sources is considered an important natural limited resources. Its importance came from the essential and vital role, "it plays a great role to maintain and permanence the human life when using for a drinking needs. Further beyond it support aspects represent many chemical, agricultures, and oil industries. For that, it meets the desired level of quality, product safety and makes the process more economical", Yahya *et al.,* [1]. Besides the mention above, other factors play a role causes increasing of limitation and lack of abundance of water, "like natural bands and social

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constraints. Being in mind that the global climate changing, and the inability of specialist departments which concern in predicating the changing in monsoon rain cycle, or reasons of regression, led to an unreliability in a near future of available water rain in the streams and rivers", Musafa *et al.,* [2]. Also, "our communities face wastage of water using, which should be considered as one of available energy sources", Rahouma *et al.,* [3]. Another reason plays vital role in limitation the rain quantity and its distribution around the earth is the global warming. "The exponential increase in global energy demand is a direct result of the rapid growth of the world's population and technological advancements. However, the use of fossil fuels to meet this demand has led to the issue of CO2 emission and global warming, which prompting nations to undertake mitigation plans for further negative repercussions", Nur *et al.,* [4]. Here comes the role of process control systems, as a modern and typical solution for existing obstacles to avoid and reduces such a worldwide problems which had been previously mentioned. Especially in many industrial processes, a controlling requirement needed to maintain water level height in a liquid tank to the desired limit, as a resource, one must economize when operating it to preserve it. The water level height could be easily changed and adjusted as desired by the human operator, which is supervise the manufacturing process, in such a way that matching the aim of production process by using the suggested mechanical control system. A best example to this systems is required in power steam industries, "which indicates that 25% of emergency shutdown cases happened in nuclear power stations caused by the weakness in controlling of steam generator water level", Mostefa *et al.,* [5]. To achieves the aspects that had been mentioned above in different control processes, the solution is coming in exiting two ways of automatic control, "an electrical electronic circuit coupled with fuzzy logic methods, and the mechanical methods", Harshdeep *et al.,* [6]. Its wide uses in "controlling systems and construction of elementary parts enters almost our life and industrial aspects", Fayçal *et al.,* [7].

In this field vary in its using to many miscellaneous research strategies, so at one of these sides dealing with types and numbers of tanks, while in the other side have been focused in a selected parameters which is represents the dynamic effect possess in the tank system. They used different kinds of technologies to analyze and operate the mathematical modeling of the control systems.

Some of the researchers studied water tank level systems that consists of only one tank. Like Qahtan *et al.,* [8] studied the performance of control systems such as P, PI, and PID to control the water level in a single tank. While research in designing and implementing a level control system of water tank using PLC controller was made by Harahap *et al.,* [9]. Other researcher study the response control of water level in a laboratory device, and represented a mathematical model of PID control by using (Matlab/Simulink) program done by Jiri *et al.,* [10]. As for others employed acquisition data cards (DAQ_s) in transfer function scheme to represent the system in mathematical modeling with the use of (Matlab/Simulink) program finished by Hayati *et al.,* [11]. In the same context of the paragraph, a study of how to improve the performance of water level controlling of such a system using gain scheduling PID coupled with anti-windup back calculation of integration completed by Sony *et al.,* [12]. Meanwhile a research compared between controller responses of PID kind, which had been synthesis its parameters by using Ziegler-Nichols (ZN) method, and the response of the same system when same parameters adjusted by practical swarm optimization (PSO) method. The latter method showed a promising results of response shape, as it reduces the overshooting amount of the response the researcher was Zahratul Laily *et al.,* [13].

Many studies have been addressed to control the water level in boilers and steam generators of power stations, Nuclear power stations, which composed of one water tank. One of these studies deals with the mathematical modeling of boiler using traditional PID controller, the results being compared with another response used fuzzy logic controller is conducted by FanSheng *et al.,* [14]. Another study derived two mathematical model of such a boiler, the first is simplified by a linearization model, and the second by a complex nonlinear PI model. Both simulation had been executed using (Matlab/Simulink) program done by Fahad *et al.,* [15].

In another context a research had been studied different kind of response controller of a system, which consists of two water tanks in laboratory apparatus. All controllers such as, on-off, PID, ANN-PID, and Fuzzy-PID are simulated by (Matlab/Simulink) program was achieved by Mehmet *et al.,* [16]. Analyzing the performance of the system controller of two water tanks for non-linear system model, was done by a study of mathematical model had been represented by using differential equations. In which, the PI controller is used to govern the water level of the second tank, it shows that this controller able to reduce the effect of the disturbances, this research conducted by Mustafa *et al.,* [17]. So, as appear from previous studies [8-17] were aims to a chives good control strategies.

In other hand, studies deals with Instructional learning in classrooms and laboratories, such as research takes the students interaction to help students understand and remember functional groups in organic chemistry done by Nurhayati *et al.,* [18]. Also, a study displaying the result of the primary objective to delve into the impact of BIM on the cost control of green buildings in Shanghai and unveil its effect during the implementation process of green building projects Yangle *et al.,* [19]. While a study showing that by using a methodological framework as an instructional learning tool have the ability to assess the website potential in learning languages within a specific context Nur *et al.,*[20].

In the area of industrial processes and steam and nuclear power plants, and in light of the repeated failures and the resulting and consequential damages, there is a gap have arises as a need for simple, reliable, cheep, low maintenance control system, as an alternative for the expensive electronic existing systems. This gap can be fill with a mechanism as proposed in this mechanical controller.

The significant of this research is to submit a unique mechanical controller system. Which is can be used in the industrial processes that deals with Liquids as the main production, as soft drinks factories, alcoholic medical supplies facilities, beverage production lines. Or just an intervene as a secondary or auxiliary part required in the production processes. Like in perfumes and cosmetic liquids production plants. Whereas is useful for controlling the height of liquids in the tanks. Also in the same context it is a practical in the industries like stem power plant for controlling and adjusting the water level in the tanks associated with boilers. Also in the same time it is useful for adjusting the level of water cooling of nuclear power station.

So, the objective of this research is to submit a mechanical water tank level controller. By designing and manufacturing a prototype mechanical controller. In the same time, as a device for experimental lesson for students laboratory in University of Mosul. Also, a mathematical model have been developed which simulated in Matlab/Simulink as a water level controller system.

2. Methodology

2.1 System Description

A general shape appearance of water tank system, front and sides is shown in Figure 1, its drawing components being in Figure 2. The system consists of the following elements as shown in Figure 2, water tank measured as (0.22×0.22×1.6) m, feeding valve (intake valve), exit valve (discharge valve), pressure sensor Figure 3, and mechanical controller Figure 4.

Fig. 1. general appearance front and side shape

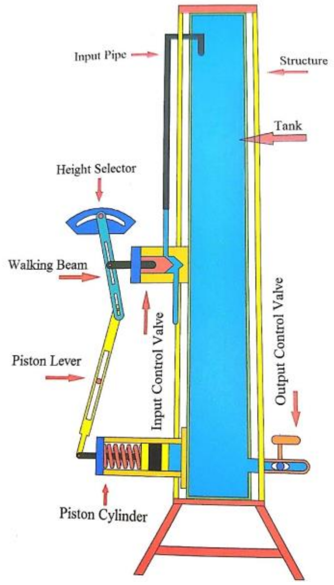

Fig. 2. components drawing

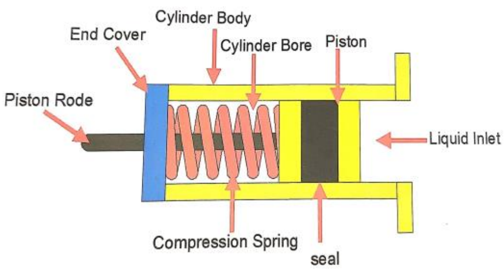

Fig. 3. pressure sensor components

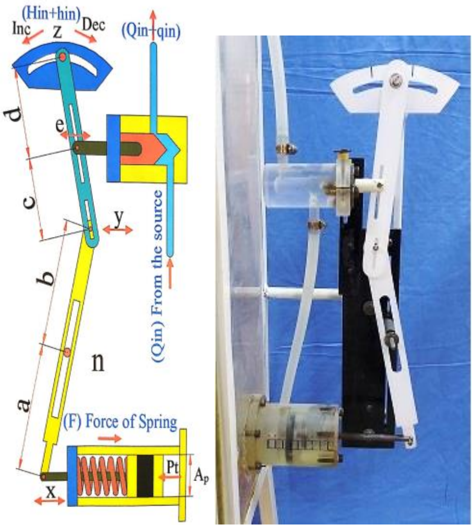

Fig. 4. Mechanical controller

2.2 System Mathematical Modeling

The overall block diagram which describes the dynamic operation of water level control system is obtained as following:

2.2.1 System input sliding lever

The displacement (Z) of the end (a) of the lever (ab) is a function of the desired water level reading (H_r) as shown in Figure 4. That is,

$Z = Z(H_r)$, linearization gives

$$z = Ah_r \tag{1}$$

Where: (z) represent the change in displacement of the end (a) (see Figure 5)

A: $A = \frac{1}{K_{G1}K_{G2}} + K_H$, where $K_{G1,}K_{G2}$ and K_H are constants of steady state system operation. Azar [21].

h_r: represent the change in required water level reading.

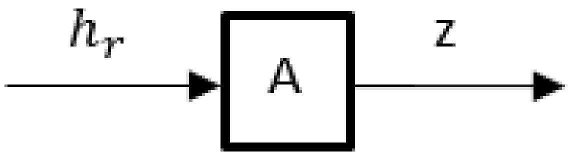

Fig. 5. Block diagram representation of Eq. (1)

2.2.2 Walking beam

The displacement of the feeding valve rod (E) is a function of two displacements at the terminal ends (z) and (r) of the lever (ab) as shown in Figure 4. That is,

$E = E(Z, R)$, linearization yields

$$e = \frac{\partial E}{\partial Z}|_R \ .z \ + \ \frac{\partial E}{\partial R}|_Z \ .r \tag{2}$$

From Figure 6(a), the triangle similarity

$$\frac{\partial E}{\partial Z}|_R \ \gg \ \frac{e}{z} = \frac{b}{a+b} \tag{3}$$

For Figure 6(b), the triangle similarity

$\frac{\partial E}{\partial R}|_Z \ \gg \ \frac{-e}{+r} = \frac{a}{a+b}$ ….. Or

$$\frac{e}{r} = \frac{-a}{a+b} \tag{4}$$

Substitution of Eq. (3) and Eq. (4) into Eq. (2) gives

$$e = \frac{b}{a+b} \ z \ - \ \frac{a}{a+b} \ r \tag{5}$$

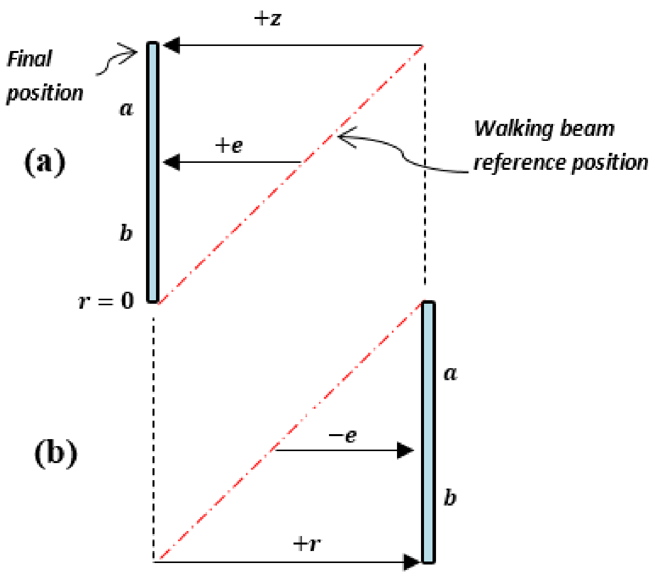

Fig. 6. Walking beam's ends displacement change **z**, **r**

2.2.3 Lever piston

From similarity of Figure 7, we get:

$\frac{+r}{+x} = \frac{c}{d}$ ……. Or

$$r = \frac{c}{d} x \tag{6}$$

Substitution of Eq. (6) into Eq. (5) yields (see Figure 8):

$$e = \frac{b}{a+b} z - \frac{a}{a+b} \frac{c}{d} x \tag{7}$$

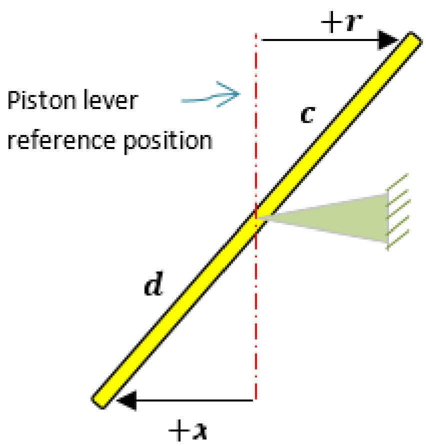

Fig. 7. Piston lever's ends displacement r, x

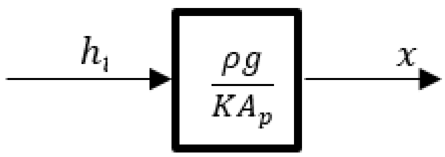

Fig. 8. Block diagram representation of Eq. (7)

2.2.4 Water supply valve (feeding valve)

The discharge of the supply valve (Q_{in}) is a function of the upper building water height (H_s) and discharge of feeding valve rod displacement (E) as shown in Figure 4. That is,

$Q_{in} = Q_{in}(H_s, E)$, by linearization gives, (8)

$$q_{in} = \frac{\partial Q_{in}}{\partial H_s}|_E \,.\, h_s + \frac{\partial Q_{in}}{\partial E}|_{H_s} \,.\, e \tag{9}$$

Where, $\frac{\partial Q_{in}}{\partial H_s}|_E$, $\frac{dQ_{in}}{dE}|_{H_s}$ are constants which can be find experimentally. We will consider the change in upper building water height (h_s) does not change in very significant amount due to big volume of upper building tanks through experiment duration. That means,

$h_s = 0$ …………… substitution in Eq. (9) yields,

$$q_{in} = c_1\, e \tag{10}$$

Where, $c_1 = \frac{dQ_{in}}{dE}$ is a constant can be find experimentally (see Figure 9).

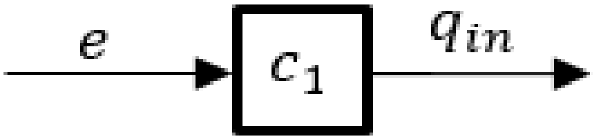

Fig. 9. Block diagram representation of Eq. (10)

2.2.5 Output discharge valve (outflow valve)

The discharge of the output valve (Q_o) as shown in Figure 2, is a function of the tank water height (H_t) and the behavior of the way of opening and closing with time for the output valve (U_v). That means,

$Q_o = Q_o(H_t, U_v)$, by linearization yields

$$q_o = \frac{\partial Q_o}{\partial H_t}|_{U_v} \,.\, h_t + \frac{\partial Q_o}{\partial U_v}|_{H_t} \,.\, u_v \tag{11}$$

Where, $\frac{\partial Q_o}{\partial H_t}|_{U_v}$, $\frac{\partial Q_o}{\partial U_v}|_{H_t}$ are constants to be find experimentally.

We shall take in the consideration that the valve opining position will be remains at fixed state throughout the experiment duration. That means,

$\Delta U_v = u_v = 0$ ……………………. substitution in Eq. (11) gives:

$$q_o = c_2\, h_t \tag{12}$$

Where, $c_2 = \frac{dQ_o}{dH_t}$ is a constant can be find experimentally (see Figure 10).

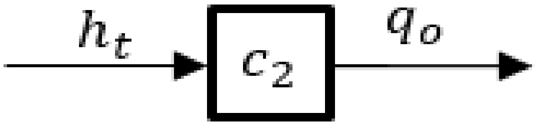

Fig. 10. Block diagram representation of Eq. (12)

2.2.6 System tank water mass balancing

The rate of water accumulation inside the system tank (Q_{acc}) equales to the area of the tank (A_t) times the velocity of water level in tank ($\dot{H_t}$). That is,

$Q_{acc} = A_t \dot{H_t}$, linearization gives:

$$q_{acc} = A_t \dot{h_t} = A_t D h_t \tag{13}$$

The rate of water accumulation (Q_{acc}) is the difference between the inflow rate and outflow water rate of the system tank. That is,

$Q_{acc} = Q_{in} - Q_o$, linearization gives:

$$q_{acc} = q_{in} - q_o \tag{14}$$

Substitution of Eq. (10), Eq. (12) and Eq. (13) into Eq. (14) yields. See Figure 11:

$$A_t D h_t = c_1 . e - c_2 h_t \tag{15}$$

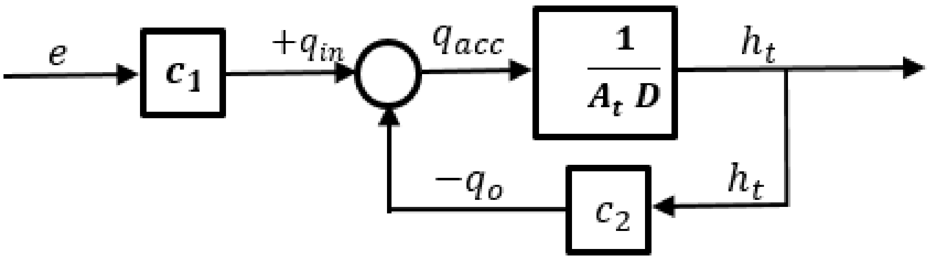

Fig. 11. Block diagram representation of Eq. (15)

2.2.7 Mechanical pressure sensor (forceses balancing)

The mechanical pressure sensor as shown in Figure 3, has two forces acting in opposite direction as shown in Figure 12. The first force is piston force (F_{pis}) which is due to water tank system head pressure (P_t) upon sensor piston area(A_p). And the second one is the spring force (F_s) which is due to reacting of the spring constant (K_s) with the spring compression displacement (X). So the balancing forces can be expressed as following:

$F_s = F_t$

$$KX = \frac{P_t}{A_p} \tag{16}$$

Since, $P_t = \rho g H_t$, Substitution into Eq. (16) and doing linearization to gives (see Figure 13):

$$x = \frac{\rho g}{KA_p} h_t \tag{17}$$

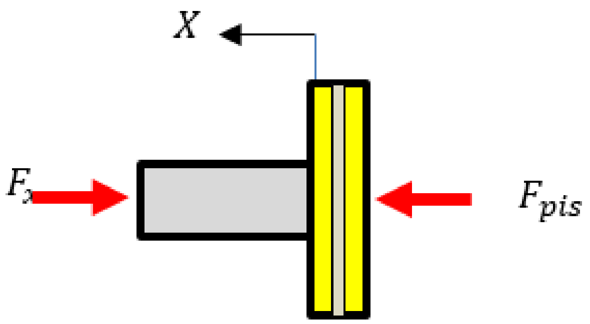

Fig. 12. Pressure sensor's acting forces

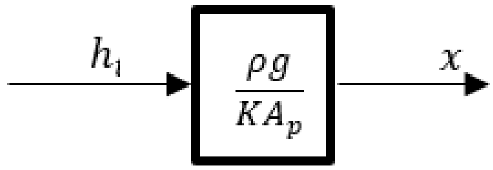

Fig. 13. block diagram representation of Eq. (17)

The overall block diagram as shown in Figure 14, can obtained by connecting the related minors block diagrams in previous articles in Figures 5, 8, 9, 10, 11 and 13 together corresponding to the direction and name of each minor block. By using the block diagram reduction technique, and by moving summing point behind block $\frac{b}{a+b}$, and finishing a few steps of corresponding deleting and curtailment, the final block diagram can obtained as shown in Figure 14.

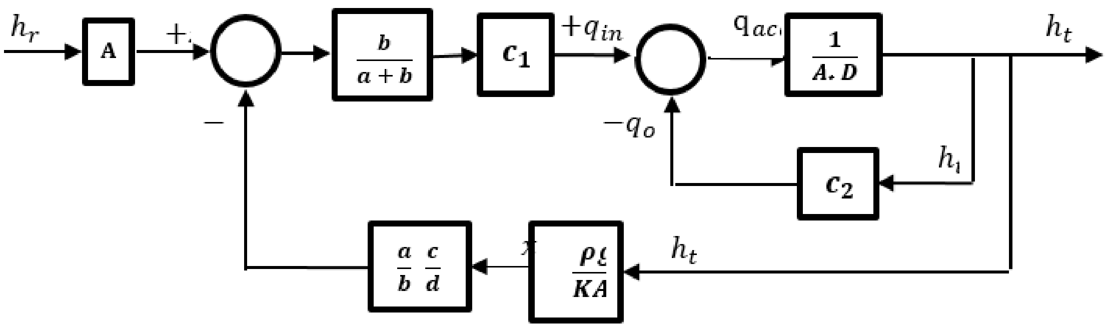

Fig. 14. Overall block diagram of water level controller representation

3. Results and Discussion

A water tank level controller system had been designed and a mathematical model being derived. Based on that a laboratory apparatus was first manufactured and tested experimentally. Then a MATLAB/Simulink software had been used to study the performance and the control response proposed by the model of the system. It is capable to maintain and control the desire water level in tank system. The proposed controller is simulated successfully and its results are promising and satisfactory. Finally, the responses results of the experimental and MATLAB/Simulink model were compared.

The water tank level control system could be adjusted to a fixing reference of a (0.8 m) head as an operating point. This can be done by moving the walking beam tip up and down over the mechanical sliding input device as demonstrated in Figure 4. The control system initiates filling the water tank of the system up to the desire level, the process takes the required time then stops. As an optionally step, if the operator wish to attain (1 m) as a new desired water level, a walking beam tip move by (0.2 m) according to the reading scale, as an input step change.

Figure 15, shows an experimental test of a response step input change by (0.2 m) as a set point and the observed thing is the response had an amount of steady state error (e_{ss}) equals ($0.03\ m$).

And has a settling time equals (40 seconds).This is not the typical representative response shape. The response curve along some parts shows slightly obvious deviation, and partially inclining in another parts. This is happen due to friction effect which is mostly induce around piston and cylinder sides of the mechanical pressure sensor, and also between the mechanical levers of the connecting joints.

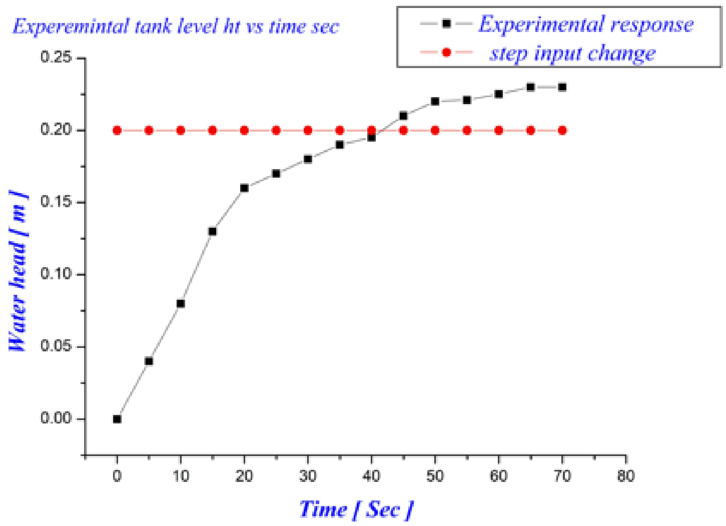

Fig. 15. Experimental Control system response of 0.2m step input change

Figure 16 shows Matlab/Simulink program representation of signal block diagram for mathematical model with 0.2 step input change. Figure 17 shows response simulation result for a step input change by (0.2 m) as set point. It obviously the curve feature owns to the standard shape of first order transfer function. It has a best performance, giving lower steady state error (e_{ss}) equals $(8.77 * 10^{-3}\ m)$ and less settling time by (20 seconds). The simulation and the experimental tests show the superiority of Matlab/Simulink modeling result over the experimental system response.

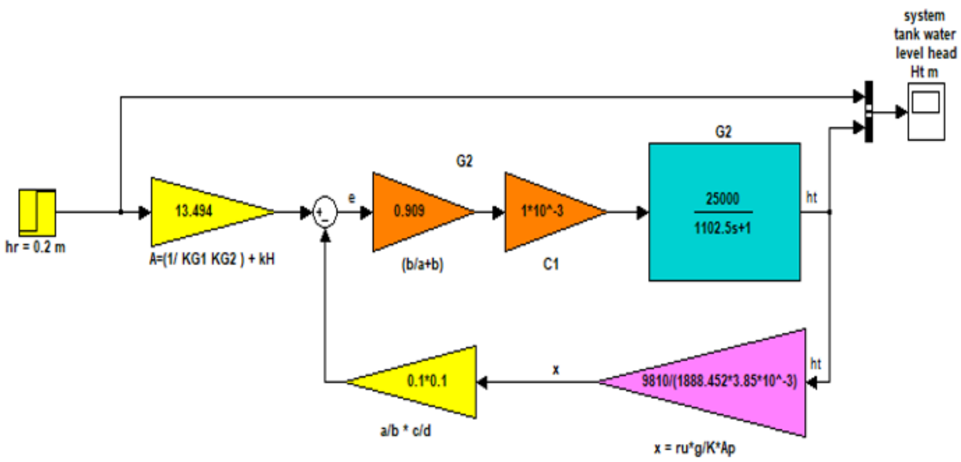

Fig. 16. Signal block diagram simulated in Matlab /Simulink program

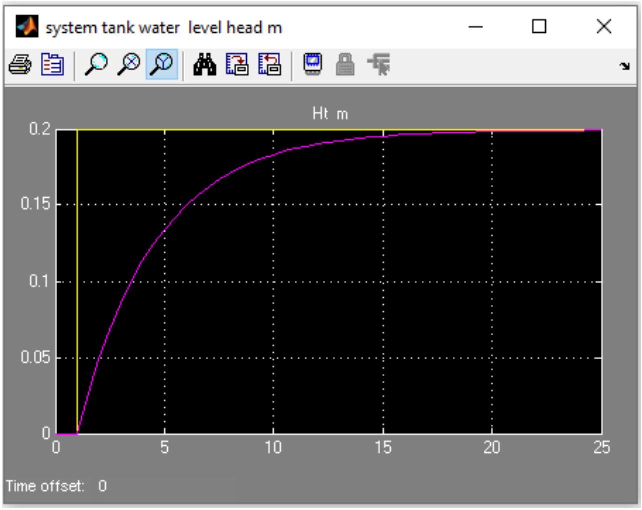

Fig. 17. Matlab/ Simulink simulated control system response of 0.2m step input change

4. Conclusion

The conclusion of this study as follows:

i. In this paper a mechanical level controller had been designed and manufactured in Mousl University for a single water tank sets earlier. The procedure steps of the mathematical model being derived completely, ending with schematic block diagram analysis. Finally a simulation of the network had been executed using Matlab/Simulink program.
ii. In general the benefits of utilizing such a simulation software is the ease of controlling such a modelling process with precise data reading outcome. It take up the educational outcomes of the students through the practical work lesson, and proved the efficiency of using such a controlling process, in which enough robust to deal with the response changing input of the system.
iii. The study shows as expected, that the response performed by the simulation has less steady state error and setting time, as compare with the response which has been done experimentally, it has a bigger steady state error and setting time, caused almost by the friction and inertia.
iv. From experimental and theoretical point of view, the automatic control study has been performed by utilizing a negative feedback corresponding to the pressure sensor.
v. The benefit of manufacturing such an apparatus structure in local markets, the ease of modification procedures and reducing maintenance steps and costs, comparing with the purchased traditional laboratory devices.

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