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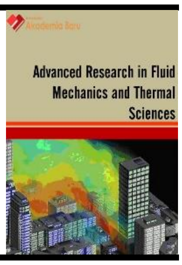

Pressure Analysis of Remotely Operated Water Hydraulics Actuator (ROWHA)

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ABSTRACT

This study proposes a development of remotely operated water hydraulic actuator (ROWHA) for industrial application. The safe, hygienic and low maintenance cost characteristics of water should provide interesting viewpoints due to concern over issues in hydraulic fluid disposal, flammability, and costly maintenance. An experiment is conducted on the remotely operated water hydraulic actuator by moving variable load up to 5 kg. The result of the remote operation of extension and retraction of the load is presented. A PS2 wireless controller is use to act as remote control for this system. Experimental result of ROWHA show same pattern of result where pressure during extension is lower than retraction.

1. Introduction

The objective of this project is to develop a remotely operated water hydraulic actuator or ROWHA for sustainable industrial application [1]. The purpose of using water as a hydraulic actuator in this experiment is to transfer the fluid energy, power and the resource sustainably, with environmental friendly impact. The safe, hygienic and low maintenance cost characteristics of water should provide interesting viewpoints due to concern over issues in hydraulic fluid contamination, flammability, disposal, and costly maintenance [2,3]. Currently, water hydraulics offer various hygiene solution in many environmental friendly applications such as in underwater application, sustainable industrial scissor lift and waste packer lorry [4-13]. Thus, the project focuses on the development of a remotely operated water hydraulic actuator, which can be used in sustainable and environmental friendly industrial application. In this paper, the pressure difference during extension and retraction of the cylinder with variable loading is presented. Pressure different is the analysis of pressure changes over time. The momentum of the fluid that being stop or flow creates a pressure wave that travels through the pipe system, causing everything in that closed system to significant forces.

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Most analysis of flow in pipelines and networks has assumed the flow to be at steady state conditions. This means that the flow does not change with time at any location in the pipeline system. The analysis becomes simpler and solutions are easy to obtain by assuming hydraulic in system is in uniform flow. Study on transient condition is important because pipeline flows are frequently in unsteady state due to the sudden opening and closing of valves. All transient flows are transitions, whether in long or short duration. Transient flow can be defined as the flow fluctuation when the velocity and pressure of a fluid or gas flow change over time due to changes in the system. Relating specifically to pressure, they are sometimes called dynamic pressure changes or pressure transients. It is not feasible to prevent pressure transient when operating a piping system, but this situation can be controlled. The main causes of transient flow conditions are closing or opening of valves in the piping system, switching off the power supply, or a power failure and/or equipment failure. The sudden closure of a control valve, stopping of a pump, and variation of discharge due to pipeline rupture lead to excess pressure in a pipeline [14]. Wood *et al.,* [15] stated that the pressure transient results from an abrupt change in the flow velocity and can be caused by main breaks, sudden changes in demand, or uncontrolled pump starting.

2. Methodology

2.1 ROWHA Analysis

In this paper, a test rig for ROWHA is designed so that it can be remotely controlled. An arduino transmitter and receiver unit have been utilized as the remote controller of an electro-hydraulic actuator. The electro-hydraulic actuator, has been fabricated by using a tie-rod cylinder, and coupled with a 24 VDC four-way electro-hydraulic valve. The overall dimension for ROWHA is 464 mm x 88.5 mm x 200mm (base x width x height), as shown in Figure 1.

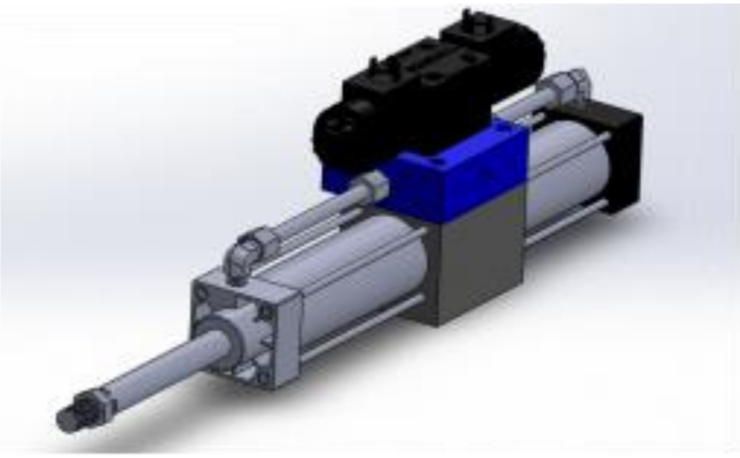

Fig. 1. Remotely Operated Water Hydraulics Actuator (ROWHA)

ROWHA is based on the single rod actuator, and is shown as a single mass-spring damper system, represented by mass, spring rate and viscous coefficient as m, c and k respectively. Figure 2 shows that PA and PB are the fluid pressures on the A and B sides of the actuator, respectively, and actuator force efficiency is represented by η_{af}. The motion of ROWHA can be represented by [16-19].

$$m\ddot{y} + c\dot{y} + ky = \eta_{af}\,(A_A P_A + A_B P_B) - F - F_o \quad (1)$$

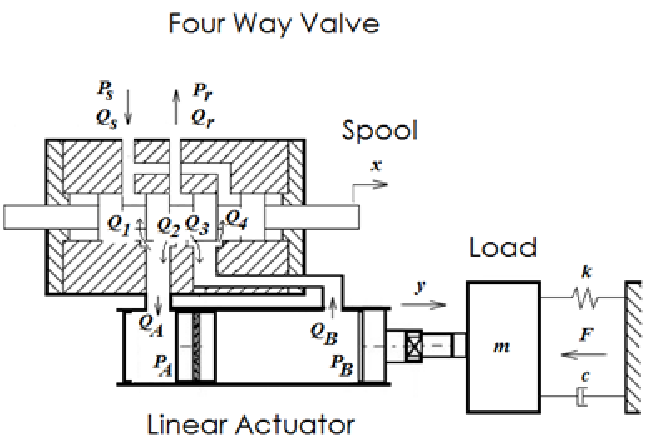

Fig. 2. ROWHA analysis of ROWHA

The assumption during a steady state condition is y = 0, $P_A = P_B = Ps/2$ and F = 0. Therefore, the nominal force exerted on the hydraulic actuator by the load given

$$F_o = \eta_{af}(A_A - A_B)P_s/2 \tag{2}$$

The following equation is produced by the substitution of the previous Eq. (1) and Eq. (2), where

$$m\ddot{y} + c\dot{y} + ky = \eta_{af}(A_A P_A - A_B P_B) - (\eta_{af}(A_A - A_B)P_s/2) - F \tag{3}$$

Thus, the following Eq. (4) can be used to describe the output dynamics of the rod,

$$m\ddot{y} + c\dot{y} + ky = \eta_{af}(A_A(P_A - P_S/2) - A_B(P_B - P_S/2)) - F \tag{4}$$

The equation shows that the actuator pressures P_A and P_B are the required input for adjusting the position of the rod. The flow going in and out at side A and B is given as

$$Q_A = \frac{A_A}{\eta_{av}}\dot{y} \tag{5}$$

$$Q_B = \frac{A_B}{\eta_{av}}\dot{y}$$

where Q_A and Q_B are the volumetric rates into and out of the actuator. The actuator volumetric efficiency is represented by η_{av}. The volumetric flow rates of Q_A and Q_B, can be represented at the spool valve in as

$$Q_A = Q_2 - Q_1 \tag{6}$$

$$Q_B = Q_4 - Q_3$$

The linearized flow equations for fluid passing across the metering lands of four-way spool valve are given by

$$Q_1 = K_C P_S/2 - K_q x + K_C x(P_A - P_R) \quad (7)$$

$$Q_2 = K_C P_S/2 - K_q x + K_C x(P_S - P_A)$$

$$Q_3 = K_C P_S/2 - K_q x + K_C x(P_S - P_B)$$

$$Q_4 = K_C P_S/2 - K_q x + K_C x(P_B - P_R)$$

where $K_c P_s$ is the flow rate across each the valve, and K_q and K_c are the flow gain and the pressure-flow coefficient. By substituting Eq. (6) and Eq. (7), and $P_r = 0$, the volumetric flow rates into and out of the hydraulic actuator can be expressed as

$$\mathrm{Q_A} = 2\mathrm{K_q x} - 2\mathrm{K_c}(\mathrm{P_A} - \mathrm{P_S}/2) \quad (8)$$

$$\mathrm{Q_B} = 2\mathrm{K_q x} - 2\mathrm{K_c}(\mathrm{P_B} - \mathrm{P_S}/2)$$

Thus, the pressures on both sides of the linear actuator may be written as

$$P_A - P_S/2 = K_p x - \frac{A_A}{2K_c \eta_{av}} \dot{y} \quad (9)$$

$$P_B - P_S/2 = -K_p x + \frac{A_B}{2K_c \eta_{av}} \dot{y}$$

where K_p is the valve's pressure sensitivity given by the ratio of the flow gain to the pressure-flow coefficient K_q/K_c. By substituting Eq. (9) into Eq. (4), the following equation for the motion of the system is,

$$\mathrm{m}\ddot{\mathrm{y}} + \left(\mathrm{c} + \frac{{A_A}^2 + {A_B}^2}{2K_c}\right)\dot{\mathrm{y}} + \mathrm{ky} = \eta_{\mathrm{af}}(\mathrm{A_A} + \mathrm{A_B})\mathrm{K_p x} - F \quad (10)$$

The equation shows the overall dynamics of the ROWHA, which is influenced by the design of the linear actuator and the spool valve. Eq. (10) may be simplified by neglecting the inertia and viscous damping, as follows

$$ky = \eta_{\mathrm{af}}(\mathrm{A_A} + \mathrm{A_B})\mathrm{K_p x} - F \quad (11)$$

Using a standard on-off controller, the control law for the displacement of the valve can be written as,

$$\mathrm{x[v]} = \begin{cases} 1\ (\mathrm{move}), \mathrm{if\ v} = 24\ \mathrm{volt} \\ 0\ (\mathrm{move}), \mathrm{if\ v} < 24\ volt \end{cases} \quad (12)$$

where v represents the input voltage on the ROWHA. This is clearly depicted in the block diagram, as shown in Figure 3.

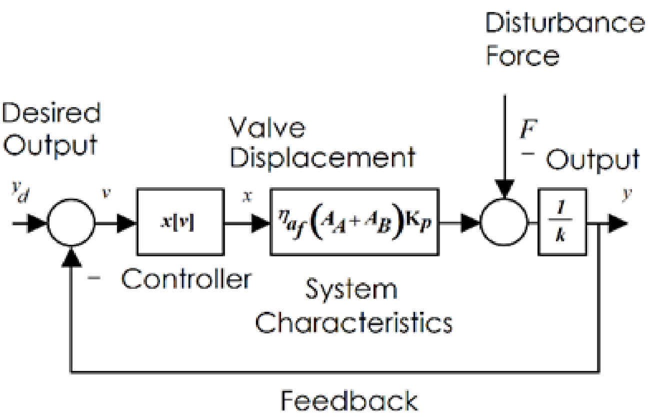

Fig. 3. The position-control block diagram of ROWHA

2.2 Flow Process

In this system, the pump, pressure relief valve, sensor and ROWHA are connected to the tank. The fluid flows from the pump to perform certain tasks and return to the tank. A controller will be used to control the flow of the fluid. The pressure of the fluid in the piping system is constant if the fluid travels at the same velocity. There will be a pressure difference when the valve is either being open or close. This is because the fluid pressure from the pump is continuously supplied to the piping system. The system is designed so that it is easily maintained at the lowest cost possible. However, such design might create a disadvantage where it could create excessive pressure when the pump is still pumping with a valve closed thus pressure relief valve is being used. Pump inlet creates a vacuum condition that allowing atmospheric pressure from surrounding to force the liquid from the tank into the pump line. Then this liquid will be transferred to the pump outlet before being delivered to the ROWHA. The water flow through the pipe, pressure relief valve, pressure sensor, ROWHA and back to the tank. The pressure of the water flow can be obtained from the pressure sensor. The valve will be closed to observe if there is pressure difference during the water flow being stopped. The setup of this experiment is shown in Figure 4.

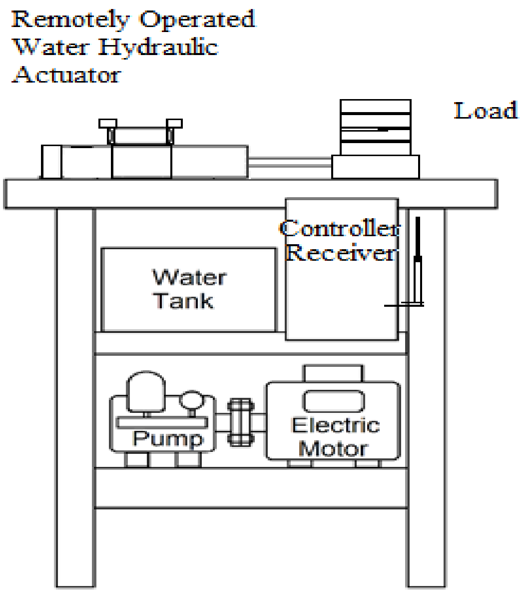

Fig. 4. Schematic Drawing of ROWHA experiment

2.3 Test Rig

i. Data logger

A set of data logger Hydrotechnik Multisystem 5060 plus in Figure 5 was used to record data of pressure flow over time in the system. It has 24 channels and 2 GB of memory. It was easy to handle since it has USB stick function that can easily transfer the data from data logger into personal computer.

Fig. 5. Data Logger Hydrotechnik Multisystem 5060 plus

ii. Pressure Sensor

Hysense PR100 from Figure 6 is one of the pressure sensor from Hydrotechnik product that was used to measure pressure changed in the ROWHA system. The HySense PR 100 with its high-grade steel membrane, is an extensively proven pressure sensor for mobile applications. It is design specifically for water application. It can measured pressure up to 60 Bar.

Fig. 6. Hysense PR100

iii. Cylinder

A single rod double acting cylinder in Figure 7 was used in this ROHWA system. The cylinder's rod can move forward (extending) and backward (retracting) direction. Water hydraulic was used as a medium to move the cylinder. This cylinder which is a product of AirTAC have bore and rod size of 63 mm and 20 mm respectively.

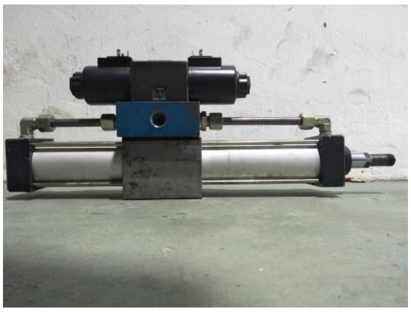

Fig. 7. AirTAC cylinder

iv. Pump

Figure 8 show a high pressure washer form EROX HP90 that was used in this experiment. This pump will push water into the ROWHA system to control the cylinder. It can supply pressure up to 250 Bar and maximum flowrates of 8 l/min.

Fig. 8. EROX HP90 pressure washer

v. Controller

A wireless Play Station controller in Figure 9 that was programmed by Arduino was used as a controller to ROWHA system. The operation of cylinder's rod extension and retraction was controlled by this controller. PS2 controller act as a command platform that giving a signals to ROWHA's actuator.

Fig. 9. PS2 controller

3. Results and Discussion

Figure 10 and Figure 11 show experiment result based on the operation of extension and retraction of ROWHA by using different load which are no load, 1 kg, 3 kg, and 5 kg. By using a controller, when x[v] = 24 volts, the actuator will receive a signal that allows the movement of ROWHA's spool. The input pressure that supplied by a pump is 12 bar. The initial drop of pressure indicates the rod extension of ROWHA. When the rod was fully extended, pressure will rise back to approximately 12 bar which same as pressure input. Time taken for the rod that have 40 cm distance to move for fully extend is 5 s. Meanwhile, the second time of pressure drop is when the rod was being retracted. After the rod was fully retracted, the pressure in the system back to approximately 12 bar. All four variables show a same pattern graph where, pressure during extension is lower than retraction. Pressure area during extension is higher compared to during retraction. This is because Eq. (2) shows that low pressure area will give high pressure to the ROWHA system.

The whole pressure flow of this experiment can be seen in Figure 10 while Figure 11 shows the combination of graph for variable of load which are no load, 1 kg, 3 kg, 5 kg of load. During extension with no load installed at the ROWHA, the pressure drop to 1.05 bar while for 1 kg, 3 kg, and 5 kg the pressure drop are 1.24 bar, 1.57 bar, and 1.78 bar respectively. Meanwhile during retraction with no load install at the ROWHA, the pressure drop to 2.07 bar, while for 1 kg, 3 kg, and 5 kg the pressure drop are 2.42 bar, 2.63 bar, and 2.87 bar respectively. The different value of those pressure can be seen in Figure 12. For all parameter when the rod is fully extended and retracts the pressure is approximately 11.5 bar to 11.98 bar. The pressure slightly loss from 12 bar since there must be a pressure loss from hydraulic flow in ROWHA system.

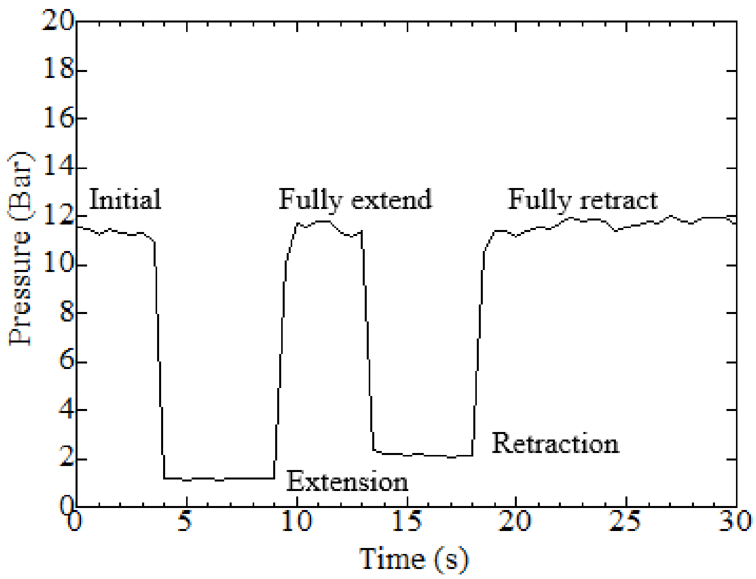

Fig. 10. ROWHA with no load

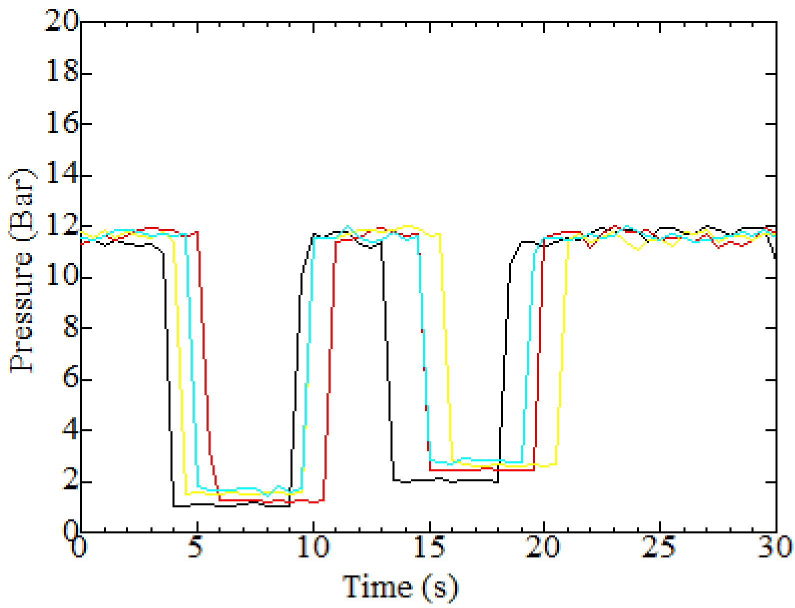

Fig. 11. Comparison during extension and retraction of ROWHA with no load (black line), 1 kg of load (red line), 3 kg of load (yellow line) and 5 kg of load (blue line)

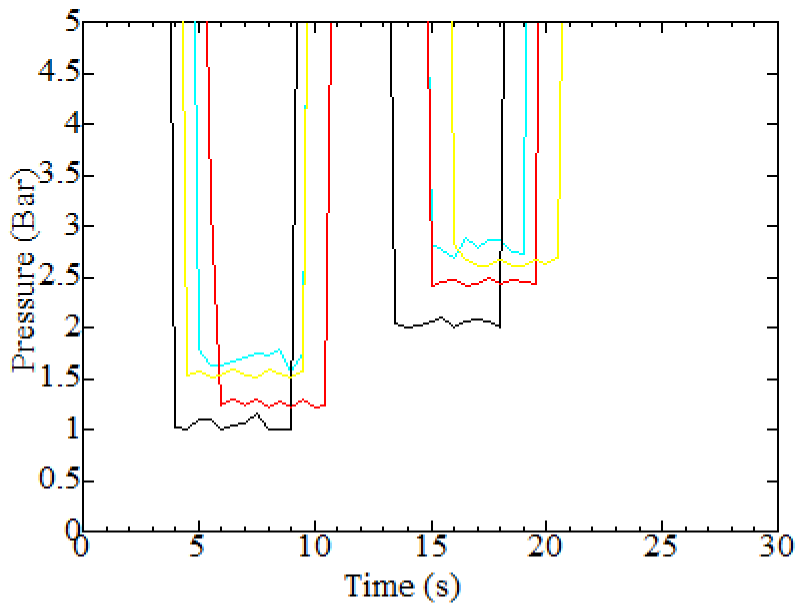

Fig. 12. Zoom in picture for clearer observation of comparison during extension and retraction of ROWHA with no load (black line), 1 kg of load (red line), 3 kg of load (yellow line) and 5 kg of load (blue line)

4. Conclusions

The fabrication of ROWHA's test rig was done in order to run the experiment. The study of hydraulic behavior in remotely operated water hydraulic actuator is still in early stage. In this paper, the main focus is on the pressure characteristic of the variable load. Based on the experiment that have been conducted, pressure during extension and retraction increased when apply additional load on the cylinder. Pressure during retraction is higher compared to extension due to different of pressure area covered in the cylinder. The study will provide information regarding to the use of ROWHA application in sustainable and environmental friendly industrial application. The important of observing the pressure in the system is to maintaining the quality and consistency of a product. Besides, to avoid excessive pressure in the system since it might cause cylinder cracked. Further study will be conducted in the measurement of flowrate and temperature behavior of the remotely operated water hydraulic actuator.

Acknowledgments

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References

[1] Trostmann, Erik, Bo Frolund, bo hojris Olesen, and Bjarne Hilbrecht (2001). *Tap Water as a Hydraulic Pressure Medium*. New York: Marcel Dekker.
[2] Krutz, Gary W., and Patrick SK Chua. "Water hydraulics—theory and applications 2004." In *Workshop on Water Hydraulics, Agricultural Equipment Technology Conference (AETC'04)*, pp. 8-10. 2004.
[3] Higgins, Mike. "Water hydraulics–the real world." *Industrial Robot: An International Journal* 23, no. 4 (1996): 13-18.
[4] Lim, G. H., P. S. K. Chua, and Y. B. He. "Modern water hydraulics—the new energy-transmission technology in fluid power." *Applied Energy* 76, no. 1-3 (2003): 239-246.
[5] Backe, Wolfgang. "Water-or oil-hydraulics in the future." In *The Sixth Scandinavian Scandinavian International Conference on Fluid Power-SICFP'99*, vol. 51, pp. 51-65. 1999.
[6] Yusof, Ahmad Anas, Shafizal Mat, and Abdul Talib Din. "Promoting sustainability through water hydraulic technology–the effect of water hydraulic in industrial scissor lift." In *Applied Mechanics and Materials*, vol. 315, pp. 488-492. Trans Tech Publications, 2013.
[7] Yusof, Ahmad Anas, Faizil Wasbari, and Mohd Qadafie Ibrahim. "Research development of energy efficient water hydraulics manipulator for underwater application." In *Applied Mechanics and Materials*, vol. 393, pp. 723-728. Trans Tech Publications, 2013.
[8] PHAM, Pha N., Kazuhisa ITO, and Shigeru IKEO. "Energy saving for water hydraulic pushing cylinder in meat slicer." *JFPS International Journal of Fluid Power System* 10, no. 2 (2017): 24-29.
[9] Zaili, Zarin Syukri, Ahmad Anas Yusof, Mohd Nor, Nur Fathiah, Mohd Hanafi, Mohd Hafidzal, and Mohd Qadafie Ibrahim. "Characteristics of a reciprocating pump for low-cost sustainable water hydraulic technology demonstrator." In *Applied Mechanics and Materials*, vol. 699, pp. 736-741. Trans Tech Publications, 2015.
[10] Sabaruddin, Saiful Akmal, Ahmad Anas Yusof, Mohd Noor Asril Saadun, and Rozaimi Ghazali. "Application of water as pressure medium in hydraulic hybrid system." *ARPN Journal of Engineering and Applied Sciences* 12, no. 16 (2017): 4824-4830.
[11] Yusof, Ahmad Anas, F. Wasbari, Mohd Shukri Zakaria, and Mohd Qadafie Ibrahim. "Slip flow coefficient analysis in water hydraulics gear pump for environmental friendly application." In *IOP Conference Series: Materials Science and Engineering*, vol. 50, no. 1, p. 012016. IOP Publishing, 2013.
[12] Fairfield, C. A. "Spatial, temporal, and thermal analysis of a cavitating high-pressure water-jet." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 18, no. 1 (2016): 1-19.
[13] Yusof, Ahmad Anas, Saiful Akmal Sabaruddin, Mohd Noor Asril Saadun, and Faizil Wasbari. "Volume displacement simulation impact on the water hydraulic hybrid driveline performance." *Journal of Advanced Research in Fluid Mechanics and Thermal Science* 43, no. 1 (2018): 20-36.
[14] Afshar, H., R. Kerachian, M. R. Bazargan-Lari, and A. R. Niktash. "Developing a closing rule curve for valves in pipelines to control the water hammer impacts: Application of the NSGA-II optimization model." In *Pipelines 2008: Pipeline Asset Management: Maximizing Performance of our Pipeline Infrastructure*, pp. 1-10. 2008.
[15] Wood, Don J., Srinivasa Lingireddy, Paul F. Boulos, Bryan W. Karney, and David L. McPherson. "Numerical methods for modeling transient flow in distribution systems." *Journal-American Water Works Association* 97, no. 7 (2005): 104-115.
[16] Manring, Noah D., and Roger C. Fales. *Hydraulic control systems*. John Wiley & Sons, 2019.

[17] Sulaiman, Hamdan, Ahmad Anas Yusof, Mohd Noor Asril Saadun, and Saiful Akmal Sabaruddin. "Simulation of tele-operated electro-hydraulic actuator and excavator's Boom." *Journal of Telecommunication, Electronic and Computer Engineering (JTEC)* 8, no. 7 (2016): 111-116.

[18] A.A. Yusof, H. Sulaiman, M. F. A. Latip, M. H. Hamzah. "Development Of Tele-Operated Electro-Hydraulic Actuator for Construction Robotic System (TEHA-CRS)." In *Proceeding of 2nd IEEE International Symposium on Robotics and Manufacturing Automation* (ROMA), Ipoh, 2016.

[19] Yusof, Ahmad Anas, Mohd Noor Asril Saadun, Hamdan Sulaiman, and Saiful Akmal Sabaruddin. "Modern practical application and research on teleoperated excavators control, feedback and perception issues in post disaster recovery operation." In *2015 IEEE International Symposium on Robotics and Intelligent Sensors (IRIS)*, pp. 179-185. IEEE, 2015.