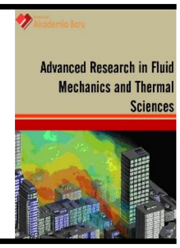
Penerbit Akademia Baru

Journal of Advanced Research in Fluid Mechanics and Thermal Sciences

Journal homepage: www.akademiabaru.com/arfmts.html
ISSN: 2289-7879



Simulation and Experimentation of Water Hydraulics Technology for Automatic Traditional Cookies Production

Open Access

Ahmad Anas Yusof[1,*], Suhaimi Misha[1], Mohamed Hafiz Md Isa[1], Faizil Wasbari[1], Mohd Qadafie Ibrahim[2], Mohd Shahir Kasim[3]

[1] Faculty of Mechanical Engineering, Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia
[2] Faculty of Engineering Technology, Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia
[3] Faculty of Manufacturing Engineering, Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia

ARTICLE INFO

Article history:
Received 18 February 2018
Received in revised form 21 April 2018
Accepted 29 June 2018
Available online 23 July 2018

Keywords:
Water Hydraulics, Food Processor, Industrial Automation, Sustainability

ABSTRACT

This study proposes a low-cost water hydraulics food processor for a traditional cookies production. The objective of this project is to introduce the design and the working principle of the water hydraulics-driven food processor, and to simulate production process performances and capabilities. The basic design is similar to that of a traditional food processor. It consists of an electrical motor, an inverter, a triplex pump, two directional control valves and cylinders. Simulation software is used to design and simulate the movement of the machine. Electro-mechanical relays and timers are used in the machine development, to balance the requirement for a low cost and modern machine automation. PLC is used in the testing of the machine. Water is used as the pressure medium for the system. Cartesian robotics movement is applied for the system, with one cylinder controlling the batches of the cookies, and the other handling the cookies extrusion system. The system is simulated with respective flow and pressure.

1. Introduction

The objective of this project is to develop a functional automatic traditional cookies production system by using water as the pressure medium and controlled low cost electro-hydraulic components and controllers. The machine is developed by using non-corrosive cylinders and a triplex piston pump. The cookies are extruded by using an extrusion system that is developed by using two cylinders. A reciprocating movement is firstly simulated by using FLUIDSIM software, and later tested using an OMRON programmable logic controller, CPM2A PLC. The system, which uses water hydraulics technology is easy to use, and practical for a clean and sustainable production system. Water hydraulics encourages a sustainable approach in power transmission [1]. Basically, the aim of using water is to transfer the fluid energy, power and the resource sustainably, with environmental friendly

* *Corresponding author.*
E-mail address: anas@utem.edu.my (Ahmad Anas Yusof)

impact. The hygienic, safe and low maintenance cost characteristics of water should provide interesting viewpoints due to concern over issues in hydraulic fluid contamination, flammability, disposal, costly maintenance and [2-3]. Currently, water hydraulics offer various hygiene solution in the food processing industry industries, as demonstrated in the water hydraulics beef cutter, burger production and ice filling machine. Other environmental friendly application also includes the use in underwater application, sustainable industrial scissor lift and waste packer lorry [4-13].

Two custom-build water hydraulics cylinder have been developed as the actuator for the system. The cylinders have double acting configuration, with bore size and stroke of 40 mm and 125 mm respectively. The piston pump used in this study is an inline triplex pump with maximum pressure up to 40 bars which is usually used for car wash. This pump has a built-in pressure regulator with an electric motor as its prime mover. The size of the pump is 64 cm x 50 cm x 50 cm. The studied piston force exerted by the cylinder is dependent upon the water pressure, the cylinder diameter and the frictional resistance of the sealing components. The cylinders are assembled into a robotic manipulator that is driven by a low-cost water hydraulic system [14]. The demonstrator is upgraded with cookies extrusion system, whereby the dough is pressed to form a unique shape for the cookies, as shown in Figure 1.

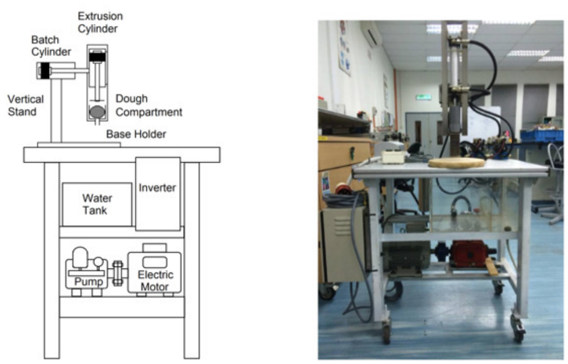


Fig. 1. Water-powered cookies production system

2. Methodology

Simulation and experimentation has been conducted on the food processor system. Mathematical equation on the system has been derived, while the circuit and simulation parameter are simulated in FLUIDSIM software. The experimentation on the system is conducted by installing an CP2M OMRON programmable logic controller system, to produce the automatic movement.

2.1 Mathematical Equation and Circuit Simulation

A triplex single-acting pump is used in this study. The triplex piston pump exhibit typical flow variations in the delivery and suction caused by the rotary motion of the electric motor, *N*, that drives the displacement volumes, V_{disp}, through the reciprocating pistons or plungers. The pump outlet flow can be represented as,

$$Q_{pump,outlet} = Q_{pump,inlet} - Q_{leakage} \quad (1)$$

The pump inlet flow can be calculated by identifying the volumetric displacement of the pump.

$$Q_{pump,inlet} = V_{disp}N \tag{2}$$

Any changes in slippage and pressure have little effect on the performance, provided that it is operating at higher rotational speeds and flow rates. The internal leakage flow, $Q_{leakage}$ is treated as laminar as,

$$Q_{leakage} = \propto \Delta P \tag{3}$$

Thus, for a triplex piston pump, the internal leakage or slip flow is shown as,

$$Q_{leakage} = SF(\Delta P) \tag{4}$$

where *SF* is the slip flow coefficient. During operation, a partial vacuum is created at the pump inlet as the piston moves. The fluid will flow into the cylinder and at this moment the liquid has chances to slip at the edge of the piston and the cylinder wall [12]. By applying the principle of continuity to the inlet and outlet pipe, the expression pump outlet, $Q_{pump,outlet}$ can be stated as,

$$Q_{pump,outlet} = V_{disp}N - SF(\Delta P) \tag{5}$$

The pump outlet flow, $Q_{pump,outlet}$, is equal to the cylinder inlet flow, $Q_{cylinder,intlet}$, as follow,

$$Q_{pump,outlet} = Q_{pump,inlet} \tag{6}$$

The velocity of the cylinder is influenced by the cylinder inlet and outlet flow, and the effective piston area, A_B. The velocity is calculated by,

$$v = \frac{Q_{cylinder,inlet}}{A_B} \tag{7}$$

The displacement of the cylinder may then be measured. The displacement of the cylinder is very important, as it is usually a factor in determining the thickness of the cookies. Thus, it can be calculated as

$$s_{cylinder} = x_{finalposition} - x_{initialposition} = vt + \frac{1}{2}at^2 \tag{8}$$

where $s_{cylinder}$ is the displacement value, $x_{finalposition}$ and $x_{initialposition}$ are the reference points for the displacement.

The circuit of the system is designed so that the machine will produce cookies in a continuous two batches assembly, two cylinders are used and assembled in a form of a Cartesian robotic manipulator, as shown in Fig. 2.

The components of the robotic manipulator are the extrusion cylinder, batch cylinder, dough compartment, vertical stand and base holder. The influence of the pump and the cylinder characteristics on the performance of the system is examined through simulation results of the proposed system. This is done before conducting a test in the future. Table 1 shows the simulated parameter used in the search for suitable displacements for both batch and extrusion cylinders. The displacement is very important as it measures the performances of the batches, and the possible thickness of the cookies. Two cases are simulated in this paper, with respect to system pressure and the flow rate of the pump. However, other effects of water hydraulics system, such as the effect of pressure transient and water hammer [15] are not simulated in this paper.

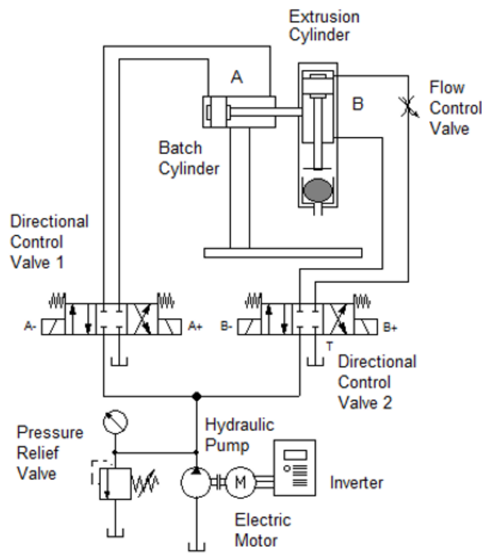


Fig. 2. Circuit Simulation

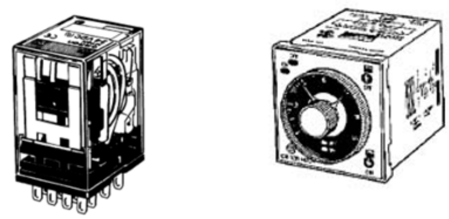
Table 1
Simulated Parameter

Parameter	Case 1 (Constant Pressure, Variable Flow)			Case 2 (Variable Pressure, Constant Flow)		
Pressure	5 bar	5 bar	5 bar	5 bar	7.5 bar	10 bar
Flow Rate	5 lpm	7.5 lpm	10 lpm	5 lpm	5 lpm	5 lpm
Slip Flow Coefficient	0.004 lpm/bar					
Piston Diameter	40 mm					
Cylinder Stroke	125 mm					

Figure 3 shows typical general-purpose relay and timer used in the control panel. The design of the control circuit will include a semi-automatic control, where the operator can control the production mode manually or automatically. The electrical circuit is based on the electro-water hydraulics system, arranged in ladder diagram schematics.

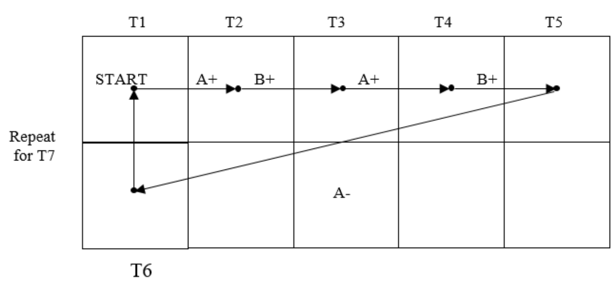
The sequence of the circuit can be represented by using a Karnaugh map. [15]. The sequence is controlled by a control panel, which is divided into three controller circuits. The circuits are known as the main circuit, automatic/semi-automatic circuit and timer circuit. The sequence of the operation will be of A+ B+ A+ B+ A- repeat.

The batch cylinder A will firstly extend, and later followed by the extension of extrusion cylinder B. After the first extrusion of a cookie, the extrusion cylinder B stops, and the sequence continues with the second extension of batch cylinder A. The process is again followed by the extrusion cylinder B, where a second batch of cookie is extruded. Later, the batch cylinder A returns to its original fully retraction position, before continues to the next cycle. The whole movement in the simulation is controlled by 7 timers, designated as T1 until T7. **Figure 4** shows the Karnaugh Map Sequence for the whole automatic operation sequence.



(a) (b)

Fig. 3. (a) General purpose relay (4 contact) (b) Timer (2 contact)



T1 = Timer Coil 1
T2 = Timer Coil 2
T3 = Timer Coil 3
T4 = Timer Coil 4
T5 = Timer Coil 5
T7 = Timer Coil 7

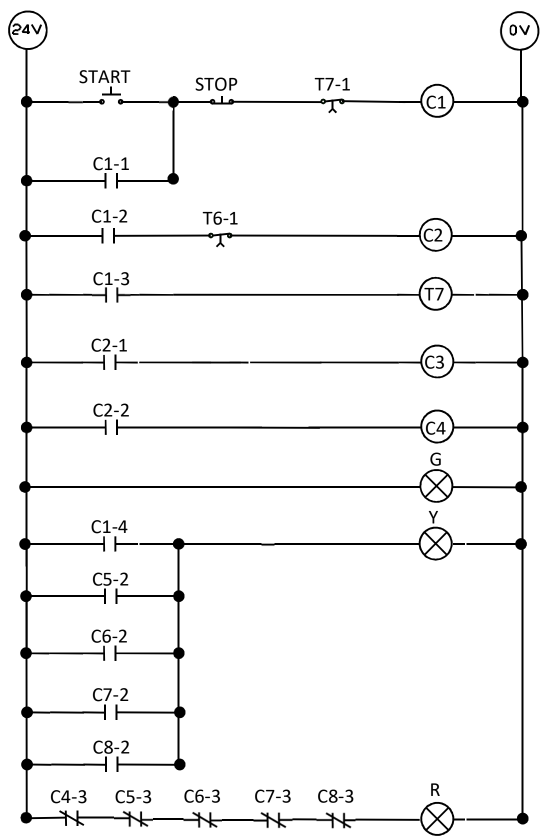
A+ = Batch Cylinder extends
A- = Batch Cylinder retracts
B+ = Extrusion Cylinder extends
B- = Extrusion Cylinder retracts
T6 = Timer Coil 6

Fig. 4. Karnaugh Map Sequence of A+ B+ A+ B+ A- repeat

2.1.1 Circuit design and arrangement

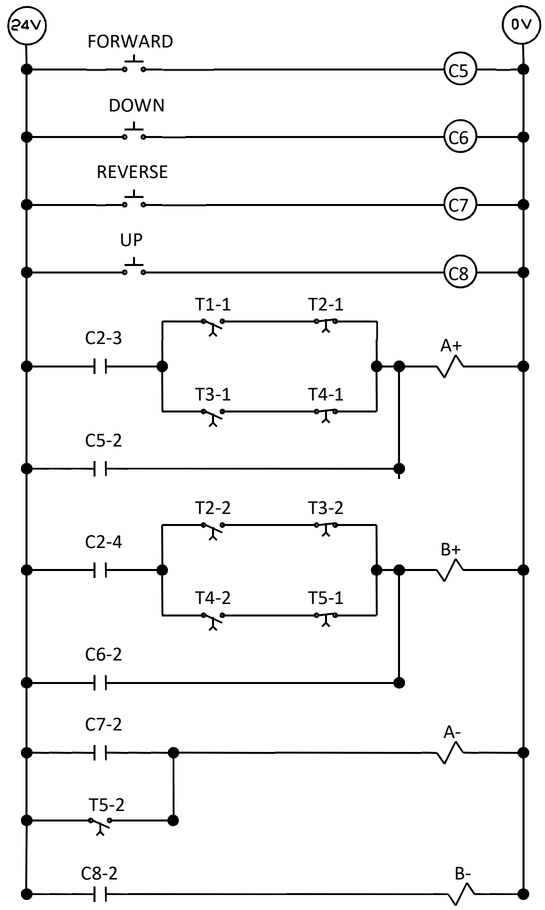
Ladder diagram is used in the circuit design and arrangement. In the main controller circuit, as shown in Figure 5, the simulated automatic control operation mode can be selected by momentarily pressing against the push button START, that will send impulse current to the relay coil C1. The relay coil C1 will energize four normally open (NO) contact of relay C1. The contact designated as C1-1 will latch the push button START. The parallel C1-1 contact is sometimes referred to as seal-in contact, whereby the word "seal" meaning essentially the same thing as the word latch. This will allow the operator to momentarily push the START push button, allowing the system to work automatically. The relay contact C1-2 will energize relay coil C2. The relay contact C1-3 will energize timer coil T7. The timer controls the overall time for the sequence of the machine. The relay coil C2 is responsible to energize relay coil C3 and C4. Both relays act as the master relay that controls the overall automation of the cookies production from the timer controller circuit.

In the automatic/semi-automatic controller circuit in Figure 6, relay coil C5 to C8 is used to manually control the movement cycle of batch and extrusion cylinders. This is possible using FORWARD, REVERSE, UP and DOWN push buttons. The same relays also light the yellow indicator, which indicates an active system. When relay coil C2 in the main controller circuit is energized, the activated normally open relay contact C2-1 and C2-2 will energize relay coil C3 and C4. Both relays are used to control the timer controller circuit, which apparently control the automatic cycle of the cylinders. Once the relay coil C3 is energized, it will activate relay contact C3-1, C3-2, C3-3 and C3-4 which will energize timer T1 until T4. Simultaneously, relay contact C4-1 and C4-2 will energize timer T5 and T6 located in the circuit, as shown in Figure 7. In the timer controller circuit, timer coil T1 until T6 basically control the extension and retraction of batch cylinder and extrusion cylinder. All timers are using delay-on mode, with T1 and T3 is used to control the batch cylinder extension (A+), T2 and T4 control extrusion cylinder extension (B+) and T5 and T6 is used to control the batch cylinder retraction. T7 is to control the whole repeating cycle, until extrusion cylinder is fully extended. Note that there is no automatic return for extrusion cylinder. The system is designed so that the extrusion cylinder can be manually controlled for new dough insertion.



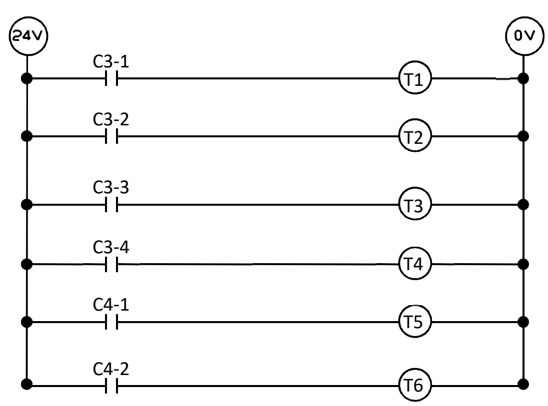
Designation	Description
0V	Electrical Connection 0 Volt
24V	Electrical Connection 24 Volt
C1	Relay Coil
C1-1	Normally Open Contact
C1-2	Normally Open Contact
C1-3	Normally Open Contact
C1-4	Normally Open Contact
C1	Relay Coil
C1-1	Normally Open Contact
C1-2	Normally Open Contact
C1-3	Normally Open Contact
C1-4	Normally Open Contact
C2	Relay Coil
C2-1	Normally Open Contact
C2-2	Normally Open Contact
C3	Relay Coil
C4	Relay Coil
C5-2	Normally Open Contact
C6-2	Normally Open Contact
C7-2	Normally Open Contact
C8-2	Normally Open Contact
T7	Timer Coil
T6-1	Normally Close Contact
T7-1	Normally Close Contact
C4-3	Normally Close Contact
C5-3	Normally Close Contact
C6-3	Normally Close Contact
C7-3	Normally Close Contact
C8-3	Normally Close Contact
R	Red Light Indicator (Off)
G	Green Light Indicator (On)
Y	Yellow Light Indicator (Active)
START	Normally Open Push button
STOP	Normally Close Push Button

Fig. 5. Main controller circuit with description



Designation	Description
0V	Electrical Connection 0 Volt
24V	Electrical Connection 24 Volt
C5	Relay Coil
C6	Relay Coil
C7	Relay Coil
C8	Relay Coil
C2-3	Normally Open Contact
C2-4	Normally Open Contact
C5-2	Normally Open Contact
C6-2	Normally Open Contact
C7-2	Normally Open Contact
C8-2	Normally Open Contact
T1-1	Normally Open Contact
T1-2	Normally Close Contact
T2-1	Normally Close Contact
T2-2	Normally Open Contact
T3-1	Normally Open Contact
T3-2	Normally Close Contact
T4-1	Normally Close Contact
T4-2	Normally Open Contact
T5-1	Normally Close Contact
T5-2	Normally Open Contact
T7-1	Normally Close Contact
T7-2	Normally Open Contact
FORWARD	Batch Cylinder Manual Extension
DOWN	Extrusion Cylinder Manual
REVERSE	Batch Cylinder Manual Retraction
UP	Extrusion Cylinder Manual Upward
A+	Batch Cylinder Automatic
B+	Extrusion Cylinder Automatic
A-	Batch Cylinder Automatic
B-	Extrusion Cylinder Automatic

Fig. 6. Automatic/Semi-automatic controller circuit with description



Designation	Description
0V	Electrical Connection 0 Volt
24V	Electrical Connection 24 Volt
T1	Timer Coil
T2	Timer Coil
T3	Timer Coil
T4	Timer Coil
T5	Timer Coil
T6	Timer Coil
C3-1	Normally Open Contact
C3-2	Normally Open Contact
C3-3	Normally Open Contact
C3-4	Normally Open Contact
C4-1	Normally Open Contact
C4-2	Normally Open Contact

Fig. 7. Timer controller circuit with description

2.1.2 Automatic circuit operation

Once the push button is pushed momentarily, it takes about 1 seconds for the timer coil T1 to energize. After that, the normally open (NO) timer contact T1-1 will be activated, together with the already activated normally open (NO) relay contact C2-3. This will energize solenoid A+, which will switch the position of 4/3-way directional control valve DCV1 controlling the batch cylinder. The batch cylinder will extend for 1 seconds, before timer coil T2 is energized. Once energized, it will activate both normally close (NC) timer contact T2-1 and normally open (NO) timer contact T2-2. The action will de-energize solenoid A+, and thus allowing the return spring in the 4/3-way directional control valve DCV1 to move the spool into a neutral position. This will halt the movement of the batch cylinder, after being displaced for some value. At the same time, the activation of normally open (NO) timer contact T2-2 will energize solenoid B+, thus switching the position of 4/3-way directional control valve DCV2 which controls the extension of the extrusion cylinder. The extension will push the dough into the nozzle extrusion die for 1 second. At this instance, the time has accumulated for a total of 3 seconds. At t = 3s, timer coil T3 is energized. This will activate both normally open (NO) timer contact T3-1 and normally close (NC) timer contact T3-2. The activation of timer contact T3-1 will again energize solenoid A+, and at the same time de-energize solenoid B+ in the automatic/semi-automatic controller circuit. This will halt the extension of the extrusion cylinder, after some displacement. Simultaneously, batch cylinder begins to extend from the previous position. The batch cylinder will again extend for 1 seconds, before timer coil T4 is energized at t = 4s. Once energized, it will activate both normally close (NC) timer contact T4-1 and Normally Open (NO) timer contact T4-2. The action will again de-energize solenoid A+, and thus allowing the return spring in the 4/3-way directional control valve DCV1 to move the spool into a neutral position. This will again halt the movement of the batch cylinder, after being displaced for another distance. The whole batch cylinder extension should provide a displacement no more than 125 mm. Concurrently, the activation of normally open (NO) timer contact T4-2 will energize solenoid B+, thus switching the position of 4/3-way directional control valve DCV2 which controls the extension of the extrusion cylinder. The extension will push the dough into the nozzle extrusion die for another 1 second. At this instance, the time has accumulated for a total of 5 seconds. For t = 5s, timer coil T5 will energize. This will activate both normally close (NC) timer contact T5-1 and normally open (NO) timer contact T5-2. The activation of normally close (NC) timer contact T5-1 will de-energized solenoid B+ for the second time. The extension of the extrusion cylinder will stop, leaving another displacement, after extending to certain distance. Simultaneously, the activation of normally open (NO) timer contact T5-2 will energize solenoid A-. This will result in the retraction of the batch cylinder. T6 must be set to a suitable time to make sure that the batch cylinder is fully retracted, before a new cycle is released. At this moment, two cookies should have been extruded. The normally open (NO) relay contact T6-1 basically controls the returning of batch cylinder to the full retraction condition, The normally close (NC) timer contact T6-2 basically will reset the relay coil C2, before moving into the next cycle. Each time the cylinders move, the green indicator will be on, together with the yellow indicator. When the T7 reaches the allocated time, the normally close (NC) timer contact T7-1 will be activated and will stop the operation of the batch cylinder. At the same time, the normally close (NC) timer contact T4-3 will be de-activated, and the green and red indicator will be on, while the yellow indicator will be off.

2.2 Experimentation and Operational Test

Figure 8 shows the PLC unit used in the experimentation. It is basically a small computer to compute the automatic program for the food processor system.

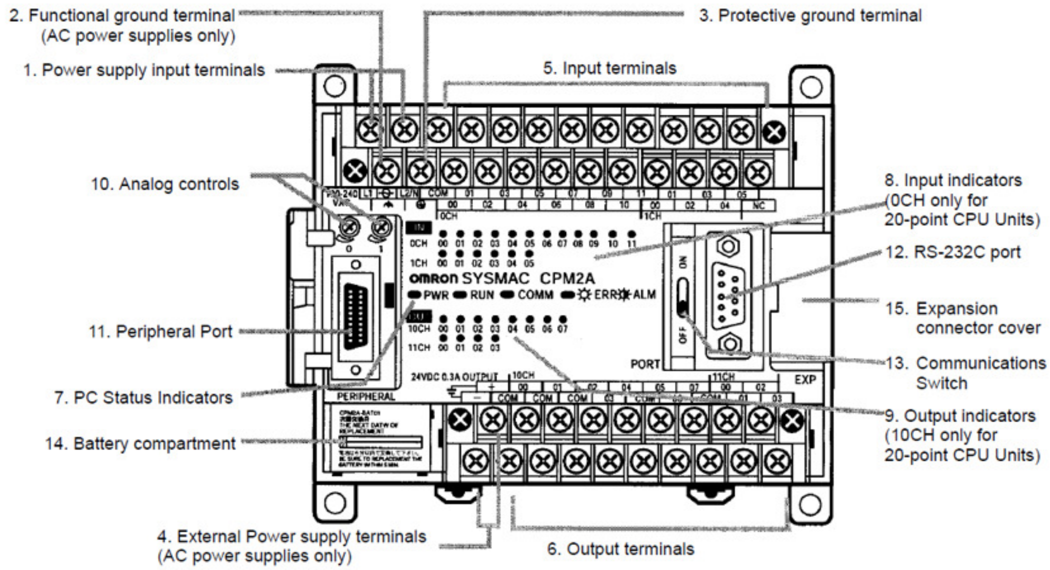


Fig. 8. CPM2A PLC from Omron

2.2.1 Programmable Logic Circuit design

In terms of practicality, PLC is more reliable than using timer and relays because timer and relays in plc exist virtually it is easier to adjust the number of timer and relay used whereas physical relays need to be hardwired to a board causing longer installation process. In order to operate the PLC, a series of code must be arranged in a software. The code is transferred from the simulated ladder diagram circuit in the previous Section 2.1. Ladder diagram is another translation of electro circuit. Because of this designing the code is just translating the previous electrical schematic diagram into a ladder diagram. The PLC used in this research is the CPM2A from Omron and the software for it is CX ONE. PLC needs to be connected physically through a 24 – 240 V connections or also known as I/O ports. The PLC is placed on a board similar to timer relay circuit board. The bracket for previous board has already been installed but the size of the hole is different so new hole is drilled on the PLC circuit board.

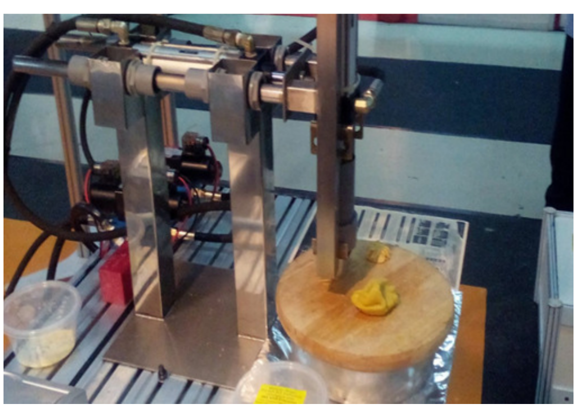


Fig. 9. Food Processor Machine and the PLC circuit board

Fig. 10. The PLC Setup and the Controller Buttons

2.2.2 PLC circuit and operation

The PLC circuit shown from Figure 11 to Figure 13 are the circuits which are built using the CX ONE programming software, as a tool for circuit arrangement and simulation. Circuit constructed in FluidSIM is not in the correct format for CX ONE software analysis. Thus, the circuit is rebuilt and remodified, for PLC application. The PLC computing unit that has been used in this project is CPM2A that reads the ladder diagram one by one from start till the end.

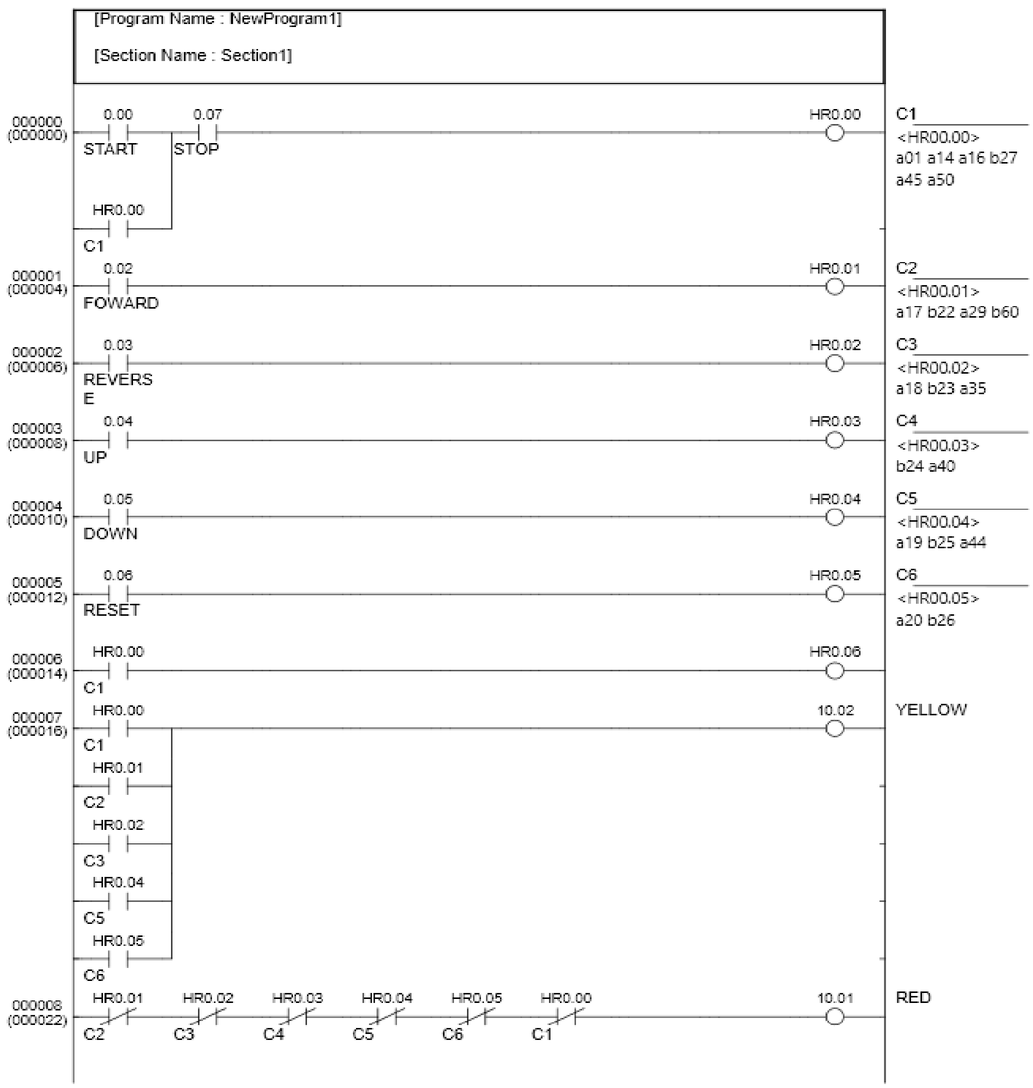


Fig. 11. PLC Programming for Main Controller Circuit

When the normally open (NO) start button is pushed, it will close the circuit, and the current will pass through both START and STOP push button, and finally will activate C1. After being charged it will allow current to past through it and charge TIMER 1. At the same time, C1 will allow current to flow through and energize solenoid B+ which will make the extrusion cylinder move downwards for 1 s. When t = 1 s, TIMER 1 will be charged and activates the timer switch at ladder 12 switching it from (NC) to (NO) which prevent current from charging solenoid B+ making it stop moving but at the same time will result in the energization of timer switch for TIMER 1 in ladder 9, changing it from (NO) to (NC). This will energize solenoid A+ and making the batch cylinder extend. Simultaneously, at ladder 14, switch for TIMER 1 will change from (NO) to (NC), allowing current to pass through and TIMER 2 will be charged for 1 s. After that, the accumulated time is t = 2s and timer switch for TIMER 2 will change from (NC) to (NO), resulting in the inability of the current to pass through solenoid A+. Thus, this resulted in the stopping of the extrusion cylinder. At the same instance, timer switch on ladder 13 for TIMER 2 will be activated, changing it from (NC) to (NO), and thus resetting the time for TIMER 1. After this, accumulated time is t = 3 s and TIMER 1 is being recharged, thus repeating the previous process. Each time solenoid A+ is energized, it will activate COUNTER 1.

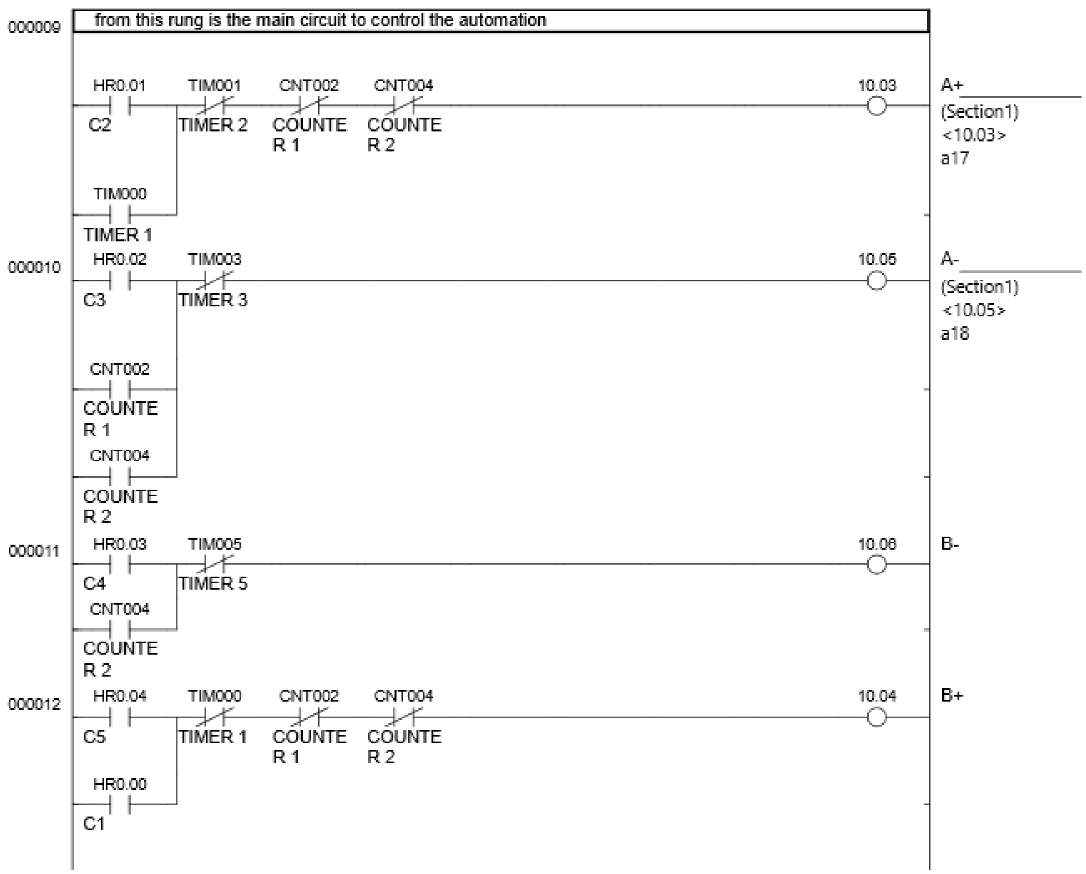


Fig. 12. PLC Programming for Timer Controller Circuit

When the counter has a count of 1 time, the counter switch at ladder 16 will then change from (NO) to (NC) and charge TIMER 3 for 1 second. In the meantime, counter switch at ladder 10 will activate and change from (NO) to (NC), which then energized solenoid A-. This will then move the batch cylinder back to its original position. Time accumulated is now 4s. Each time solenoid A- is energized, COUNTER 2 will be activated. COUNTER 2 has been set to 4 counts, thus this process will repeat 4 times. After COUNTER 2 has a count till 4, it will then activate counter switch on ladder 18 and 11 changing both switch from (NO) to (NC). At this moment, total time is t = 16 s. For counter switch on ladder 18 it will charge TIMER 5 for 12 seconds, whereas for counter switch on ladder 11 it will energize solenoid B- making the extrusion cylinder retracts for 12 s returning to initial position and thus resetting the process. The total time for 1 complete process is 28 seconds.

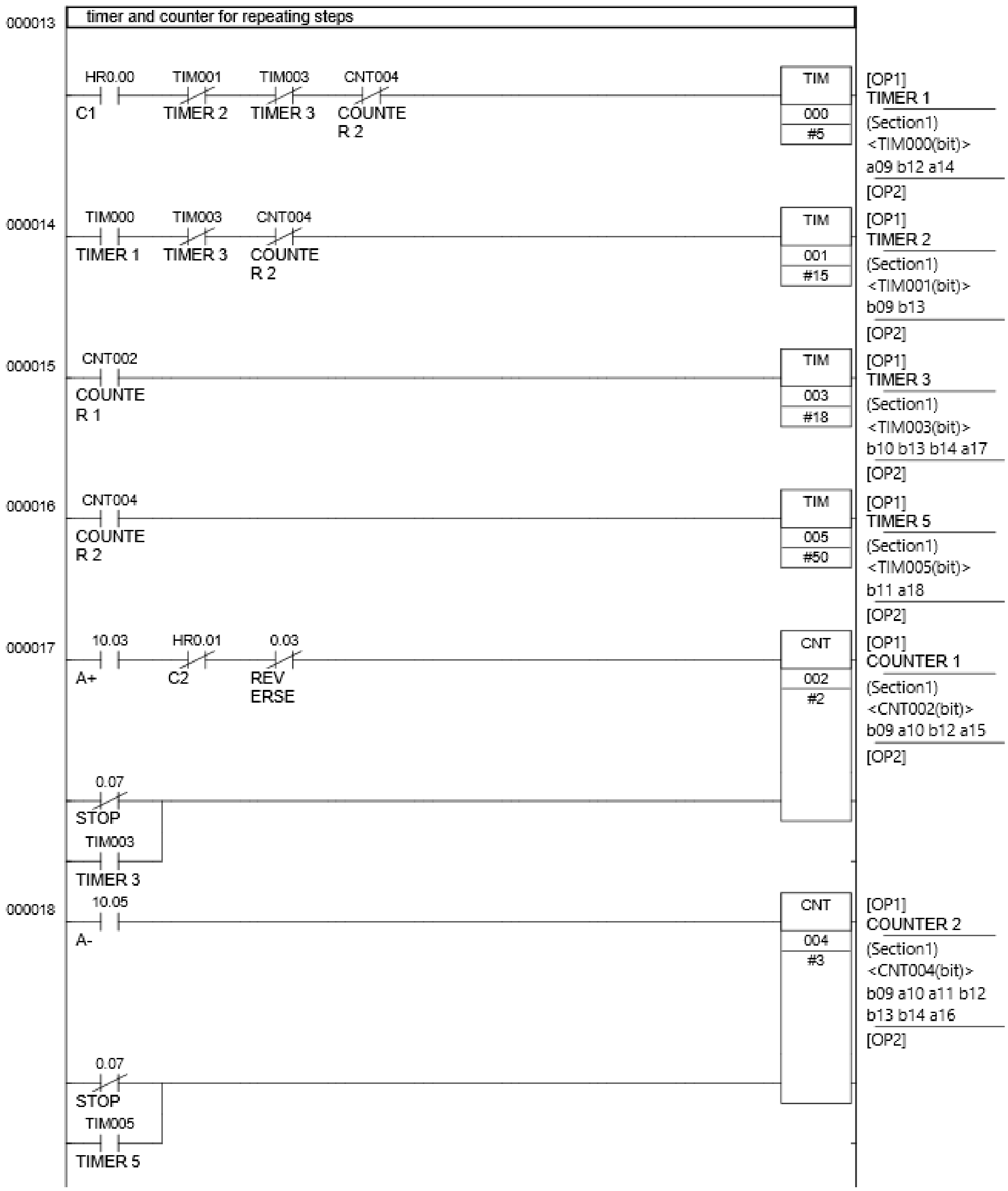


Fig. 13. PLC Programming for Automatic/Semi-automatic controller

3. Results and Discussions

3.1 Simulation Result

Table 3 shows the result of the simulation of ladder circuit. The simulation parameter is set at 5 bar, 7.5 bar and 10 bar of pressure. The flow is set at 5, 7.5 and 10 liter per minutes, which goes into the batch cylinder. About a quarter of the flow goes into the extrusion cylinder, since the opening of the flow control valve is set at 25% opening. The maximum stroke of the cylinder is 125 mm, while the diameter of the piston is set at 40 mm. The increment of 1 second is introduced to all timers, from timer coil T1 until T5. T6 is set for 8 s, while T7 is set for 50s. In Case 1, the result shows that a constant of 12 cookies can be produced, even if the flow rate is increased. However, an increasing displacement of batch cylinder is noticeable, with the increase of flow rate. It is noted that the space between two cookies per cycle will be reduced, during the extrusion. The result also shows that, in Case 2, the increase in pressure reduces the cycles of the batch cylinder. Thus, the amount of the produce cookies is also reduced, but with an increase in thickness. This is due to the increase of extrusion cylinder displacements.

Table 2
Description of Contact and Address in the PLC programming

Contact	Address
Start button (START)	0.00
Stop button (STOP)	0.07
Limit switch 1 (FORWARD)	0.02
Limit switch 2 (REVERSE)	0.03
Limit switch 3 (UP)	0.04
Limit switch 4 (DOWN)	0.05
Limit switch 5 (RESET)	0.06
Relay 1 (C1)	HR0.00
Relay 2 (C2)	HR0.01
Relay 3 (C3)	HR0.02
Relay 4 (C4)	HR0.03
Relay 5 (C5)	HR0.04
Relay 6 (C6)	HR0.05
Relay 7 (C7)	HR0.06
Timer 1	TIM000
Timer 2	TIM001
Timer 3	TIM003
Timer 4 (TIMER 5)	TIM005
Counter 1	CNT002
Counter 2	CNT004
Yellow LED (YELLOW)	10.02
Green LED (GREEN)	10.07
RED LED (RED)	10.01
Solenoid A+	10.03
Solenoid A-	10.05
Solenoid B+	10.06
Solenoid B-	10.04

Table 3
Simulated Result using FLUIDSIM Ladder Diagram

Parameter	Case 1			Case 2		
Pressure	5 bar	5 bar	5 bar	5 bar	7.5 bar	10 bar
Flow Rate	5 lpm	7.5 lpm	10 lpm	5 lpm	5 lpm	5 lpm
Possible Cycles	6 cycles	6 cycles	6 cycles	6 cycles	5.5 cycles	4 cycles
Possible Cookies	12 cookies	12 cookies	12 cookies	12 cookies	10 cookies	8 cookies
Extrusion Cylinder Displacement/	11.04 mm	11.04 mm	11.04 mm	11.04 mm	13.43 mm	15.5 mm
Batch Cylinder 1st Displacement	66.66 mm	73.28 mm	73.29 mm	66.66 mm	66.73 mm	66.81 mm
Batch Cylinder 2nd Displacement	122 mm	125 mm	125 mm	122 mm	124.86 mm	125 mm

3.2 PLC Experimentation Result

The result of this experimentation is shown in Table 4. In this experiment, the pressure is set to at constant 5 bar. The flow rate of the water hydraulics in the system is represented by the variable frequency setup used in the experiment. The machine is equipped with frequency inverter which controls the motor speed by adjusting the electrical frequency. The maximum stroke of the cylinder is 125 mm, while the diameter of the piston is set at 40 mm. The increment of 1 second is set to all timers inside the PLC. The result shows that 12 cookies can be produced if the frequency is set to 10.5 Hz, while for 11.5 Hz and 12.5 Hz can only produce up till 10 cookies. However, the cookies made by higher frequency is much more attractive. In terms of the cookies mass and size, the one produced by higher frequency is much more acceptable.

Table 4
Experimentation Result using CPM2A Omron PLC

Parameter	Case 1		
Pressure	5 bar	5 bar	5 bar
Frequency	10.5 Hz	11.5 Hz	12.5 Hz
Possible Cycles	6 cycles	6 cycles	6 cycles
Possible Cookies	12 cookies	10 cookies	10 cookies
Extrusion Cylinder Displacement/	11.04 mm	11.04 mm	11.04 mm
Batch Cylinder 1st Displacement	63.88 mm	70.45 mm	75.66 mm
Batch Cylinder 2nd Displacement	122.45 mm	125 mm	125 mm

4. Conclusions

This study proposes a low-cost water hydraulics food processor for Malaysian traditional cookies production. The objective of this paper is to introduce the design and the working principle of the food processor, and to present the fundamental characteristics by circuit simulation. The operational of an automatic food processor is also tested, while the quality of the produced cookies is observed. In the simulation of the ladder diagram circuit, the cylinder displacement depends on the flow rate from the pump, the flow rate that goes into each cylinder, the cylinder piston size, the cylinder rod size and the time delay setting of the individual timers. The result shows that the increase in pressure will reduce the production amount of the cookies and increase the thickness. The maximum number of cookies that can be produced is 12 cookies, in a maximum of 6 cycles. The cookies made by higher frequency is much more attractive in texture term. In terms of the cookies mass and size, the one produced by higher frequency is much more acceptable.

Acknowledgments
This work was funded by Ministry of Higher Education (MOHE) of Malaysia, under the Fundamental Research Grant Scheme (FRGS). FRGS/1/2016/TK03/FKM-CARE-F00317. The authors wish to thank Mr. Ariff Shazal Mohd Salim for his contribution in the simulation and experimentation of the project.

References
[1] Trostmann, Erik, Bo Frolund, bo hojris Olesen, and Bjarne Hilbrecht. *Tap Water as a Hydraulic Pressure Medium*. New York: Marcel Dekker, 2001.
[2] Krutz, Gary W, and Patrick S K Chua. “Water Hydraulics – Theory and Applications 2004 by.” *Workshop on Water Hydraulics, Agricultural Equipment Technology Conference (AETC’04)*, 1–33.Louisville, Kentucky. United States. 2004.
[3] M. Higgins. “Water Hydraulics – The Real World.” *Industrial Robot: An International Journal* 23, no. 4 (1996): 13-18.
[4] G. H. Lim, P. S. K. Chua, Y. B. HE. “Modern water hydraulics- The New Energy Transmission Technology in Fluid Power.” *Applied Energy* 76 (2003): 239-246.
[5] Finn Conrad. “Trends in Design of Water Hydraulics – Motion Control and Open-Ended Solutions.” *Proceedings of the 6th JFPS International Symposium on Fluid Power*, Tsukuba, Japan (2005): 420-430.
[6] W. Backe. “Water or Oil Hydraulic in The Future.” *The Sixth Scandinavian International Conference on Fluid Power, SICFP’99*, Tampere, Finland (1999): 51-65.
[7] Ahmad Anas Yusof, Shafizal Mat, Abdul Talib Din. “Promoting Sustainability through Water Hydraulics Technology: The Effect of Water Hydraulics in Industrial Scissor Lift.” *Applied Mechanics and Materials*, 315 (2013): 488-492
[8] Ahmad Anas Yusof, Faizil Wasbari, Mohd Qadafie Ibrahim. “Research Development of Energy Efficient Water Hydraulics Manipulator for Underwater Application.” *Applied Mechanics and Materials*, 393 (2013): 723-728.
[9] P. N. Pham, K. Ito, S. Ikeo. “Energy Saving for Water Hydraulic Pushing Cylinder in Meat Slicer.” *JFPS International Journal of Fluid Power System*, Vol. 10, No. 2 (2017): 24-29
[10] Zarin Shukri Zaili, Ahmad Anas Yusof, Nor Fathiah Mohd Nor, M. H. M Hanafi, Mohd Qadafie Ibrahim. “Characteristics of a Reciprocating Pump for Low-Cost Sustainable Water Hydraulic Technology Demonstrator.” *Applied Mechanics and Materials*, 699 (2015): 736-741.
[11] Saiful Akmal Sabaruddin, 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*, Vol. 12, No. 16, (2017): 4824-4830.
[12] Ahmad Anas Yusof, Faizil Wazbari, Mohd Shukri Zakaria, Mohd Qadafie Ibrahim. “Slip Flow Coefficient Analysis in Water Hydraulics Gear Pump for Environmental Friendly Application.” *IOP Conf. Series: Materials Science and Engineering*, 50. (2013):
[13] C. A. Fairfield. “Spatial, Temporal, and Thermal Analysis of a Cavitating High-Pressure Water-Jet”. *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 18 (2016): 1-19
[14] Avvaru Ravi Kiran, B. Venkat Sundeep, Ch. Sree Vardhan, Neel Mathews. “The Principle of Programmable Logic Controller and its role in Automation.” *International Journal of Engineering Trends and Technology* 4, Issues 3 (2013):
[15] B. J. Callear, M. J. Pinches. Power Pneumatics. Prentice Hall, 1997.