Design and analysis of hydraulic ram water pumping system

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Abstract. The current pumping system (DC water pump) for agriculture is powered by household electricity, therefore, the cost of electricity will be increased due to the higher electricity consumption. In addition, the water needs to be supplied at different height of trees and different places that are far from the water source. The existing DC water pump can pump the water to 1.5 m height but it cost money for electrical source. The hydraulic ram is a mechanical water pump that suitable used for agriculture purpose. It can be a good substitute for DC water pump in agriculture use. The hydraulic ram water pumping system has ability to pump water using gravitational energy or the kinetic energy through flowing source of water. This project aims to analyze and develop the water ram pump in order to meet the desired delivery head up to 3 meter height with less operation cost. The hydraulic ram is designed using CATIA software. Simulation work has been done using ANSYS CFX software to validate the working concept. There a three design were tested in the experiment study. The best design reached target head of 3 m with 15% efficiency and flow rate of 11.82 l/min. The results from this study show that the less diameter of pressure chamber and higher supply head will create higher pressure.

1. Introduction

The hydraulic ram is used for agriculture purpose and it can be a good substitute for DC water pump. Hydraulic ram water pumping system is operated automatically without using any external energy. The device is called as hydraulic ram pump has the ability to pump the water to a certain height with no external energy. It uses only the potential energy of the water such as spring, stream or river which caused by the gravitational force [1]. Basically, the system of the hydraulic ram pump consists of two basic parts which are waste valve and the delivery valve as shown in Figure 1. The system also consists of an air chamber and an air valve. Sequences processes of hydraulic ram pump are intermittent due to the opening and closing behavior of the waste and delivery valves. The behavior of hydraulic ram pump relies on water hammer phenomenon which represent on the closing and opening of the waste and delivery valves. The process begin when water entering the derive pipe coming from specific elevation height with high pressure. Therefore, the waste valve is closed by water momentum [2]. Thus, high pressure is created that will cause the delivery valve to open allowing pressurized water to rise in vacuum air chamber. Therefore, the air chamber will pressurize the water causing delivery valve to close and air valve will open allowing water to rise through delivery pipe reaching the desired place [3].

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2. Literature Review

In 2007, Shuaibu [5] has designed and fabricated hydraulic ram pump that capable to lift the water to reach 2 m of head pump from depth of 2 m below the surface without any external energy required. The supply head was 1.5 m and delivery head was 2.87 m. The result shows the volume flow rate of the derived pipe and the power was $4.5238 \times 10^{-5}$ $m^3/s$ and 1.273 kW respectively. The efficiency of this water ram is about 57.3%. The author found that the total cost for the design and fabrication of hydraulic ram pump is cheaper than the current pumps.

In addition, the other authors [6] have investigated hydraulic rams with self-built valves with two size of pressure chamber for high water supply. The aim of this investigation was to construct a reliable and low-cost ram. An efficiency of 44% was achieved for the performance of the hydraulic ram. However, there was no significant difference in in term of system efficiency for the design with the large (3.6 l) and medium size (2.3 l) pressure chamber (33.1% and 32.6%, respectively).

Besides, the result from the previous study shows that the pressure of the output increases as the drive pipe length increases. The drive pipe length of 2 meter the discharge at the outlet is maximum compared to the other two cases. This design also produces a power of 0.73 kW and the efficiency of 59.5% [4].

Furthermore, Balgude [7] presented the techniques and guidelines in designing a hydraulic ram pump. There are three essential factors need to considers in order to determine the quantity delivered by the hydraulic pump. These factors could be represented in the distance between the heights of the water source to the ram pump level, the distance between the desired place height and the ram pump and the volume of water source which are the basic factors of hydraulic ram pump.

The current pumping system is powered by household electricity (AC water pump) and the cost will be increased due to the higher electricity consumption. In some cases in the agricultural field, the water needs to be supplied at different height of trees and different places that are far from the water source. Besides, the existing DC water pump only can pump the water to 1.5 m height. Therefore, a water ram pumping system is proposed to deliver the water at height higher than 1.5 m.

**Figure 1.** Hydraulic water pumping system configuration [4].
3. Methodology

3.1. Hydraulic Ram Design Parameter
A number of parameters is considered in designing hydraulic ram water pump. The parameters including volumetric flow rate (Q), velocity of the fluid flow (V_d), power (P) and the system efficiency (\eta). The data from the experiment is needed in order to validate with theoretical knowledge. These data can be calculated using Equation (1) to (4).

\[ Q = \pi r^2 L n/60 \]  
\[ V_d = Q / A_d \]  
\[ P = \rho g h Q \]  
\[ \eta = (H Q_{out})/(F Q_{in}) \times 100 \]

Where Q represent flow rate, r is radius of the pipe, L is length of the pipe and n is speed of revolution.

Where \( V_d \) indicates the velocity of fluid, \( Q \) if fluid flow rate and \( A_d \) is area of the pipe.

\[ P = \rho g h Q \]

Where \( \rho \) is density of fluid, \( g \) is acceleration of gravity and \( h \) is net head

\[ \eta = (H Q_{out})/(F Q_{in}) \times 100 \]

Where \( H \) is a delivery head, \( Q_{out} \) is the outlet flow rate, \( F \) is the supply head and \( Q_{in} \) is the inlet flow rate.

3.2. Simulation study
The simulation study divided into design and analysis stage. The hydraulic ram pumping system modeling have been design using CATIA software as shown in Figure 2. The analysis study for pressure, velocity and volume of water and air inside the system have been done using ANSYS CFX software.

![Figure 2](image-url) System design using CATIA software.
3.3. Experimental work
The experiment rig as shown in Figure 3 have been set up at Universiti Malaysia Perlis Main Campus, Arau, Perlis. There are 3 designs with different diameter and volume of the pressure chamber have been tested for this experiment. All the parameters of the designs as listed in Table 1 are similar except the diameter and volume of the pressure chamber.

![Figure 3. Experimental set up]

Table 1. Design Specification

| Parameter                      | Design 1 | Design 2 | Design 3 |
|-------------------------------|----------|----------|----------|
| Supply head (m)               | 1.8      | 1.8      | 1.8      |
| Delivery head (m)             | 3        | 3        | 3        |
| Minimum delivery head (m)     | 2.85     | 2.75     | 2.6      |
| Number of pushes on waste valve| 1        | 7        | 9        |
| Drive pipe length (m)         | 2.25     | 2.25     | 2.25     |
| Delivery pipe length (m)      | 4        | 4        | 4        |
| Inlet pipe diameter (mm)      | 32       | 32       | 32       |
| Outlet pipe diameter (mm)     | 19.05    | 19.05    | 19.05    |
| Pressure chamber diameter (inch) | 2        | 3        | 4        |
| Pressure chamber volume (l)   | 1.013    | 4.56     | 4.05     |
4. Results and discussion

4.1. Simulation results
Simulation analysis has been done using ANSYS CFX software. The analysis including the pressure, velocity behavior and also the volume of water inside the hydraulic ram pump system. Figure 4 shows the pressure simulation results for the hydraulic ram pump. The inlet side has the highest pressure with red colour which means high pressure area. Then the water pressure dropped relatively after falling down to the critical part of the system causing the waste valve to close and check valve to open to allow water to enter the pressure chamber. Inside the pressure chamber water will be pressurized in order to go out to through outlet pipe to be raised to certain height.

![Figure 4. Pressure simulation result using ANSYS CFX software.](image_url)

Figure 5 illustrates the velocity behavior of the hydraulic ram pump. Water enter the inlet pipe with relatively high velocity which indicated by green color. After that velocity drops until reaching the pressure chamber. Water velocity will be increased by going up to the outlet pipe which indicated by blue color.
Figure 5. Velocity simulation result using ANSYS CFX software.

Figure 6 shows the volume of water inside the hydraulic ram pump system which indicated by blue colour. Also the figure illustrates the air volume inside the pressure chamber by white colour. Water enters to pressure chamber which will compress the air until a point that the air cannot be compressed anymore so that will pressurize the water causing it to get out to outlet pipe.

4.2. Experimental results
The experiment results are divided into 3 design configuration as shown Table 2. Design 1 has reached target head of 3 m with 15% efficiency and flow rate of 11.82 L/m. Design 2 also has achieved the target head with 14% efficiency and 10.8 L/m flow rate. For design 3, even though it could reach target head but it has less efficiency with 13% and flow rate of 10 L/m. Therefore, Design 1 is the best design.
Table 2. Experimental result

| Parameter               | Design 1       | Design 2       | Design 3       |
|-------------------------|----------------|----------------|----------------|
| Flow rate, Q            | 11.82 l/min    | 10.82 l/min    | 10.2 l/min     |
| Velocity, V             | 0.69 m/s       | 0.65 m/s       | 0.59 m/s       |
| Reynolds number (Re)    | 1.83×10⁴       | 1.72×10⁴       | 1.59×10⁴       |
| Friction factor (f)     | 0.027          | 0.027          | 0.028          |
| Head loss (Hₜ)          | 0.138 m        | 0.13 m         | 0.11 m         |
| Pressure drop (AP)      | 1.35 kPa       | 1.2 kPa        | 1.06 kPa       |
| Pumping Power (P)       | 2.3 W          | 2.2 W          | 2 W            |
| Potential energy (PE)   | 32 J           | 32 J           | 32 J           |
| Efficiency (η)          | 15%            | 14.4%          | 13.1%          |

4.3. Discussion

The experiment work has been done inside the area with limited source of water which is different from the running source (river, pond etc.). There are 3 basic designs have been set for this experiment. All the parameters of the designs are similar except the pressure chamber diameter and volume. There are several factors were considered in the experiment which are the height of supply head, pressure chamber diameter and source of the supply source. From the observation of this experiment, the pressure chamber diameter is a critical point to increase the water pressure. The smaller pressure chamber diameter, the greater water pressure. In addition, supply head plays an essential role in hydraulic ram pump system. If the supply head is increased, the water pressure will be increased. Another important factor is the quantity of available source. The more water quantity, the more pressurized water will be. In the pre experiment attempts, water has been failed to get the target delivery head due to small amount of water source. While in the actual experiment, water could reach the target delivery head due to the large amount of water source.

Unfortunately, there were some undesired issues during the experiment which can cause other people not to use the hydraulic ram pump if these issues are not solved. One of these issues is the large amount of the waste water through the waste valve. The tank of supply source could contain 50 gallon but the outlet net volume is less than 20 gallon. So, about 30 gallon is wasted. Which means the hydraulic ram pump is more suitable for running source place rather than stable and limited amount of source. This problem also can be solved by putting a system can collect and return the wasted water to the tank. In addition, another problem occurs for the hydraulic ram pump has been observed during the experiment is the high noise resulted from the waste valve behavior by open and close. This action caused by the waste valve creates high noise which actually is unwanted by the user.
5. Conclusion
The hydraulic ram water pumping system was fabricated and tested. The simulation study also has been done using CATIA software and ANSYS CFX software to validate the working concept. Three design were tested in the experiment study. The best design reached target head of 3 m with 15% efficiency and flow rate of 11.82 l/min. The results from this study show that the less diameter of pressure chamber and higher supply head will create higher pressure.

6. Acknowledgments
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