Senior Design Project: Design, Construction and Testing of a Hydraulic Ram Pump

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Abstract

In accordance with recent ABET criteria, students should be able to "design and realize" a design project/problem. The search for design problems that can be designed and built is continuing. Constraints that should be observed in such designs include: safety, manufacturability, cost effectiveness, efficiency, reliability, and more. This paper describes the final design of a hydraulic ram pump device and steps in realizing it. Included as well are descriptions of components used in the design process and the total cost. The project was completed in a two-semester senior design class and meets ABET criteria, making it suitable for a design problem.

Keywords

hydraulic ram pump

Senior Design

Senior Design at the University of Memphis is a two-semester sequence. Students are given a project to work on and the first semester is devoted to obtaining background information on the subject. The students are required to design and realize the project. Realizing the project means that a working model or prototype will be produced. At the conclusion of the second semester, students summarize and present their work in an oral and in a written report. Faculty and the department Industrial Advisory Board are invited to grade the students on their work. The project described in this paper is the Design of a Hydraulic Ram Pump.

Project Description

The Hydraulic Ram Pump is a mechanical device that uses potential energy of water in a reservoir to pump water to a much higher elevation, and do so without electricity [1]. This project involved the construction and testing of a hydraulic ram pump as a senior design project.

Consider, for example, a village in an elevated region where people live without electricity and without water due to storm (or other) damage [2]. There may be a water source nearby but at a lower elevation. The water source (e.g. a river), can be used by the ram pump to bring water up to where the people are living. Without electricity and other sources of power, a ram pump will be able to provide drinking water where it is needed [notably 3].

Project Overview and Description

A Hydraulic Ram Pump is used to pump water uphill without electricity. These pumps are widely used because of their multiple advantages, especially in areas where electricity is not always available. The pump uses potential energy generated by momentum to pump water to a much higher elevation. Figure 1 is a sketch of a ram pump. The figure and the description following are modified from [4].

A pipe inlet is situated close to a water source (a river). Through several pipeline features (t-joints, elbows, two-way valves, and an air chamber), water is moved in the pipeline downstream to the pump (valve box).

> "When the inlet valve (not shown) fitted on the drive pipe is opened, water starts flowing from the supply tank to the pumping chamber (valve box). The chamber has two valves, "wastewater valve" and "delivery valve." The delivery valve is fitted to an air vessel. As water is flowing from the supply tank, the chamber gets filled up and the wastewater valve starts to move upwards. A moment comes when the wastewater valve suddenly closes. This sudden closure of valve creates high pressure inside the chamber. This sudden increase in pressure opens the delivery valve. The water from the chamber enters the air vessel and compresses the air inside the vessel. A small quantity of water is raised to a greater height. As the water in the chamber loses momentum, the wastewater gradually opens in downward direction and flow of water from the supply tank starts flowing to the chamber and the cycle will be repeated."

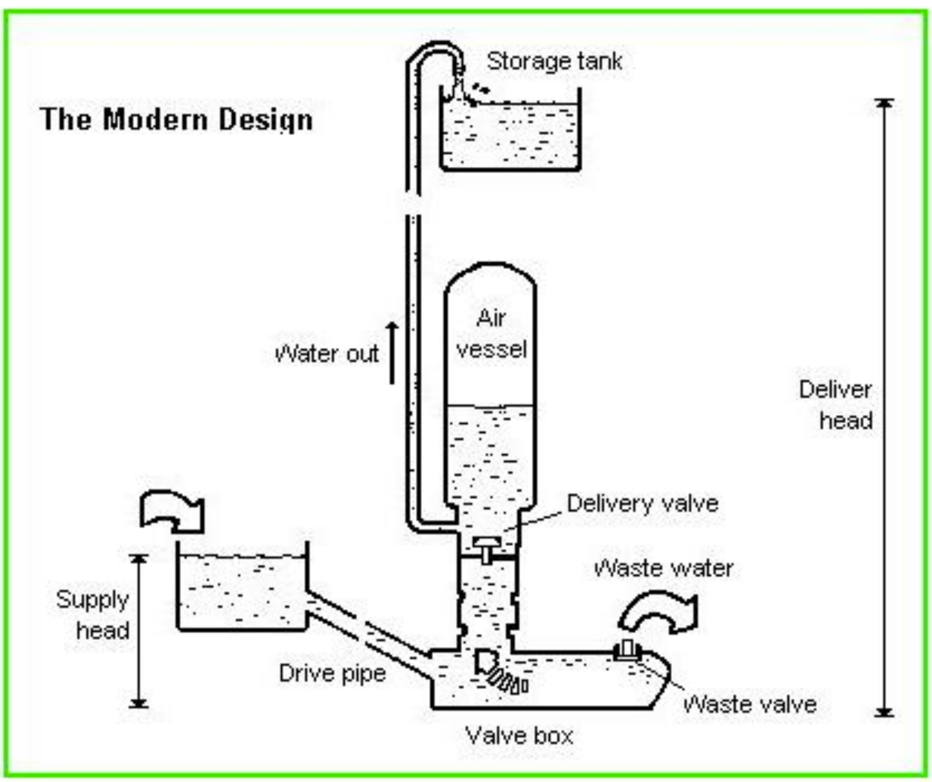

Figure 1: Design of the Hydraulic Ram Pump

Design and Constraints

Most ram pumps have only two moving parts, which makes them highly reliable and requires low maintenance efforts. Flow is controlled by the interaction of the two one-way valves. The inertia of the water in the drive pipe is what moves the water upward [5].

Students first researched the internet for existing construction details. The majority of these designs used galvanized pipe for the pipeline. Students considered this material but rejected it in favor of PVC. The cost for galvanized steel needed to build a ram pump was significantly more than the cost of PVC, whether socket or threaded. PVC met much of the criteria: manufacturability, cost effectiveness, efficiency, reliability. The coefficient of friction for PVC is negligible compared to that for galvanized steel. PVC threaded and slip fittings were both used due to the versatility of the threaded pipe when switching between different pipe sizes and the availability of the slip fittings in the correct sizes.

Two one-way valves in this system were made of brass to improve the life of the pump as these are the moving parts and will be the first parts to show any wear [6]. The main modification to an existing design is the addition of the waste water catch tank. In most applications, the waste water is just released to the environment to eventually find its way back to the body of water. Due to the constraints of being indoors in a laboratory setting, this was not a viable option. Students constructed a container to catch the water extruded by the waste water valve and direct it to a proper drain area. Also, due to the laboratory setting the flowing body of water will be imitated by a draining tank.

The original plan was to build three separate pump systems to acquire data for different sizes. This would require the students to spend an inordinate amount of time on this project, so only one pumping system could be made and modified to allow for different size pipes to be attached. This approach allowed for lower costs as well as faster change over time which in turn allowed students to perform more trials in the allotted time.

The available lab space dictated the final design: discharge (11 ft) and inlet height (2.2 ft) constants; drive pipe size, drive pipe length, delivery pipe size; air chamber size. One goal for the experiment was to see how the drive pipe affected the frequency and in turn, if it affects the flow rate. Through the research it was found that there was a correlation between cycle frequency and flow rate. The sizes that were chosen for testing are shown in Table 1.

Drive Pipe Size (in)	**Drive Pipe Length (ft)**	**Delivery Pipe Size (in)**	**Air Chamber Length (in)**
1.25	25	0.75	18
1.50	30	1.00	24

Table 1: Pipe Dimensions

A main consideration in the selection of these certain sizes was the availability of the pipe and fittings that are required. After assembly, students tested each of these variables with the pumping system to find the optimal setup as well as the effect of each variables on the frequency and flow rate. It was found that overcoming frictional head loss was the major task in improving efficiency. The next design consideration was the air chamber. The size of the air chamber is important to find the frequency of the compression and expansion of the air inside versus the frequency of the wastewater valve. The size of the chamber relies on the weight of the waste valve and length of drive pipe. The waste valve was modified to change its weight to achieve different frequencies. In addition to the size of the chamber, a viable material to fill the chamber itself was selected. A partially inflated inner-tube was inserted to ensure that the chamber does not become waterlogged. If the tube were ever to become deflated completely one could simply air it back up without having to replace the entire air chamber.

Data/Results

Students found a significant correlation between frequency and flow rate as well as between the drive pipe length and frequency. The air chamber had a specific optimum frequency regardless of the sizes of the drive and delivery pipes. Students determined other relationships as well.

Space constraints made the drive pipe length a max at thirty feet, so students opted to modify the weight of the waste valve itself to slow the frequency to an optimum value. The objective was to maximize the flow rate. With the modified waste valve, the cycle frequency is easily changed and tuned to achieve the best flow rate. There is an optimal frequency, and each air chamber size had a different optimal frequency. For example, a twenty-four-inch air chamber had an optimum frequency of 39 cycles/min while the eighteen inch air chamber preformed the best at 43 cycles/min.

The flow rate for this system is roughly 0.4 gpm. It should be noted that the efficiency of the hydraulic ram pump is usually less than 9%. That is, only 9% of the water entering the drive pipe makes its way to the 11 ft height. The rest is discharged at the one-way valve. The cost of the piping and fittings was under $100. Construction details (not provided here) may be found on the internet, as well as pipe size and pipe fittings. Details of the experimental results are as yet incomplete.

Video

The students produced a video of the ram pump while in use; and it will be shown here.

Discussion and Conclusions

The primary goal of this project was to have the students design, construct and demonstrate the workings of a hydraulic ram pump. A secondary, but not emphasized, goal was to test the pump and determine possible correlations between the variables. During the course of testing the students found that there was indeed a relation between the frequency of the cycle and the resulting flow rate of delivery water. It was found that by lengthening the drive pipe or adding weight to the waste valve one could slow the frequency. Then these results were used to find that with each air chamber there was a different optimum frequency that resulted in the highest flow rate. A flow rate of ~0.4 gpm was pumped upward to an elevation of eleven feet using around two feet of vertical drop (water level in supply tank to drive pipe inlet). The pumping design was found to have a volumetric efficiency of 9%. Further testing would be required to expand the data and determine an equation to accurately predict the optimum frequency of any size air chamber. Due to the meeting of the primary our goal, this project is determined to be a success.

The data proves that there is an optimum frequency for a given pump system and that this value is directly related to the available volume inside the air chamber.

Evaluation

Students were provided with the list of constraints regarding a "realized" design. The students were then asked to provide Lessons Learned from their self-evaluation. These were:

How to work together effectively as a group.
Important safety features of this design.
In the absence of machinery or volatile fluids, the system is deemed safe.
Using PVC as the pipe material, and assembling the system using PVC adhesive, the system is easily manufactured.
The system is not efficient, but without the need for electricity, it is very useful.
With only two moving parts, the system should operate reliability for many years.

The project and student performance were evaluated by other students, by faculty, and by members of the Industrial Advisory Board. The constraints were addressed and successfully met. The study is one that can be designed, realized and economically constructed. It is therefore concluded that it is suitable for a Mechanical Engineering Senior Design Project.

References

There are numerous ram pump articles on the internet, far too many to list here. Many of those studies have been written for the lay person wishing to build a ram pump for economic and/or environmental reasons. There are also academic studies, some of which are listed here:

1 Sampath, S.S. & Shetty, Sawan & Mathew Pendanathu, Allan & Javaid, Waleed & Chithirai Pon Selvan, M. (2015). Estimation of Power and Efficiency of Hydraulic Ram Pump with Re-circulation System. International Journal of Computer-aided Mechanical Design and Implementation. 1. 7-18. 10.21742/ijcmdi.2015.1.1.02.

2 Hydram Pump Calculations, aquatext.com/tables/hydram.htm

3 "Design of a Low Cost, Self-Operating Hydraulic Ram Pump for Water Retention and Lifting in Developing Countries: Bringing Clean Water to Haiti." *EPA*, Environmental Protection Agency, 27 Feb. 2015, cfpub.epa.gov/ncer_abstracts/index.cfm/fuseaction/display.highlight/abstract/9549/report/F.

4 https://www.brighthubengineering.com/hydraulics-civil-engineering/44729-learn-about-hydraulic-ram-pumps/

5 Teferi Taye, "A hydraulic ram pump" Journal of the Ethiopian Society of Mechanical Engineers, Vol.II, No, 1, July 1998

.6 Shende, Piyush B, and S K Choudhary. "Design and Analytical Calculation for a Hyram Using Individual Head Losses." *International Journal of Science Technology and Engineering*, vol. 2, no. 02, Aug. 2015, www.ijste.org/articles/IJSTEV2I2048.pdf.

7 T.H.Thomas," Algebraic Modeling of the Behavior of Hydraulic Ram Pumps"

Jeffrey G. Marchetta is a Professor of Mechanical Engineering at the University of Memphis. He is a lifetime senior member of the American Institute of Aeronautics and Astronautics (AIAA) and a member of the American Society of Gravitational Space Research (ASeSR). He received the AIAA Abe Berman Award for Distinguished Achievement in Research, and is the faculty advisor for the AIAA Student Branch. His research interests focus on the modeling of flows with free surfaces, having applications in the management of fluids in reduced gravity.

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