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Investigation on flow pattern in a hydraulic ram pump at various design and setting of its waste valve

M Suarda[1], M Sucipta[1] and I G K Dwijana[1]
[1]Mechanical Engineering Department, Faculty of Engineering, Udayana University, Indonesia

Email: made.suarda@unud.ac.id

Abstract. A hydraulic ram pumps are simple structures, consisting of two moving parts, the waste valve and the press valve. The waste valve mainly affects the magnitude of the impulse force generated. However, interaction of all elements of hydraulic ram pump system influence each other makes its operation becomes complex. Moreover, a detailed description of this hydraulic ram pump has not been well understood. In order to get the hydraulic ram pump designs, it needs to recognize comprehensively the water flow phenomenon that take place in the hydraulic ram pump working cycles. Therefore, visualization of the water flow characteristic in the hydraulic ram pump is done by constructing a hydraulic ram pump model using a transparent material that is acrylic. The characteristics of the waste valve are affected by parameters such as the orifice diameter of the valve, the diameter of the valve disk, the step length, and the valve weight and the discharge and water head of the hydraulic ram pump drive. Besides all these parameters affect each other. Therefore, in this experiment, experimental testing was conducted in the laboratory on hydraulic ram pump waste valve model to investigate the effect of waste valve orifice and disk diameter on hydraulic ram pump. The results showed that the diameter of orifice and disk of the waste valve have significantly influencing the flow pattern in the hydraulic ram pump body and its time movement each stage of the cycle. The greater the diameter of the orifice and the disk of the waste valve the velocity of water that has vortex more and more, so the speed of water flow in the body of the pump also decreases. Furthermore, the larger the diameter of the waste valve disk the shorter the interval of the hydraulic ram pump valve movements, so the frequency of the hydraulic ram pump valve movement increases.

1. Introduction

A hydraulic ram pump is a water pump powered by water with a height difference, to pump some of the falling water to a higher elevation than it originated [1]. As such, the hydraulic ram represents a renewable energy device [2]. It operates around two simple valves. Therefore, it is theoretically adaptable for manufacture in developing countries, and maintenance at village level.

In addition, the hydraulic pump system is very simple, consisting of two types of piping (drive and delivery pipe), pumping body, two valves (waste and delivery valve), and air vessel [3]. Therefore, ideally, the different combinations of head and discharge of the source water flow, the valve stroke and the weight of the valve, the ratio of length to the diameter of the driving pipe, and the volume of the air vessel are parameters of the hydraulic ram pump design [4]. The design of the waste valve and the delivery valve are essential in hydraulic ram performance [5]. Moreover, the valve is a key component of the hydraulic ram pump, which requires further focus and optimization to improve the overall efficiency of the pump [6].

Basically, the both valves of hydraulic ram pump, impulse valve and delivery valve [7], are non-return valves, as in Figure 1. The impulse valve is a simple valve that is closed by the drag force induced by a high through flow. The geometry of the valve is such that these drag forces increase rapidly as the valve moves towards its closed position, then inducing a rapid "sudden" closure. In addition, the sudden closure of the impulse valve induces a pressure rise in the drive pipe that is proportional to the velocity of the fluid in the pipe immediately before the valve closure. This pressure is maintained while pressure waves propagate along the drive pipe. During this period in which the drive pipe sustains a high pressure, a small discharge occurs through a non-return valve (delivery

valve) into a vessel containing air at a pressure approximating to the delivery pressure of the pump. This discharge continues until such time as the pressure in the drive pipe subsides, at which stage, the non-return valve closes, and the discharge ceases [8,9].
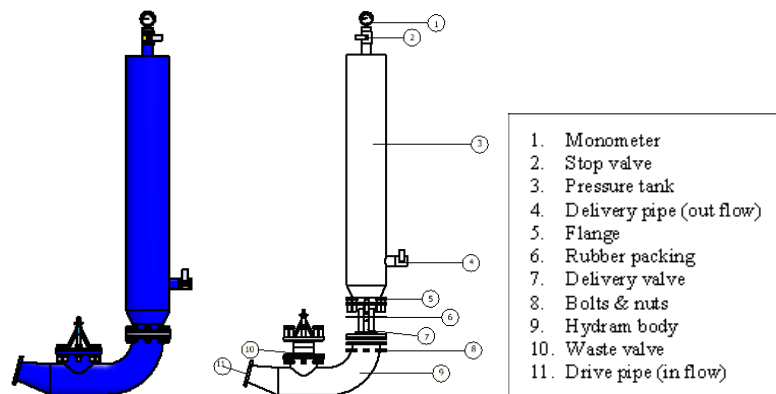

1. Monometer
2. Stop valve
3. Pressure tank
4. Delivery pipe (out flow)
5. Flange
6. Rubber packing
7. Delivery valve
8. Bolts & nuts
9. Hydram body
10. Waste valve
11. Drive pipe (in flow)

Figure 1. Components of a hydraulic ram pump.

The hydraulic ram pump has been designed using a conventional plat plate shaped delivery valve. Due to it has large dimension and works on high head, according to Pascal's law then its delivery valve receives a large water hammer force that proportional to the area of the plate valve, so it is very easily damaged or less reliable. Then, various shaped valve model for Hydraulic ram pump have been made and tested [10]. They are plate, membrane, spherical and half-spherical shaped. The test results showed that the spherical shaped delivery valve model produces the best volumetric efficiency, followed by membrane, half-spherical shaped, and the plate model gives the lowest efficiency.

The flow behind a sphere and a disk has been investigated experimentally with flow visualization and Particle Image Velocimetry [11]. They have observed in the two cases how the steady axisymmetric flow with toroid recirculation zone behind the body bifurcates to a steady flow with a planar symmetry containing two longitudinal counter-rotating vortices. A further instability leads to oscillation of these vortices, and for larger Reynolds numbers, to unsteady flow with regular hairpin shedding [12, 13, 14]. A significant research effort has been made into studying the flow past a stationary sphere over a wide range of Reynolds numbers both experimentally [15] and numerically [16]. Furthermore, Numerical solutions for the flow past stationary and rotating spheres at varies Reynolds number are calculated and performed using the finite volume solver CDP [17. The effect of rotating the sphere in either the stream wise or transverse direction on the wake structures and hydrodynamic forces are analysed.

Grygo develops mathematical equations of the performance stream of a water ram with regard to the height of water delivery [18]. The main aim of this work is to define the mathematical relationship that allows determination of the impact of the height of water on the performance of water ram. The obtained mathematical dependence (regression equation) shows that by increasing the height of water delivery it will reduce the performance. Then, Harith et al study how to determine the effect of improved design to significant effect on flow analysis and simulation study [19]. They confirmed that the by adding control mechanism to the newly design component delivery and waste valve have enhance about 20% more efficiency than current design. Moreover, they study on waste and delivery valve design modification to the pump performance [20]. The results of the investigation show that the projection of velocity vector for every details case and pressure contour.

In addition, Mondol built a design, manufacture and test a hydraulic ram [21]. Then, he observed that if the water in the tank decreased the time taken between strokes increased and the pump ceased to work. Shortening the stroke increased the frequency of strokes. Thus, a certain amount of water has to be maintained in order to pump water via the ram pump satisfactorily. Furthermore, Guo et al. develop a method for the optimal design and performance analysis of hydraulic ram pump with numerical

simulation and model experiment [22]. They argue that when the delivery head is less than 50 m, the efficiency of the new product ranges from 50% to 70% while the delivery flow is the largest.

Detailed mechanism of hydraulic ram pump operations are not well understood yet. Therefore, Taye [8] conducted a laboratory test of a hydraulic ram pump to determine some parameters associated to hydraulic ram pump operation. A draft waste valve designed such that the weight and its stroke can be varied depending on the head of driving water supply. Furthermore, Filipan et al. [23] create a mathematical model of hydraulic ram pump system and explain the simplified working cycle of hydraulic ram pump. Because of the flow of water in the hydraulic ram pump system is unsteady, then the equation of unsteady flow in a pipe and method of characteristic (MOC) is used.

In the latest of this decade, CFD (Computational Fluid Dynamics) simulation methods tends to be used, as was done by Maw and Hte [24]. They created hydraulic ram pump design then simulated the phenomenon of water flow through a waste valve with commercial CFD software that is Solid Work software. However, this paper only show the pressure distribution and velocity on the waste valve, as shown in Figure 1, and did not identify any waste valve design influence on the hydraulic ram pump performance. Furthermore, analysis of the hydraulic ram pump performance using CFD was conducted by Shende and Choudary [25]. Analysis of the hydraulic ram pump performance was done by using one of the commercial CFD software ie. Fluent. The simulation results show that the mass flow rate of water through the new design of the waste valve is smaller than the old model, and provide a better performance of hydraulic ram pump system. The analytical calculations can be made further simple by writing a computer programme which will help to determine the optimum solution. Modelling and analysis can be carried out using Ansys Fluent software which determines the various design parameters [26].
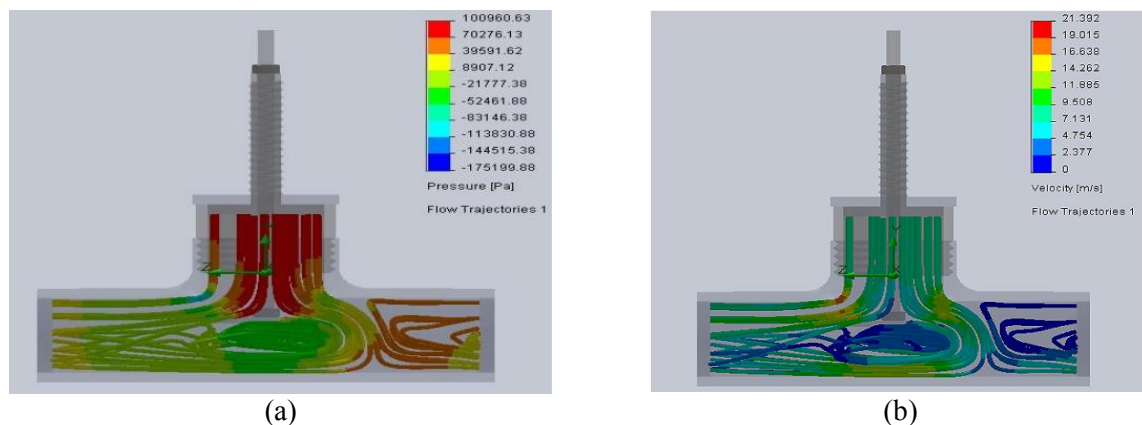

Figure 2. Pressure (a) and velocity (b) variation in waste valve.

In the latest of this decade, CFD (Computational Fluid Dynamics) simulation methods tends to be used, as was done by Maw and Hte. They created hydraulic ram pump design then simulated the phenomenon of water flow through a waste valve with commercial CFD software that is Solid Work software. However, this paper only show the pressure distribution and velocity on the waste valve, as shown in Figure 1, and did not identify any waste valve design influence on the hydraulic ram pump performance. Furthermore, analysis of the hydraulic ram pump performance using CFD was conducted by Shende and Choudary. Analysis of the hydraulic ram pump performance was done by using one of the commercial CFD software ie. Fluent. The simulation results show that the mass flow rate of water through the new design of the waste valve is smaller than the old model, and provide a better performance of hydraulic ram pump system. The analytical calculations can be made further simple by writing a computer programme which will help to determine the optimum solution. Modelling and analysis can be carried out using Ansys Fluent software which determines the various design parameters [26].

There is limited information in the literature about experimental flow characterization studies of hydraulic ram pump system. Flow visualization methods are very useful for identifying these deviations from the ideal conditions. Particle Image Velocimetry (PIV), Particle Tracking Velocimetry (PTV), Laser Doppler Anemometry (LDA) and smoke or dye injection are experimental flow visualization methods that have been used for this purpose [27]. One of the most important contributions was the use of aniline dye to produce coloured water in the Osborne Reynolds experiment conducted in 1883.

In a very recent study, Goshayeshi and Chaer [28] experimentally investigated the flow visualization in a closed-loop OHP which is constructed using a Pyrex glass with kerosene as the working fluid. The phase change phenomena and bubble generation in the heating section were recorded using a high-speed video camera (Panasonic VX87) with frame rate of 100 frames per second. The internal flow pattern in pipe or tube could be studied using flow visualization.

The waste valve mainly affects the magnitude of the impulse force generated. In the implementation of the adjustment of this valve waste takes a long time, because there is no reference or sufficient reference in making the design of the valve waste. The characteristics of the waste valve are affected by parameters such as the orifice diameter of the valve, the diameter of the valve disk, the step length, and the valve weight and the discharge and water head of the hydraulic ram pump drive. Besides all these parameters affect each other. Therefore, in this experiment, experimental testing was conducted in the laboratory on hydraulic ram pump waste valve model to investigate the effect of waste valve orifice and disk diameter on hydraulic ram pump.

2. Research Methods

2.1. Experimental Setup

In this study, an experimental work was carried out on the installation of hydraulic ram pump system as shown in Figure 3. All hydraulic ram pump components are created using the clear acrylic material. Flow visualization is carried out in water flow throughout the hydraulic ram pump model. The water is injected with dyes of three different color liquids through small orifices in the drive pipe of the hydraulic ram model so as to act as streamline tracers. The water flow phenomena in the hydraulic ram pump was recorded using a high-speed video camera (Sony RX100-IV) with frame rate 960 frames per second. Body and air vessel of the hydraulic ram pump have 55 mm of diameter, and its drive pipe diameter is 25 mm with length of 2270 mm.

Model desain waste valve adalah seperti pada Figure 4. Variasi diameter orifice waste valve adalah 25 mm, 30 mm, 35 mm dan 40 mm pada diameter disk of the waste valve 45 mm. Sedangkan variasi diameter disk of the waste valve adalah 40 mm, 41 mm, 42 mm dan 43 mm pada diameter orifice of the waste valve 32 mm.
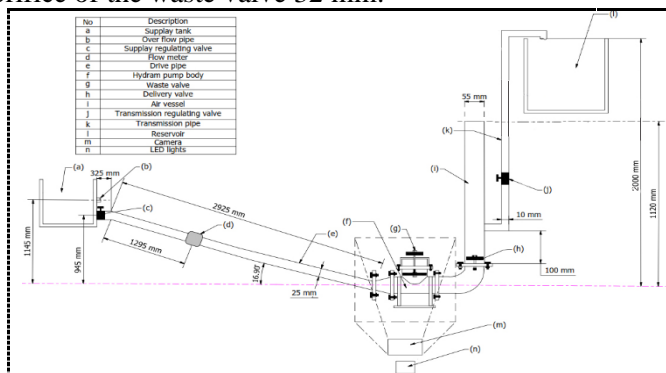

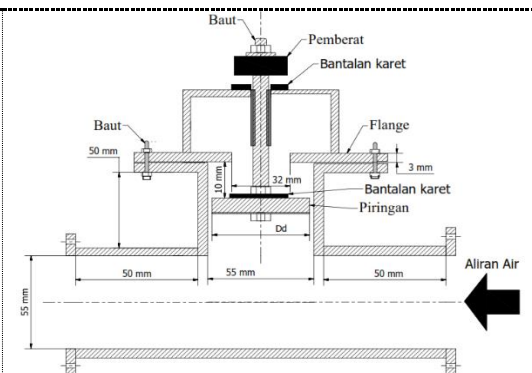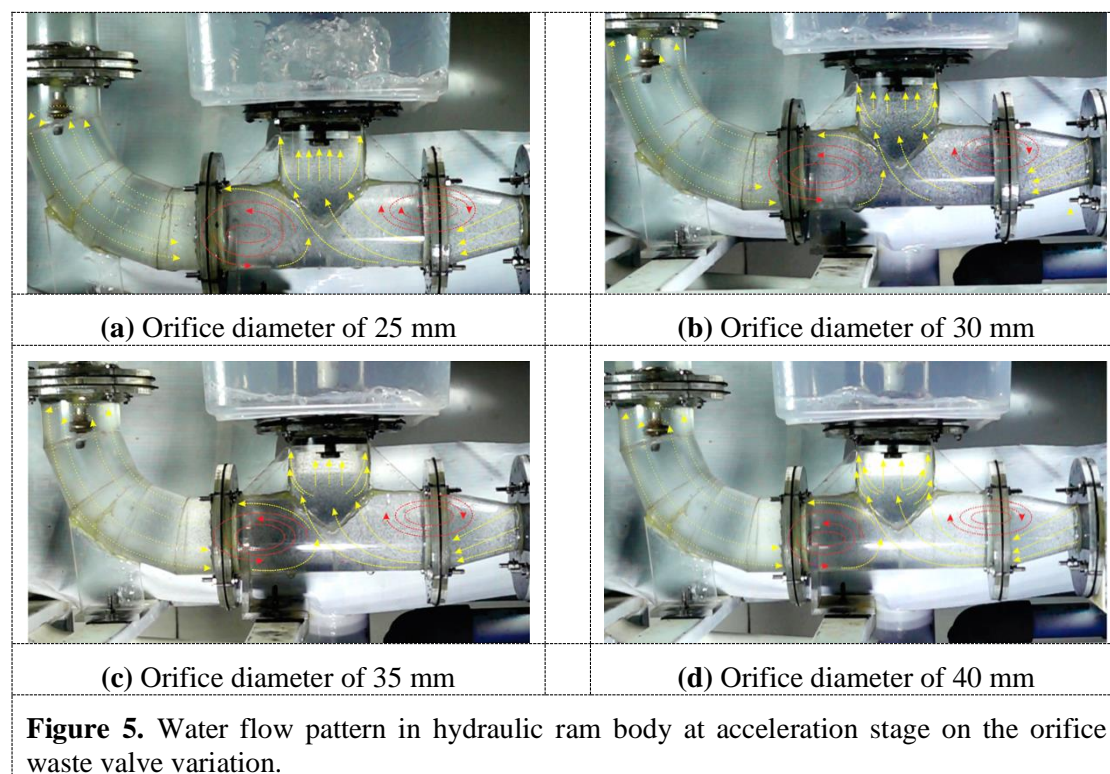| **Figure 3.** The experimental setup of hydraulic ram pump.	**Figure 4.** The waste valve model

2.2. Experimental Procedure

The initial observation of the video, which has been taken using a Sony Digital camera RX100-IV. The video is first processed or converted into an image. So the technique used in this research is image processing techniques because the data is processed data in the form of images. The video that has become the image will be processed to create flow patterns and frequency of hydraulic ram pump valve movement. Measurement of flow velocity is done by measuring the length of trace of the implanted particles using ImageJ software, and then the track length of the particle movement divided by the speed of the camera taking the video (shutter speed), in this study using shutter speed 0.001 seconds.

3. Results and Discussions

3.1. Flow pattern

(a) Orifice diameter of 25 mm	**(b)** Orifice diameter of 30 mm
(c) Orifice diameter of 35 mm	**(d)** Orifice diameter of 40 mm

Figure 5. Water flow pattern in hydraulic ram body at acceleration stage on the orifice waste valve variation.

Movement of paint particles on the hydra pump is illustrated in each cycle of the hydra pump, so that the 2.07-second video must be converted to split into 2,070 images, and then selected four images representing each cycle of the hydra pump at each variation of the diameter of the valve sewage hole. Figure 5 show the water flow pattern in hydraulic ram body at acceleration stage where the waste valve at opening condition at the orifice of waste valve variation. Water coming out of the moving pipe is illustrated with a dotted line of yellow. The rotating stream (vortex) occurs in two parts illustrated by a dotted line of red. Water begins to enter the pumping body, partially discharged through the sewage valve, as the tap valve is still covered with water again turning towards the waste valve. The flow pattern is almost the same, but the obvious difference occurs in the flow of water that suppresses the waste valve disk, the amount of flow decreases as the diameter of the valve sewer diameter is enlarged, represented by the straight line of yellow dots.

(a) Disk diameter of 40 mm	**(b)** Disk diameter of 41 mm
(c) Disk diameter of 42 mm	**(d)** Disk diameter of 43 mm

Figure 6. Water flow pattern in hydraulic ram body at acceleration stage on the disk waste valve variation.
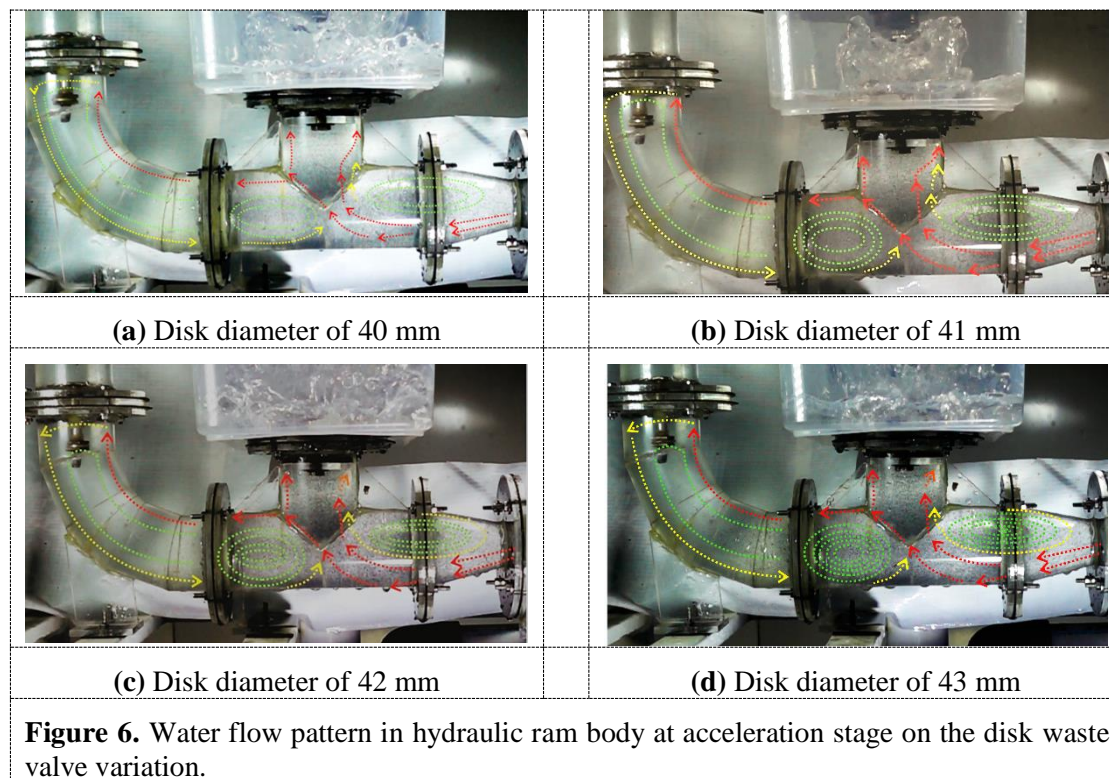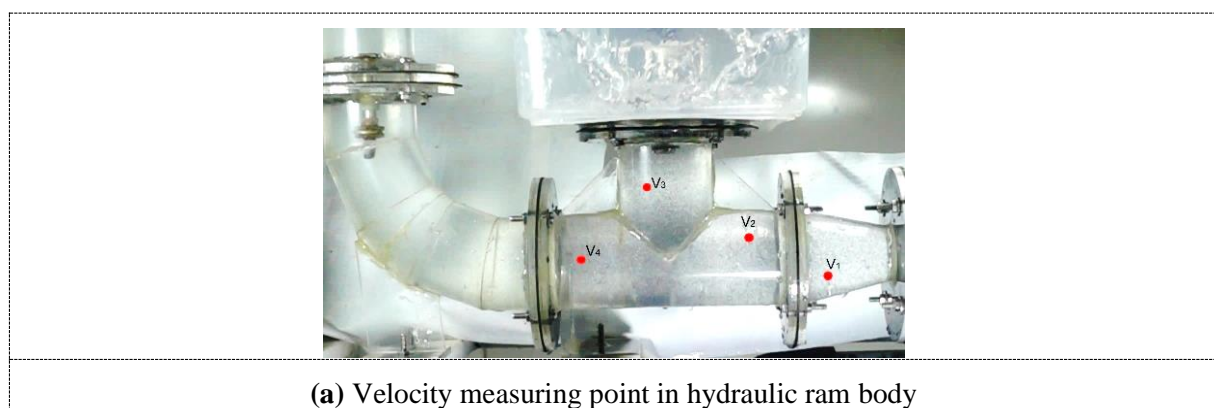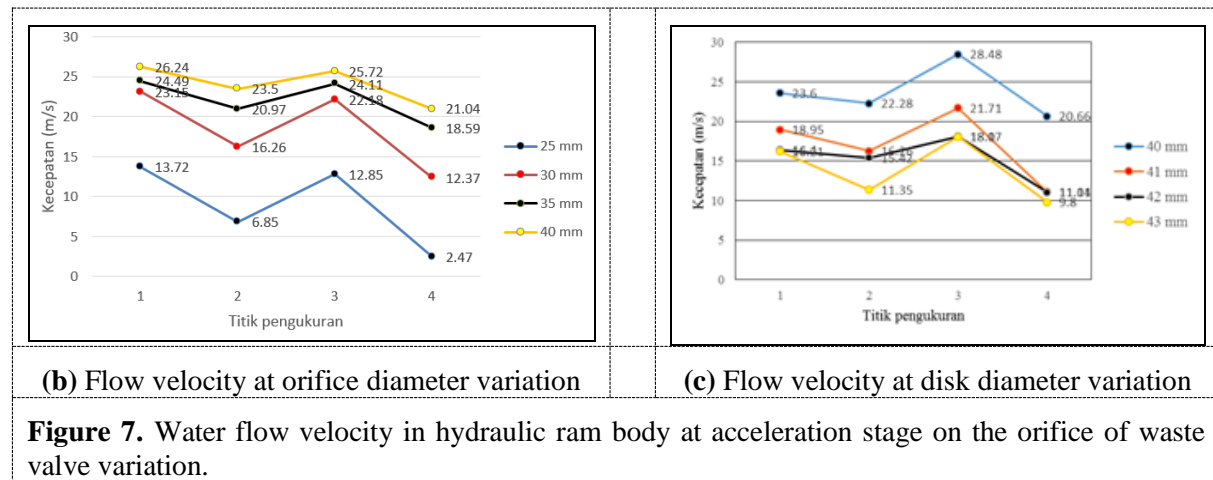
Figure 6 show the water flow pattern in hydraulic ram body at acceleration stage where the waste valve at opening condition at the disk of waste valve variation. Incoming water will start to get out of the waste valve. The red dotted line indicates the direction of movement of the incoming water from the moving pipe, the water entering outward from the sewage valve and partially to the press valve and turning again to the waste valve. The circular green dotted lines indicate the existence of a rotating stream (vortex), and the yellow color indicates the direction of movement of the water being turned.

3.2. Flow velocity in hydraulic ram pump body
The more rotation of the flow of water that has a vortex of course the distance of the particle closer and closer, because the distance has to do with the speed it is necessary to measure the movement distance of paint particles (glitter) and then later used to determine the speed of water flow that occurs inside the hydra pump body. Speed measurements are made at four points as in Figure 7.

(a) Velocity measuring point in hydraulic ram body

(b) Flow velocity at orifice diameter variation	**(c)** Flow velocity at disk diameter variation

Figure 7. Water flow velocity in hydraulic ram body at acceleration stage on the orifice of waste valve variation.

Point 1 (at the reducer) is the highest speed, due to the water from the reservoir directly to the pump, then at point 2 (before the waste valve) the speed begins to decrease due to the vortex. At point 3 (in the waste valve) the water velocity increases again due to the open sewage valve, the decline occurs at point 4 (after the waste valve), in addition to the occurrence of the whirlpool as well as the closed pressure valve. The enlargement of the waste valve diameter hole resulted in an increase in speed at the 4 points. The distance of the furthest speed increase occurs between holes diameter 25 mm to 30 mm.

In addition, the increase in velocity occurs at point 3 which is directly below the waste valve disk, as it is currently only open sewage valve so that water is subjected to pressure from the reducer pipe or point 1 and from the T pipe after reducer or point 2 and also driven from the flow behind the press valve that is at point 4 located on the T tube after the waste valve. The larger the diameter of the waste valve disk, the water velocity will decrease as the gap of water discharge decreases.

3.3. Duration of the waste valve movement
Frequency of the movement of the waste valve is obtained from the video that has been decoded into the image, the video recorded for 2.07 seconds is decomposed into 2070 images then the image is identified according to the characteristics of each cycle of the hydra pump work. Four cycle of hydram pump work is acceleration, compression, delivery, and recoil consist of 1385 picture (frame). The movement of the next valve is made curve, as for the curve as in Figure 8.
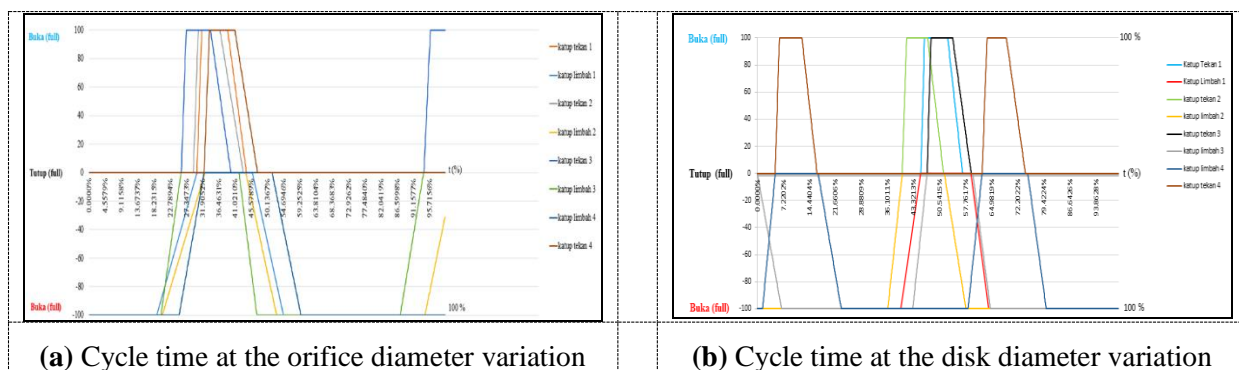

(a) Cycle time at the orifice diameter variation	**(b)** Cycle time at the disk diameter variation

Figure 8. Duration of time each stage of the waste valve movement.

Table 1. Length of time each stage of the waste valve movement at the orifice diameter variation.

DL_{KL} (mm)	Waktu (s)									
	Katup Limbah					Katup Tekan				
	Buka Penuh	Proses Menutup	Tutup Penuh	Proses Terbuka	Jumlah	Tutup Penuh	Proses Terbuka	Buka Penuh	Proses Menutup	Jumlah
25	0.438	0.055	0.167	0.051	0.711	0.583	0.015	0.078	0.066	0.742
30	0.442	0.062	0.179	0.055	0.738	0.595	0.015	0.075	0.063	0.748
35	0.45	0.132	0.126	0.095	0.803	0.65	0.015	0.067	0.072	0.804
40	0.416	0.124	0.172	0.096	0.808	0.654	0.015	0.125	0.058	0.852

Table 2. Length of time each stage of the waste valve movement at the orifice diameter variation.

DL_{KL} (mm)	Waktu (s)									
	Katup Limbah					Katup Tekan				
	Buka Penuh	Proses Menutup	Tutup Penuh	Proses Terbuka	Jumlah	Tutup Penuh	Proses Terbuka	Buka Penuh	Proses Menutup	Jumlah
25	0.438	0.055	0.167	0.051	0.711	0.583	0.015	0.078	0.066	0.742
30	0.442	0.062	0.179	0.055	0.738	0.595	0.015	0.075	0.063	0.748
35	0.45	0.132	0.126	0.095	0.803	0.65	0.015	0.067	0.072	0.804
40	0.416	0.124	0.172	0.096	0.808	0.654	0.015	0.125	0.058	0.852

Table 1 indicated that there is an increase in time due to the magnification of the diameter of the valve waste hole, this is because the larger hole allows more water to go directly to the sewer valve hole rather than pressing the waste valve disk first so that the movement of the valve in one cycle of the hydraulic ram pump becomes longer. In addition, Table 2 presents the greater the diameter of the waste valve disk, the faster the frequency of the hydraulic ram pump valve, when the time is faster the hiccups also increase.

4. Conclusion
The diameter of orifice and disk of the waste valve have significantly influencing the flow pattern in the hydraulic ram pump body and its time movement each stage of the cycle. The greater the diameter of the orifice and the disk of the waste valve the velocity of water that has vortex more and more, so the speed of water flow in the body of the pump also decreases. Furthermore, the larger the diameter of the waste valve disk the shorter the interval of the hydraulic ram pump valve movements, so the frequency of the hydraulic ram pump valve movement increases. The pumping discharges and efficiency are also influenced by the diameter of the hydraulic ram pump waste valve disk, the larger the diameter of the hydraulic ram pump waste valve disk, the pumping discharge and the efficiency of the hydraulic ram pump are also increasing.

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