Analysis of Two Hydraulic Ram Pumps in Parallel Operating with Single-vertical Supply

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Abstract. Experimental information of the behavior of two hydraulic rams connected in parallel, as well as a single ram operating with an installation using a vertical-radial supply was obtained and compared. In both connections, the height of the supply flow rate was varied and the pressures in the supply pipe, impulse valves, air chambers, and delivery pipe with and without return pipe (vertical descending section) were measured. Thus, the proper operation of the proposed supply line was verified, and it was observed that the connection with two hydraulic rams pumped more water than when operating with a single ram. However, the delivery flow rate is lesser than the sum of the flows pumped by each ram when operating independently. This behavior was found to be similar to that of radial pumps connected in parallel. Also, the vertical return-pipe increases the delivery flow rate by a factor more than three times. This proposed configuration provides an alternative to develop cheap, small, and environment-friendly technologies.

1. Introduction

The hydraulic ram (hydram) is a cheap and simple pump driven by potential energy that is environment-friendly and requires no electricity. Some of these features have renewed interest in its use by means of experimentation and numerical simulation, to predict the pumped flow, its efficiency and the frequency of the blow analyzing an operating cycle [1], [2], [3]. In recent studies, its performance was theoretically modeled with a simplified operating cycle [4], [5], and studied by combining theory and numerical simulation [6], [7], [8]. More recent approaches have evaluated the effect of the length of the impulse pipe [9], [10], and the influence of the diameter of the orifice of the reset valve and its position with respect to the delivery valve [11]. Likewise, the influence of the volume of the air chamber on the pumped flow [12], [13], was investigated and its performance has been improved by modifying the delivery valve [14] and its angle of inclination [15].

Due to the low initial cost and maintenance, hydraulic ram [16] has become a clean alternative for supplying water to isolated populations [17], because it does not use electricity or fossil fuels, and does not produce polluting gases [5]. Today, the demand for water in isolated and depressed areas has reinforced its use to supply water for human consumption, irrigation and cattle raising in hillside areas [18], [19].

In this study, the behavior with vertical-radial supply of a single or two hydraulic rams operating in parallel was explored using an experimental installation that operates under both conditions and that was designed in a previous work [20]. Under identical hydrodynamic conditions, the pumped flow at different supply heights and the same delivery height and the pressures at different points of the pipeline...
were measured. Thus, experimental information was obtained to compare the flow pumped by a single ram with that of the two rams operating in parallel. The pressure at similar points in both configurations were measured to observe their behavior. Up to our knowledge, with the exception of the work of Bayu Ari Promono et al. [21], no studies of hydraulic rams operating under these conditions have been reported.

2. Materials and Methods

The experiment was carried out in a recirculating hydraulic circuit that consists of a single vertical supply pipeline. At its upper end, it is attached to the supply tank, and at its lower end, it is coupled to an inverted T-joint, where two horizontal pipelines drives the supply flow towards two hydrams, as depicted in Figure 1(I). Water in two discharge tanks is recirculated to the supply tank using two radial flow centrifugal pumps.

The supply flow rates were measured with Doppler flowmeters (Greyline Instruments Inc, DFM 5.0, Birmingham, UK), while the delivery flow rate with a turbine flow meter (EDM, Kobold, Peru). Pressure was measured in different points on pipes with piezoresistive transducers (Danfoss, MBS1900, Nordborg, Denmark). A photo of the experimental setup is shown in Figure 1(II). The impulse valve is a commercial hydraulic foot-valve with a mechanical spring guided, on one side, by a bolt of adjustable length and three nuts, and on the other side, pushed by a piston to allow the opening and closing of the valve, as shown in Figure 1(III).

At each supply height, the supply \( Q_T \) and pumped \( q \) flow rates and the pressures in the supply pipe \( T_3 \), impulse valves \( T_2, T_6 \), air chambers \( T_1, T_7 \), and at the beginning of the delivery pipe \( T_4 \), with and without vertical return pipe \( H' \) were measured for both single and parallel configurations. The water hammer frequency of the hydrams was also estimated from the signal of the pressure transducers at the impulse valves.

It was found that the best operating condition of the impulsion valve corresponds to a spring length of 7.5 cm, since at shorter lengths it did not work and at longer lengths the delivery flow rates were lower. This spring length allowed a reliable operation of the impulse valve only for supply heights of 1.5, 1.7 and 1.9 m. Each test lasted 240 second. The measured flow rate and pressure signals were offline processed by software. The Short-Time Fourier Transform (STFT) was used to estimate the frequency of the water hammer at the impulse valves.

3. Results

Pressure in the supply pipe \( T_3 \), and in the hydram \( T_2 \), for the two configurations of operation is presented in Figure 2. While the amplitude of the pressure decreases for higher supply height \( h \), the frequency of the water hammer in both configurations increases with \( h \) and is more evident when the
two hydrams operate simultaneously. As a result, the delivery flow pumped $q$ increases. Likewise, it was observed that the pressure in the air chamber ($T_1$) decreased with $h$ (Figure 3 (a, c)). Consequently, the pumping frequency $F_p$ increases, as shown in Figure 3 (b, d). Figure 4 describes the influence of the return-delivery pipe ($H'$) on the supply ($Q$) and delivery ($q$) flow rates during four minutes for both configurations. The examination of the flow rates indicates that two hydrams operating simultaneously, in parallel, can pump more water than with a single hydram, but this resultant flow rate is lesser than the sum of the flow delivered by each of them operating independently. This is a similar behavior observed for radial-flow centrifugal pumps when operating in parallel.

The effect of the return-delivery pipe is to significantly increase the delivery flow $q$. This may be associated to the acceleration of the flow during the vertical descending section [22] of the delivery pipe. As a consequence, a pressure drop in the air chamber (Figure 3(c)) and an increase in the total efficiency $\eta$ (see Figure 4(c,f)) is observed.

![Figure 2. Measured pressure in the supply pipe ($T_3$) and impulse valves ($T_2$) for a single and two-armed hydraulic ram at (a,d) $h=1.50$ m, (b,e) $h=1.70$ m, and (c,f) $h=1.90$ m. Delivery height $H=6$ m.](image)

![Figure 3. Experimental results of the (a,c) pressure in the air chamber, and (b,d) pumping frequency $F_p$ for a single and two-armed hydraulic ram. Delivery height $H=6$ m.](image)
4. Conclusions
A new configuration based on a single vertical supply pipeline with the capacity to drive a single or two hydrams operating simultaneously was presented. The effect of considering a return-delivery pipe was analyzed. The supply and delivery flow rates, as well as the pressure in the supply pipe, hydrams, and air chamber were measured. The study of this work was based on the operation of a single hydram working at three different supply heights and constant delivery height. The experimental results obtained allow to conclude that:

1. The configuration proposed for two hydrams operating simultaneously, with a single supply-pipeline, and considering a return-delivery pipeline was tested and verified.
2. It was observed that the delivery flow rate when two hydrams are working simultaneously is greater than when a single hydram is operated. However, the resultant delivery flow rate is lesser than the sum of the delivered flow rate when each hydram is operating independently. This result is similar to that of radial-flow centrifugal pumps when operating in parallel.
3. It was observed that the effect of the return-delivery pipe is to increase the pumped flow several times.
4. The configuration presented in this work opens up new alternative options to design and fabricate pumping systems with the capacity to operate regardless the topography of the terrain at lower costs.

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5. References
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