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EXPERIMENTAL INVESTIGATION OF OPEN LOOP MULTI-STAGE IMPEDANCE PUMPING SYSTEM

VINCENT C. C. LEE[1], YOUSIF A. ABAKR[1]*, K. C. WOO[2], MUSHTAK AL-ATABI[3]

[1]Energy, Fuel and Power Technology Division
Department of Mechanical, Materials and Manufacturing, Faculty of Engineering
Jalan Broga, 43500 Semenyih, Selangor Darul Ehsan, Malaysia.
[2]Materials, Mechanics and Structures Division
Department of Mechanical, Materials and Manufacturing, Faculty of Engineering
Jalan Broga, 43500 Semenyih, Selangor Darul Ehsan, Malaysia
[3]School of Engineering, Taylor's University
No. 1 Jalan Taylor's, 47500 Subang Jaya, Selangor Darul Ehsan, Malaysia
*Corresponding Author: Yousif.Abakr@nottingham.edu.my

Abstract

Impedance pump is a simple valveless pumping mechanism, where an elastic tube is joined to a more rigid one; a periodic asymmetrical pinching on the elastic tube will produce a unidirectional flow. This pumping concept offers a low energy, low noise alternative at both micro and macro scales. This paper describes an experimental investigation of the performance of a two-stage, open loop impedance pump. The results show that, when compared to a single stage open loop impedance pump, the two-stage impedance pump can achieve a significant pressure head and flow rate increment. A pressure head increment of 240 Pa is obtained in the single stage system compared to 480 Pa for the two-stage system. The corresponding flow rates were 5 mL/s and 8 mL/s respectively. This is an indication that impedance pumping system can be scaled up to achieve a variety of pumping assignments.

Keywords: Valveless pump, Impedance pumping system, Multi-stage pump, Unidirectional flow.

1. Introduction

Impedance pump is a valveless pump, which does not require vanes or blades to operate. It is formed by joining a flexible tube to a rigid one. Asymmetrical pinching at a single location of the fluid-filled elastic tube results in unidirectional flow as a result of the mismatch in acoustic impedance[1-8]. The pumping mechanism is dependent on the impedance of the tube, the location and frequency of pinching [3, 4, 6, 7, 9].

The first demonstration of valveless pumping through an impedance pump, also known as Liebau effect, was done by Gerhart Liebau in 1954, using an elastic tube connected to reservoirs at different heights. Hickerson [4] conducted a comprehensive experimental study on impedance pumps performance demonstrating their intrinsic behaviours. Bringley et al [5] used experimental investigation and a simple mathematical model, which can be described by ordinary differential equations, to provide a physical explanation of valveless pumping and identify the essential pumping mechanisms. Other experimental studies shown that the flows are highly sensitive to duty cycle and pinching frequency and demonstrated that an open loop system can create and sustain a pressure head, and that an elastic material is not a necessary condition for impedance driven flow [10].

The concept of multilayer impedance pump, a pumping mechanism inspired by the embryonic heart structure was studied by Loumes [9]. Flow output and inner wall motion are found to be maximal when the pump is actuated at the resonant frequency and only a small excitation is needed to produce a significant flow. Occurrence of valveless pumping in a fluid-filled system consisting of two open tanks connected by an elastic tube was investigated studying the relationship among wave propagation velocity, tube length, and resonance frequencies associated with shifts in the pumping direction using numerical simulations [7]. The study showed that the eigenfrequencies of the system constitute the resonance frequencies and the horizontal slope frequencies. Numerical simulations of single open-loop impedance pumping system [11] and multi-stage system, integrated from a number of single system [12] showed that the pressure head of multistage system is double that of the single system. These results, however, were not validated by comparison with any experimental work.

A multi-pincher impedance pump was studied using a one-dimensional numerical model [13]. The results indicated that flow rate can significantly increase when using a sequential array of pinchers operating in resonance frequency with the appropriate phase between them. However, the results were not compared with experimental data as well.

This paper experimentally studies an open loop two-stage impedance pumping system and compares its performance to an open loop single-stage impedance pump. The aim of this work is to investigate the pressure head and maximum flow rate that is achievable with the two-stage system.

2. Experimental Set-Up

Two experimental configurations were used in this study. The first configuration is shown in Fig. 1 and it comprises of two reservoirs and one impedance pump in the middle. This single-stage open-loop configuration was used as a baseline for comparison. The second configuration is shown in Fig. 2 and it has three reservoirs with an impedance pump between each two adjacent reservoirs. No phase difference between the two pumps is implemented in this investigation. A driving frequency of 5 Hz was applied through all these investigations.

2.1. Single-stage impedance pumping system

Figure 1 shows a schematic diagram of a conventional impedance pumping system which consists of two reservoirs and a single pinching mechanism. The pump is made of a silicon rubber tube of hardness 60 Shore A, 500 mm in length, 30 mm in diameter and 2 mm in wall thickness, held horizontally. The tube ends were fixed and connected to two reservoirs at each end of the test section. Each reservoir has a 90 mm inner diameter and height of 500 mm. These two reservoirs merely serve as storage for the fluid. Water with standard properties at 25°C was used as the working fluid. The actuator which powers the pinching mechanism was built using a vibroimpact machine that consumes a power of 60 Watts and creates actuation amplitude of 34 mm with pinching width of 50 mm. The actuator is placed at a location of 1:10 of the length of the tube from one side; the actuator is not connected to the outer surface of the tube. Contact between the actuator and tube only happens during the compression.

2.2. Two-stage impedance pumping system

The experimental set up of a two-stage, three reservoirs, two actuators impedance pumping system is as shown in Fig. 2. Both actuators are located at the position of 1:10 from the left of the respective tube forming pumps that are identical to the pump described in the previous section. Table 1 briefly summarises the parameters used in the experiment.

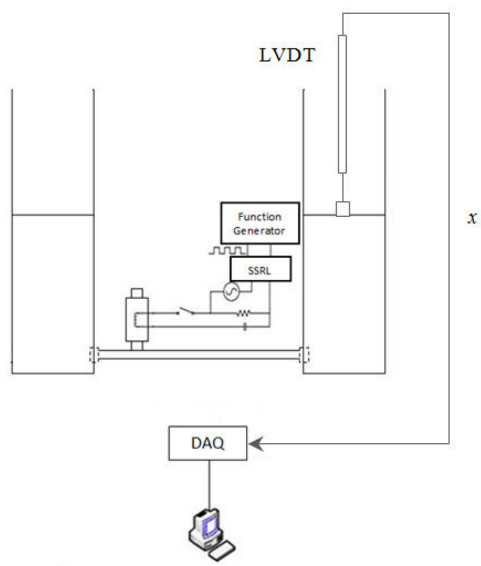

Fig. 1. Schematic Diagram of a Single-Stage Impedance Pumping System.

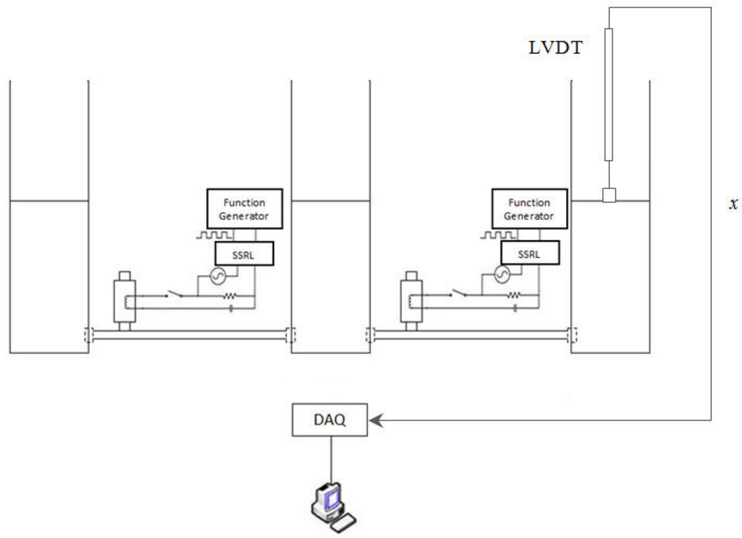

Fig. 2. Schematic Diagram of a Two-Stage Impedance Pumping System.

Table 1. Important Values of Parameter for the Experiment.

Driving power for vibroimpact machine	60 Watts
Control frequency and waveform	5 Hz Sine wave
First actuation location	10% of tube length from left
Second actuation location	10% of tube length from left
Total volume of fluid in reservoir	1963.5 mL each
Tube length	500 mm each
Tube inner diameter	30 mm
Tube thickness	2 mm

2.3. Measurement

Measurement was done using the linear variable displacement transducer (LVDT) to measure the total displacement of water in the reservoir. As illustrated in the Figures 1 and 2, the LVDT is placed at the last reservoir for measurement of displacement. This measurement is logged using a data acquisition system (DAQ) and used to calculate the pressure head using the static pressure equation by multiplying the displacement by ρg (981 kg m^{-1} s^{-2}). Similarly for the flow rate, multiplying the displacement with the cross-section area of the reservoir (0.00636 m^2) gives the total volume displacement induced from the system. Dividing the volume displaced with respect to the time elapsed will deduce the average flow rate induced by the pump.

3. Results and Discussion

Figure 3 shows the displacement of water in the reservoir for both the single-stage and two-stage impedance pumping systems. As expected, the two-stage impedance pumping system is capable of sustaining a bigger water displacement. The maximum water displacement for the two-stage system is 50 mm compared to 25 mm for the single-stage system.

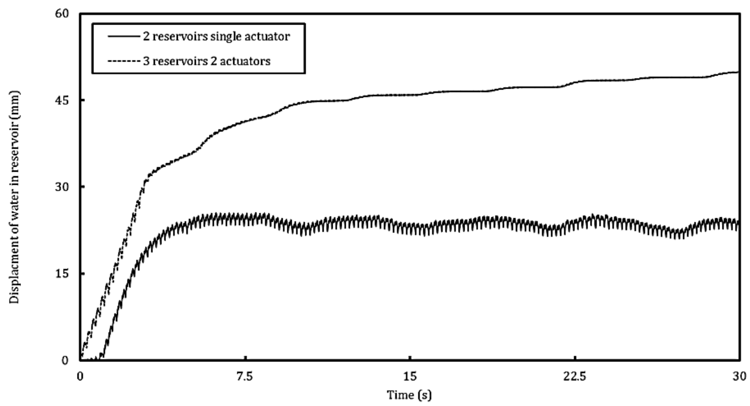

Fig. 3. Water Displacement in Reservoir.

Figure 4 shows the maximum pressure head obtained during the experiments. The two-stage system is capable of achieving a maximum pressure head of 480 Pa which is double that achieved by a single-stage system. This is an indication that transportation of fluid is viable in an open-loop system and that scaling up of the system is possible. Figure 5 shows the flow rate through the pumping configurations studied. A maximal flow rate of 5 mL/s for the single-stage system, and 8 mL/s for the two-stage system.

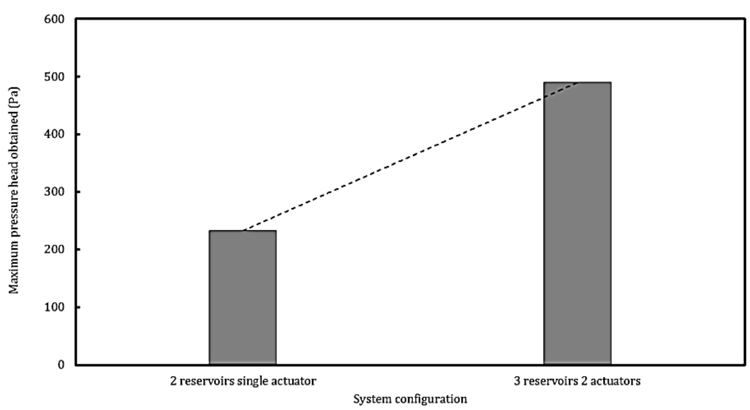

Fig. 4. Maximum Pressure Head in Reservoir.

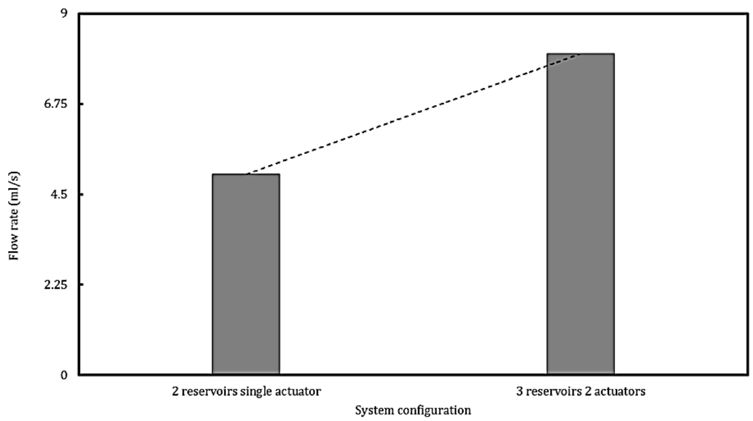

Fig. 5. Maximum Flow Rate through the System.

4. Conclusions

Experiments were conducted to compare the performance of single-stage and two-stage open loop impedance pumping systems. Results show superior performance for the two-stage impedance pump with a pressure head increment of 480 Pa, which is double that recorded for the single-stage impedance pump, and a flow rate of 8 mL/s, compared to 5 mL/s for the single-stage configuration. These results are indicative of the possibility of systematic scaling up of the system to support various pumping requirements.

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