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Nonuniform resonator based valve-less standing wave suction pump for gases

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ABSTRACT

Performance of a nonuniform resonator based valve-less standing wave suction pump for gases is evaluated. Nonuniform resonator with a linear area variation was used to achieve high amplitude standing wave. High oscillating pressure at the small end of the resonator was rectified by fluidic diodes. Experiments were done with pairs of rectifiers, each of which consisted multiple diode elements in series. The performance of the valve-less standing wave pump is evaluated in terms of suction flow rate and suction pressure achieved. It was found that higher driving amplitudes gave higher flow rates and higher suction pressures. Increasing the number of diode elements also did the same. Smaller diode diameter cases produced higher suction pressures at similar flow rates. The measured maximum suction pressure was 4900 Pa and the maximum flow rate observed was 10.2 slpm of air respectively, while operating around 925 Hz.

1. Introduction

Valve-less pumping is an exciting field of research in view of its many applications. A review by Tesar [1] provides details of different types of valve-less pumping principles. Another review by Woias [2] gives a complete review of micropumps that employs both moving and no moving part valves. Two popular valve-less pumping principles are, valve-less impedance pumping [3–6] and valve-less reciprocating pumping [7–14]. A third type of pump referred to as an acoustic pump or simply standing wave pump (SWP) was investigated by many researchers. A high amplitude standing wave is established in the resonator which compresses the gas to higher oscillating pressures, which is then rectified to give net flow.

Acoustic pumps (standing wave pumps) can be classified based on resonator geometry and rectification. The earliest SWPs [15–18] used uniform resonator (constant cross section) and moving part rectifying elements. Nabavi *et al.* [19] and Nabavi and Mongeau [20] used no moving part rectifying elements (fluidic diodes) along with a uniform resonator. Further, Nabavi *et al.* [19] showed that, pumping increases with increase in standing wave pressure amplitude at the pressure antinode. They used fluidic diodes to rectify the oscillating pressure to effect net flow.

It is a well-known fact that high amplitude gas oscillations result in shock formation inside cylindrical tube (uniform resonator) [21]. Shock free high amplitude gas oscillations in a closed tube can be achieved by making the resonator cross-section nonuniform. One end of the resonator has large area while the other end has small area, like in the cases of Lawrenson *et al.* [22], Ilinskii *et al.* [23,24] and Hamilton *et al.* [25]. High pressure amplitudes achieved at the small end by employing nonuniform resonators in Lawrenson *et al.* [22], were rectified by reed valves [26]. Reed valves can respond at kHz range, but still have moving parts which will wear out over a period of time, thus making the pump less reliable. Efficient no-moving part rectifiers like vortex diodes cannot be used here due to their long response times compared to high frequency oscillations in standing wave pumps. Instead, the nozzle- diffuser based diodes (which are quick to respond but are less efficient) can be used.

Very recently, Thomas and Muruganandam [27] developed a standing wave pump/blower[1] (to pump air from atmospheric pressure to higher pressure), using a linear area variation nonuniform resonator along with nozzle-diffuser fluidic diodes. They placed both the inflow and outflow diodes at the pressure antinode location (small end of the resonator) unlike Nabavi et al. [19] who used inflow diode at pressure node and outflow diode at pressure antinode. Thomas and Muruganandam [27] showed marked

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[1] Some authors use the term ‘blower’ when the fluid pumped is compressible gas, and ‘pump’ when the fluid is incompressible. The present author will be using the terms ‘blower’ and ‘pump’ interchangeably.

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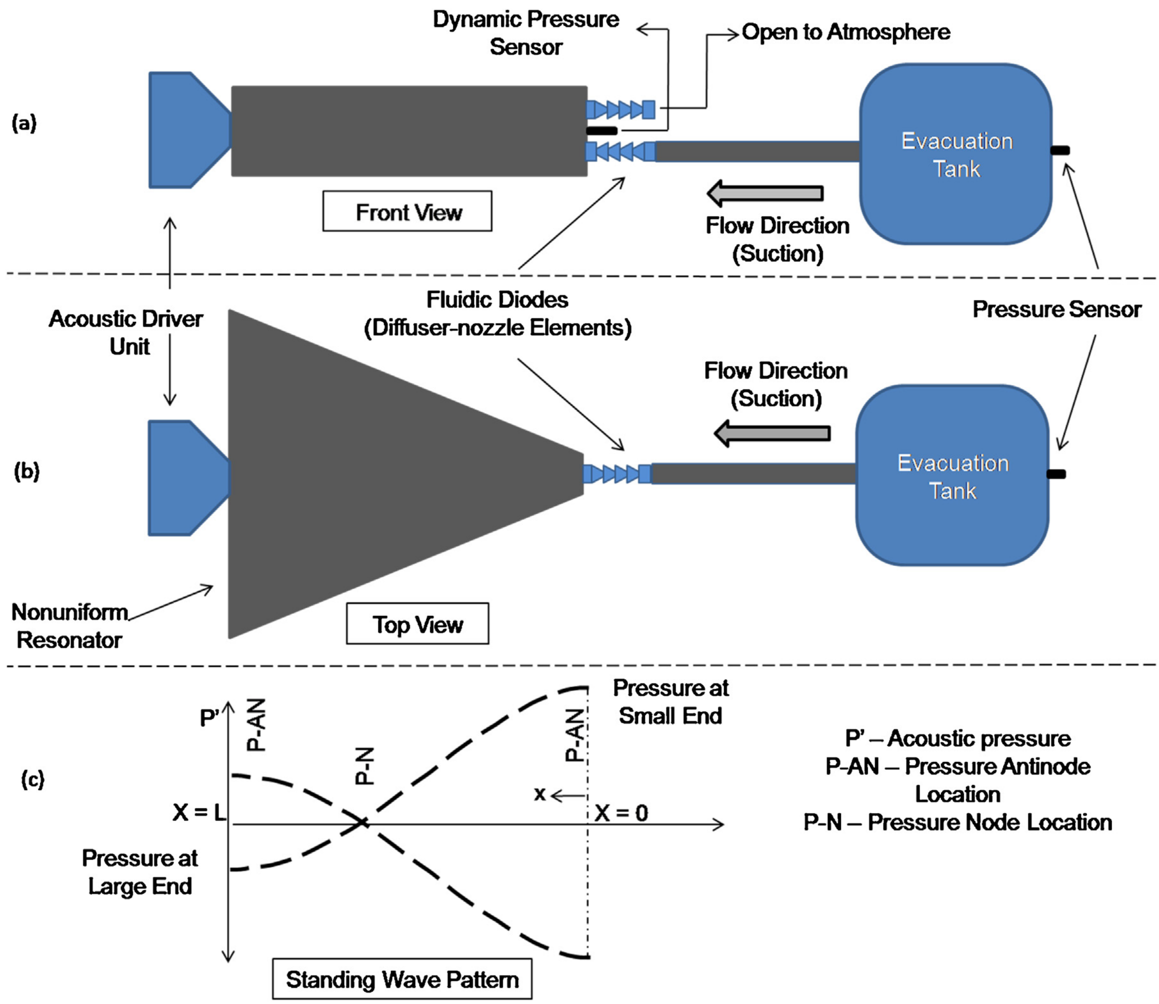

Fig. 1. Schematic of the nonuniform resonator based valve-less standing wave suction pump (a) Front view of the pump, (b) Top view of the pump and (c) The standing wave pattern inside the nonuniform resonator.

improvement in the pumping performance by achieving flow rates around 11070 ml/min of air at 15400 Pa peak pressure amplitude, whereas Nabavi et al. [19] obtained maximum flow rate of 606 ml/min of air at 535 Pa peak pressure. Resonator in their work had a square cross-sectional area 70 × 70 mm^2 with the length of 740 mm and the diffuser-nozzle element used had 5 mm diameter at the narrowest section and 13 mm at the widest section with 28° cone angle. These numbers are comparable to those used by Thomas and Muruganandam [27] and in the present work, except for the resonator length (and consequently frequency) which is of similar order.

From the literature, it is clear that these valve-less standing wave pumps have been used for the purpose of pumping from ambient to higher pressures alone. Suction can be achieved by connecting the inflow diode of nonuniform valve-less SWP to an evacuation tank, and outflow diode to atmosphere. However, there is no work in literature which explores the applicability of the standing wave pump in suction mode. This also opens up new avenues of research where one can test the applicability limits for acoustics in sub-atmospheric pressures. The present work, is an extension of the work on nonuniform valve-less SWP [27], which evaluated the blower performance. This work evaluates the performance of the pump in suction mode.[2]

2. Experimental setup

2.1. Construction of nonuniform resonator based valve-less standing wave suction pump

A nonuniform resonator based valve-less standing wave pump for gases is developed. The performance of this valve-less standing wave suction pump is evaluated in terms of suction flow rate and suction pressure achieved. Nonuniform resonator with a linear area variation was used to achieve high amplitude pressure at the small end of the resonator, where the fluidic diodes were located. Experiments were done with pairs of rectifiers, each of which consisted, multiple diode elements in series.

Fig. 1 shows the schematic of the nonuniform resonator based valve-less standing wave pump. The figure shows two views of the same setup, along with the schematic of standing wave pattern in the resonator. In this study, a nonuniform rectangular cross section duct with linear area variation was used as the resonator. The

[2] Application No:201641031825 (Patent Pending), S. K. Thomas and T. M. Muruganandam, “Nonuniform Valve-less Standing Wave Suction Pump”, 2016.