Acoustic Compressor Coupled with Fluidic Diodes

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4pEAb12. Acoustic Compressor Coupled with Fluidic Diodes

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Performance of a fluidic diode coupled with an acoustic compressor is studied. Fluidic diodes are arranged in series to improve the rectification. Experiments were done in configurations of 1, 2, 3 and 4 diodes in series. The volume flow and pressure measurements are presented. Better rectification is achieved by arranging the diodes in series. Also it was found that fluidic diodes worked at operating frequencies of the order 900Hz

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ABSTRACT

Performance of a fluidic diode coupled with an acoustic compressor is studied. Fluidic diodes are arranged in series to improve the rectification. Experiments were done in configurations of 1, 2, 3 and 4 diodes in series. The volume flow and pressure measurements are presented. Better rectification is achieved by arranging the diodes in series. Also it was found that fluidic diodes worked at operating frequencies of the order 900Hz.

INTRODUCTION

The idea of compressing the gas using sound waves has invited great attention in recent times. Gas compression can be achieved by using an acoustic compressor which works on the idea of Resonant Macrosonic Synthesis (RMS) technology. This technology was demonstrated by Lawrenson et al[1]. Acoustic energy is one form of oscillatory energy with zero mean value. To extract the energy, it is necessary to rectify this oscillatory flow to obtain non zero mean value. A conventional reciprocating pump contains a cavity, which is connected to the inlet and outlet pipes through one-way valves. These valves have moving mechanical components which may fail due to wear and tear. Thus for the sake of reliability, elimination of these movable parts is important. Rectification function of these one-way valves can also be achieved by fluidic devices, which are basically no-moving-part rectifiers. Due to the absence of movable components, no-moving part fluidic devices cannot close off the return flow completely. In spite of this limitation the reliability and simplicity of such devices makes them a suitable choice for oscillatory flow rectifying applications. Also other added advantages of such fluidic devices are that they are less expensive to manufacture, extremely reliable, ease of production in different scale ranging from micro to macro sizes. and long operating life.

There are many known fluidic elements that can perform the rectification function. The work by Yastrebova [2] and by Priestman and Tippetts [3] discuss different types of rectifiers. The oldest among these diodes has to be one by N. Tesla in 1920[4].The rectification element (sometimes called ‘fluid diode’, or ‘dynamic passive valve’, etc.) can look like a convergent/divergent duct. Such fluidic devices have directional asymmetry characteristics which results in the directional pressure drop. Stemme and Stemme [5] designed the first valveless pump with convergent/divergent ducts where the pump operating frequency was of the order of 100Hz with water as working fluid. Gerlach et al. [6] used truncated pyramid shaped channels, where the dominating direction of flow corresponded to that of convergent flow whereas in the divergent flow direction, the high duct angle results in flow separations. Forster et al. [7] used a valvular conduit bifurcating a channel flow as the rectification element. Also theoretical analysis of such valve-less micropumps was done by Pan et al[8]. A recent paper by Tesar [9] discuss different no-moving-part pumps used for safe pumping of hazardous liquids.

The flow rectification process is analogous to rectifying an electric AC current to obtain DC output. The flow analogy for an electric AC current is a Synthetic Jet. *Synthetic jets* [10] (SJs) are generated by ejection and suction of fluid through an orifice. The time-mean mass flux of the oscillatory flow in the orifice is zero, hence they are also commonly known as zero-net-mass-flux (ZNMF) jet. Synthetic jets can be combined with any type fluidic devices mentioned above to produce a non-zero-net-mass-flux (NZNMF) jet. Such jets are also called as Hybrid Synthetic Jets (HSJs) [11]. The name and also the basic idea of this concept was introduced by Travnicek in 2004. Also a recent paper by Tesar[12] discusses the configurations and topology of jet type rectifiers used to generate HSJs.

There are two things that gives rise to non zero mean mass flux: one, entrainment of surrounding fluid due to the interaction of individual vortical “puffs” (similar to SJs) [13] and, another by non-zero-net-mass-flux pumping (similar to flow through an rectifying element). Thus its volume flow and momentum are higher in comparison with a “pure” SJ[14]. Significant experimental work has been conducted in the field of no-moving-part rectifying elements. Yet, little attention seems to have been given towards the question of how to increase the mass flux through these rectifying elements. The main motivation of this work is to use a no-moving-part fluidic device to rectify the oscillatory acoustic energy in RMS cavities. The idea used here is to arrange fluidic devices in series and study their performance. Focus is on understanding the effectiveness of the fluidic diodes in series.

EXPERIMENTAL SETUP

Figure 1. shows the schematic of the experimental setup. In this study a non axisymmetric duct with linear variation in area, was used as an acoustic compressor. The linear variation is given by the equation (1). The compressor was driven by a 150W acoustic driver unit with a diaphragm of diameter 35mm. The frequency and amplitude of

vibration of diaphragm were controlled using a function generator and an amplifier. The driving signal is a plane sine wave. Arrangement was made to mount the pressure transducers along the side wall of the resonator for pressure measurements. Two holes were made in the top cap of resonator to have two diode arrangements, one outward favoring and another inward favoring. Four sets of fluidic diodes were used as shown in **Figure 2**.

$$A(x) = ax + b \text{ , where a=2.25 cm, b=10 cm}^2 \text{ and } 0 \le x \le 20cm \tag{1}$$

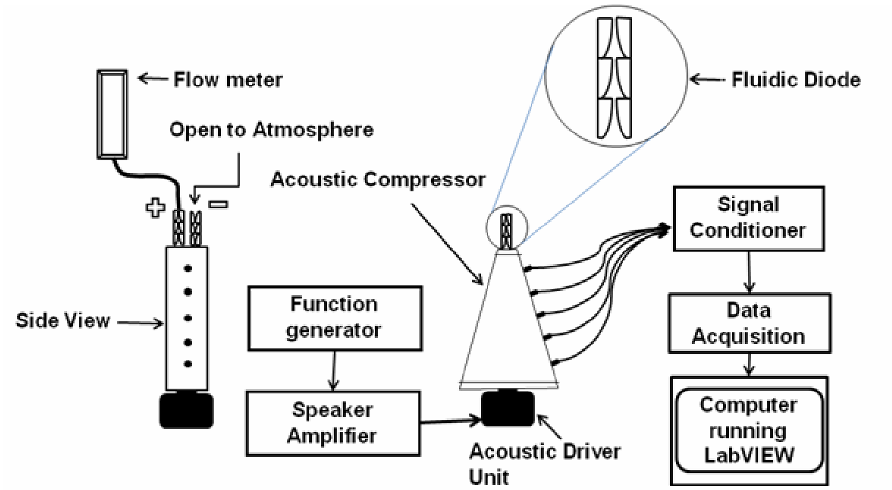

FIGURE 1. Schematic of the Experimental Setup

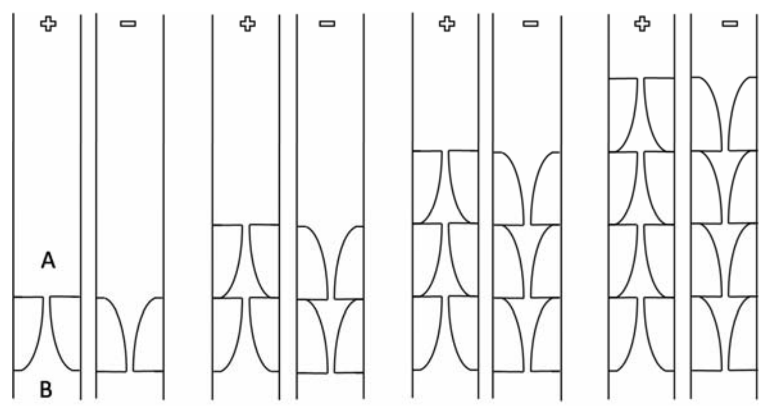

FIGURE 2. Four different fluidic diode configurations used in the present study.

INSTRUMENTATION

PCB® Piezotronics Inc. dynamic pressure transducers (model 113B27) were used to measure dynamic pressure inside the resonator. Also a rotameter was used to measure the net volume flow rate.

METHODOLOGY

Each diode set in the pair of diodes mounted on the acoustic compressor was arranged in two different configurations (as shown in **Figure 2**). One diode was arranged in a positive configuration indicated by a '+' sign (here after D1) and another diode in negative configuration indicated by a '-' sign (here after D2). Consider Diode D1. The flow patterns are much like jet driven streaming patterns discussed by Said and Morris[15.] Here an oscillatory flow, experiences a contraction as it flows from B to A and an expansion on the way back. During the suction part of acoustic cycle the flow comes from all sides and the flow pattern is much like a sink. On the other hand jet is produced during the ejection due to the flow separation around the edge at A. This results in a net mean pressure difference between points A and B. The losses are different in case of sudden expansion and sudden contraction. Thus a pressure difference is generated between the two points. The entire length of such fluidic device is only a small fraction of the acoustic wavelength (λ). Thus time-mean mass flux of the oscillatory flow in a fluidic device is non zero.

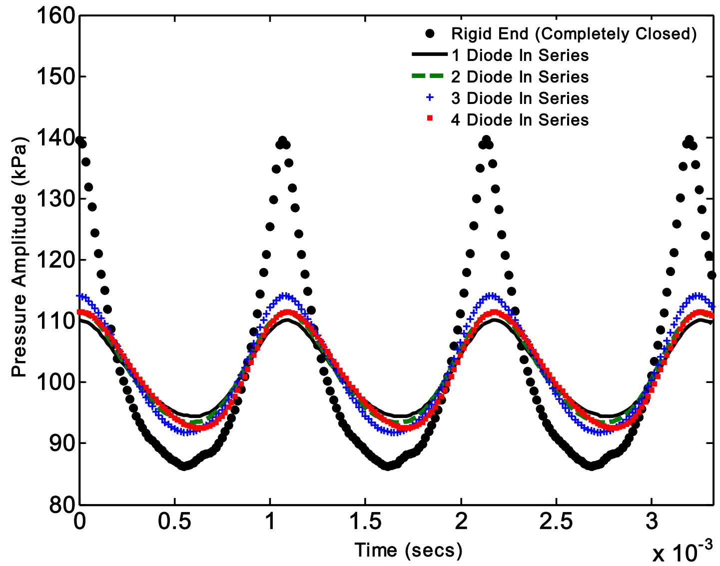

FIGURE 3. Pressure time series for different diode configurations.

TABLE 1. Overpressure & Volume Flow for different diode configurations.

No of Diodes	Overpressure (kPa)	Volume Flow Rate for D1 (LPM of Air)	Volume Flow Rate for D2 (LPM of Air)	Resonance Frequency (f_o in Hz)
Rigid End	38.300	NA	NA	939
1	08.900	3.5	3.9	922
2	10.100	4.1	3.5	925
3	12.900	4.6	0	926
4	10.175	4.9	0	924

RESULTS AND DISCUSSIONS

Figure 3 shows the pressure measurements for five different cases i.e., completely closed duct, 1 diode, 2 diodes 3 diodes and 4 diodes. It can be seen that there is substantial drop in the overpressure in presence of diodes as compared to completely closed duct. This is expected as rigid end is an ideal case where acoustic impedance is maximum. End condition is altered due to the presence of fluidic diodes. It can be seen that the overpressure is higher in the case of 3 diodes in series as compared to 1 diode case. This is due to the fact that higher impedance is provided by more number of diodes. Having said this, it is interesting to note that the overpressure in the case of 2 diodes and 4 diodes in series are almost same.

Volume flow measurements were done for both D1 and D2. When D1 was connected to rotameter, D2 was kept open to the atmosphere and vice versa (see **Figure 1**). The volume flow rate in D1 increases as the number of diodes increases (see **Table 1**). This suggests that with more number of diodes in series better rectification can be achieved. In contrast, the volume flow rate decreases for D2 and is zero in the case of 3 & 4 diodes in series. Volume flow rate decreases in the case of 1 diode and 2 diodes in series due to increase in the resistance. Whereas, in the case of 3 & 4 diodes in series, higher mass ejection from D1 results in a partial vacuum inside the resonator, which in turn is compensated by mass suction through D2. That's why the rotameter shows zero reading for D2 in the case of 3 & 4 diodes in series due to reverse flow. Volume flow in the 4 diodes in series case is higher than that of 2 diodes case, even though the overpressures are same.

The different end conditions also had an effect on the resonance frequency (f_o) of the duct. It is evident from **Table 1** that apart for completely closed end case there is no significant change in f_o for different diode arrangements. Also it should be noted that the results presented in **Table 1** strongly depend upon the shape of resonator and power of acoustic driving.

CONCLUSIONS

Resonant behaviors at five different boundary conditions for a given area variation was investigated. Experiments show that the resonant frequencies were not affected significantly in the case of 1, 2, 3 and 4 diodes in series. The effect of fluidic diode was to allow the flow in one tube (D1) while constricting the flow in the other (D2). This can result in a flow in a desired direction, thus proving the fact that fluidic diodes can be coupled with an acoustic compressor to make an acoustic pump. Also fluid diodes were found to work well at high operating frequency. This data also suggests that fluidic diodes could be used to obtain differential flows in the tubes and thus could be used to effect a flow in a desired direction.

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