AN EXTENSIVELY MODIFIABLE PIEZOELECTRIC COMPRESSOR APPARATUS: THE CREATION PROCESS

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Abstract. Positive displacement compressors necessitate the use of valves or internal volume ratios. The majority of compressor losses are caused by these two factors. The peristaltic compressor is a novel compressor design. It is an efficient compressor due to its variable volume ratios and valve less compression. The design, actuation pattern, and compression chamber construction of a prototype peristaltic compressor will be demonstrated in this talk. By sealing and pushing a flexible diaphragm on a female die, a compression chamber is formed. By continually squeezing the female die diaphragm, a linear motor squeezes and displaces fluid. The working fluid in the early tests was air, with volume ratios ranging from 1.143 to 8 and operation frequencies ranging from 1.28 to 2.31 Hz. These results show that the actuation pattern influences the compressor's primary performance parameters. Take into account mass flow, volume displacement, and pressure ratio.

Keywords: peristaltic compressor, valves or internal volume ratios, compressor losses

1. INTRODUCTION

The vapor compression cycle is used in systems such as transportation, industry, residential, and aerospace. Refrigerators and air conditioners are examples. To improve gas compression efficiency, new compressor technologies are required. During gas compression, the compressor generates more heat than the rest of the apparatus. Leaking valves, port losses in reciprocating and rotary compressors, and set volume ratios that over compress or under compress scroll and screw compressors are the most typical causes of these losses in positive displacement compressors.

Peristaltic compressors are employed in HVAC&R because they may operate at various volume ratios without the usage of valves. The cylinder chamber of the compressor aligns. A flexible diaphragm is used in cylinder manufacturing. Space can be divided into smaller ones using electromechanical motion control. Electromechanical devices form a pocket that completely shuts off the room. This compression does not require any valves or volume ratios. Finally, the HVAC&R industry will investigate this technology and its numerous applications.

Islam and Bradshaw created a basic peristaltic compressor thermal model in another investigation. The model included diaphragm types, materials, actuation speeds, and volume ratios. The compressor's major physical measurements were estimated using this model, and a reconfigurable prototype was created. The prototype facilitates testing of this compression method in order to find the ideal volume ratio, diaphragm arrangement, and material composition for maximal capacity and volumetric efficiency. The experiment makes use of air for simplicity. The primary goal is to squeeze refrigerant.

2. LITERATURE REVIEW

Recently, there has been a lot of interest in air compression with diaphragms during vapor compression cycles. According to new study, the diaphragm may be more effective at preventing leaks [4]. Initially, a tiny compressor squeezed and released gas using peristaltic actuation by placing electrostrictive ceramic blocks inside an elastic cylindrical tube. The system is inefficient due to excessive power consumption and huge capacitors. Saif et al. predicted diaphragm internal stress and deformation using a mathematical model. With circular and parabolic chambers, the model was tested. A bidirectional membrane reached the ground after pushing the first trigger. During the second condition, the bottom membrane sank and pressed on the hollow base. The findings revealed that pressure increases in parabolic circumstances. Mass flow increases when the diaphragm covers the compression chamber gap zone.

A new mesoscopic peristaltic compressor actuation design resulted from computational research. A sinusoidal wave was created by the electric field pattern in a diaphragm, allowing fluid to flow via a conduit. The depth of the hole has a direct impact on the compression ratio. The diaphragm motion, energy output, and structure were all measured by the authors. The theoretical research in the paper demonstrated the compressor-related capabilities of the peristaltic compressor. The results of physical tests and the heat transfer mechanism were ignored.

Sathe et al. proposed increased compressor diaphragm actuation. DC voltage provided diaphragm force. After the input valve is opened, refrigerant enters. Following the vacuum stroke, the discharge valve opens with backwards voltage. The removal of the diaphragm completes compression. A sample was used to determine diaphragm effectiveness. For R134a, the prototype showed a 1.5 kPa pressure rise, whereas the simulation expected 30. The method's main disadvantage is the extended diaphragm pressure.

The discharge rate and pressure are controlled by the diaphragm. When compression and release occur simultaneously, the pressure is greatest. Fluid flow is improved by diaphragmatic prolapse. The compressor is operating at maximum capacity. Electrostatic control may ionize liquids, rendering it ineffective. Like other approaches, electrostatic actuation has a limited motion range. According to Chen et al., a rhombic micro displacement amplifier can boost piezoelectric actuator motion by 100 m. Aside from the theoretical model of microscale compressors, electro statically powered diaphragm-driven peristaltic compressors are incapable of accomplishing specific tasks. Making a compressor reversible can significantly increase its performance. Perovskite compressors are desirable because they squeeze without using valves or internal volume ratios. Previous research used small examples to investigate these aspects. In this study, a more fully formed prototype design will be demonstrated to investigate the effects of changing volume ratio, valveless function, and adjustable shape.

3. RECONFIGURABLE PERISTALTIC COMPRESSOR MECHANISM

The diaphragm is moved straight by ten linear motors. This compression can be obtained without the use of discharge or vacuum valves due to diaphragm adjustability. Changing the internal volume ratio of the compression chamber takes simply switching actuations. The compression chamber is filled with air for these preliminary tests. Figure 1 depicts a schematic of the re-configurable peristaltic compressor prototype. A cylinder compression chamber is formed by pressing and holding the diaphragm against a female die. The diaphragm and linear actuator close the chamber and drive the male die, also known as the piston, against the female die.

Figure 1 depicts an in-house reconfigurable peristaltic compressor platform.

The peristaltic compressor's motors, which are critical to its operation, are controlled by PLC. Rockwell Automation Studio 5000 is used to program these actuators. The application was created to make compressor management easier. Users merely need to activate the servos, select a motion pattern, and begin and end the compression cycle.

By alternating between a valve actuator (which creates multiple small compression pockets) and a central piston actuator (which notifies when compression chamber fluid leaks), the compression ratio of the test can be altered. We demonstrate the activation modes Mode 1 and Mode 2, which provide variable volume ratios. The pattern of each mode controls compression differently.

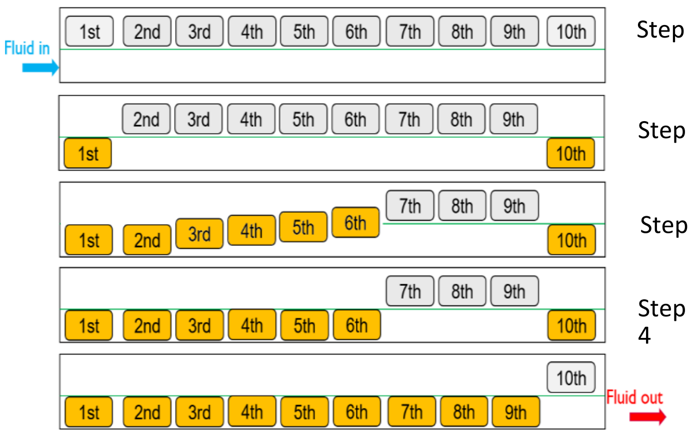
Mode 1 Actuation

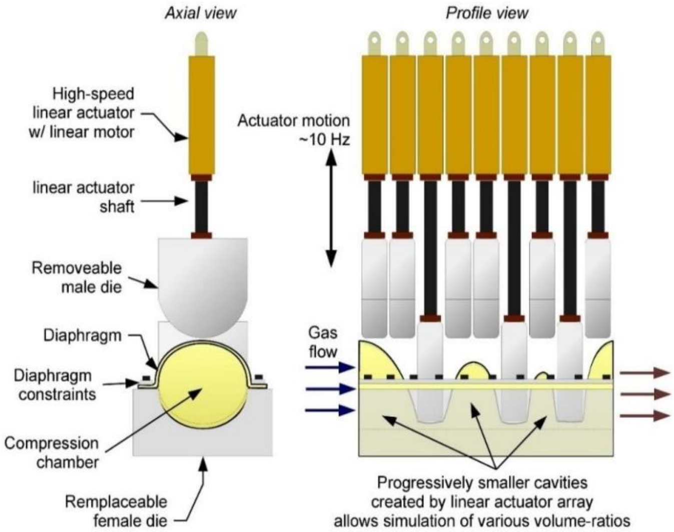
The first and tenth pistons operate the compressor's suction and discharge valves early on. Figure 2 depicts how to turn the seventh piston into the central piston. Each piston rises as working fluid enters the diaphragm. The first and tenth pistons split the compression chamber fluid in half in Step 2. In the third stage, the second through sixth pistons press on the diaphragm, compressing the fluid. Steps four and five include depressing the seventh piston, allowing the seventh through ninth pistons to press the diaphragm and the tenth piston to rise, releasing fluid.

=Piston compressing the diaphragm

=Piston on the diaphragm

Figure 2 depicts how to operate the Mode 1 pivoting piston 7.





Mode 2 Actuation

The second stage involves the use of a valve to split an existing compression pocket in half in order to produce a new one. In Figure 3, the hole is represented by piston 7, and the main piston is represented by piston 4.

=Piston compressing the diaphragm

=Piston on the diaphragm

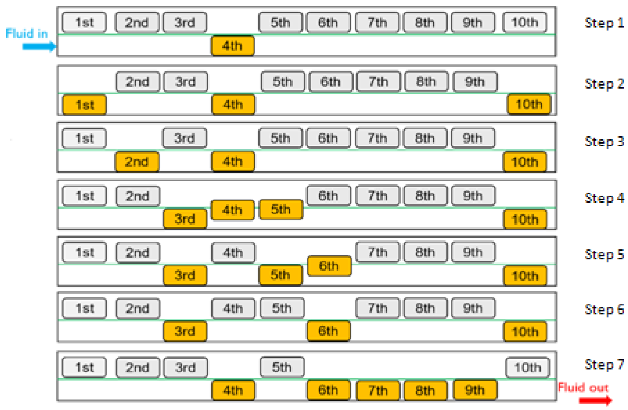


FIGURE 3: Schematic of a Mode 2 system with valve 4 and central piston 7.

To begin functioning, the fourth piston presses the diaphragm. In the second phase, pistons 1 and 10 are lowered, resulting in two compression gaps. Fluid is prevented from entering the passage between the first and fourth pistons by the first component. Finally, piston descent initiates compression. In step four, the rising valve piston is completed. After the third piston squeezes the diaphragm, the fluid is transported to the next compression stage. The second half of the process will be identical to Mode 1. After separating the fluid, the fifth and tenth pistons in the second pocket squeeze it one by one. When the system activates key piston no. 7 in steps 6 and 7, the tenth piston rises and the seventh through ninth pistons descend. When the first and fourth pistons create a pocket, a new cycle begins. The procedure is repeated until the compressor is turned off.

Pivoting pistons and valves in each configuration allow for numerous volume ratio variations. The compression chamber volume ratio ranges between 1.143 and 8. Researchers will be able to explore the association between volume ratio and compressor parameters such as volumetric efficiency using data from a wide range of volume ratios.

4. RECONFIGURABLE PROTOTYPE DESIGN

This section discusses the time-consuming process of creating a prototype. The compressor prototype is stored on a mobile cart. The compressor frame was transported on this trolley. The finished compressor design parts list from SOLIDWORKS is shown in the frame.

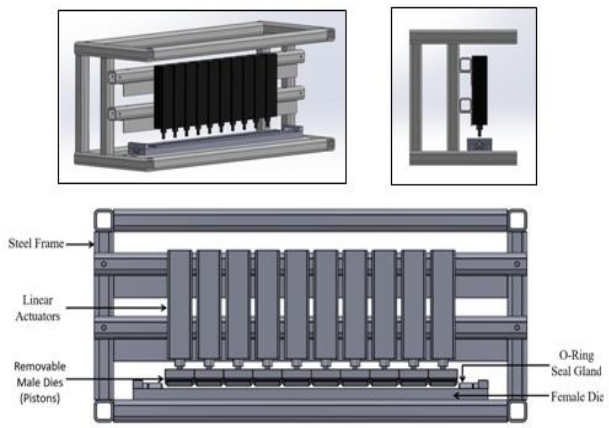


Figure 4 depicts a compressor.

A machined metal channel, steel frame, sealing elements, and linear actuators are all part of this architecture. It was difficult to find the seal channels of a component with a flexible diaphragm and "modular" properties that made it easy to modify or replace. The female die seals the diaphragm, and the actuators are attached to the male dies, or "buttons." The modular design of the compression chamber will help the study team by allowing them to adjust its dimensions and shape by replacing out a component. The thermodynamic model indicated that diaphragm sealing would come next. This model determined the amount of space required for each component. Along the compression chamber, O-ring seals and seal bars sealed the ends and diaphragm margins. Figure 5 depicts a cross-section of the components listed below. The O-ring gland outer diameter seal was created using Marco gland design specifications. The bore of the seal was 0.0254 [m], while the ring size was -020.

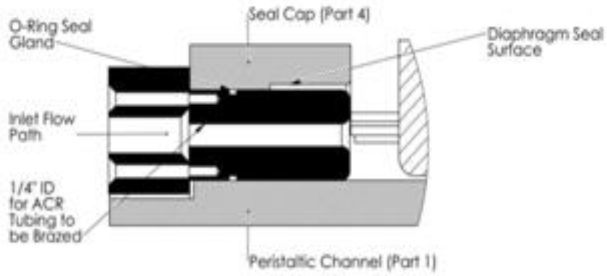


Figure 5 depicts a component architecture with a focus on the seal path.

All steel construction components were tightly fastened. A pressure transducer and RTD installed in a pipe network measure pressure and temperature at the peristaltic compression chamber's intake and outflow. At the compressor inlet, an Omega mass flowmeter with an analog output monitors mass flowrate. Each sensor is integrated into the analog I/O module, which reads the data and presents it to Studio 5000. The recovery tank holds compressed fluid to keep the metering valve discharge pressure constant. Fluid flow and backpressure are controlled by the metering valve at the compressor output. The pressure ratio of the compressor is altered by adjusting the measurement valve. The measuring sensors can be seen in Figure 6's mock-up prototype.

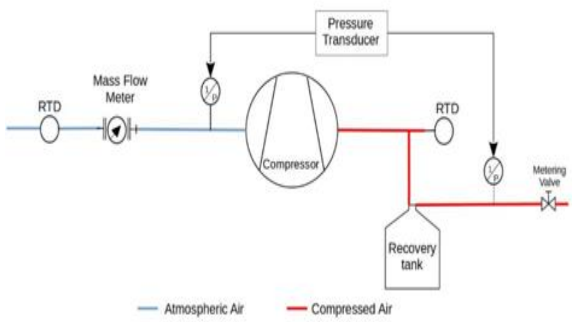


Figure 6 depicts a common compressor sensor configuration.

Figure 7(a) shows an experimental diaphragm configuration. Seal bars and caps connected the female die to 40-durometer neoprene rubber. When linear motors force the diaphragm against the female die while the compressor is running, a vacuum pocket is formed. The compression chamber's lid opening draws in outside air.

The trial prototype is depicted in Figure 7. An RTD, mass-flow meter, and pressure sensor are located at the inlet. The outlet is equipped with an RTD, a pressure gauge, and a recovery tank.

Figure 7: (a) Experimental prototype, (b) RTD, Mass-flow meter and Pressure transducer at inlet, (c) Pressure transducer, RTD and Recovery tank at outlet.

5. PRELIMINARY TEST RESULTS

The various diaphragm types of the experimental compressor are simulated. The circular shape of the compression chamber hampered linear diaphragm actuation. While the diaphragm stayed on the female die, the system's mass flow rate and pressure ratio increased. A semicircle compression chamber was formed as a result of the sealing operation. According to additional studies, the diaphragm stretches because it is elastic and linearly displaced. As a result, the volume of the compression chamber changes regularly. After actuation, diaphragm stabilization takes an hour. To determine the efficacy of the prototype, measure its displacement volume. Compressor pressure ratio is regulated by two distinct test models for Modes 1 and 2. These models take actuation speed, pivoting piston positioning, valve and metering valve into account.

The metering valve regulates the loss of system pressure. The maximum pumping capacity of the prototype compressor is found by testing several metering valve types, including a fully closed one. The first and tenth pistons include intake and exhaust valves, respectively; the total areas of pistons two through nine determine displacement volume. This is calculated using compressor displacement volume and MFR:

$$\eta_{vol} = \frac{\dot{m}}{\rho_{in}\, f\, V_{disp}}$$

In this case, "d" stands for input density, while "v" stands for compressor displacement volume. Figure 8 depicts how changing the pressure ratio impacts mass flow and volumetric efficiency. A higher pressure ratio reduces mass flow and bulk efficiency. When the pressure ratio increases, a larger critical piston squeezes fluid over a larger area, whereas a smaller piston releases it sooner.

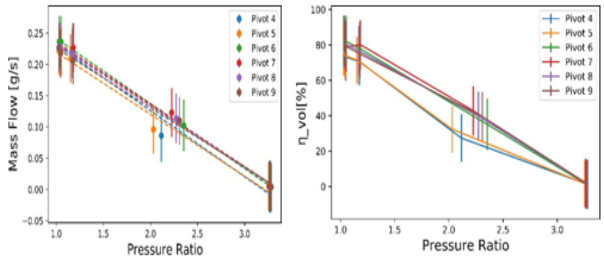


Figure 8 depicts the effect of pressure ratio on Mode 1 mass flow rate and volumetric efficiency.

In Mode 2, a separate actuator (numbered 3-6) changes the compression chamber displacement volume and activation pattern. According to research, valves 3 and 4 have a small initial compression pocket. Because not enough fluid was pushed into the second compression pocket to compress it, the mass flow rate changed and the system's effectiveness diminished. The problem was solved by adjusting valves 5 and 6 on important pistons.

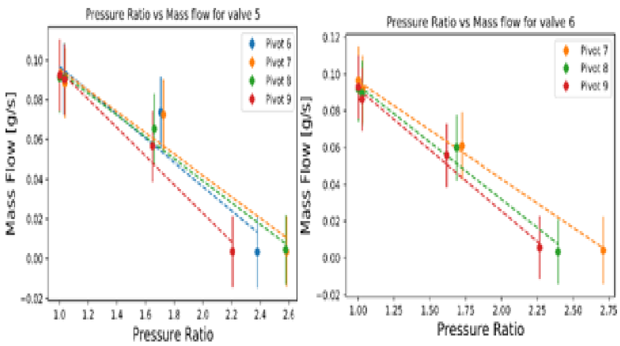


Figure 9 depicts the time-varying mass flow rate of Mode 2. Actuator 5 is a valve in this case.

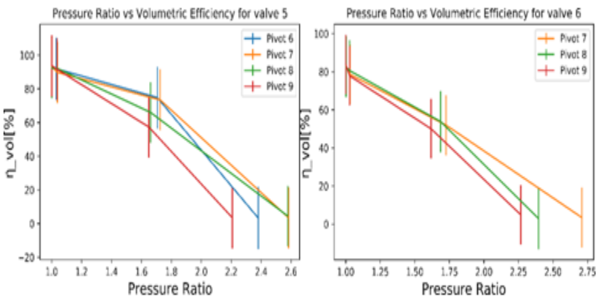


Figure 10 depicts improvements in Mode 2 volumetric efficiency: a) Actuator 5 valve operation.

According to Mode 2 study, mass moves rearward into the first compression pocket while the second gets squashed. The actuation system is subjected to less force. The final piece deepens the Mode 1 pattern, preventing the fluid from moving rearward. Mode 2 outcomes often include extending the middle piston to minimize the system pressure ratio.

6. CONCLUSION

This paper demonstrates how to construct a reconfigurable peristaltic compressor and explains how it operates. The sample design presents results for two modes of operation and demonstrates how simple it is to optimize piston actuation by adjusting dies or compression chamber size. According to preliminary data from both modes, the peristaltic expander could improve volumetric efficiency by adjusting volume-to-pressure ratios, which would benefit the firm. The design may produce a big mass flow while maintaining a low volumetric efficiency. The design and construction of the diaphragm, which limits pump pressure, is one of the system's weak points. Because the elasticity of the diaphragm controls fluid pumping, it must be soft. This causes the diaphragm to wear out and must be replaced. The displaced volumes of diaphragms vary due to their bending. This may have an impact on compression chamber volume changes. According to studies, high fluid compression increased mass efficiency.

The progress of these pieces and the prototype compressor will decide how well we understand the creative design. The prototype will be used to validate a thorough mechanical thermodynamic model. After air testing, the compressor's refrigerant processing will be incorporated in the model and sample. The efficiency of the new compressor will be evaluated during a vapor compression cycle.

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