Simulation of Standing wave Thermoacoustic prime mover using DeltaEC

Krishna moorthy[1*], Uma Praveen[1], Jaanaki S.M[2], N.M.Hariharan[3], S.Kasthurirengan[4]
[1]Department of Physics, MVJ College of Engineering, Bangalore,
[2]Department of Electrical and Electronics, MVJ College of Engineering, Bangalore,
[3] Departments of Bio Technology, Sri Sastha institute of Engineering Technology, Chennai
[4] Center for Cryogenic Technology, Indian institute of Science, Bangalore

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ABSTRACT *Thermo Acoustic Prime Movers (TAPMs) are one of the renewable sources of energy. These systems convert the excess industrial heat into acoustic power that can be utilized to drive cryocoolers. The efficiency of TAPMs depends on paremeters such as dimensions of the prime mover, working gas and operating temperature. This paper presents the effect of the geometric parameters such as resonator length, stack and buffer volume on the efficiency of TAPMs using DeltaEC software. The simulation results shows that the amplitude of the acoustic wave and the resonant frequency depend on the geometry of the TAPMs and properties of the working fluids.*

Keywords: *Thermoacoustics, Prime mover, Cryocoolers*

1. Introduction

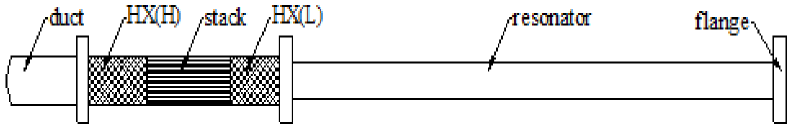
The efficiency of conventional Cryocoolers such as GM, Stirling, are low due to the moving components both at ambient and cryo temperature. The Pulse Tube Cryocoolers although eliminates moving parts at cryogenic temperatures, still there are moving components at ambient temperature. The TAPMs are a solution due to the total absence of moving components. A typical thermoacoustic engine consists of a heater, stack (equivalent to the regenerator of a cryocoolers), heat exchangers and resonator. The appropriate phase relationship of intrinsic pressure and velocity components lead to the conversion of heat energy to acoustic oscillations.

The TAPM was first used by Swift and Radebaugh in 1990 [1] to drive a Pulse Tube Cryocooler. As on date, this field is well developed by several experimental and theoretical studies with the focus of developing highly reliable thermoacoustic prime movers. The development of a TAPM should be guided by numerical modeling and this may be carried out by several techniques such as solving energy equations, enthalpy flow model, DeltaEc, CFD etc. However, in this work, we present the Delta EC analysis of single ended and twin ended prime mover, where both geometrical and operational parameters have been varied.

2. Standing wave prime mover model using DeltaEC

The performance of the standing-wave thermoacoustic prime mover was simulated using DeltaEc program (Design Environment for Low-Amplitude thermoacoustic Energy Conversion) developed by Ward and Swift in Los Alamos National Lab. This program can be used to calculate the details of how the thermoacoustic mover performs, and reflect the variation trend of the performance influenced by the working fluid parameters, operating parameters, geometrical parameters and so on.

Fig.1 shows the schematic diagram of the simulation model of the symmetric standing-wave thermoacoustic prime mover. The system includes the resonance tube, hot buffers, hot heat exchangers (hhe), stacks, and cold heat exchangers (che), which were symmetrically arranged on the both sides of the resonance tube. the stacks and heat exchangers were prepared with stainless steel and copper plates respectively, using 0.5 mm thickness plates, while the space between two plates were 1.0 mm.



Single mover

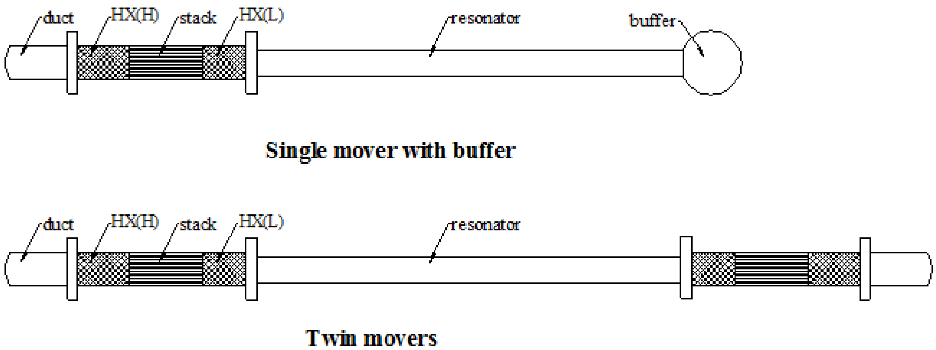


Fig.1 schematic diagram of the simulation model of the Single and Twin symmetric standing-wave thermoacoustic prime mover

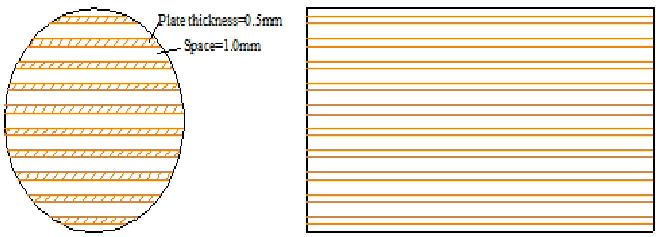


Fig.2 Cross section of the stacks and heat exchangers

Fig.2 shows the cross section of the stacks and heat ex63hangers. The plates were separated from each other by the thin sticks. The oscillating gas flows in the spaces between the plates. The hot heat exchangers were insulated with ceramic fiber. The resonance tube was a copper tube of 1.5 m length. Dimensions of the main parts of the thermoacoustic prime mover are presented in Tab.1

Items	Hot buffer	HHE	Stack	CHE	Resonance tube
Inner diameter (mm)	51	51	51	51	38
Length (mm)	110	80	200	40	3300

Tab.1 Dimensions of the main parts of the thermoacoustic mover.

3. Results and analysis

3.1 Influence of working fluids

The effects of the working gas with different charge pressures on the performance of the movers were simulated. The system charge pressure was varied from 0.4MPa to 1.3MPa. The ambient temperature was 300K. The input power of each heater was kept at 1kW. The wall temperature of the cold heat exchanger was assumed constant at 300K. The working gases were helium, argon, nitrogen and He-Ar mixture (50%-50%) in different cases, respectively.

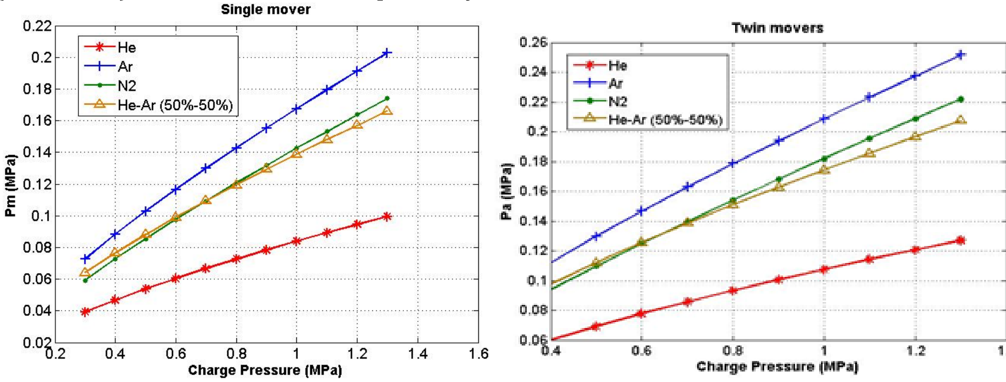


Fig. 3 The comparison of the performance of the movers using different working gases with different charge pressures and pressure amplitude.

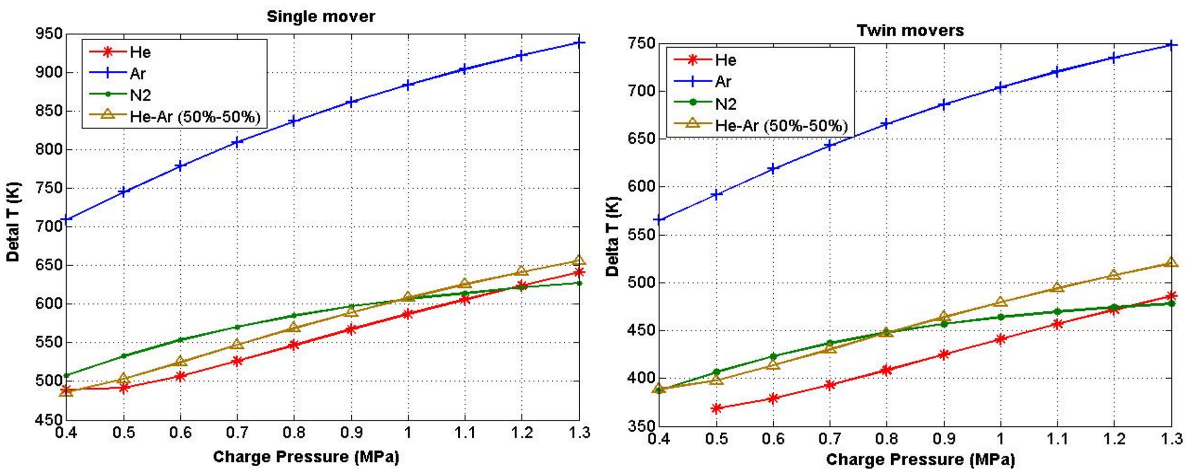


Fig. 4 The comparison of the performance of the movers using different working gases with different charge pressures and Delta T

Fig.3 showed the comparison of the performance of the movers using different working gases with different charge pressures. The comparison of the simulation results indicated the simulation can reflect the variation trend of the working gas parameters on the performance of the movers. It is indicated that The minimum resonance frequency can be achieved using argon gas in the test working gases due to its lowest acoustic speed. The pressure amplitude and onset temperature difference of the mover increased with the charge pressure of the working gases. The maximal pressure amplitude of the mover can also be achieved using argon gas; however, the larger onset temperature difference was also essential for this gas. In addition, the mixtures of helium gas and argon gas were tested. The results indicated the mixtures can improved the onset temperature difference and pressure amplitude compared to the pure argon gas and pure helium gas, respectively.

3.2 Influence of Resonator length

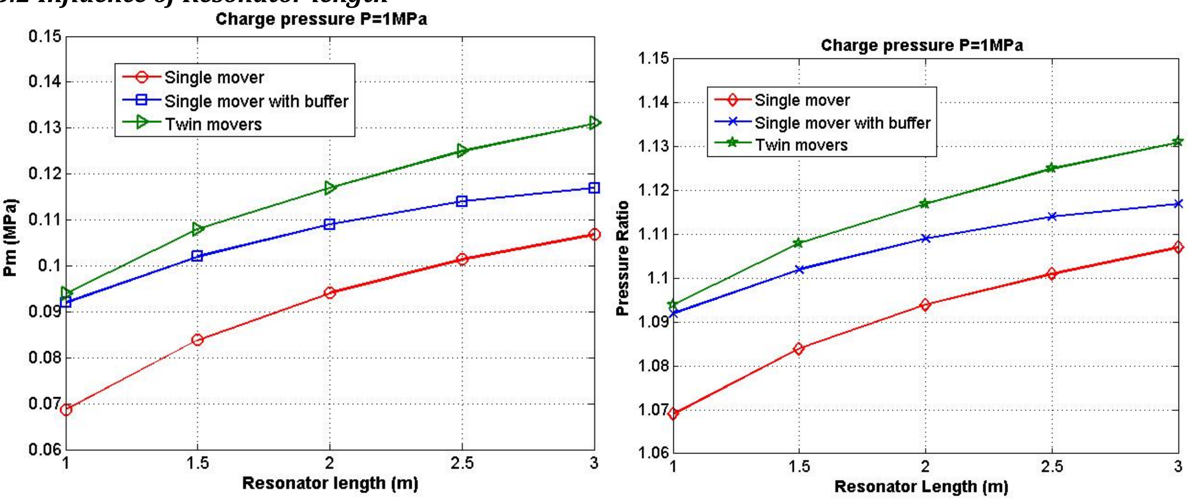


Fig. 4 The comparison of the performance of the movers with resonator length (a) Pressure amplitude (b) Pressure ratio

Fig.4 showed the comparison of the performance of the movers with different resonator length. The results indicate that Twin symmetric prime mover has higher pressure ratio and it increases with increasing resonator length.

3.2 Influence of stack geometry

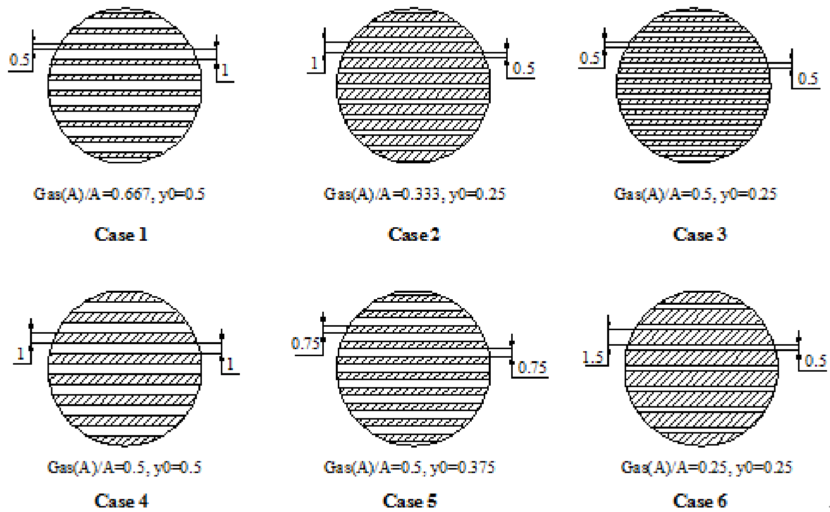


Fig. 5 The different design of parallel plate stack

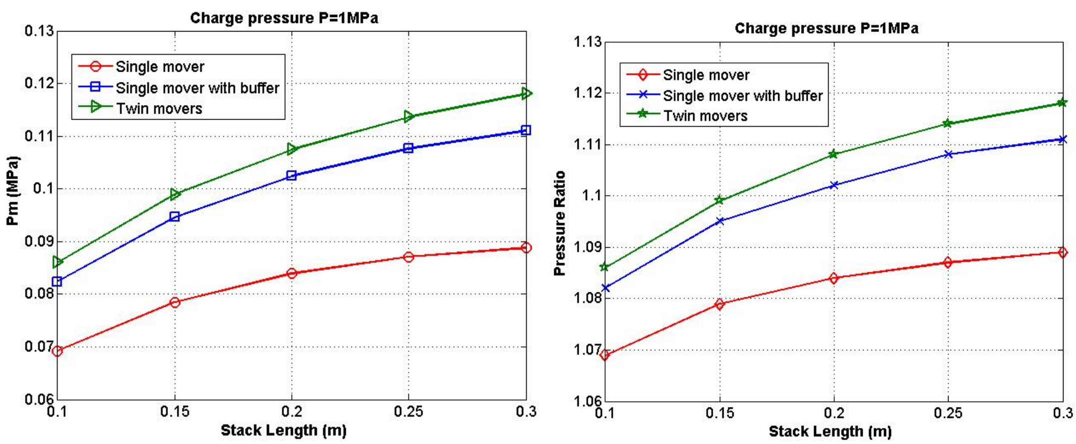


Fig. 6 The comparison of the performance of the movers with resonator length (a) Pressure amplitude (b) Pressure ratio

The geometry of the stack is very critical in the design of TAPM [9].There are different stack geometrics such as parallel plates, circular pores, pin arrays, triangular pores, etc. Pin arrays stacks are the best, but they are too difficult to manufacture. In the simulation studies, three basic geometries are considered. The pin arrays and parallel-plates stacks are suitable for TAPMs. Hence, we choose to use a stack made of parallel-plates. Our simulation results indicate that stack length improves the pressure amplitude as well as higher pressure ratio.

4. Conclusions

The effects of the working gas and different geometrics of TAPMs with different charge pressures have been simulated.

(1) The resonance frequency of the mover increases with the acoustic speed of the working gas. The minimum resonance frequency can be achieved using argon gas in the test working gases.

(2) The pressure amplitude and onset temperature difference of the mover increase with the charge pressure of the working gases.

(3) The maximal pressure amplitude of the mover can also be achieved using argon gas, however, the onset temperature difference increases correspondingly, resulting in the problem of the reduction of the system efficiency. The argon gas mixed with helium gas can improved the onset temperature difference and pressure amplitude compared to the pure argon gas and pure helium gas, respectively.

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6. References

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