

Simulation of Standing wave Thermoacoustic prime mover with different working fluids

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Received: May 20, 2018

Accepted: June 28, 2018

ABSTRACT

Thermo Acoustic Prime Movers (TAPMs) work on the principle of conversion of heat energy to sound energy which is used to drive engine by the variation of pressure created by acoustic power. In order to develop a system theoretical knowledge about the dimension of a prime mover, working gas and operating temperature are required. This paper presents the studies of influence of working fluid in Thermoacoustic Prime mover using DeltaEC software. The analysis indicates that the variation of resonant frequency, Amplitude of the acoustic wave depends on the properties of working gas(es).

Keywords: Thermoacoustics, Prime mover, Cryocoolers

1. Introduction

Recent developments in space technology and industries indicate the need of cryocoolers with high performance and long term reliability with minimum maintenance schedules. Conventional Cryocoolers such as GM, Stirling, etc., do not meet these demands due to the moving components both at ambient and cryo temperature that lowers their efficiency. 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. Also experimental studies have been carried out on the standing wave twin TAPM, built in our laboratory. The theoretical results predicted by DeltaEC are reasonably in good agreement with experimental studies.

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.

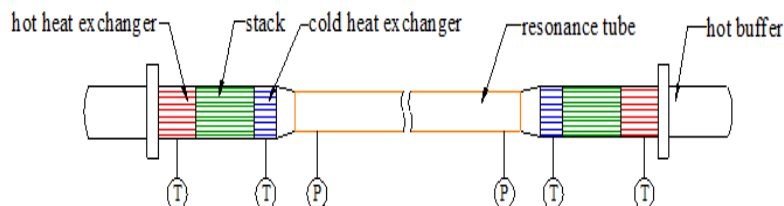


Fig.1 schematic diagram of the simulation model of the Twin symmetric standing-wave thermoacoustic prime mover

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.

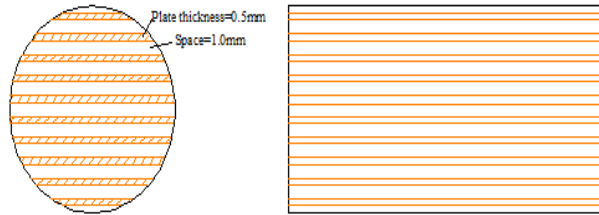


Fig.2 Cross section of the stacks and heat exchangers

Fig.2 shows the cross section of the stacks and heat exchangers. 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

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.

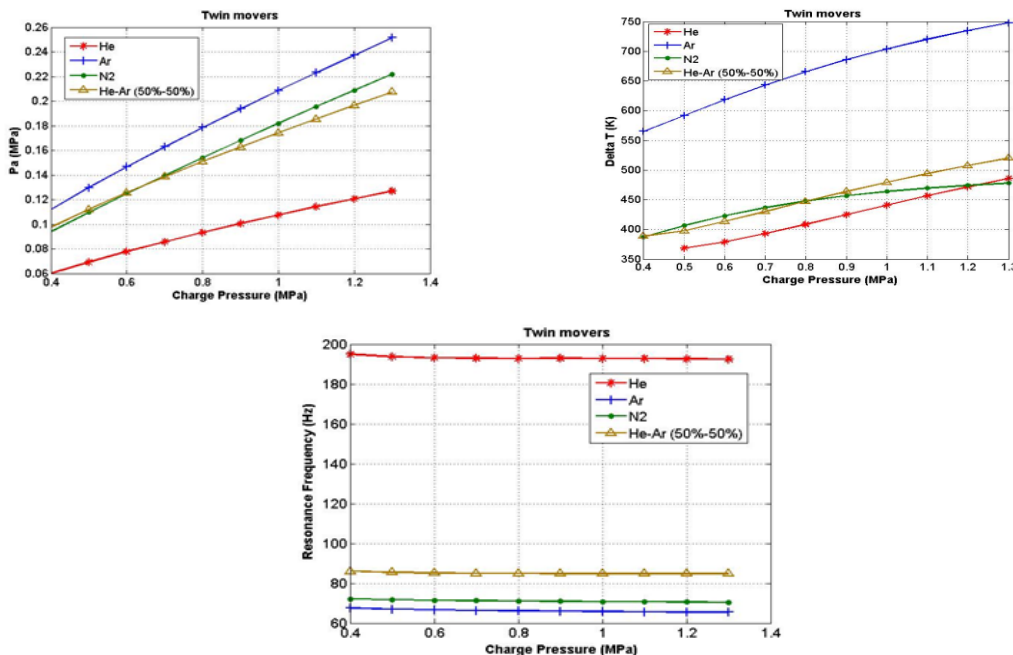


Fig. 3 The comparison of the performance of the movers using different working gases with different charge pressures: (a) resonance frequency; (b) pressure amplitude; (c) Delta T.

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 and experimental data indicated the simulation can reflect the variation trend of the working gas parameters on the performance of the movers. However, there were large differences between the absolute values. The author considered the reasons came from the followings: (1) the wall temperature of the cold heat exchanger was assumed to be constant at 300K, and the heat load can be completely released in the simulations. Unfortunately, the efficiency of the cold heat exchanger was low in the tests, resulting in the high temperatures (320~330K) at the cold heat exchanger; (2) the cross sections of the stacks and heat exchangers were assumed uniform in the simulations, however,

the spaces between the plates were irregular in the fabrication, resulting in the large flow resistance for the working gases through the channels.

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 improve the onset temperature difference and pressure amplitude compared to the pure argon gas and pure helium gas, respectively.

4. Conclusions

The effects of the working gas with different charge pressures on the performance of the standing-wave thermoacoustic prime mover 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 improve the onset temperature difference and pressure amplitude compared to the pure argon gas and pure helium gas, respectively.

5. Acknowledgements

The author is grateful to Prof. Kasthuriengan for valuable suggestions and contributions in the simulation study. The author is also thankful to the staff of Centre of Cryogenic Technology, Indian Institute of Science, for their kind help in the modeling thermoacoustic system.

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