Development of the Thermoacoustically Driven Pulse Tube Cryocooler

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ABSTRACT:
Thermoacoustic engines can be an attractive alternative for specialized applications because of their simplicity, and their absence of lubrication, seals, and environmentally harmful working fluids.The high-efficiency thermoacoustic engine provides an alternative to the research and development of long-life cryocoolers. Thermoacoustic engine consist of tubes, heat exchangers, and we are making the pressure and velocity oscillations in the sound field and as a result we are realizing that the heat energy is converted into mechanical energy, which is used to drive pulse tube cryocooler. The Cryocoolers are driven by a mechanical compressor, which is a moving component. Application of cryocoolers as, in cryopumps, liquefying natural gases, cooling of radiation shields, magnetometers, SC magnets, SQUID (super conducting quantum interference device). The present research work developed the pulse tube cryocooler, and coupled to engine and observations will be made over the set up.
Key Words: Thermoacoustic Engines, Cryocooler, Pulse Tube Cryocooler and heat exchangers.

1.0 INTRODUCTION
Cryogenics comes from the Greek word "kryos", which means very cold or freezing and "genes" means to produce. Cryogenics is the science and technology associated with the phenomena that occur at very low temperature, close to the lowest theoretically attainable temperature. A few applications of cryogenic temperatures are in space research, cryotreatment, cryosurgery, liquefying of gases and in super conductivity etc. Thermoacoustics, as the name might imply, is the study of interactions between thermal and acoustic processes. In the acoustics community, the term "thermoacoustic" applies specifically to a class of devices whose primary purpose is to convert thermal energy to acoustic energy, or vice versa. These devices take advantage of the fact that temperature oscillations accompany the pressure oscillations resulting from acoustic perturbations in a fluid. According to the energy conversion, there are two kinds of thermoacoustic effects: one is the acoustic oscillation powered by heat energy, and the other is the heat flow driven by acoustic power. According to this classification, thermoacoustic machines may be categorized as thermoacoustic engine (prime mover or compressor) and thermoacoustic refrigerator. According to the sound field, thermoacoustic machines may also be categorized as standing-wave and travelling-wave systems.

Cryocooler is a refrigeration machine with refrigeration temperature below 123K and with a small refrigeration capacity. These cryocoolers are mainly used for cooling of the infrareds sensors in the missile guided system and satellite based surveillance, as well as in the cooling of superconductors and semiconductors. According to the classification by Walker (1983) there are two types of cryocoolers: recuperative type and regenerative type. The Recuperative types utilize a continuous flow of the cryogen in the one direction, analogous to a DC electrical system. The recuperative coolers use only recuperative heat exchanger and operate with a steady flow of cryogen through the system the compressor operates with a fixed inlet and outlet pressure. In the Regenerative cycles the cryogen undergoes an oscillating pressure analogous to an AC electrical system. The compressor or pressure oscillator for the regenerative cycles needs no inlet or outlet valve. The former includes the Joules Thomson cryocooler and the Brayton cryocooler. The latter includes the Stirling type cryocooler and the Gifford-McMahon type cryocooler and Pulse Tube Crycooler.

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ISSN: 2278-0181
Vol. 2 Issue 12, December - 2013

3.WORKING PRINCEPLE OF PULSE TUBE CRYOCOOLER

Pulse Tube Cryocooler was built by Gifford and Longworth in 1960's. It has no moving part in low temperature region and is inherently simple and reliable, with low vibration and long lifetime. Mikulin et al invented Orifice Pulse Tube Cryocooler. He has reached 3.6K with 3-stage Orifice Pulse Tube Cryocooler. It uses modest pressure and pressure ratio. It has low refrigeration rate per unit mass flow. In 1989, Shaowei introduced the double inlet method. They obtained the lowest temperature of 132k using Double Pulse Tube Cryocooler while it was 175k obtained from Orifice Pulse Tube under the same operating conditions. S.Zhu built the latest development in the field of Pulse Tube Cryocooler. It has higher efficiency than the previous types. In stirling and GM type moving parts are there at cold end space and atmospheric end space, moving parts will reduce life of cryocooler. Pulse tube cryocooler is the absence of moving parts.

The working principle of pulse tube cryocooler are when a gas at room temperature is admitted to one end of tube (shown in Figure 1.1), closed at far end, so that pressure in tube is raised, there will be a tendency for a temperature gradient to be established within part of the tube.

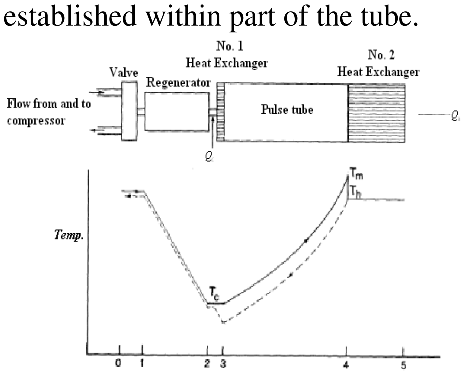

Fig 1.1: principle of pulse tube cryocooler.

This gradient will be most pronounced if the gas enters with plug flow, without turbulent mixing in tube and with minimal heat transfer to the wall. Then all gas initially within the tube will under go isentropic compression and its temperature T can be given by relationship:

$$\frac{T}{To} = \left[\frac{P}{Po}\right]^{\frac{\gamma-1}{\gamma}}$$

This gas is displaced towards the closed end of the tube. Between, gas at hot end region that is at higher temperature due to isentropic compression and the gas at the open end of the tube, which is still at T_0, a temperature gradient will be established in the tube. If heat is rejected in the region of closed end (hot end) of the tube to restore the gas temperature to near To and the pressure suddenly released through the opened end of the tube, the gas will be expanded by a near isentropic process back to its original pressure and will reoccupy most of the tube. This gas will be at the temperature below T_0, and there for will be capable of performing refrigeration.

In the field of cryogenics Pulse Tube Cryocooler is attractive as a high reliability and low vibration cryocooler because there is no moving part at the cold section. Also due to improved thermodynamic efficiency the Pulse Tube Cryocoolers are now getting more importance.

Thermoacoustic engine consist of tubes, heat exchangers. Making the use of pressure and velocity oscillations, we are realizing the heat energy is converted into mechanical energy by appropriate thermal contact conditions. Sound wave consists of pressure oscillations and when heat is flowing we will observe temperature oscillations. Combination of these oscillations will give "rich" variety of thermoacoustic effects. According to the energy conversion there are two kinds of thermoacousic machines. One is acoustic oscillations are powered by heat energy called as thermoacoustic engine. Second one is heat flow is driven by acoustic power called as thermoacoustic refrigerator.

According to the sound field thermoacousic machines are two types of thermoacoustic machines. One is standing wave engine and second one is travelling wave engine.

4. EXPERIMENTAL SETUP

Fig 4.1: Standing wave engine driven pulse tube cryocooler.

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Standing wave engine driven pulse tube cryocooler. Here the heat input at the hot heat exchanger is supplied from the solar energy. The temperature difference is created across the stack and thermoacoustic phenomena are observed in engine. The pressure oscillates which are coming from the engine are connected to pulse tube cryocooler as shown in fig 4.1, by that way the thermoacoustically driven pulse tube cryocooler is completely absence of moving parts.

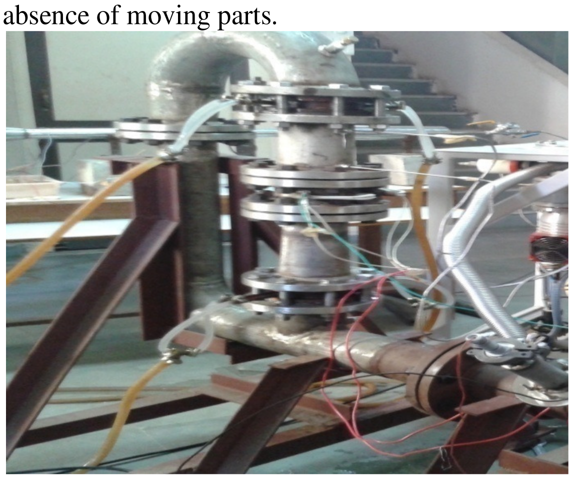

Fig 4.2 Travelling wave engine driven pulse tube cryocooler

Fig. 4.2 is a travelling wave engine driven pulse tube cryocooler. Here the pressure and velocity are in phase, because of this more acoustic power is achieved in travelling wave engine compared to standing wave engine. Since gaskets are used at the heat exchangers so the limited temperature at the hot heat exchanger is 400 ^{0}C. In this system there is a leakage at the gaskets so the system is charged to 20 bars for initial running purpose. Because of increase in temperature at hot heat exchanger the leakage is also increasing, due to this system is produced insufficient pressure ratio to drive pulse tube cryocooler.

5. RESULTS AND DISCUSSION

For the system configuration [12] we are given input parameters to Delta EC software, achieved the numerical results and analyzed the pressure amplitudes, pressure ratios and acoustic powers

He gas as the working fluid at 300HZ, 40bar, 1000W, T_H=700 the following results are shown

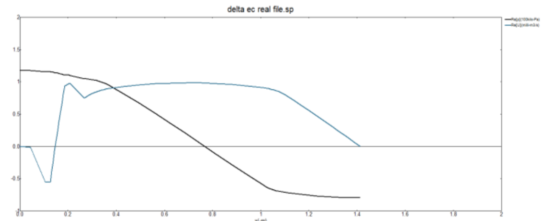

Fig 4.1: For helium gas variation of real pressure (__) and real velocity (__) along the length of engine.

He as working gas: charging pressure, pressure amplitude, drive ratio

charging pressure	**pressure amplitude**	**drive ratio**
25	0.86475	0.03459
30	0.96697	0.0322
35	1.07	0.03057
40	1.1762	0.0294

Table 5.1: DeltaEC pressure amplitude, drive ratio results of standing wave engine for given charging
pressure, hot HE temperature is 700, power is 1000W

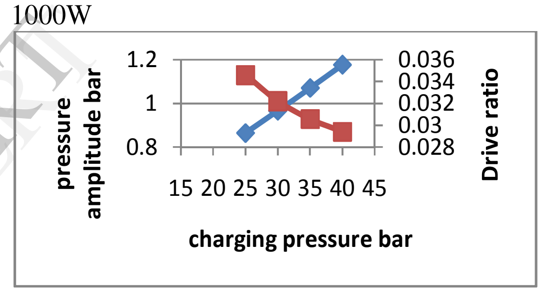

Fig 5.1: variation of pressure amplitude and drive ratio along with charging pressure of helium Gas.

Charging pressure vs acoustic power

charging pressure in bar	**acoustic power in W**
25	12.384
30	12.531
35	12.688
40	12.819

Table 5.2 : acoustic power results from DeltaEC for given charging pressure, hot HE temperature is
700, power is 1000W.

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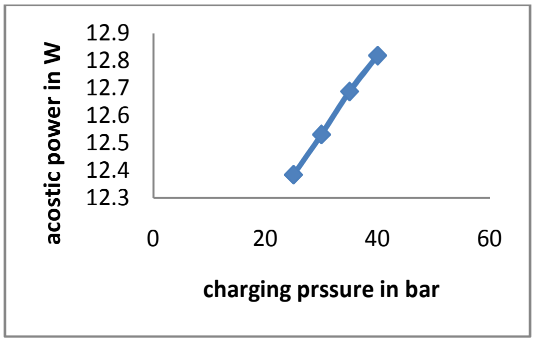

Fig 5.2: variation of acoustic power along the charging pressure for helium gas

Length vs drive ratio for charging pressure of 40 bar , helium gas as working fluid

Length in m	Drive ratio
0	0.029315
0.1	0.02891
0.2	0.02755
0.3	0.02564
0.4	0.0202
0.5	0.01277
0.6	0.00884
0.7	0.00076177
0.8	-0.003305
0.9	-0.011315
1.0	-0.015184
1.1	-0.01787
1.2	-0.01897
1.3	-0.019739
1.4	-0.0199
1.2	-0.01897
1.3	-0.019739
1.4	-0.0199

Table 5.3: drive ratio variation along the length of the engine.

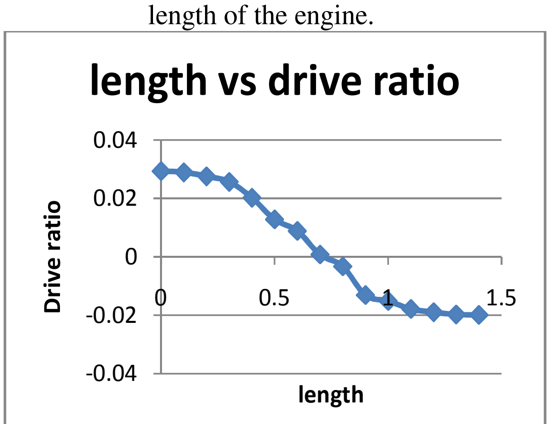

Fig 5.3: variation of drive ratio along the length of engine for helium gas

6. CONCLUSION

Developed pulse tube cryocooler is connected to standing wave engine and travelling wave engine. In case of standing wave engine once the hot end of engine reaches to 420 ^{0}C the cooling started in cryocooler. In case of travelling wave engine once hot end reaches to 320 ^{0}C the cooling started in cryocooler. In both the cases for same amount of temperature drop travelling wave engine will take less time compared to standing wave engine.

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