ELECTRCITY GENERATION FROM THERMOACOUSTIC ENGINE

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ABSTRACT:

Thermo acoustic combine thermodynamics, fluid dynamics and acoustics to describe the interactions that exist between heat and sound. Under the right conditions, these interactions can be harnessed to design useful devices that convert heat into large amplitude sound waves and vice-versa. A thermo acoustic engine turns part of the heat flowing through a temperature gradient inside a porous solid into sound waves. The work in these sound waves can then be harnessed with a piston to drive a flywheel or a linear alternator, or it can be used to transport heat from a lower to a higher temperature reservoir in what is known as a thermoacoustic heat pump or refrigerator. Two major advantages over conventional technologies: their inherent mechanical simplicity and the use of environmentally friendly working gases. Despite these qualities, most thermo acoustic engines, heat pumps and refrigerators built to this day were for research purposes, and are seldom encountered in the industry. Design and assembly of thermo acoustic engine to generate electricity using heat source, thermo acoustic engine prototype intended for low temperature electricity generation.

Keywords:*Thermo acoustic, fluid dynamics, temperature reservoir, sound waves*

1. INTRODUCTION

Thermoacoustic combine thermodynamics, fluid dynamics and acoustics to describe the interactions that exist between heat and sound. Under the right conditions, these interactions can be harnessed to design useful devices that convert heat into large amplitude sound waves and vice-versa. A thermo acoustic engine turns part of the heat flowing through a temperature gradient inside a porous solid into sound waves. The work in these sound waves can then be harnessed with a piston to drive a flywheel or a linear alternator, or it can be used to transport heat from a lower to a higher temperature reservoir in what is known as a thermoacoustic heat pump or refrigerator .Two major advantages over conventional technologies: their inherent mechanical simplicity, and the use of environmentally friendly working gases. Despite these qualities, most thermoacoustic engines, heat pumps and refrigerators built to this day were for research purposes, and are seldom encountered in the industry. Design and assembly of thermo acoustic engine to generate electricity using heat source, thermoacoustic engine prototype intended for low temperature electricity generation.When a system is displaced from its equilibrium state, forces and torques tend to restore that equilibrium. However, the system being “pulled back” towards equilibrium often overshoots this equilibrium and goes into oscillatory motion. Such system is said to be under damped. In the absence of friction, these oscillations would continue forever. In real-life, however, the oscillations’ amplitude tends to decrease with time and the system eventually settles back into equilibrium. This phenomenon is known as damping.Although it is usually calculated using the properties of a traveling wave, in non-dispersive media the acoustic impedance is a property of the medium alone, not the wave. In dispersive media, however, the acoustic impedance is determined by both the medium properties and by the frequency of the wave propagating in it. Nitrogen and oxygen that make up about 99 % of the air around us constitute a non-dispersive for audible sound, which is defined as sound waves having frequencies between 20 and 20 000 Hertz.At resonance, the driving force and mass velocity are in phase. This implies that the force is always performing positive work on the mass, pointing to the right whenever the mass is moving to the right and pointing to the left whenever the mass is moving to the left. For any other phase, there are times when the force is doing negative work, that is, times when the mass is performing work on the force. Because the driving force performs the largest possible amount of work on the system at resonance, the amplitude is the greatest possible and takes the value $F_A/\gamma m\omega_0$. Therefore, thermo acoustic engines are typically dimensioned to produce a wave at a frequency as close as possible to their linear alternators’ natural frequency, in order to harness the largest possible amount of energy from the acoustic wave.

METHODOLOGY

The thermoacoustic engine prototype built for this thesis project will later be tested at four different internal mean pressures (ranging from atmospheric to 3 bars gauge pressure) and with one, two, three and four regenerator units in order to measure how these parameters affect the performance of a low cost engine. This chapter details how performance and efficiency will be determined based on data collected during the tests.

Fig 1.**Thermo acoustic engine using heat source**

The temperature difference across the regenerator(s) will be calculated from the temperatures measured on both sides of one of the regenerators. The pressure oscillation amplitude will be found by subtracting the mean pressure value from the maximum pressure amplitude recorded at a certain time. The temperature near the pressure sensor will also be recorded and will serve to determine the mean density and thus the speed of sound and the characteristic acoustic impedance of the medium near the pressure sensor. Knowing the characteristic acoustic impedance and the pressure oscillation amplitude, the particles velocity amplitude will be calculated. Once both the pressure and the particles velocity oscillation amplitudes are known, the acoustic power in the engine can be determined. The acoustic power will be plotted as a function of the temperature difference across the regenerator. In total, sixteen power versus temperature difference curves will be obtained, which will provide a good insight of how the internal mean pressure and number of regenerator units affect the engine's performance. When an odd number of regenerators is used, an extra volume has to be added to the feedback loop after the last hot heat exchanger, in order to lower the acoustic impedance and allow oscillations to start. This is done simply by adding an extra pipe section at a distance of about one tenth of the wavelength from the last hot heat exchanger. The extra section has a length of about one tenth of the wavelength.

Efficiency:

The theoretical upper limit for a heat engine’s efficiency is defined as the Carnot efficiency:

$$\eta_{Carnot} = 1 - \frac{T_C}{T_H}$$

where T_C is the temperature (in Kelvins) on the cool side of the regenerator and T_H that on the hot side of the regenerator.The actual engine’s overall efficiency will be calculated by dividing the acoustic power $\bar{P}_{ac}$ produced once the hot heat exchangers have reached their maximum temperature by the amount of electrical power $\bar{P}_{el}$ consumed by the heating elements.

$$\eta = \frac{\bar{P}_{ac}}{\bar{P}_{el}}$$

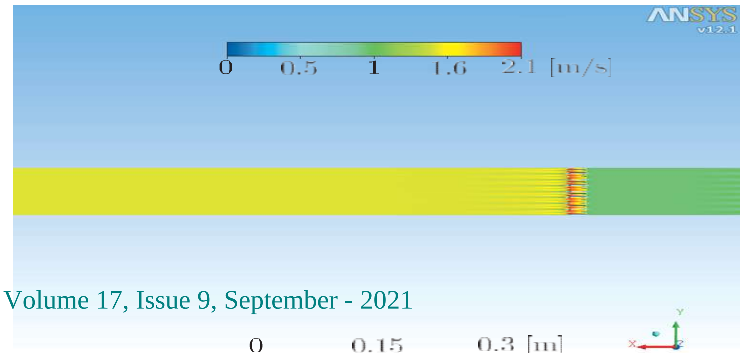
It is important that this measurement be done once the engine has reached steady state, that is, once the hot heat exchangers have reached their maximum temperature and this temperature remains stable over time. In transient state, part of the electrical power supplied to the heating elements is used to raise the temperature of the heat exchangers, thus giving a false reading of the actual efficiency.

The efficiency of a heat engine is also typically expressed as a percentage of the Carnot efficiency:

$$e = \frac{\eta}{\eta_{Carnot}} \cdot 100 \qquad \bar{P}_{el} = \frac{\left(\frac{1}{\sqrt{2}}V\right)^2}{R} = \frac{V^2}{2R}$$

SOFTWARE ANALYSIS

In this taking the initial boundary conditions of the glass tube and for a steady state solution i.e. the working fluid inside the tube, the velocity and temperature variations can be noted using software analysis using ansys.



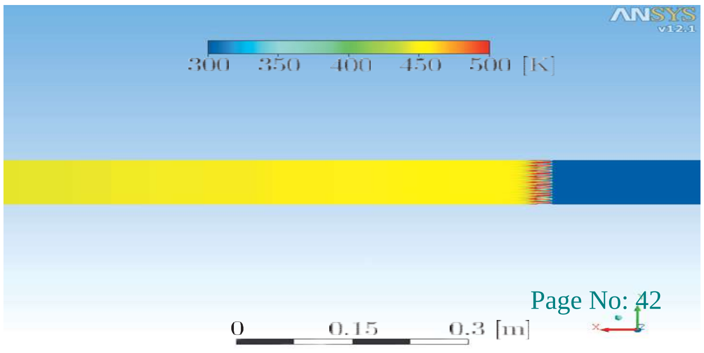
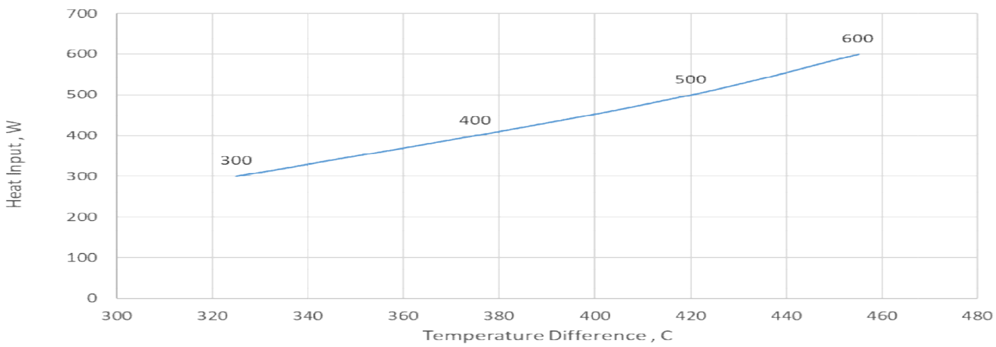
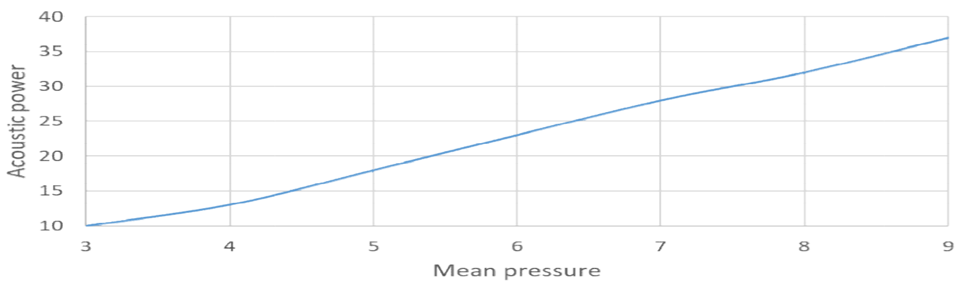


Fig 2.Velocity contour for steady state solution

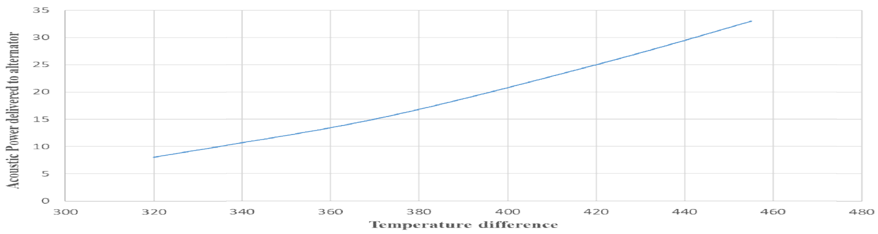
The velocity contour as we can see 1m/sec to 2.1 m/sec for a 0.3 m long galsstube.In the starting section of the stack end we can see the velocity is high ass pressure increases with the temperature analysis shows that it varies from 300 to 500k for that velocities as seen in above. Exactly at the stack end we see high temperature.



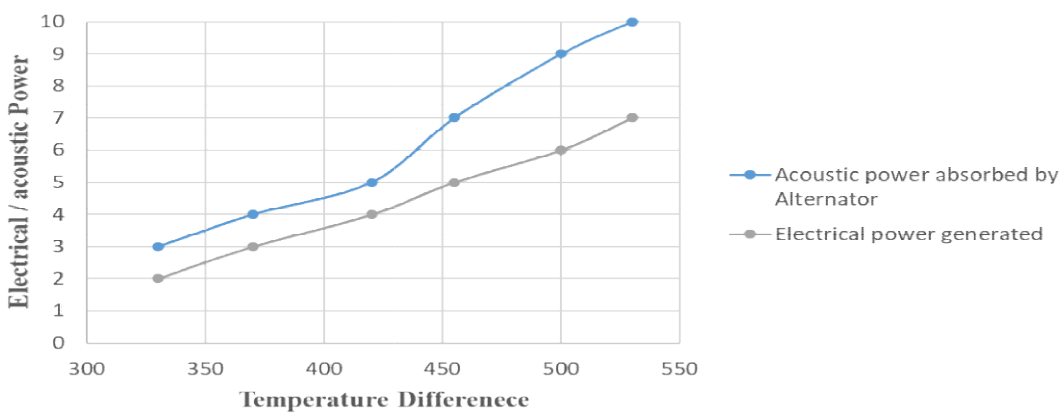
The graph is plotted heat input v/s temperaturedifference, it was draw from the temperature difference between heat exchanger from which we are able to find out how much amount of heat is used as source.



Graph is plotted between Acoustic power generated by the device vs mean pressure , The stack which is placed in between the heat exchanger is able to create the pressure drop from which waves are created gains movement ,Therefore it as able to displacement the piston with mean pressure from the acoustic power



The graph is plotted Acoustic Power delivered to alternator v/s temperature difference.



The graph is plotted Electrical power/ Acoustic Power v/s temperature difference in which Acoustic power absorbed by Alternator and Electrical power generated in observed.

RESULT & DISCUSSION

The regenerators start generating weak oscillations when air at the hot side of the regenerator reaches a temperature of 230 ◦C at a temperature difference of 185 ◦C. Normally, the engine does not amplify the weak acoustic oscillations (even at much higher temperature differences) to a level intense enough to drive the linear alternator. However, it has been found that in practice the intense acoustic wave can be excited by driving the linear alternator as an acoustic driver at a specific frequency. For instance, a few cycles of the piston excitation using a function generator and an amplifier at a frequency of 50.8 Hz was enough to excite the intense oscillation. This allows delivering an acoustic power to the cold side of the regenerator at a favourable acoustic phasing. An electrical control circuit was designed to protect the alternator and facilitate starting the engine. It switches the linear alternator connection in three ways based on the piston displacement measured by the laser displacement sensor: namely to function generator/amplifier, load resistance and a short circuit. At no oscillations present, the circuit connects the linear alternator to the function generator/amplifier which excites the piston for a few cycles at about 1.5 mm peak displacement. Once the engine amplifies the acoustic power and drives the piston over 2 mm peak displacement threshold, the circuit connects the linear alternator to the load resistance to dissipate the generated electricity and control the piston displacement. In case the engine drives the linear alternator close to its maximum stroke of 6 mm, the circuit switches the connection of the linear alternator to a short circuit to protect the alternator by stopping the piston oscillation. At no oscillation condition, there is a high heat loss of about 450 W per stage from the hot heat exchanger. As the hot heat exchanger is manufactured as one piece with the thermal buffer tube and the regenerator holder, the hot heat exchanger cannot be insulated from these two pieces. This gasket material has a low thermal conductivity of 0.3 W/m.K. For example, the regenerator temperature difference increased from 297 ◦C to 308 ◦C and the generated electricity from 48.6 W to 62.2 W at 900 W heating power, 28 bar mean pressure and 30.8 Ω load resistance. All the left-hand side (LHS) points which are facing the armature of the linear alternator have slightly higher amplitudes than the right-hand side (RHS) points which are facing a flat side of the piston.

Effect of mean pressure:

The values of the mean pressure will affect both the power density of the acoustic field and the thermodynamic properties of the working gas Higher power density will enable the thermoacoustic engine to run at higher acoustic impedance which in turn will allow higher acoustic to electric conversion at the linear alternator.The mean pressure was varied in the range of 6-9bar and heating power of 600 W. However, significant discrepancies are observed, Focusing on the low mean pressure range, it is not clear why the generated electrical power, generated acoustic power, drive ratios.

Effects of Heating Power:

Heating power and oscillation intensity are the two parameters determining the regenerator hot side temperature. However, heating power is the dominant parameter determining the ability to maintain a high temperature difference across the regenerator during the oscillation. In this section, the value of the heating power represents the summation of the equal heating power of the two stages. At no oscillation, there is a high heat loss of about 450 W per stage from the hot heat exchanger which is deducted in performance calculations in this paper. The heating power was varied from the minimum power of 500 W capable of maintaining oscillations to a maximum of 1700 W, at 8 bar mean pressure and load resistance of 30.8 Ω.In the experiments, a maximum electrical power output of 72.5 W was obtained at 5.58% of thermal-to-electric efficiency, while the maximum efficiency of 7.3% was obtained at heating power of 700 W generating 51.1 W of electricity.

Reference :

1. Beyer, RT 1999, Sounds of Our Times: two hundred years of acoustics, Springer-Verlag, New-York.

2. Crowell, B 2002, Vibrations and Waves, edition 2.1, Fullerton.

3. De Blok, K 2010, “Novel 4-stage traveling wave thermoacoustic power generator”, Proceedings of ASME 2010 3rd Joint US-European Fluids Engineering Summer Meeting and 8th International Conference on Nanochannels, Microchannels, and Minichannels, ASME, Montreal.

4. In’tpanhuis, PHMW 2009, “Mathematical Aspects of Thermoacoustics”, PhD thesis, Eindhoven University of Technology, Eindhoven

5. Swift, GW 2002, Thermoacoustic: A unifying perspective for some engines and refrigerators, Acoustical Society of America, Melville NY

6. Rijke, PL 1859, “Notice of a New Method of causing a Vibration of the Air contained in a Tube open at both ends”, The London, Edinburgh and Dublin Philosophical Magazine and Journal of Science, vol. 17, Fourth series, pp. 419-422