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Experimental Study on Thermo – Acoustic Stirling Engine

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Abstract: Fossil fuels are abundantly used in recent decades which have resulted in its depletion. With a vision of reducing the usage of conventional fuels and also to produce clean energy vast research activities are carried out in the field of Thermo-acoustics. Thermo-acoustic systems have been a focus of recent research due to its structural simplicity, high reliability, and can be driven by low grade energy such as solar energy, waste heat etc. Since we have been using conventional fuels such as coal, fossil fuels etc. from the very past. Due to continuous use of these conventional sources of energy it would be completely depleted over a span of 100-200 years. There are other sources of energy which are available such as heat energy, solar power, and wind power. We are already using wind energy and solar energy to generate electricity. Our aim is to use heat energy to produce mechanical work. Thermo-acoustic engine uses heat energy to produce a mechanical work which can be further converted into electrical energy. This research aims to develop a small scale working model of a single cylinder standing wave thermo-acoustic engine. Working fluid used here is air. The expansion and sudden compression of the working fluid is utilized to generate power. Regenerator section consists of a hot heat exchanger made of brass and cold heat exchanger. Coolant used here is air (Natural Convection) and water (Forced Convection). The stack present between HHX and CHX is empty space having high pressure air. The resulting pressure difference is used to run a flywheel hence generating mechanical power.

Keywords: Stack, Hot Heat Exchanger, Cold Heat Exchanger, Regenerator, Acoustics.

I. INTRODUCTION

The main source of energy are fossil fuels like petrol, diesel etc. The use of these fossil fuels has increased day by day to produce power and the cost of these fossil fuels is increasing due to their continuous usage. In coming years these fossil fuels might be extinguished due to their regular usage. Also use of these fossil fuels leads to air pollution which has adverse effects on the environment and also on all living things.

Therefore different other method to produce energy which does not use fossil fuels is very much essential. Thermo-acoustics is a one such field which is used to produce energy without the use of any fossil fuels. Thermo-acoustics uses non-conventional sources of energy to produce power.

A non-conventional source of energy is the natural sources of energy. Even if the consumption of the non-conventional energy is more it will not affect its supply. Non-conventional energy is abundant in nature. The only thing which needs focus is harnessing the energy from these non-conventional sources. The cost of harnessing the energy is very high that is reason non-conventional sources are not in use much.

We need non-conventional energy sources because the growing consumption of conventional energy has resulted in the whole world becoming increasingly and very much dependent on fossil fuels such as coal, oil and gas. Since the consumption of oil and gas has been increasing thereby resulting in the shortage and increase in their prices. This potential shortage of oil and gas has raised concern about the preservation for the supply of energy in the near future, which has serious impact on the growth of national economy.

Use of fossil fuels also causes serious environmental problems. Fossil fuels are formed by anaerobic decomposition of dead buried organisms. Fossil fuel contains large amount of carbon and also contains petroleum, natural gas and coal. The combustion of fossil fuel produces many dangerous gases such has carbon dioxide, nitrogen, carbon monoxide etc.

These gases are harmful for living organism as well as it has adverse effect on the environment leading to depletion of ozone layer, unnecessary weather change etc. They are eco-friendly and pollution free. They can be renewed with minimum effort and cost.

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II BASICS OF THERMOACOUSTICS

Acoustics is the branch of science that deals with the types of mechanical waves generated in gases, liquids and solids and also including topics like vibration, ultrasound and infrasound. According to Rayleigh, thermo-acoustic effect is defined as "If heat is supplied to the air at its point of great condensation or heat is removed from air at the point of greatest rarefaction, vibration is encouraged" [1]. The thermo-acoustic engine works on the principle of thermo-acoustic effect.

This research concentrates on working of standing wave thermo-acoustic engine to produce mechanical work. A thermo-acoustics engine uses high amplitude of waves to transfer heat along the stack (in a standing wave) or regenerator (in a travelling wave type). A thermo-acoustic engine consists of a regenerator, two heat exchangers (one high heat exchanger and one cold heat exchanger) and a tube or a resonator. Here a regenerator or stack is sandwiched between the two heat exchangers in the tube. When we supply heat to the heat exchanger a temperature gradient is setup along the stack by the heat transfer and due to this temperature gradient an acoustic wave having pressure and mean velocity is spontaneously produced. Due to high temperature, the gas expands and it starts to move from high heat region to cold region and compression takes places. This spontaneously produced acoustic wave forces the gas parcel in the stack to undergo a thermodynamic cycle consisting of compression, heating, and expansion and cooling. This acoustic power produced from the heat input can be utilized in many ways. The one way is to move a prime mover such as piston with the help of pressure and velocity variation in the stack.

III METHODOLOGY

A. REVIEW OF LITERATURE AND COLLECTION OF DATA

In this part of methodology we collect all the data and information required about the prototype we are going to work with like principle, working and construction.

B. FABRICATION OF COMPONENTS OF THE THERMO-ACOUSTIC PRIME MOVER

In this part we are going to specify what all components or parts or equipment will be needed for the design of thermo-acoustic engine and we will make a detailed information about the parts we are using by considering their mechanical properties like density, thermal conductivity, thermal diffusivity etc. in the first place and then the physical properties like colour, shape etc.

C. ASSEMBLING, INSTRUMENTATION AND COMMISSIONING OF THE EQUIPMENT

In this part we assemble all the parts and equipment to the body of the prime mover as per the design and we route the system with the equipment and command it.

D. RECORDING AND ANALYSIS OF THE RESULT

In this we are tabulating the output power generated to that of supplied heat input. We are analysing the pressure and cross-sectional mean velocity variation along the stack due to rapid compression and expansion in the heat exchangers.

IV DESIGN

A. RAW MATERIALS

- **Borosilicate Glass**

It is used because of its low thermal expansion coefficient (3.3×10^{-6} $k^{-1)}$. This reduces the stresses developed in the material due to temperature gradient, which makes borosilicate glass better option to use here.

Fig. 1 Borosilicate Glass Test Tube

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- **Mild Steel**

In this study mild steel is used for construction of flywheel, because of its high density and high strength. High density material like mild steel was preferred to store the energy which is necessary to run the engine.

Fig. 2. Mild Steel Material

- **Brass**

Brass is a metal alloy made of copper and zinc. It has relatively low melting point (900 - 940 ^{0} C). Brasses are valued for their machinability and the ease with which the metal can be formed into desired shapes and forms while retaining high strength. It is excellent for cold working, hot working and casting.

Fig. 3. Brass Rod

- **Aluminium**

Aluminium is a silvery-white, lightweight metal. It is soft and malleable. It is most commonly used material due to its low density and good thermal conductivity. It has low weight to high strength ratio also Aluminium is very easy to recycle. For such components as automobile pistons, strength, rigidity and ductility are not the only requirements in a material of constructions. A further advantage of aluminium consists in its ductility, which in cast iron is very low, being roughly 1 percent. For one of the duties of the piston is to waste as easily and efficiently as possible the heat in combustion chambers which cannot be converted into power. It has excellent corrosion resistance.

Fig. 4. Aluminium Rod

- **Stainless Steel**

Stainless steel has higher strength and hardness. It is also corrosion resistant. It has good weldability. Here we require high strength material to resist stress. We are using oil to reduce the friction between the mating surfaces of connecting rod, where stainless steel corrosion resistant property is used. We are making piston hook from stainless steel which to be weld with Aluminium piston using gas welding, where its weldability property is used.

Fig. 5. Stainless steel Rod

B.COMPONENTS

The various components used for this research trial is as listed in the table below

Table 1: List of Components

Sl. No.	COMPONENT	MATERIAL	DIMENSION (mm)
1	Glass Tube	Borosilicate	22.85×200
2	Flywheel	Mild Steel	75×20
3	Connecting Rod	Stainless steel	2×150
4	Piston	Aluminium	22.75×24
5	O-Ring	Rubber	21×1.78
6	Mesh	Brass	0.1×0.1
7	Pressurised Head	Brass	22.75×24

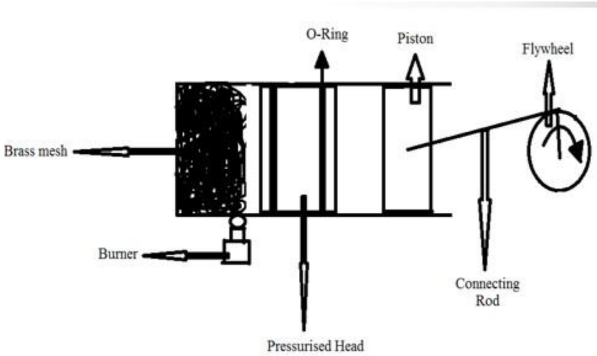

Fig. 6. Line diagram of Standing wave thermo-acoustic engine

- **Glass Test Tube**

In glass test tube, mesh is heated due to which waves are generated. Due to these waves the piston arranged in the glass test tube reciprocates. When the mesh is heated, the waves generated travel from the hot junction to the cold junction which results in the formation of temperature gradient. Test tube made of Borosilicate was used to develop the regenerator section. For this trial we have used a test tube having a ID of 22.85mm and a length of 200mm.

Fig. 7. Glass Test Tube

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- **Flywheel**

Flywheel made of **Mild Steel** was used. Flywheel is used to store the rotational energy and transfer when the energy required for upcoming strokes. Hence a material which has high density and relatively low cost like mild steel was preferred. The flywheel has a total external diameter of 75mm. Small holes having a diameter of 6mm each are placed at different radii which is used to link the connecting rod.

Fig. 8. Flywheel

- **Connecting Rod**

Aluminium connecting rod was used. It is used to converts reciprocating motion into rotary motion. Aluminous was preferred because of its less weight, thereby reducing the weight of the whole prototype. The connecting rod had a length of 150mm.

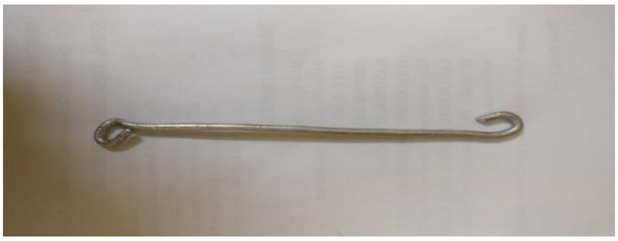

Fig. 9. Brass Mesh

- **Piston**

For piston we will use **Aluminium**. The piston will reciprocate in test tube due to temperature gradient, hence it needs to withstand high temperature and also have less friction with the glass tube. The friction between the different materials are not specified, hence we try the piston made up of different materials. The material which has low coefficient of friction with glass is used. The hole which is provided in the piston is used to connect the connecting rod with the piston. The piston had a OD of 2mm and

Fig. 10. Piston(Top View)

Fig. 11. Piston(Front View)

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- **Regenerator**

The mesh we will use is of **Brass** because it has high thermal conductivity. To obtain a high temperature gradient within the regenerator section both HHX and CHX were made of Brass, hence a material with pretty high thermal conductivity was chosen.

Fig. 12. Brass Mesh

Fig.13 Assembly

C.TRIAL

This trial is done using Immersion Heater. We have designed all the components according to parameter as described in table 1 above.The use of Immersion Heater requires some substance wasn’t feasible since the temperature range was too high for the glass test tube material. But in our trial we have used immersion heater without any medium. It becomes red hot and Borosilicate test tube does not able to resist that temperature, which led to the glass test tube is broken as shown in figure below. However the small amount of pressure difference was seen within the test tube but wasn’t sufficient enough to oscillate the piston.

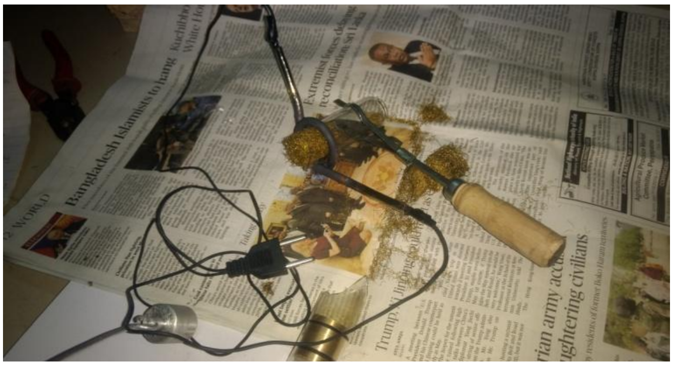

Fig. 14. Broken Test Tube

VII. CONCLUSION

The pressure developed in the test-tube chamber was not sufficient enough to run the engine. The temperature gradient within the regenerator section wasn’t satisfactory enough to move the piston. Hence change in the mesh material used for HHX and CHX is proposed for the preceding trials. Since the suction pressure developed within given regenerator (test tube) wasn’t sufficient enough, change of test tube inside diameter is necessary.Use of a much low temperature heating methods using a spirit lamp or kerosene burner is proposed to avoid cracking of the test tube.

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