DESIGN AND DEVELOPMENT OF THERMOACOUSTIC ENGINE

Sumeet Turup
ME Design
Jayawantrao Sawant College ofEngineeringHadapsar, Pune
turup_sumeet@yahoo.com

Prof. Mahesh Gaikwad
Department of Mechanical Engineering
Jayawantrao Sawant College ofEngineering
Hadapsar, Pune
maheshgaikwad5981@gmail.com

ABSTRACT

Today's world is world of nonconventional energy sources. Due to limitation on use of the conventional energy sources many researchers are interested in new field; one of these fields is a thermoacoustic. In this field there is an interaction between the heat and sound. Traveling-wave thermoacoustic heat engine is a special device capable of converting external heat to acoustic work with high reliability. This paper focused on design and manufacturing of thermoacoustic engine. Study different ways to enhance its efficiency and overall performance of the system.

Keywords: Thermoacoustic, Engine

I. INTRODUCTION

An engine extracts heat from a high-temperature source, converts part of it into work and rejects the other part to a low temperature sink. Thermoacoustics combines 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 intosound or pressure wavesand vice-versa. A thermoacoustic engine turns pressure waves flowing through a temperature gradient inside a porous solid into sound waves. The work in these sound waves can then be harnessed with suitable conversion devices. Thermoacoustic devices have two major advantages over conventional technologies: their inherent mechanical simplicity, and the use of environmentally friendly working gases.S.Backhaus and G.W.Swift et. al.They have proposed that new type of thermoacoustic engine based on travelling wave and ideally reversible heat transfer. Measurement and analysis of its performance are presented [8].M.E.H. Tijaniet. al author focused on about energy saving technique by coupling thermoacuostic engine with thermoacoustic heat pump.The engine is driven by a burner and produces acoustic power and heat at the required temperature [1]. M. Chen et. al.In this paper author designed, constructed and tested Stirling-thermoacoustic engine with only 1m resonator length by using nitrogen as working gas [2]. Wei Dai, Ercang-Luo et.al as the author made a prototype of 1 kW traveling-wave thermoacoustic generator was designed and tested[3]. J.A. Mumith, C. Makatsoris et.al, Author described method of reuse of waste heat from industrial processes with approaches that requires low investment and low cost by using thermoacoustic engines [4].

II. DESIGN AND CONSIDERATIONOF ENGINE

Any device which can convert heat energy of fuel into mechanical energy is known as engine or heat engine. Thermoacoustic engine use a heat difference to induce high-amplitude sound waves. In general, thermoacoustic engines can be divided into standing wave and travelling wave devices.

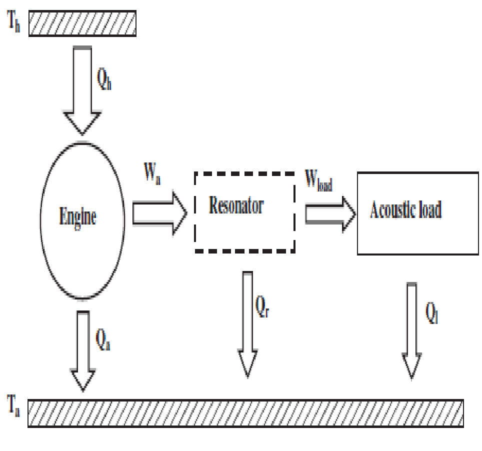

Figure1. Engine working

III. MATERIAL SELECTION

Considering the working conditions in mind, it is treated to design thermoacoustic engine as a pressure vessel for design purpose and the material is selected accordingly. For elevated temperature range between (1101-1500) °F or (593.33-815)^{0}C Stainless steel SA-347H is selected [9].

IV. THERMAL BUFFER TUBE (TBT)

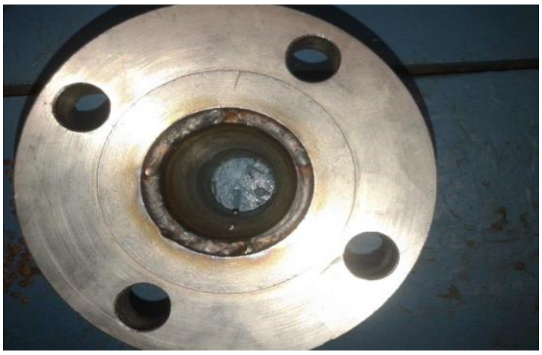

Fig3. Thermal buffer tube

Thermal buffer tube is connected right below the hot heat exchanger .Thermal buffer tube is subjected to pressure. So it is necessary to estimate the pressure TBT is going to sustain. For calculating maximum pressure in TBT using following equation, the maximum pressure is around 57 Mpa A stainless steel pipe is taken which is having length 160 mm and having outer diameter 60.3 mm and inner diameter 42.9 mm. A taper of 2.7^{o} is given from inner side of the pipe upto length 80 mm from bottom face of the pipe to avoid resistance to fluid flow.

$$P_{tbt(max)}=\frac{2 \times \sigma_{all} \times j \times t_{tbtmax}}{R_{tbtmax} - 0.4 t_{tbtmax}}$$

where,
$t_{tbt.max}$ =maximum thickness of thermal buffer tube.
$r_{tbt.max}$=maximum radiusof pipe.
σ_{all} = maximum allowable stress.

V. REGENERATOR

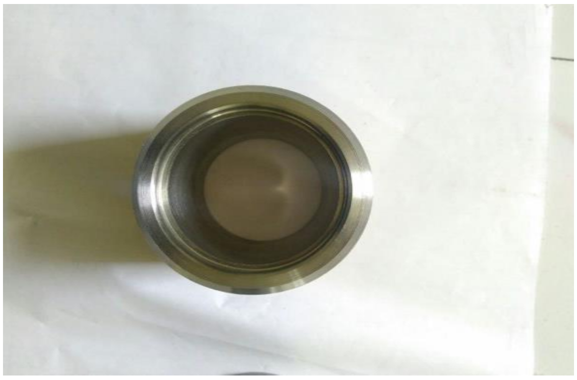

Figure 4: Regenerator

TBT and Regenerator are subjected to maximum thermal stresses.Hence it is necessary to calculate the maximum thermal stress material can sustain. A volume porosity of the wire mesh is 79% and hydraulic radius of 43µm. The hydraulic radius of the regeneratorshould be smaller than the thermal penetration depth of thehelium gas.

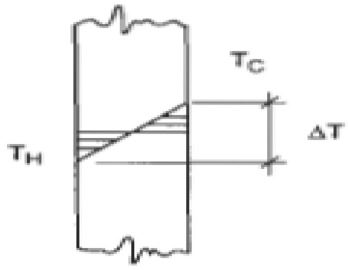

Figure 5: Thermal linear gradient across the shell.

$$\sigma_x = \sigma_y = \frac{\alpha \times E \times \Delta T}{1 - ΰ}$$

Where,
σ_x= Thermal stress
T_1 = Initial temperature
T_2 = New temperature
α = mean coefficient of thermal expansion
E = Modulus of elasticity
ΰ = Poisson's ratio (0.3 for steel)
ΔT = Mean temperature difference

The thermal penetration depth can be calculated from the following equation,

$$\delta_k = \sqrt{\frac{2k}{\rho_m c_p \omega}}$$

where,
k = Thermal conductivity, W/m-k
ρ_m = Density of fluid, kg/m^3
C_p = Specific heat capacity, kJ/kg-K
ω = Angular velocity, rad/sec

VI. HOT HEAT EXCHANGER (HHX)

Figure 6: Hot heat exchanger

Hot heat exchanger is used to introduce heat in surrounding fluid. The HHX is made up of steel casing in which Ni-Cr wires are used to heat the fluid medium. The wires are wound on ceramic rods which are not affected by the heat.It is necessary to calculate total number of Ni-Cr coils required so that required amount of heat can be added to the fluid to get the required temperature.Three ceramic rods of 12mm each are encased in the pipe of length 160mm.Each ceramic rod has seven holes of 3mm diameter each. The pipe is held between two flanges one on each end. The Nichrome wire is passed through the holes of the ceramic rods.The quantity of heat supplied to helium gas is given by the following equation;

$$\dot{Q} = \dot{m}Cp\Delta T$$

Where,
$\dot{Q}$= Heat carried away by Helium
$\dot{m}$= mass flow rate of Helium
C_p = Specific Heat of Helium
ΔT = Temperature difference

$$\dot{Q} = \dot{m}Cp\Delta T$$

Table1. Helium gas property table for specific temperature

Temperature (^{O}C)	Pressure (bar)	Density Kg/m^3	Enthalpy (kJ/kg)	Entropy (kJ/kg-K)	C_p (kJ/kg-K)
662.5	35.00	1.7937	4873.8	26.550	5.1913

C_p = 5.1913 kJ/kg = 1.2402 kcal/kgK

VII. COLD HEAT EXCHANGER (CHX)

Figure 7: Cold heat exchanger

Cold heat exchanger is used to create temperature difference in the system. It connected before the regenerator.For CHX, water is used as a cooling medium which is circulated at a fix discharge rate.CHX is useful to maintain the temperature range required of fluid, but it is necessary to obtain the number of passes required to maintain the required temperature.A shell and tube type heat exchanger is taken into consideration given its effectiveness to carry away the heat.It consists of a cylindrical brass block containing 40 parallel channels with an inside diameter of 4 mm up to depth of 14mm.

VIII. SECONDARY HEAT EXCHANGER

Secondary heat exchanger is connected right after the Thermal buffer tube (TBT).It is used for cooling down the TBT as well as to cool down the fluid. This is also a shell and tube type of heat exchanger in which water is used as cooling medium.It is crucial to maintain the temperature of fluid coming from the regenerator; hence the number of passes for water tubes at particular water discharge rate is necessary to calculate.
Here, taking the velocity of water = 1m/s and applying the law of thermodynamics,

$$(\dot{m}Cp\Delta T)\text{Water} = (\dot{m}Cp\Delta T)\text{ Helium}$$

The cooling capacity of water is given by the equation [10],

$$\dot{Q} = U_o \times A_c \times \Delta Tm$$

Where,
Uo= Overall heat transfer coefficient
Ac = Heat transfer area
ΔTm= Temperature difference
Now, using log mean temperature difference (LMTD) method for calculatingΔTm,

$$LMTD = \frac{\theta_1 - \theta_2}{ln\frac{\theta_1}{\theta_2}}$$

Where,
θ1= Temperature difference between water and Helium at outlet
θ2 = Temperature difference between water and Helium at inlet.

IX. RESONATOR

Figure 9: Resonator

Resonator is a tube in which sound wave propagates. Purpose of resonator is to store acoustic energy and obtain proper phasing of pressure and velocity. A cylindrical solid block of length 100mm and 110mm diameter taken for manufacturing the resonator. The central drilling of 42.9mm is done trough out the block, and then from one side drilling of 73mm is done for a 20mm length. As per the dimension of the pipe of 75mm and 60.3mm counter boring is done for a length of 20mm.Then the taper drilling is done from 42.9mm to 73mm.

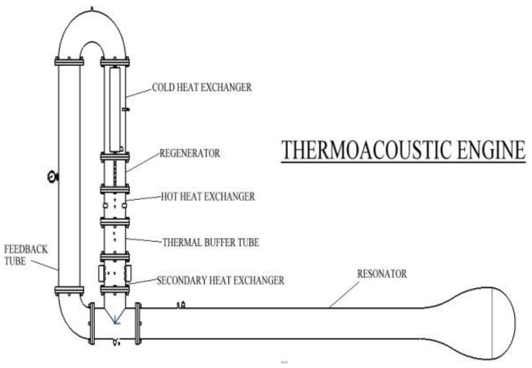

Figure 10: Experimental setup

Figure shows the torus-shaped section which contains first ambient heat exchanger (AHX1) to remove the ejected heat from the engine, regenerator (REG), hot heat exchanger (HHX) to supply heat to the engine, and thermal buffer tube (TBT), second ambient heat exchanger (AHX2). The gas column in TBT provides thermal insulation between HHX and AHX2. AHX2 is not required for the operation of the engine but it is useful to intercept heat leaking down the TBT.

X. CONCLUSION

Studying the necessary theoretical background required to understand the concept of Thermoacoustics. Designing of the components required for the engine and assembly; and drafting and modelling based on design calculations that can be further used for manufacturing of a prototype engine is completed. Validation and simulation part is underway.

XI. FUTURE SCOPE

Time management has been a major issue in this project and the main reason behind the fact that the prototype could not be developed was insufficient funds. Many elements in the design of the engine had to be re-calculated, either because material required for the parts was not available or because it made the design bulky and less effective.More experimental work can be done for a better understanding of the relative performance of different type regenerator materials. This may require some modifications in the design to permit more flexibility required in testing. Also a better comparison between different regenerators might be achieved by considering in parallel a wider range of parameters, such as hydraulic radius, porosity, geometry and the physical properties of the material being used.

REFERENCE

[1] M.E.H. Tijani, S. Spoelstra, “A hot air driven thermoacoustic-Stirling engine”, applied thermal engineering 61, Elsevier ltd, 2013, pp. 866-870

[2] M. Chen, Y.L. Ju, “Design and experimental investigations on a small scale traveling wave thermoacoustic engine”, cryogenics 54, Elsevier ltd, 2013, pp. 10–15

[3] Zhanghua Wu, Limin Zhang, Wei Dai, ErcangLuo, “Investigation on a 1 kW traveling-wave thermoacoustic electrical generator”, applied energy 124, Elsevier Ltd, 2014, pp. 140–147.

[4] Zhanghua Wu, Guoyao Yu, Limin Zhang, Wei Dai, ErcangLuo, “Development of a 3 kW double-acting thermoacoustic Stirling electric generator”, Applied Energy, article in press, 2014, Elsevier ltd, pp. 3-7

[5] J. A. Mumith, C. Makatsoris, T. G. Karayiannis, “Design of a thermoacoustic heat engine for low temperature waste heat recovery in food manufacturing a thermoacoustic device for heat recovery”, applied thermal engineering 65, Elsevier ltd 2014, pp. 588-596

[6] Daming Sun, Limin Qiu[et.al],“Investigation on traveling wave thermoacoustic heat engine with high pressure amplitude”,Energy Conversion and Management 46 (2005), pp.281–291.

[7] Iwona Nowaket.al “Analytical and numerical approach in the simple modeling of thermoacoustic engines”,International Journal of Heat and Mass Transfer 77 (2014), pp. 369–376

[8] S.Backhaus and G.W.Swift et. Al, Condensed Matter and Thermal Physics Group, Los Alamos National Laboratory, Los Alamos, New Mexico 87545, Received 11 April 2003; revised 29 July 2003; accepted 4 August 2003.

[9] “Pressure Vessel Design Manual”, Dennis Moss; Gulf Professional Publication.