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Theoretical Assessment of Traveling Wave Thermoacoustic Engine

KEYWORDS: Thermoacoustic Effect, Thermoacoustic Engine, Traveling Wave

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ABSTRACT *Thermoacoustic engine is a device which can transform thermal into acoustic energy due to thermal conversation between oscillatory compressible flow and solid structure such as thermoacoustic regenerator. There has only gas which is moving parameter in thermoacoustic engine and the working gas is environmental friendly. In recent years, much work has been stimulated on the research of thermoacoustic effect. Thermoacoustic electric generators are composed of thermoacoustic engines and linear alternators. These technologies are in harvesting solar energy and waste heat from plants, industrial facilities. It is also useful for low temperature. A thermoacoustic engine converts heat into high-intensity acoustic oscillations based on the time-averaged thermodynamic interaction between working gas and solid. Referred to old fashioned heat engines, it has no mechanical moving parts and simply consists of a few pipes and heat exchangers. Thus, it has the worth of simple structure, high reliability, and low manufacturing and maintenance costs.*

INTRODUCTION

Now a day's thermoacoustic technology has gaining significant consideration of researcher. Lot of work is carried out in this technology using waste heat as input source. Using this waste heat thermoacoustic engine produces sound waves which then run the alternator to produce the electricity.

Traveling-wave thermoacoustic electrical generator is a machine capable of converting heat into electricity, which has vantage on reliability, heat source flexibility and efficiency. Main distinguishing feature is impedance coupling relationship was the true excuse for the performance improvement. [5-10]

For the travelling-wave engines, the phase difference between the pressure and velocity oscillations is close to zero within the thermoacoustic core, and these distinctive effects have a major influence on the reversibility as well as efficiency of the associated thermodynamic cycles. The term ''core'' denotes an arrangement of the thermoacoustic regenerator and juxtapose heat exchangers. [11]

Traveling wave feedback is found not only to have less acoustic losses but also to increase acoustic gain even at low engine input temperatures. [4]

THERMOACOUSTIC ENGINE

In 1999, Backhaus and Swift [5-10] developed a TWTAHE, which consists of an engine loop and a resonance tube. They achieved 30% thermoacoustic efficiency, comparable to 25–40% efficiency of the conventional internal combustion engine, and a maximum acoustic power of about 710W (about 140W was dissipated in the resonance tube and 570W was outputted to its load). In 2004, Luo et al. [10] informed an energy-focused TWTAHE with a tapered resonance tube which could achieve a high pressure ratio above 1.3 with helium gas and a net acoustical power output of more than 450W, a high pressure ratio above 1.40 was achieved using nitrogen as working gas. Later, 801W and 1220.9W [10] net output acoustic powers with about 32% heat-to acoustic conversion efficiency were measured in 2008 and 2011, respectively. The TWTAHE generates an acoustic power which can be used to drive different types of acoustic loads, such as linear alternator, thermoacoustic refrigerator and pulse tube Cryocooler. In their system, the TWTAEG was consists of an engine loop and a linear alternator without a resonance tube. An electric power of 58 W with 15% heat-to-electrical conversion efficiency was obtained. After further improvement, 70W electric power was obtained with 16.8% thermal-to-electrical efficiency.

Ceperley [8] said that when a travelling wave goes through a porous material that is regenerator, the heat transfer interaction between the gas and solid material causes the gas to maintain or work a Stirling like thermodynamic cycle.

The wood burning thermoacoustic engine was successfully produced about 22.7 W of acoustic power at low flame temperature of wood by alternator. [6] The waste heat near about 70°-200° c appears to be most vow and commercial engrossing realm of applications for thermoacoustic systems. [9]

In a thermoacoustic engine, the alteration of thermal to acoustic energy takes place in a porous media called regenerator. This contrivance is retained between two heat exchangers (HEXs) to constitute the heart of the engine called the wave generator. Connected to thermal reservoirs, the cold heat exchanger attaching to the sink at Tc and the hot heat exchanger attaching to the source at Th are able to preserve a temperature gradient (δT), alongst the regenerator. Due to this temperature gradient a sound wave is provoked and is able to be amplified by extracting the heat (Qh) from the hot source and evacuate the unconverted residual heat (Qc) to the cold sink. Actually the oscillation in motion of the wave displaces the parcel of the working fluid in a way that the parcel of gas experiences compression and expansion depending on the oscillation in pressure while it is exchanging heat with the solid boundaries in the porous media. As such, the gas parcel will embark a thermodynamic cycle and acoustic power is produced by the wave generator. [6]

In the regenerator region of compression the pressure is high, and in the region of rarefaction the pressure is low. [4] A well-known thermoacoustic effect elaborated by Lord Rayleigh: "if heat be given to the air at the moment of greatest condensation, or be taken from it at the moment of greatest rarefaction, the vibration is encouraged."[8] When temperature difference between the hot side and cold side of a regenerator transcends a critical value, the thermoacoustic phenomenon begins and oscillations produced. [3] Gas present in the regenerator forces to maintain a cycle of compression, heating, expansion and cooling due to temperature gradient. [6]

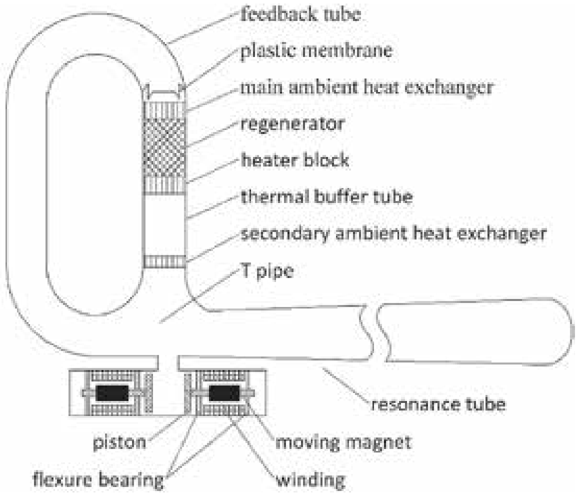

Fig.1 Configurations of TWTAEG Diagram [5]

Fig. 1 shows the schematic diagram of traveling wave thermoacoustic engine. This engine consists of [1] resonance tube, a linear alternator, a feedback tube, a hot heat exchanger that is heater block, an ambient heat exchanger, secondary ambient heat exchanger and also a thermal buffer tube. The arrangement of the main ambient heat exchanger, the regenerator and the hot heat exchanger is called as "the thermoacoustic core" [3].

Some of the parts of travelling wave thermoacoustic engine are as follows-

Resonance tube

It is used [4] to increase impedance matching between the alternator and engine. It has tapered tube [1] and ended [3] with ellipsoid cap.

Feedback tube

It is used [1] to accomplish connection between pressure and velocity. It is also referred [4] for reducing acoustic losses. Its length [6] is equal to a quarter wavelengths and three quarter wavelength to minimize reflections at optical frequencies as well as effect of impedance must produce near traveling wave in feedback tube.

Plastic Membrane

It [1] is used to forbid the DC flow in the engine loop which can decrease the engine performance.

Main ambient heat exchanger

It has [1]-[4]-[6] placed between feedback tube and regenerator. In main ambient heat exchanger there [6] is water tap provided in series in tubes and outside the tube working gas is passes which is coming from feedback tube and goes to regenerator

Regenerator

It is filled [1] with screen mesh. The thermoacoustic effect [1] takes place in the solid wall of the mesh wire and working gas. When screen mesh [8] is inserted in the regenerator, that mesh gives geometrical properties like porosity, hydraulic radius and wire diameter. This geometrical property [8] is used to calculate the flow resistance in the regenerator as decrease in porosity, there is increase in flow resistance which increases viscous losses and causes a higher acoustic impedance in the regenerator, also reduces the acoustic power.

Hot heat exchanger

This contrivance is [1] placed between the regenerator and thermal buffer tube. Heat [7] is provided by cartridge heaters. They can be specified as per temperature requirement. Its purpose [8] is to give a uniform heat flux to one end of the regenerator.

Thermal buffer tube

It is used to slug of oscillating gas long enough to provide good thermal insulation between hot heat exchanger and secondary ambient heat exchanger [7].

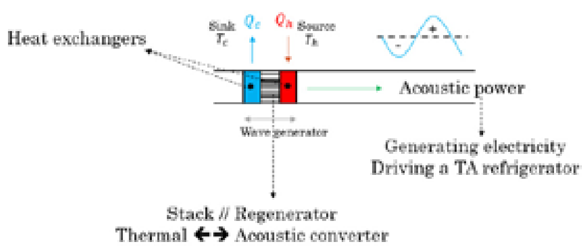

Fig.2 Scheme of wave generator in thermoacoustic engine [2]

Secondary cold heat exchanger

It [1]-[3] is placed after the thermal buffer tube which acts like main ambient heat exchanger. Also it consists of tap water supply at opposite to the hot heat exchanger to maintain temperature difference.

Linear alternator

It is used [4] for extracting power from thermoacoustic core. Pressure wave [1]-[2] drives the piston and magnet of the linear alternator to produce electricity.

Other Apparatus

As per requirement thermocouples, pressure gauge, valves must be provided to that engine to take reading and for calculation purpose. The hot heat exchanger, regenerator and thermal buffer tube must be insulated properly to avoid heat leakage.

CONCLUSION

The transformation from thermal to acoustic energy and the heat flow occurs without any moving parts or devices in the system. Compared with old thermodynamic systems, thermoacoustic engine has vantages like a simple structure, no moving parts, low cost of manufacture, and high reliability.

By using inert gases as working fluids, this is environmentally friendly contrivance. The thermoacoustic devices can be driven by low quality energy source such as the exhausting thermal energy and the solar energy, so it is significant for remote rural areas where there may be no access to electricity grid.

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