DESIGN OF A LOW-COST SOLAR POWERED RINGBOM STIRLING ENGINE

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ABSTRACT

Water supply in rural areas requires the use of conventional pumps. Application of such technology in most rural areas of developing countries has met a number of problems such as maintenance and repair difficulties. In this paper an attempt has been made to design a simple and low-cost solar powered Stirling Engine (SE) which can be manufactured locally. The authors have applied a modified design method used by Uriel and Berchowitze to design a Hybrid Ringbom SE operating with overdriven characteristics. To implement parameter optimization, a computer programme has been written to simulate the engine operation. By varying some design parameters, it was possible to achieve an optimal operation efficiency of the engine. The performance results of the model have been found to be satisfactory.

INTRODUCTION

In rural areas clean water can be provided from boreholes or covered wells. Traditionally, water pumping has been done manually. However, the principal source of mechanised power is the use of internal combustion engine. Recently, several efforts have been made to utilize the sun's energy instead, thus saving the increasingly scarce and expensive fossil fuels. The most widely known technology which uses solar energy in water pumping or similar application, is the use of photovoltaic system. The other technology is the use of thermal machine which directly converts solar irradiation to mechanical energy. Among the different thermal machines employed, SE seems to be particularly promising[1] as it can be operated with air as a working medium and does not need any valves and thus no complicated control mechanisms[2]. Besides, SE is less pollutant, an important aspect in today's environmental concerns.

In this paper, the authors present a SE design based on a hybrid concept. In the study, parameter variations were conducted to determine optimal operational efficiency. The results obtained using the proposed design indicate that a fairly good performance of the physical model can be expected.

THE OPERATION PRINCIPLE

By definition a Stirling engine is a mechanical device which operates on a *closed* regenerative thermodynamic cycle, with cyclic compression and expansion of the working fluid, at different temperature levels. The flow of the working fluid is controlled entirely by the internal volume changes. The first SE was invented back in 1816 by Robert Stirling[3]. Since then, this engine has been the subject of many new research activities[4]. The invention of the Free Piston Stirling Engine (FPSE) by Beale, W.T. (1973)[5] renders it possible to build a SE without even a crankshaft, thus avoiding the need for bearings and sealings. With this configuration, the power piston and the displacer are hermeticaly sealed inside the machine's casing. The working fluid is itself used to prevent friction between the relative moving surfaces (thin-film-gas bearings), reducing the need for lubrication.

The main features of the design presented in this paper are shown in Fig.1. The design is based on a hybrid concept, attributed to Ossian Ringboom[6], of both a Ringbom-type SE and a FPSE[2]. This type of SE resembles the FPSE as the displacer is free, moved only by the acting gas forces, whereas the power piston is linked to the output rod by a magnetic coupling. The magnets provide the displacement mechanism of the piston.

ENGINE DESIGN FEATURES

The power piston shown in Fig. 2 is made of rolled mild steel (MS) sheet in the form of a cylinder with ring magnets at the center. The magnetic field leakage is avoided by separating the magnets from each other and from the cylinder (piston) walls by rings of teflon rubber. The rings (magnets and rubber) are then fixed inside the cylinder by means of two side covers. The covers are shaped in the form of dashpots (pneumatic cushions) which provide a back pressure (act as gas springs) to reduce the impact between the two displacers and the power piston, and at the same time to allow operation beyond the *overdriven* range. Since a thin film of the working gas flows continuously between the piston and the casing, there is absolutely no need of bearings or lubrication oil.

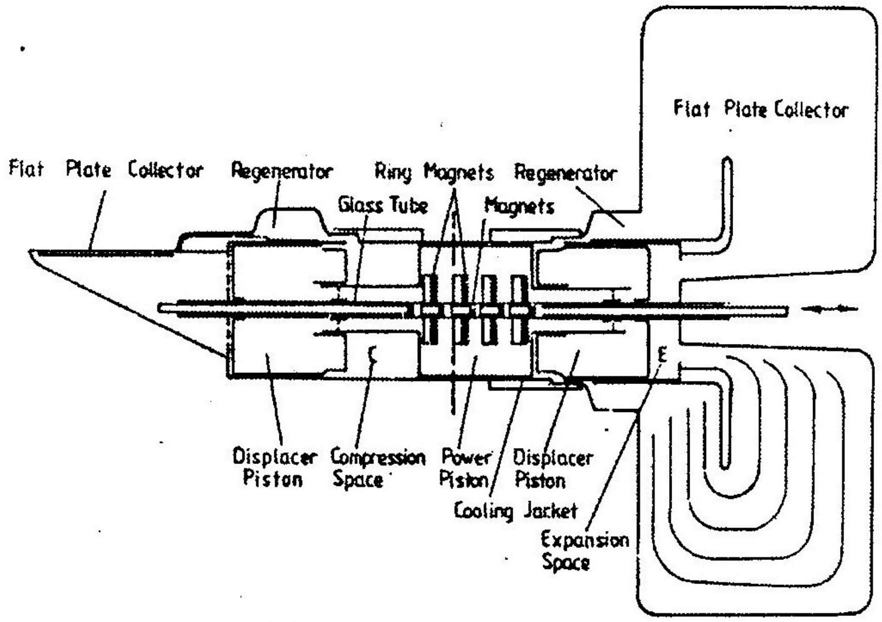

Fig. 1: Solar powered hybrid linear SE

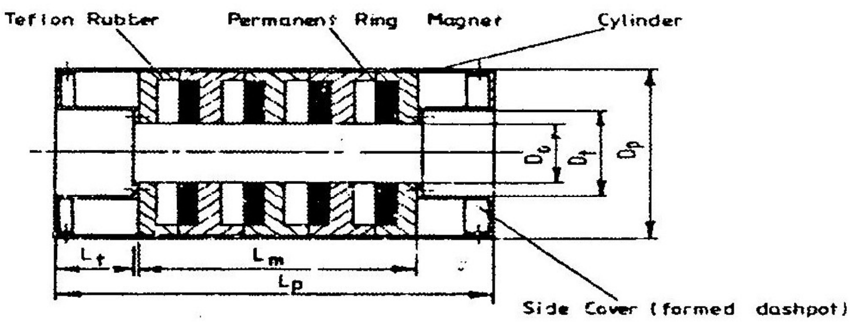

Fig. 2: A cross section of the power piston

The output rod is made of a MS round bar, and is connected to the driven device for linear actuation. At the center of this rod, concentric ring magnets are mounted to provide the magnetic coupling between the shaft and the power piston (see Fig. 3). The reciprocating motion of the output rod is transferred to rotary motion by means of the Ringbom-type linkage mechanism. The displacer, moved by the acting gas forces, is made of MS sheet rolled in the form of a cylinder as shown in Fig. 4.

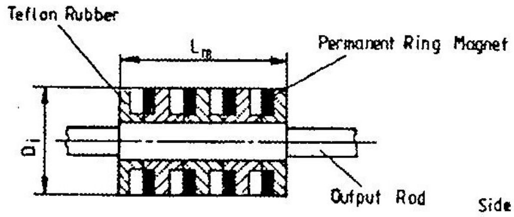

Fig. 3: Cross section of the output rod

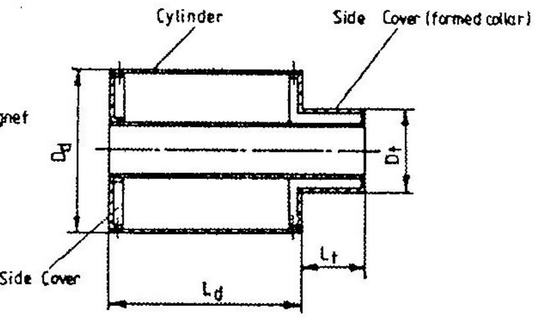

Fig. 4: Cross section of the displacer

Fig. 5 shows the casing made from rolled MS; and mounted on it are four flat plate collectors made of copper tubes (have high heat conductivity coefficient) clamped on a MS sheet, about 8 regenerators, and two cooling jackets. The casing can be manually swivelled in the direction of the sun. This is to avoid the sophisticated sun-tracking mechanism.

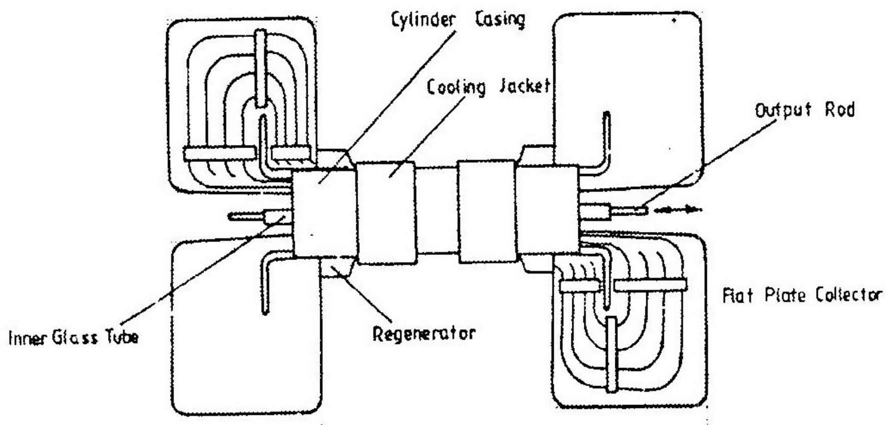

Fig. 5: The casing

The regenerator is a thermodynamic sponge absorbing and releasing heat to the working fluid. It acts as an energy depository when the working fluid flows from the heater to the cooler, and then acts as an energy source for the fluid as it returns to the heater. It is made of fine wire meshes stacked together in a round MS tube as shown in Fig. 6.

Thin rings of plastic/polyethylene are placed between the meshes and heated in an oven, at a moderate temperature of about 320K, for about 20 minutes. The polyethylene rings when heated melt and act as a bonding material between the wire meshes and the tube. In order to reduce the void volume, the contents are thereafter compressed to make a compact assembly of fine wire matrix. Epoxy resin is then applied to bind the outer wire meshes to the tube.

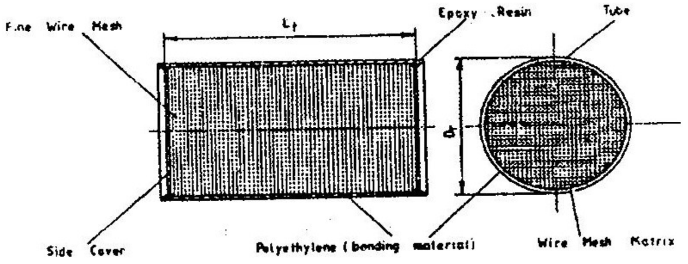

Fig. 6: Cross section of the regenerator

DESIGN PARAMETERS CONSIDERATION

The design of a SE depends on the choice of a handful of parameters. These parameters include heat exchanger dimensions; regenerator dimensions, and wire mesh matrix; piston and displacer dimensions, strokes, and phase relationship; charge pressure; operating frequency; temperature diffeience between the cold and the hot ends. For practical design purpose, some of these parameters were set to serve as initial values based on intuitive logical reasoning and the knowledge of the operation principle of the machine.

To avoid the need for redesigning a high pressure vessel, the mean pressure of the casing was set at a moderate pressure level of five bar. Tests conducted by Selemani[7] in Dar es Salaam show that the temperature of water boiled by solar irradiation could reach up to 453 K. Based on this, the heater wall temperature was set at 453 K. It was decided to use tap-water for cooling, thus the temperature of cooling was set at 293 K. Due to heavy mass of the piston (essentially of the magnets) and the low mean pressure, the frequency of the machine was anticipated to be low as well and was therefore set at 1.2 Hz.

The diameter of the displacer was selected to be the same as that of the power piston in order to avoid a doubly stepped casing. The length of the displacer was selected such that the hot and cold ends of the engine are far eneough to avoid excessive cantilever loading on the gas bearing surfaces.

The length of the regenerator was determined from the requirement that it should cover the distance from the cold end to the hot end of the casing. The regenerator packing consists of a wire mesh having 40 micron diameter, and the porosity was set at 0.7.

Other parameters such as diameter and number of heater pipes and regenerators, displacer lead angle to expansion and compression sides, were varied for a number of test runs in order to determine the combination which yields the optimal results (at highest efficiency). The results obtained from this design study are discussed below.

SIMULATION RESULTS

The evaluation and optimization of the engine design parameters has been achieved through the application of a modified version of the computer program by Uriel and Berchowitz[8]. The earlier version was written to simulate the three basic common drives - Sinusoidal, Rhombic, and Ross-Yoke. This version was expanded to include modules to simulate Hybrid Ringbom engine operating with overdriven characteristics.

Some of the engine's geometrical and operating parameters which were used as input in the study were: Air as working fluid; piston diameter 300 mm (to match the size of the ring magnets used), piston length 150 mm, piston amplitude 120 mm; displacer diameter 300 mm, displacer length 300 mm; compression clearance volume 630 cm^3; expansion clearance volume 700 cm^3. The cooler has 280 pipes of 3 mm diameter and 45 mm in length. The heater has 40 copper tubes of 3 mm diameter and 245 mm in length. The regenerator has an inner diameter of 25 mm, outer diameter 30 mm, and 75 mm in length.

The output results indicating the engine's operating range on an assumption of an Isothermal process were: The indicated (thermal) efficiency is 35.11% ; total mass of air in the engine is 81.3 gm; total wetted area and void volume of the regenerator are 21,976 cm^2 and 50.55 cm^3 respectively, hydraulic diameter of 0.09 mm; regenerator wall heat leakage of 432.86 W; total work done is 3.27kJ, and indicated power output of 3.93 kW.

The corresponding pv-diagram with Isothermal expansion and compression is shown in Fig. 7, while Fig. 8 shows how the expansion volume, compression volume, and engine pressure vary with the crank angle.

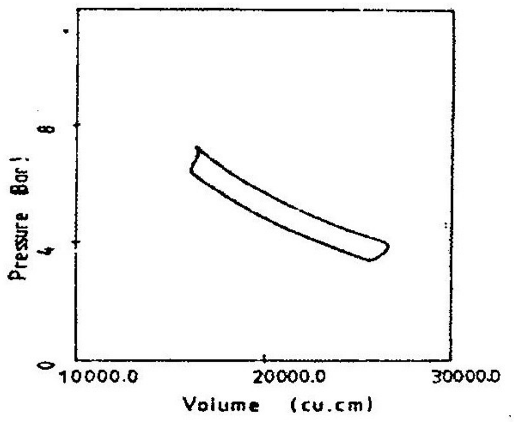

Fig. 7: Pressure Vs Volume diagram

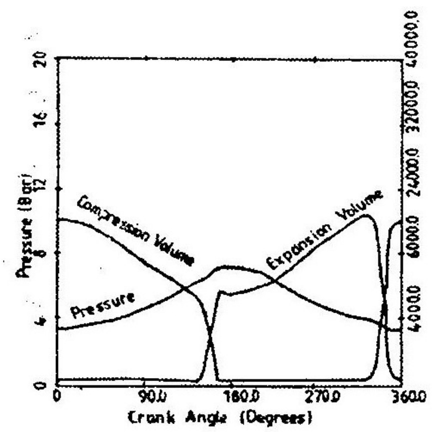

Fig. 8: Pressure and Volume Vs Crankangle diagram

CONCLUSION

The design configuration of the SE type adopted in this study has been based on selected components that could easily be manufactured in ordinary workshops. As simulation results did suggest, it is possible to obtain fairly good performance results on a physical model.

However, the thermal efficiency and the output power indicated are theoretical values obtained from a matherntical model. In order to obtain confidence and compare these results in a practical situation, tests on a physical model must be carried to determine the actual values of the engine. Construction of the engine to close tolerances will improve the overall performance of the engine.

ACKNOWLEDGEMENT

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