N84 28239

SPIKE-2 - A Practical Stirling Engine For Kilowatt Level Solar Power

William T. Beale
Sunpower, Inc.
Athens, Ohio USA

ABSTRACT

Recent advances in the art of free piston Stirling engine design make possible the production of 1-10kW free piston Stirling-linear alternator engines, hermetically sealed, efficient, durable and simple in construction and operation. These machines can operate either as independent units or ganged together for higher power. They may also operate directly connected to the grid without need of any intermediary.

Power output is in the form of single or three phase 60 Hz. AC, or DC. The three phase capability is available from single machines without need of external conditioning. Engine voltage control regains set voltage within 5 cycles in response to any load change.

The existing SPIKE-2 design has the following characteristics and measured performance.

Weight - 38kg
Length - 50cm
Diameter - 25cm
Power - 1.5kW
Working Gas - helium at 7 bar pressure
Engine-Alternator Efficiency - 25% at 650°C heater wall temperature
Life - over three years in solar service
Cost in Production - less than $1,000

The same system can be scaled over a range of at least 100 watts to 25kW.

For longer life, non contact bearings may be used without adding to system complexity or failure modes.

INTRODUCTION

The very rapid advance in the art of free piston Stirling design has recently made possible the construction of these machines at low cost with attractive performance characteristics, making them suitable as electric power generators in many applications, especially with concentrating solar collectors. The distinguishing features of this new generation of Stirling machines are low pressure, usually between 5 and 30 bar, relatively short stroke and large piston diameter, and relatively high frequency, 50 to 60 Hz.

The design described here was intended from the beginning as a simple, low cost and producible free piston Stirling of minimum complexity, but with reasonably good over all thermal efficiency at moderate temperatures. The target was 25% at a heater head temperature of 650C. These design goals were met, and the engine is entering the preproduction prototype stage with a delivered electrical power output of 1.5kW maximum. Its life is expected to be at least three years in solar service, and probably much longer

ADVANTAGES OF LOW PRESSURE OVER HIGH PRESSURE FPSE

The use of low charge pressure, about one order of magnitude lower than typically used in the past, permits very large clearances between sliding surfaces and consequent ease of fabrication of components. Whereas a 70 bar 30 hz. engine requires clearances on the order of 10 microns to avoid excessive losses from gas leakage, the 7 bar engine can acceptably use over 50 micron gaps without serious penalty. This makes it much less succeptable to damage from foreign particles inside the pressure enclosure. In addition these loose fits make repair and rework of bearing surfaces much easier.

With low internal pressure, it is possible to more readily use plastic and ceramic components. While these are not used in the existing prototypes, they may be worked into the production versions with consequent advantages of lower weight and cost, and higher efficiency.

In addition to the structural advantages, low pressure large diameter designs enjoy an additional benefit from the fact that the working space spring effect is strong enough to resonate the piston and alternator at the desired frequency, thus obviating the need for an additional spring. This considerably reduces the system complexity and cost.

DESCRIPTION OF ENGINE

Figure 1 shows the external appearance of the engine-alternator, and Figure 2 the internal arrangement. There are only two primary moving parts, the displacer and the coaxial piston with its attached alternator magnets. The heater head is internally and externally finned, and the heat sink is a liquid circulated around the cooler section which contains a large number of gas flow passages. A central rod provides a multiple service of alignment of the moving parts and bearing surface, as well as the gas spring piston for the displacer. Teflon based solid lubricants are used on all moving parts.

A more detailed description of the engine is given in Reference 1.

ALTERNATOR CHARACTERISTICS

The alternator is a very simple device using a light moving magnet (Samarium Cobalt) directly attached to the piston. Its structure allows the use of conventional flat transformer laminations and makes its fabrication no more complex than that of ordinary rotating machines. Alternator power/mass ratio is approximately 7kg/kw.

At the cost of nominal increase in complexity, the alternator may be designed to produce three phase power. The method by which this is achieved is proprietary and cannot be revealed at this time, but it results in power output indistinguishable from that of conventional three phase rotating machinery.

The alternator responds to load change rapidly with the aid of a simple control system. It will recover set voltage in 3 to 4 cycles after and 80% load variation. Newer control schemes give promise of recovery in two cycles from a 100% load change. The control system does not add significantly to the engine-alternator complexity or number of failure modes. In the reduced load condition, system efficiency is reduced only a moderate amount.

OPERATING CHARACTERISTICS

The engine is started by a small electric impulse to the alternator after the heater head has reached about 450C. At this temperature its power is only about 300 watts, which rapidly rises to the set power and voltage as the heater head temperature rises to about 550C. As temperature rises above this, power rises rapidly, but voltage is held constant by the controller, or if the engine is on the electric grid, the uncontrolled current increases while voltage remains at the grid value.

Changes in solar input simply change engine power with only relatively small changes of heater head temperature. Engine efficiency remains relatively constant as delivered power varies between maximum and .5kW. This operation does not require any change in engine pressure and hence needs a minimal control, or none except a disconnect in the case of a grid connection (Figure 3).

When the solar input is below the minimum, engine voltage drops below the set (or grid) value, and the engine idles, producing no power until the heat input is once again adequate. The engine will run down to a very low heater head value, about 80 degrees above coolant temperature, before it actually stops oscillating. This is because of the extremely low mechanical friction in the free piston machine.

Operation is very quiet, and cylinder oscillation is very low in amplitude, about 1mm excursion. This low amplitude vibration can easily be isolated by mounting springs.

The cooling system may be mounted on the engine, or on the ground as preferred. Engine efficiency is of course affected by coolant temperature, which should be as low as reasonably achievable, unless it is desired to use the hot coolant for some other purpose.

SPIKE-2 FOR SOLAR USE

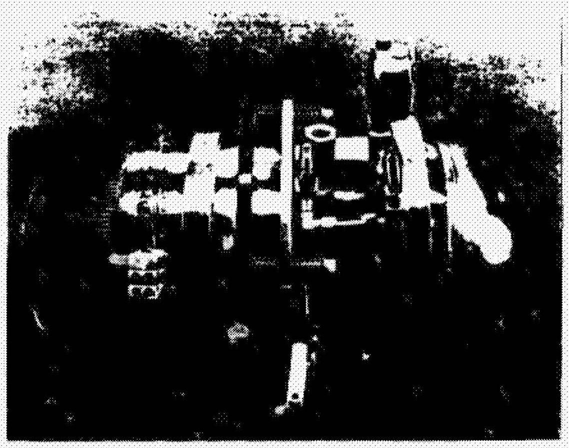
A SPIKE-2 solar system can be expected to have an overall conversion efficiency of about 17% when used with a good quality concentrator and absorber and a well designed heat rejection system. This is high enough to warrant consideration for use in some applications, and is also attractive for experimental or evaluation purposes. For this system a dish between 3.5 and 4 meters would be required to produce a net 1.5kW to a load.

Expected cost of the engine-alternator in reasonably large scale production is about $800, but the presently available prototype costs much more.

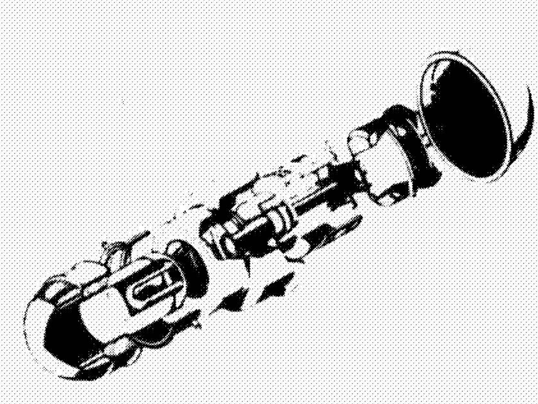
A more advanced version, producing three kW, three phase is expected to be available for experiment and evaluation in late 1984.

REFERENCE

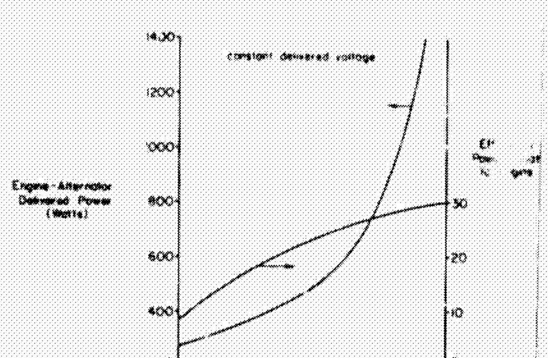
David Berchowitz - The Development of a 1kW Electric Output Free Piston Stirling Engine Alternator Unit. Presented at the 18th IECEC, Orlando, Florida, August 1983.



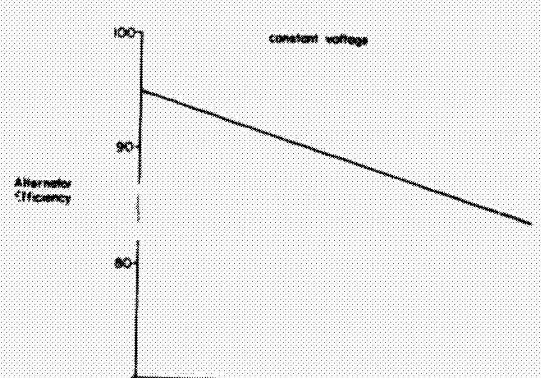
Engine-Alternator
Figure 1



Exploded View
Figure 2



Efficiency and Power Vs
Temperature
Figure 3



Alternator Efficiency Vs
Power
Figure 4