3-STAGE FREE PISTON–STIRLING ENGINE PUMP FOR FLUID/GAS HEATING AND/OR CIRCULATION IN LOW THERMAL ENVIRONMENTS

What is the proposed concept?

As NASA's man missions get further away from the sun (e.g., Mars or farther), solar energy becomes less available. Thus alternative methods are needed to provide power to various subsystems on spacecraft and/or planet side structures to reduce the demand on the electrical energy power plants (e.g. nuclear power generators), which would advance NASA's capability during space missions. One method is to combine the available waste thermal energy and/or the available solar energy into one unit to produce heat and electrical power. Therefore, the thesis is to study a 3-Stage Free Piston–Stirling Engine Pump (3S-SEP) concept powered by the available solar energy and/or thermal waste heat with partial conversion to electrical energy to provide fluid/gas heating and circulation, on spacecraft and/or in planet side structures at pressures higher than the Stirling engine can deliver at the reduced available thermal energy. The temperature of the fluid/gas will depend on the temperature of the available solar energy and/or thermal waste heat.

The 3S-SEP is a Stirling engine [for example, 1, 2] pump combined with an energy efficient Dual Position Linear Motor (DPLM) [3] controlled with a Pulsed Capacitive System [4] to heat and circulate fluids or gases, whereby the 3S-SEP utilizes both thermal and electrical energy in one unit. In the 3S-SEP, the available waste heat or the available Concentrated Solar Power (CSP) is used to operate the Stirling engine with partial conversion to electrical energy, Photovoltaics (PV) or Thermal electric Generators (TEG), to power the energy efficient DPLM, providing a cost-effective and energy efficient way to heat and circulate fluids or gases to higher pressures than can be accomplished with conventional solar Stirling engines at lower available solar or thermal energies.

Stirling engines [for example, 1, 2] are a mature technology and pose no technology risk. The energy efficient DPLM [3] is based on the Dual Position Linear Solenoid (DPLS) technology [4-7] and is basically a single moving coil DPLS [see; 3] composed of a moving coil section, a fixed permanent magnet section, flexure springs, pusher, and a controller that is a small variation of the DPLS controller [4]. The moving coil section is composed of a magnetic core encasing the coil. The fixed Permanent Magnet Section is composed of an outer and inner magnetic core about a toroidal and radially poled, permanent magnet. A pusher is attached to flexure springs and the moving coil section, extending through, and allowed to freely move through the fixed permanent magnet section; whereas in the 3S-SEP, would be attached to pistons that transfers the impulse power to a fluid/gas, that is transposed through and out of the 3S-SEP by the piston movement at pressures higher than the Stirling engine can deliver at the reduced available thermal energy.

As the energy efficient DPLM is dual poled – allowing for two pistons, the 3S-SEP is proposed to have two Stirling engines to circulate/pump the fluid/gas from each Stirling engines per cycle.

What makes it exciting?

Using a 3S-SEP will enable a cost-effective and energy efficient way of combining both PV/TEG and CSP/Thermal energy.

The 3S-SEP can be used in providing fluid/gas circulation for various spacecraft or planet side systems (e.g., structural heating, clean/reuse/waste fluid/gas, and etc.) to reduce spacecraft and planet side electrical energy power plants (e.g. nuclear power generators) usage when there is lower available solar energies.

Is the concept unexplored?

The concept of using a 3S-SEP is Ground Breaking, as it has not been previously considered for NASA's space missions.

Why is the concept credible and technically sound?

Stirling engines [for example, 1, 2] are a mature technology and pose no technology risk. Combining the DPLM with the Stirling engines is also not considered to pose any technology risk.

The DPLM [3] is basically a higher oscillated DPLS [4-7] and an $203\ mm\ (\sim 8\ inch)$ diameter DLPS for pumping fluids to 2000 psi, that demonstrated $>13kN\ (3000\ lbf)$ due to the permanent magnets at ~1 mm (0.004 inch) separation, under no power, was built and demonstrated. However, as the DPLM is a new unreported technology (except patents), to demonstrate the DPLM's feasibility toward use as a high oscillating linear motor, an ~63.5 mm (2.5 inch) diameter DPLM with an ~22.9 mm (0.9 inch) thick moving coil section and ~15.2 mm (0.6 in) thick permanent magnet section was built and tested. The magnetic core material used was low carbon steel. The permanent magnet was composed of N42 Neodymium permanent magnets assembled in a radial fashion about the central dual poled magnetic core. At ~1 mm (0.004 inch) separation and under no power, the magnetic attraction force between the moving coil section and the permanent magnet section was ~110 lbs. With an input voltage $V \sim 25\ V$ to the controller and within an optimum frequency range $f \sim 66\ Hz - 74\ Hz$, the movement distance was ~ 4 mm and the force swing was ~ 100 lbs. It is noted that this DPLM continued to operate down to ~15V with reduced movement distance. This bring the TRL of the DPLM to ~TRL 4 – Component and/or Breadboard Laboratory Validated.

However, neither a DPLM compressor nor an integrated 3S-SEP have been built and tested. Therefore, this exciting TRL 1 (Basic principles observed and reported) technology is ready to take the next step toward the development of this new in-space capability.

Briefly, what do you plan to accomplish in the Phase I study.

Our initial Phase I effort will have two tasks:

1. Conduct an engineering study of a 3S-SEP used in the solar energy environment of Mars. The study will address the types of Stirling engines best suited for integration with the DPLM compressor.

2. Design and develop a dual piston DPLM fluid/gas compressor with the DPLM having double the force attained in the previous DLPM tests to demonstrates a dual DPLM compressor under relevant conditions and show scalability of the DPLM, for use in the engineering study and to bring the DPLM compressor to between TRL 3 – Proof-of-Concept Demonstrated, Analytically and/or Experimentally and TRL 4 – Component and/or Breadboard Laboratory Validated.

Development and testing of the integrated 3S-SEP will be done in Phase II, to bring the technology to between TRL 5 – Component and/or Breadboard Validated in Simulated or Real space Environment and TRL 6 – System Adequacy Validated in Simulated Environment.

References

1. Stirling engine, for more information see: https://en.wikipedia.org/wiki/Stirling_engine or research the internet.
2. Radioisotope Heater Unit-Based Stirling Power Convertor Development at NASA Glenn Research Center, https://ntrs.nasa.gov/api/citations/20180003522/downloads/20180003522.pdf
3. Robertson, G. A., Dual Poled Linear Motor (DPLM) as described in US patent application 1767146, Feb. 19, 2022.

4. Robertson, G. A., Dual Acting Solenoid Valve Using Bi-Stable Permanent Magnet Activation for Energy Efficiency and Power Versatility 10,024,453, July 17, 2018.
5. Robertson, G. A., Divergent Flux Path Magnetic Actuator with Reciprocating and Rotatable Shaft, US Patent 9,136,052, Sep. 15, 2015.
6. Robertson, G. A., Energy Efficient Bi-Stable Permanent Magnet Actuation System, US Patent 9,343,216, May 17, 2016.
7. Robertson, G. A., Power Versatile and Energy Efficient Electric Coaxial Valve, US patent 9,702,477, July 11, 2017.

3-Stage Free Piston-Stirling Engine Pump (3S-SEP)

What is it?

3S-SEP

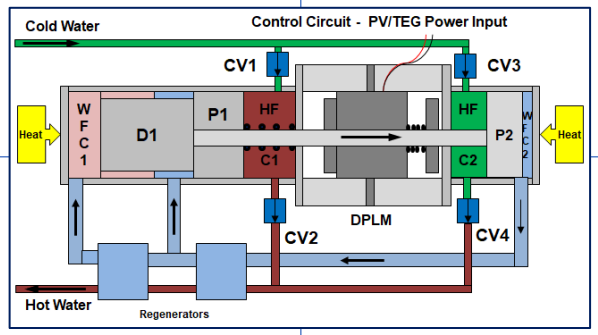
- A combined DPLM compressor and Stirling engine heater and pump for reduced thermal environments
- <TRL 1, Component integration and lab experiments required

How can it be used?

To heat and circulate fluids or gases.

Study Approach

1. Conduct an engineering study of a 3S-SEP used in the solar energy environment of Mars.
2. Design and develop a dual piston DPLM fluid/gas compressor for use in the engineering study and to bring the DPLM compressor to between TRL 3 – Proof-of-Concept Demonstrated, Analytically and/or Experimentally and TRL 4 – Component and/or Breadboard Laboratory Validated.



Potential & Benefits

- The 3S-SEP is design to operate like a Stirling engine heater/pump at reduced available thermal energy.
- Using a 3S-SEP will enable a cost-effective and energy efficient way of combining both PV/TEG and CSP/Thermal energy.