DEVELOPMENT OF A 12 kWe STIRLING POWER CONVERSION UNIT FOR FISSION POWER SYSTEMS – STATUS UPDATE. S.M. Geng[1], J. Stanley[2], J.G. Wood[2], E. Holliday[2], [1]NASA Glenn Research Center, Cleveland, OH 44135, [2]Sunpower, Athens, OH 45701.

Background: Fission power systems (FPS) are being developed for use on the surface of the Moon, Mars, or other moons and planets of our solar system. FPSs are capable of providing good performance at any location, including those near the poles or other permanently shaded regions, and offer the capability to provide on-demand power at any time, even at long distances from the Sun. Fission-based systems also offer the potential for outposts, crew, and science instruments to operate in a power-rich environment.

Introduction: One of the key technologies associated with the FPS is the Power Conversion Unit (PCU). In the FPS application, the PCU converts thermal energy produced by a fission reactor to electrical power. In 2010, Sunpower, Inc., of Athens, Ohio, and the NASA Glenn Research Center began development of a Stirling 12 kWe PCU under contract NNC09CA23C. An illustration of the PCU is shown in Figure 1. The unit is approximately 0.3 meter (12 inches) diameter by 1.2 meter (43 inches) in length.

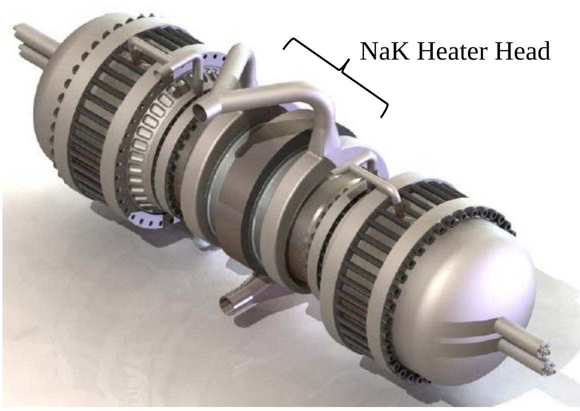

Figure 1 – 12 kWe Power Conversion Unit.

The PCU currently under development is intended for use in a non-nuclear, system-level Technology Demonstration Unit (TDU) [1] of a fission reactor power system.

The PCU was designed to operate at 60 Hz to produce 12 kWe of AC power at a brake thermal efficiency (AC electrical out / head input) of 27% with helium as the working space fluid. The design parameters of the PCU are shown in Table I.

The 12 kWe PCU is comprised of two 6 kWe free-piston Stirling engines that are thermodynamically coupled in a dual-opposed configuration [2] [3]. Both of the 6 kWe free-piston engines have been built and tested, and easily achieved full design power [4] when operated individually. More testing is planned with the engines mounted in the dual-opposed configuration prior to integration with the TDU.

Table I – Basic PCU Design Parameters

Parameter (per 6 kWe engine)	Value	Units
Heating Fluid Inlet Temperature	577	°C
Coolant Inlet Temperature	102	°C
Power Output	6	kWe
Brake Thermal Efficiency	27	%
Frequency	60	Hz
Helium Charge Pressure	6.2	MPa
Cylinder Bore	127	mm
Regenerator Outer Diameter	210	mm
Piston Amplitude	16	mm
Displacer Amplitude	12	mm
Displacer Phase	60	°
Heat Acceptor Length	90	mm
Regenerator Length	55	mm
Heat Rejector Length	55	mm

Due to funding difficulties, progress on the development of the 12 kWe PCU has slowed over the past two years. Delivery of the PCU to GRC has been delayed by over a year relative to the original plan, and is now scheduled for delivery in May of 2014.

The PCU will be integrated with the TDU for full-scale demonstration testing in GRC's Vacuum Facility #6. TDU testing is expected to begin in August of 2014. An illustration of the TDU assembly in GRC's vacuum facility is shown in Figure 2. A photo of the actual TDU hardware is shown in Figure 3.

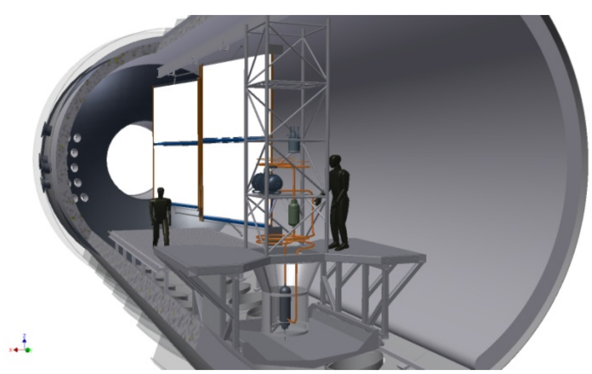
Figure 2 – TDU in GRC Thermal Vacuum Facility.

Figure 3 – Build-up of TDU on Test Platform.

PCU Development Status: The first test run of the 12 kWe PCU (two 6 kWe engines thermodynamically coupled in dual-opposed configuration) occurred in April 2013. Extended testing of the PCU revealed two areas of structural weakness: 1) the displacer spring mounting structure, and 2) the displacer dome-to-body attachment. During testing, the displacer mounting structure experienced higher stresses than anticipated which eventually led to partial failure. In addition, the displacer dome detached from the displacer body due to stress risers introduced during the fabrication process. Both areas have now been redesigned to correct these issues.

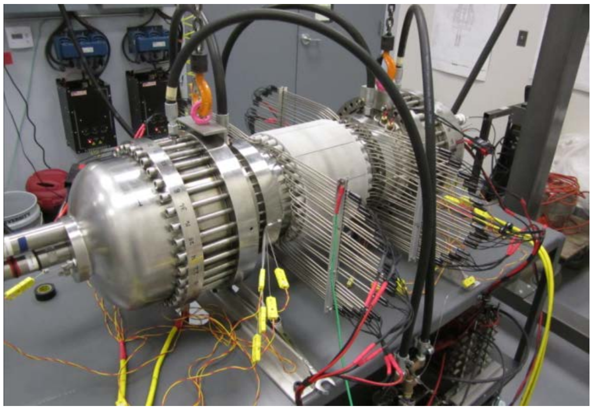

Figure 4 – PCU Test Setup (shown without insulation)

PCU will be tested further at Sunpower to demonstrate the integrity of the hardware modifications. Testing at present is performed using an electrically heated head which contains 60 separate 1-kW cartridge heaters. The cartridge heaters are pressed into nickel blocks which are brazed onto the outside of the heater head as shown in Figure 4. This head eventually will be replaced with a NaK heater head prior to PCU delivery to NASA. The NaK heater head allows the PCU to be directly integrated with a pumped NaK loop.

The NaK head is visible in Figure 1. Hot NaK enters a central manifold then flows axially adjacent to the heat accepters of both engines. Details of this arrangement have been described previously (Wood 2010, Wood 2011, and Stanley 2013). The major components of the NaK head, which are the inner finned tube and the outer support tube, are shown in Figure 5. These components, along with the rest of the pressure wall and the internal heat exchangers, have already been fabricated and are currently going through the assembly welding and brazing processes.

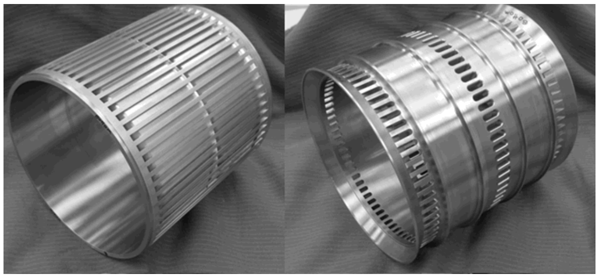

Figure 5 – NaK Head Inner and Outer Support Tubes

Controller Development Status: The controller has now been demonstrated on a single 6 kWe engine operated at full power. Previously, the controller had been demonstrated on a pair of dual-opposed 1-kW engines (Stanley 2013). Due to funding constraints, the final DC/DC controller stage will not be demonstrated in the TDU. This would have reduced the basic controller output of 700V DC down to 120V DC.

Concluding Remarks: Significant progress has been made toward the development of a 12 kWe PCU over the past year in spite of the project funding difficulties. Some minor PCU internal structural issues did surface after extended testing, but all have now been corrected. PCU testing at Sunpower will continue, in an attempt to verify and demonstrate that the hardware is sound prior to shipment to NASA. Delivery of the PCU to GRC is planned for May of 2014.

References: [1] Mason L. et al. (2011) *Design and Test Plans for a Non-Nuclear Fission Power System Technology Demonstration Unit,* NASA/TM—2011-217100, [2] Wood J. et al. (2010) *Free-Piston Stirling Power Conversion Unit for Fission Power Technology Demonstration, Phase I Final Report,* NASA/CR—2010-216750. [3] Wood J. et al. (2011) *The Design and Development of a 12 kWe Stirling Power Conversion Unit,* in Proceedings of Nuclear and Emerging Technologies for Space, paper 3488. [4] Stanley J. et al. (2013) *Progress in the Development of a 12 kWe Stirling Power Conversion Unit for Fission Power Systems,* in Proceedings of Nuclear and Emerging Technologies for Space, paper 6753.