Modeling and Analysis of Stirling Power Convertors

Luis A. Rodriguez[1] Steven M. Geng, Terry V. Reid, Scott D. Wilson
NASA Glenn Research Center, Cleveland, OH, 44135, USA

NASA Glenn's Thermal Energy Conversion Branch is supporting the development of the next generation free-piston Stirling power convertors for Dynamic Radioisotope Power Systems (DRPS). American Superconductor (AMSC) and Sunpower Inc. are the two firms under contract to develop the Flexure Isotope Stirling Convertor (FISC) and the Sunpower Robust Stirling Convertor (SRSC), respectively, to meet DRPS requirements. To comprehend and forecast convertor performance, Sage, ANSYS® Maxwell, and ANSYS® Fluent were used to model the Stirling thermodynamic cycle, alternator electromagnetics, and piston and displacer dynamics.

I. Introduction

Free-piston Stirling convertors are being developed by NASA as a steady source of electrical power for NASA's future space science missions. Currently, NASA Glenn Research Center has two contracts with American Superconductor (AMSC) and Sunpower Inc., for the development of the next generation of free-piston Stirling convertors for Dynamic Radioisotope Power Systems. AMSC is developing the Flexure Isotope Stirling Convertor (FISC), which uses flexures to provide axial springing and radial stiffness which prevents contact of the moving components. Similarly, Sunpower Inc, is developing the Sunpower Robust Stirling Convertor (SRSC). The SRSC uses gas bearings to provide radial stiffness which also ensures non-contact of the moving components. These two means of ensuring non-contacting free-piston Stirling convertor operation is well proven with earlier representative multiple convertors of each type exceeding 10-14 years of operation at GRC. The FISC and SRSC represent the newest designs to address anticipated DRPS flight requirements. As convertor development continues, it is increasingly important to understand and predict the interactions of components in the system, how they respond to one another, and how they perform as a response to changes in operating conditions. A suitable and enlightening way to demonstrate and foresee these interactions is with the use of accurate modeling software. Sage, ANSYS® Maxwell, and ANSYS® Fluent are the current modeling tools used by NASA to analytically determine convertor performance.

Sage is a one-dimensional object-oriented commercial software package used for modeling and optimizing Stirling convertors for Dynamic Radioisotope Power Systems (DRPS) and it is one of the most accurate Stirling convertor codes in use by NASA. This code is the successor to GLIMPS (Globally-Implicit Stirling Cycle Simulation) and GLOP (GLIMPS Optimization) software created by Gedeon Associates [1]. Model input parameters are typically material/gas type, component physical dimensions, temperatures, frequency, charge pressure, and number of time/space nodes. Sage is used to model both the FISC's and SRSC's Stirling cycle thermodynamics and piston/displacer dynamics. Performance maps were created and analyzed for both power systems to better understand the relationship between the following conditions: cold-end temperature, hot-end temperature, piston/displacer amplitudes, pressure drop, and thermal input power. The synergy between these conditions will help determine parameter sensitivity.

ANSYS® Maxwell was used to create a three-dimensional (3-D) axisymmetric model for both FISC and SRSC alternators. The significant physical components included in each model are the magnets, magnet carrier, outer/inner laminations, and the coil. Inputs to the model are piston amplitude, piston frequency, alternator load, coil resistance, tuning capacitance, and specific material properties. The alternator models calculate terminal voltage, current, piston/current phase, voltage/current phase, coil inductance, terminal power and efficiency. The RI^2 losses, core (hysteresis and eddy) losses, and magnet/can eddy losses are also a part of the final results.

[1] Stirling Convertor Analyst, Thermal Energy Conversion Branch.

ANSYS® Fluent is used to build 3-D computational fluid dynamic (CFD) models to examine the Stirling cycle thermodynamics for both the FISC and SRSC systems. Three-dimensional Computer Aided Design (CAD) models were used to create the physical components of each convertor. Steady-state simulations were conducted for hardware testing, prediction of environmental losses during testing, and generation of radiation look-up tables. The model inputs to the aforementioned analysis are the material properties and boundary thermal conditions. The steady-state model calculates temperature and heat flow distributions.

Transient 3-D calculations were also part of the CFD analysis. In this study a physically reduced version of the FISC is used to obtain a prediction of available engine power. For the gas bearing SRSC, the transient effort is used to obtain a prediction of bearing pad performance and its sensitivity to micro-channel geometric variation. The model inputs to the transient simulations are the piston amplitude, displacer amplitude, frequency, displacer/piston phase angle, dynamic deforming CFD grid, temperature boundary conditions, and user defined files describing motion profile of piston/displacer. The results of the model are temperature distributions, heat distributions, and PV power produced at pre-determined conditions.

References

[1] Gedeon, David. "Sage: Object Oriented Software for Stirling Machine Design," AIAA Paper 94-4106-CP. 1994. https://doi.org/10.2514/6.1994-4106