Advanced Stirling Convertor Durability Testing: Plans and Interim Results. David W. Meer[1], [1]Lead Aerospace Engineer, Sest, Inc., 18151 Jefferson Park Road, Suite 101, Middleburg Heights, OH 44130, USA (David.Meer@sestinc.com) .

Introduction: The U.S. Department of Energy (DOE), Lockheed Martin Space Systems Company (LMSSC), and NASA Glenn Research Center (GRC) have been developing the Advanced Stirling Radioisotope Generator (ASRG) for use as a power system for space science missions. In support of this program, GRC has tested developmental Advanced Stirling Convertor (ASC) units for use in the ASRG. This testing includes EMI/EMC, structural dynamics, advanced materials, organics, and unattended extended operation testing [1]. The purpose of the durability tests is to demonstrate experimentally the margins in the ASC-E2 convertor design. The ASC-E2 convertor is the predecessor to the flight design. Due to the high value of the hardware, previous ASC tests focused on establishing baseline performance of the convertors over the nominal operating parameters. The durability tests present the first planned extension of the operating conditions into regions beyond those intended to meet the product specification, where the possibility exists for lateral contact, over-stroke, or over-temperature events. These tests are not intended to cause damage that would shorten the life of the convertors, so they can transition into extended operation at the conclusion of the tests. This abstract describes the four tests included in the durability test sequence: 1) start/stop cycle testing, 2) exposure to constant acceleration at a centrifugal test facility, in the lateral direction and axial directions (centrifugal acceleration testing), 3) random vibration at increased piston amplitude to induce contact events that might occur during launch (contact during launch), and 4) overstroke testing to simulate potential failures during processing or during the mission life, such as controller switchover, where contact events could occur. The abstract also summarizes the analysis and simulation used to predict the results of each of these tests.

Implementation: The durability tests utilize a convertor with a removable pressure vessel, to allow for partial disassembly and inspection of internal components as a means to evaluate the impact of the tests on the convertor. Upon receipt of the ASC-E2 convertor configured with the durability test pressure vessel, the convertor will undergo the standard GRC processing sequence including heater head measurement, instrumentation, and operational checkout. Following the standard GRC processing, the durability test unit operated at nominal conditions for 200 hours to establish a performance baseline. At this point, the convertor underwent the first inspection to characterize the pre-test surface conditions of the convertor internal components. After reassembly and operational verification, the convertor began the sequence of durability testing described earlier: start/stop cycle, centrifugal acceleration, contact during launch, and overstroke

Following each test, the convertor will undergo the partial disassembly and inspection described previously. At the completion of the durability tests, the convertor will return to Sunpower for installation of the production pressure vessels and completion of the normal processing sequence, including hermitic sealing, before entering into the extended test program.

Start/Stop Cycle Test. The purpose of this test is to operate the convertor repeatedly through the start/stop cycle to exacerbate any possible wear caused by running the convertor without a fully functional gas bearing. The number of cycles will exceed that expected for a flight convertor by a factor of 2, for a total of 301 cycles. Table I summarizes the variable operating conditions for the start/stop test. These conditions represent the various operating conditions experienced by the convertor at Sunpower and LMSSC.

For the tests conducted at LMSSC, the current plans call for motoring the convertors once per startup, with all temperatures at room temperature, or roughly 23 °C, primarily in the horizontal configuration. During the testing of the ASRG EU, the convertors underwent approximately 44 start / stop cycles at LM.

Table I.- Operating Conditions for Start/Stop Test.

Number of Cycles	Cold-End Temperature (°C)	Pressure Vessel Temperature (°C)	Orientation
67	23	23	Vertical
67	38	46	Vertical
67	52	61	Vertical
100	23	23	Horizontal

For the testing at Sunpower, the circulators are set for the beginning of mission low reject: 52 °C cold-end and 61 °C pressure vessel. The hot-end, cold-end, and pressure vessel temperatures all move toward their target values simultaneously. The convertor is motored at three hot-end temperatures: room temperature, 400-450 °C, and 700–750 °C, the cold-end and pressure vessel temperatures move from room temperature to their final values simultaneously with the hot-end temperature. Sunpower generally operates the convertors in a vertical configuration. Since the hot-end temperature plays a very small role in the operation of the gas bearings and to reduce the risk to the convertor, all testing will run at a hot-end temperature of 23 °C. Based on the testing of ASC-E2 #3 and #4 at Sunpower, the convertors underwent 21 and 22 startup cycles respectively, including the workmanship vibration testing.

ASC-E2 #7 successfully completed the start/stop cycle test in September, 2011, and showed only a light buffing of the Xylan coating on the piston after 301 cycles, with no change in gas bearing operation.

Centrifugal Acceleration Test. The second proposed test in the durability test sequence will utilize a centrifugal acceleration facility to expose the convertors to a constant acceleration load for a specified period of time. The ASC Product Specification includes a requirement the convertors must operate through a 30 g static load. This requirement has yet to be verified.

The results of a System Dynamic Model (SDM) simulation with a constant acceleration of 30 g towards the pressure vessel of the convertor [2] show that the both the piston and displacer have more than sufficient margin when exposed to this acceleration. With the acceleration directed toward the heater head, however, the simulation indicates the margin between the displacer and heater head becomes very small. Similarly, analysis of the strength of the gas bearings that support the displacer rod have indicated that rubbing may result with exposure to a lateral acceleration above 10 g., possibly producing some wear on the displacer rod Xylan surface and a temporary reduction in power.

Contact During Launch Test. The contact during launch test seeks to explore potential contact of internal components in the ASC convertor when exposed to launch vibration, Figure 1 presents results from earlier vibration testing to qualification levels using ASC-E #1. The figure shows the maximum piston position excursions as a function of vibration level in g_{rms}.

During this test, both the in (toward the heater head) and out (away from the heater head) margins were set 0.5 mm away from the hard stops. As the plot shows, the margin was exceeded for a single point during testing at the qualification level. Note that the input spectra used during this test was shaped base on the results of the dynamic test to qualification level of the ASRG Engineering Unit (ASRG EU) conducted at LM in the spring of 2008. For details of the overall vibration test approach for ASC units, see [3].

SDM has been used to predict the increase in operational amplitude required to potentially lead to a limited number of contact events during vibration. Due to the random nature of the vibration testing, some adjustment during the test is likely.

Overstroke Test. The goal of the final durability test is to simulate possible contact events during processing or during the mission life. One scenario

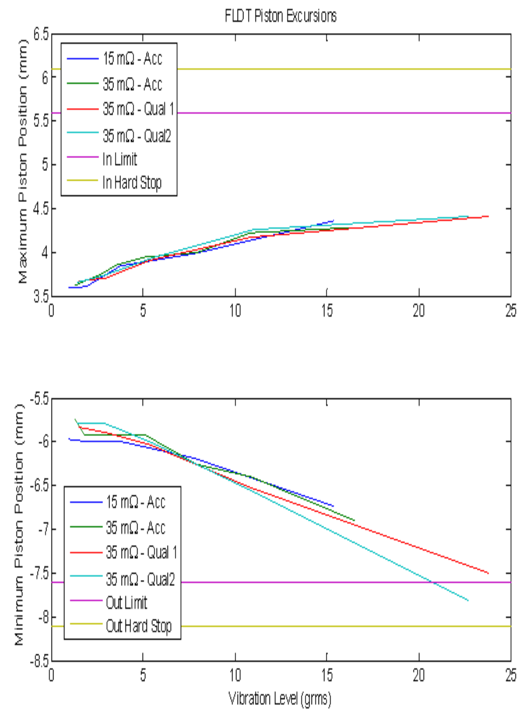

Figure 1. – Piston amplitude excursions as a function of vibration input level.

that could cause a contact event involves the switchover within the ACU from one control card to another in the event that the controller determines one card is not performing correctly. At the present time, the estimated switchover time due to relay closure is less than 2 ms. Even with switchover times in that range, SDM simulations have shown the possibility of collisions occurring depending upon the point in the Stirling cycle at which the switchover begins. Analysis performed on the internal components has produced collision velocity limitations to prevent permanent damage.

References: [1] Schreiber, J. G., Thieme, L. G., and Wong, W. A., (2008) *6th IECEC*, AIAA–2008–5790. . [2] Meer, D.W. and Lewandowski, E. J. (2010) *8th IECEC*, AIAA-2010-7094. [3] Meer, D. W., Hill, D., and Ursic, J. (2009) *7th IECEC*, AIAA-2009–4552

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