Extended Operation of Stirling Convertors

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A high-efficiency 110 watt Stirling Radioscope Generator 110 (SRG110) is being developed for potential NASA exploration missions. The SRG system efficiency is greater than 20%, making it an attractive candidate power system for deep space missions and unmanned rovers. The Department of Energy SRG110 Project team consists of the System Integrator, Lockheed Martin (LM), Stirling Technology Company (STC), and NASA Glenn Research Center (GRC). One of the GRC roles is to provide Independent Verification and Validation of the Stirling TDC’s. At the request of LM, a part of this effort includes the extended operation of the TDC’s in the dynamically balanced dual-opposed configuration. Performance data of Stirling Convertors over time is required to demonstrate that an SRG110 can meet long-duration mission requirements. A test plan and test system were developed to evaluate TDC’s #13 and #14 steady-state performance for a minimum of 5000 hours and insure safe, round-the-clock operation of the TDC’s. This paper will discuss the design and development, and status of the Extended Operation Test.

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NASA - Users

DOE - Customer

LOCKHEED MARTIN
Valley Forge - System Integration, Fab & Test

NASA
GRC: Component/Converter Tests & Modeling Support

STC
Stirling Convertors

LOCKHEED MARTIN
Newtown - Electronic Controller

LOCKHEED MARTIN
Palo Alto - Producibility Support

LOCKHEED MARTIN
Denver - Mars Requirements

LOCKHEED MARTIN
ANL-W, LANL, ORNL:
Fuel & RPS Operations

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**SRG110**

**DESIGN METRICS**
- **Design Life:** 14 Years + Storage
- **Power:**
  - BOM – 112 We
  - EOM Mars (3 Yrs) -- 99 We
  - EOM deep space (14 Yrs) -- 97 We
- **Mass:** 34 kg
- **Size:** 11.5”W x 15”H x 37.5”L

**ATTRIBUTES**
- Two Stirling convertors
  - Co-axially aligned for dynamic balance
  - One GPHS (Step 2) per convertor
- Integrated, on-board controller
  - Externally mounted
- Beryllium external housing
- Operates open to vacuum or Martian atmosphere
- Detachable cooling system (not shown)

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TDC's #13 & #14 Testing

Status
- TDC's #13 & #14 delivered to GRC February 2003
- Installation on test stand
- 500-hour bake out completed, April
- Thermal insulation loss test completed, May
- Full power test completed, May 22
- Single-shift extended operation initiated in June
- Continuous unattended operation began July 18
- TDC's #13 & #14 have accumulated 9,035 hours through August 16, 2004
- Shutdown due to utility grid, faulty TC wire, etc
- Completed gas analysis through 5,000 hours
- Investigate performance degradation
  - Oxidation
  - Argon purge
  - Helium purge
TDC #13 & #14 Test Stand Design

- **Standard test stand**
  - Table for mounting convertors
  - Rack with data and control system
  - Chillers to circulate liquid coolant

- **Enhancements for Unattended Operation**
  - Modifications to data system software
  - Addition of uninterruptible power supply
  - Failsafe Protection Circuit
  - Gas charging system

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Failsafe protection circuit

Gas charging system
TDC #13 & #14 Bakeout

Thermal Loss Test
- Reduced thermal loss at 650°C to about 69 watts on TDC #13 and 65 watts on TDC #14

Bakeout
- Bakeout completed on April 9, 2003
- Water vapor partial pressure about $1 \times 10^{-6}$ torr
- After 25.8 hours of operation since bakeout reduced water vapor, however CO is now present
- Still some argon remains from insulation test
- Water vapor and oxygen in supply was absent from TDC
- Water vapor partial pressure $\sim 1 \times 10^{-10}$ torr

Full Power Test
- Full Power Test Completed May 22, 2003
TDC #13 & #14 Performance

- Performance for TDC #13 & #14 has generally been steady

- However, a more detailed look at the performance has shown some change in power and efficiency

- The story is not simple
TDC #13 & #14 Early Operation

- Weekly pressure variations were observed
  - Each TDC lost about 2 psi per week
- Through 2800 hours, performance fell slowly
  - Rate of about 0.4 – 0.5 watts per 1,000 hours
- All data were being studied to identify changing performance
  - Steady state data
  - Accelerometers
  - Gas analysis data
Gas analysis through 2800 hours

- Nitrogen appeared to be increasing linearly with time
- Argon appeared to be increasing, but reaching an asymptote
- Gas analysis from both convertors appeared very similar
- Helium was found in the vicinity of both o-ring flanges on both TDC’s

- Argon was believed to be residual gas from thermal loss test
- Source of nitrogen was theorized to be ambient air permeating inward
- Oxygen was not being observed, thought to be consumed by hot components

- Purge rings were installed and argon purge initiated
Results through 5860 hours

- Nitrogen content leveled immediately
- Argon content rose
- Performance remained nearly level
Results through 8700 hours

- Changed to helium purge after 5860 hours to reduce impact of argon on performance
- Convertor performance tracks the trends in the gas analysis
- Degradation observed early in the test are believed to be due to permeation through the o-rings, which is not an issue in flight system
Dynamic signature through 8700 hours

- TDC's #13 & #14 are operating in the dual-opposed, dynamically balanced configuration
- Dynamic forces are the result of mismatch permitted within the fabrication process
- No effort was made to achieve minimal dynamic signature
- There has been no change observed in the dynamic signature
TDC #14 Performance

- TDC #14 performance is nearly level, but not quite
- It is becoming more level over time
- This may be attributed to heater temperature distribution,
- This is, once again, a ground test issue, not a Stirling issue

Spread ~9°C

Average temperature is decreasing
Conclusion

- TDC’s #13 & #14 have reached over 9,000 hours of operation at GRC
- Facility modifications for unattended operation have been successful
- All shutdown have been facility or instrumentation related
- Permeation through the o-rings has been the major concern, but will not exist in the flight units
- Real-time gas analysis capability has proven to be beneficial
- Since permeation has been eliminated, performance has been generally constant
- There has been no changes in performance measured that are attributed to the TDC’s
- The current plan is to continue with the Extended Operation Test