Supplemental Information
For
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Documentation of Stainless Steel Lithium Circuit Test Section Design

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GENERAL NOTES UNLESS OTHERWISE SPECIFIED:
1. REMOVE ALL BURRS AND SMOKE ALL SHARP EDGES.
2. FIELD TO FILL ALL TIES IN CONNECTIONS.
3. ALL HOODED PORTS TO HAVE A 0.002 MACHINERIES HEIGHT RADIUS SURFACE FINISH.
4. THE SYSTEM SHALL BE RADIATED TO 2.0 TIMES THE WORKING PRESSURE OF THE SYSTEM.
5. ALL HOODED PORTS TO HAVE A 0.003 MACHINERIES HEIGHT RADIUS SURFACE FINISH.

SPECIAL NOTES:
8. MATERIAL SPECIFICATIONS FOR THERMOSHELLED TUBES:
   1. INSTRUMENTATION TUBING:
   2. MATERIAL:
   3. WALL THICKNESS:
   4. TUBE LENGTH:
   5. CONNECTORS:
   6. FITTINGS:
   7. VALVES:
   8. SLEEVE:

SPECIFIC NOTES:
1. THERMOSHELLED TUBE SYSTEM:
   1. TUBING:
   2. MATERIAL:
   3. WALL THICKNESS:
   4. TUBE LENGTH:
   5. CONNECTORS:
   6. FITTINGS:
   7. VALVES:
   8. SLEEVE:

SUGGESTED MANUFACTURER:
1. BLOOMING FLEX SYSTEM TECHNOLOGIES INC.
2. ROYAL VACUUM EQUIPMENT CORPORATION
3. MANUFACTURING

PRELIMINARY
HAS NOT COMPLETED REVIEW CYCLE
AND IS SUBJECT TO CHANGE
2-17-05

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SECTION I — CALCULATION OF REQUIRED TRANSDUCER STANDOFF LENGTHS: E.T. STEWART
These plots are *not* the temperatures along the length of the tube. They are the end temperatures for a given length. In other words, to use the plots, for a given x-value (i.e., tube length) the value of the plot is the temperature at the end. The straight line shows the target end temperature 453 K (180 C). The intersection of this line with the curve gives the required tube length. The center curve is the preferred plot with the upper and lower being an approximated error bound.

The required tube length is not greatly sensitive to the lithium-circuit temps because even though the amount of heat to be rejected rises as the lithium-circuit temp rises so does the ability to reject heat via radiation. The error bounds spread (i.e., increase) as the lithium-circuit temp rises because of the averaging of the end temperature and the lithium circuit temp used for both the effective heat transfer coefficient and the lithium thermal conductivity. I assumed that the tubes were radiating with an unobstructed view to chamber walls at 28 C. I assumed the emissivity of steel tubing to be 0.2, which should be in the ball park and is dependent on surface finish/condition. Raising emissivity would shorten the required tube while lowering would lengthen it.

The x-axis is stand-off tube length in meters while the y-axis is the lithium circuit temperature in Kelvin.

![Figure 1: Tube end temperature (K) versus tube length (m) for a lithium-circuit temperature of 300 C](image-url)
Figure 2: Tube end temperature (K) versus tube length (m) for a lithium-circuit temperature of 400 C

Figure 3: Tube end temperature (K) versus tube length (m) for a lithium-circuit temperature of 500 C

Figure 4: Tube end temperature (K) versus tube length (m) for a lithium-circuit temperature of 600 C
SECTION K—HEAT EXCHANGER ANALYSIS: T.J. GODFROY
Appendix L: NaK Heat Exchanger Analysis
This analysis assesses the axial temperature profiles along the length of two heat exchanger options, one measuring 0.6 meters the other 1.2. The inlet NaK-78 conditions and heat exchanger geometric cross-section values used in the assessment in include:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>NaK flow rate</td>
<td>1 kg/s</td>
</tr>
<tr>
<td>NaK inlet temp</td>
<td>923 K</td>
</tr>
<tr>
<td>He pressure</td>
<td>200 psi</td>
</tr>
<tr>
<td>Number of tubes</td>
<td>107</td>
</tr>
<tr>
<td>OD of tubes</td>
<td>0.3125 in</td>
</tr>
<tr>
<td>ID of tubes</td>
<td>0.2565 in</td>
</tr>
<tr>
<td>Tube length</td>
<td>0.6096 m</td>
</tr>
<tr>
<td>flow area per tube</td>
<td>3.337E-05 m²</td>
</tr>
<tr>
<td>Total flow area</td>
<td>0.0035671 m²</td>
</tr>
<tr>
<td>HT perimeter</td>
<td>2.66819391 m</td>
</tr>
<tr>
<td>Total HT area</td>
<td>1.62653101 m²</td>
</tr>
<tr>
<td>ID of shell</td>
<td>5.295 in</td>
</tr>
</tbody>
</table>

Figures 1 to 12 show results for He (mdot 0.1 kg/s, 0.2 kg/s), N2 (mdot 0.1 kg/s, 0.2 kg/s), and He-Ar (mdot 0.2 kg/s, 0.3 kg/s) with heat rejection rates of 30 and 60 kW. The NaK inlet temperature was assumed fixed at 650 °C (923K). The He/Ar mixture is 80% helium by volume. See captions of each plot for specific conditions.

Figure 1: Fluid Helium (flow rate 0.1 kg/sec), heat rejection 30 kW
Figure 2: Fluid Helium (flow rate 0.1 kg/sec), heat rejection 60 kW

Figure 3: Fluid Helium (flow rate 0.2 kg/sec), heat rejection 30 kW
Figure 4: Fluid Helium (flow rate 0.2 kg/sec), heat rejection 60 kW

Figure 5: Fluid Nitrogen (flow rate 0.1 kg/sec), heat rejection 30 kW
Figure 5: Fluid Nitrogen (flow rate 0.1 kg/sec), heat rejection 30 kW

Figure 6: Fluid Nitrogen (flow rate 0.1 kg/sec), heat rejection 60 kW

Figure 7: Fluid Nitrogen (flow rate 0.2 kg/sec), heat rejection 30 kW
Figure 8: Fluid Nitrogen (flow rate 0.2 kg/sec), heat rejection 60 kW

Figure 9: Fluid Helium Argon (flow rate 0.2 kg/sec), heat rejection 30 kW
Figure 10: Fluid Helium Argon (flow rate 0.2 kg/sec), heat rejection 60 kW

Figure 11: Fluid Helium Argon (flow rate 0.3 kg/sec), heat rejection 30 kW
Figure 12: Fluid Helium Argon (flow rate 0.3 kg/sec), heat rejection 60 kW
SECTION L—ELECTROMAGNETIC PUMP EXHAUST CALCULATIONS: N.O. RHYS
The following three pages comprise an estimate of the pressure drop along the exhaust tube exiting the EM pump housing. This analysis assumes simple straight tubing, no elbows, no fittings. Actual pressure drop is expected to exceed this estimate as components are added to the exhaust tube.

Page 1: Gas Properties and Flow Rates (GN2, 30 psi, 60 C, 0.1 kg/s)
Page 2: Pressure Drop if 2" Tubing is used = 0.33 psi
Page 3: Pressure Drop if 1" Tubing is used = 10.42 psi

The calculations show that 2" tubing should be specified for fabrication of the exhaust tube.

\[
g = 32.2 \, \frac{\text{ft}}{\text{sec}^2} \quad \text{Mwt} := 28 \, \frac{\text{kg}}{\text{mole}} \quad k := 1.4 \quad Rbar := 8315 \, \frac{\text{joule}}{\text{mole} \cdot \text{K}}
\]

\[
Rgas := \frac{Rbar}{\text{Mwt}} \quad Rgas = 296.96 \, \frac{\text{joule}}{\text{kg} \cdot \text{K}} \quad Rgas = 0.071 \, \frac{\text{BTU}}{\text{lb} \cdot \text{R}}
\]

\[
\rho_{air} := 0.07528 \, \frac{\text{lb}}{\text{ft}^3}
\]

\[
P_1 := 30 \, \text{psi} \quad \text{Temp}1 := 333 \, \text{K} \quad \rho := \frac{P_1}{Rgas \cdot \text{Temp}1}
\]

\[
P_1 = 2 \cdot \text{atm} \quad \text{Temp}1 = 599.4 \cdot \text{R} \quad \rho = 2.092 \, \frac{\text{kg}}{\text{m}^3}
\]

\[
\mu := 0.000012 \, \frac{\text{lb}}{\text{ft} \cdot \text{sec}} \quad \text{SG} := \frac{\rho}{\rho_{air}} \quad \rho = 0.1306 \, \frac{\text{lb}}{\text{ft}^3}
\]

\[
\mu = 0.000179 \cdot \text{poise} \quad \text{SG} = 1.73
\]

Desired Flow Rates

\[
\text{mdot} := 0.1 \, \frac{\text{kg}}{\text{sec}} \quad Q := \frac{\text{mdot}}{\rho} \quad Q_s := \left( \frac{\text{mdot} \cdot 13.55 \, \frac{\text{ft}^3}{\text{lb}}}{60 \, \text{sec}} \right)
\]

\[
\text{mdot} = 0.22 \, \frac{\text{lb}}{\text{sec}} \quad Q = 1.69 \, \frac{\text{ft}^3}{\text{sec}} \quad Q_s = 179.24 \, \frac{\text{ft}^3}{\text{min}}
\]

\[
Q = 101.3 \, \frac{\text{ft}^3}{\text{min}}
\]
Component #1: Exhaust Tubing (Diameter = 2 inches)

\[ L := 20 \text{ ft} \quad P_1 = 30 \cdot \text{psi} \quad \text{Temp}_1 = 599.4 \cdot \text{R} \]

\[ D_{\text{tube}} := 2 \text{ in} \quad A_{\text{tube}} := \pi \cdot \frac{D_{\text{tube}}^2}{4} \]

\[ D_{\text{tube}} = 0.17 \cdot \text{ft} \quad A_{\text{tube}} = 0.0218 \cdot \text{ft}^2 \]

\[ A_{\text{tube}} = 3.14 \cdot \text{in}^2 \]

\[ V_{\text{tube}} := \frac{Q}{A_{\text{tube}}} \quad \text{Re} := \frac{\rho \cdot V_{\text{tube}} \cdot D_{\text{tube}}}{\mu} \quad \frac{\varepsilon}{D_{\text{tube}}} := 0.003 \text{ ft} \]

\[ V_{\text{tube}} = 77.4 \cdot \frac{\text{ft}}{\text{sec}} \quad \text{Re} = 1.4 \cdot 10^5 \quad \frac{\varepsilon}{D_{\text{tube}}} = 0.0018 \]

Lookup \( f \) using Moody Chart, \( \text{Re}, \frac{\varepsilon}{D_{\text{tube}}} \ldots \)

\[ f := 0.024 \]

\[ P_2 := P_1 - \frac{\rho \cdot V_{\text{tube}}^2}{2} \left( 1 + f \cdot \frac{L}{D_{\text{tube}}} \right) \]

\[ P_2 = 29.67 \cdot \text{psi} \]

\[ P_{\text{drop}} := P_1 - P_2 \]

\[ P_{\text{drop}} = 0.33 \cdot \text{psi} \]
Component #1: Exhaust Tubing (Diameter = 1 inches)

L := 20 ft \hspace{1cm} P1 = 30 \cdot \text{psi} \hspace{1cm} \text{Temp1} = 599.4 \cdot \text{R}

Dtube := 1 \text{ in} \hspace{1cm} \text{Atube} := \pi \cdot \frac{\text{Dtube}^2}{4}

Dtube = 0.08 \cdot \text{ft} \hspace{1cm} \text{Atube} = 0.0055 \cdot \text{ft}^2
\hspace{1cm} \text{Atube} = 0.79 \cdot \text{in}^2

V_{\text{tube}} := \frac{Q}{\text{Atube}} \hspace{1cm} \text{Re} := \frac{\rho \cdot V_{\text{tube}} \cdot \text{Dtube}}{\mu} \hspace{1cm} \varepsilon := 0.0003 \text{ ft}

V_{\text{tube}} = 309.6 \cdot \frac{\text{ft}}{\text{sec}} \hspace{1cm} \text{Re} = 2.8 \cdot 10^5 \hspace{1cm} \frac{\varepsilon}{\text{Dtube}} = 0.0036

\text{Lookup f using Moody Chart, Re, } \varepsilon/\text{Dtube} \ldots

f := 0.028

P2 := P1 - \frac{\rho \cdot V_{\text{tube}}^2}{2 \cdot \left(1 + f \cdot \frac{L}{\text{Dtube}}\right)} \hspace{1cm} P2 = 19.58 \cdot \text{psi}

P\text{drop} := P1 - P2

P\text{drop} = 10.42 \cdot \text{psi}
SECTION M—REMOTE OPERATED VALVE SPECULATIONS: T.J. GODFROY
Pneumatic Actuators

Features
- Reliable piston design for enhanced cycle life
- Low actuation pressure

Actuator Series
- 6 series actuator for 4U, 6U, and 8U series valves. See the Swagelok Pneumatic Actuators for B and U Series Bellows Valves catalog for more information.
- 8 series actuator for 12U series valves

Actuation Modes
- Normally closed—air opens, spring closes
- Normally open—air closes, spring opens
- Double acting—air opens and closes

Materials of Construction

<table>
<thead>
<tr>
<th>Component</th>
<th>6</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Actuator Series</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Housing</td>
<td>Cast aluminum</td>
<td></td>
</tr>
<tr>
<td>External hardware</td>
<td>Stainless steel</td>
<td></td>
</tr>
<tr>
<td>O-rings</td>
<td>Buna N</td>
<td>Fluorocarbon FKM</td>
</tr>
</tbody>
</table>

Technical Data

<table>
<thead>
<tr>
<th>Valve Series</th>
<th>Actuator Series</th>
<th>Pressure Rating psig (bar)</th>
<th>Temperature Rating °F (°C)</th>
<th>Displacement in³ (cm³)</th>
<th>Weight lb (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4U, 6U, 8U</td>
<td>6</td>
<td>65 to 150 (4.4 to 10.3)</td>
<td>-10 to 300 (-23 to 149)</td>
<td>0.88 (14.4)</td>
<td>C—7.3 (3.3)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>O—4.9 (2.2)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>D—4.8 (2.1)</td>
</tr>
<tr>
<td>12U, 12UA</td>
<td>8</td>
<td>40 to 150 (2.7 to 10.3)</td>
<td></td>
<td>0.68 (11.0)</td>
<td>C—24 (10.9)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>O—13 (5.9)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>D—11.5 (5.2)</td>
</tr>
</tbody>
</table>

Dimensions and Ordering Information
Add an actuator series designator, then an actuation mode designator to the valve ordering number.

Example: SS-4UW-6C

Dimensions, in inches (millimeters), are for reference only and are subject to change.

**6 Series Actuator**

**8 Series Actuator**

<table>
<thead>
<tr>
<th>Valve Series</th>
<th>Actuator Series</th>
<th>Dimensions, in. (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4U</td>
<td>6</td>
<td>A—6.60 (168)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>B—6.76 (172)</td>
</tr>
<tr>
<td>6U, 8U</td>
<td></td>
<td>C</td>
</tr>
<tr>
<td>12U</td>
<td>8</td>
<td>A—10.47 (266)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>B—2.75 (69.9)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>C—1.88 (47.8)</td>
</tr>
<tr>
<td>12UA</td>
<td></td>
<td>A—10.03 (255)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>B—2.56 (65.0)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>C—1.75 (44.5)</td>
</tr>
</tbody>
</table>
Pneumatic Actuator Performance

6 Series Actuator
The minimum actuation pressure for normally closed, normally open, and double-acting actuators is 65 psig (4.4 bar).