Ident.	**Title**	**Doc. Num. and Issue**	**Author**
RD-1	SPIRE Spectrometer Mechanism Subsystem: Fatigue test specifications	SPI.MEC.00.ST.01.1	P. Dargent
RD-2	Smithell's Metals Handbook, 17th Ed.		
RD-3	Space Engineering, Mechanical, Part 3. Mechanisms	ECSS-E-30A, 25 April 2000	
RD-4	http://www.yutopian.com/Yuan/prop/BCopper.html		

Introduction

During the SPIRE CDR, a RID was raised on the project team to assess the validity of life-testing the SMEC at room temperature when it is to be operated at 4K on orbit.

It is argued in RD-1 that conducting life testing of the flex-pivots at room temperature is a more severe test of the fatigue resistance than a test at cryogenic temperature. The basis of the argument is that Young's Modulus (E) increases proportionately less than the Yield Strength (σ_y) as the temperature falls from room temperature to L-He temperature.

Elaborating the argument slightly - for a given mechanism displacement (i.e. flex pivot rotation angle) the stress will be higher at cryogenic temperature because E is higher. However this higher stress would be more than compensated for in terms of fatigue life and crack growth by the fact that σ_y has increased by a proportionately larger fraction.

Comments

In considering the validity of testing at room temperature, the following factors should be taken into account:

1. The blades of the pivots are fabricated from Beryllium Copper. These blades are clamped into a 316L Stainless Steel pivot housing. There will be a CTE mismatch between these two materials giving rise to thermal stresses at cryogenic temperature. These thermal stresses will combine with the displacement stresses. The combined stresses may potentially reduce the fatigue life at cryogenic temperature.
2. Beryllium Copper has a face centred cubic crystal which means that there is no ductile to brittle transition temperature. The following data has been extracted from RD-2. The blades of the flex pivots will almost certainly be Heat Treated and Precipitation hardened. The particular grade of copper probably does not correspond to the grade used in the pivots, so the data should be considered as indicative only.

Test Temperature	Heat Treated	Heat Treated and Precipitation Hardened
20 °C	36%	2.6%
-80°C	38%	0.6%
-180°C	41%	3.0%

Table 1 - Elongation

The increase in the elongation at lower temperatures[1] implies a slower growth rate of any fatigue cracks. This is because there will be more plastic deformation at the crack tip absorbing energy and retarding propagation.

Test Temperature	Heat Treated	Heat Treated and Precipitation Hardened
20 °C	171 MPa	865 MPa
-80°C	201 MPa	1016 MPa
-180°C	344 MPa	1069 MPa

Table 2 - Yield Strength

The increase in the yield strength (24% for the Precipitation hardened material) at cryogenic temperature implies that a greater stress level will be required to cause the crack tip to propagate than at room temperature.

RD-4 gives details of the Yield Strength and Young's Modulus an unspecified grade of Beryllium Copper. It states that the Yield Strength increases by 113% between room temperature and L-He while the Young's Modulus increases by only 6.5%.

Test Temperature	Heat Treated	Heat Treated and Precipitation Hardened
20 °C	55.5 J	2.7 J
-80°C	54.2 J	4.1 J
-180°C	54.2 J	4.1 J

Table 3 - Izod – Impact toughness

The impact toughness does not fall at cryogenic temperatures which would imply that the flex pivot blades will not become brittle at cryogenic temperature.

3. The relevant ECSS standard (RD-3) states the following;

   "4.8.3.3.9 Life test model requirements

   The model and lifetime testing shall be valid with respect to the representation of the following lifetime influencing parameters:

   1. Thermal conditions, loading conditions, contact stress, motion profile and speed during testing appropriately representative of the operational conditions;

   2. Lubrication regime representative of worst cases anticipated operational conditions, and for durations factored as a minimum according to subclause 4.8.3.3.6. Where relevant, extended life durations to be agreed by the customer shall be implemented to satisfy the simulation of realistic conditions during accelerated tests."

   This indicates that the SMEC flex-pivots should be tested at the operating temperature.

4. There are sixteen pivots on the SMEC – all of which are non-redundant single-point failure locations for the Spectrometer side of SPIRE. This would indicate that an extra degree of conservatism should be adopted in their qualification.

[1] Apart from the seeming anomaly of the Precipitation Hardened material at -80°C

5. The BSM has Beryllium Copper pivots (supplied by a different manufacturer and of a different design). These pivots have successfully been life tested at cryogenic temperature.
6. The relative durability of the Aluminium anti-slip bands at cryogenic temperature vs. room temperature is an added uncertainty.

Conclusions/recommendations

It is recognised that the fatigue life of Beryllium Copper under fixed displacement loading is almost certainly higher at cryogenic temperature. The fact that the flex-pivot blades are mounted in a Stainless Steel sleeve means that there will be thermal stresses in the pivots at cryogenic temperature. Although cryogenic life-testing of the SMEC is considerably more complex and costly than ambient testing, it would certainly represent the most conservative approach.

The scheduling of the test needs to be discussed with the Project Team to optimise the instrument development schedule.

Douglas Griffin