Development and evaluation of various design concepts for stress relief brackets of space craft component MUX using CAE tools

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***Abstract*—Design and development of space craft components operating for high power application involve combinations of different materials to satisfy the functionality. Such combinations of different materials are likely to undergo thermal excursions during the operational life. Combinations of different materials with different linear coefficient of thermal expansion "α", when subjected to predominant thermal excursions tend to develop complex thermal stress fields. This in combination with the elastic constraints may be adhesive bonding or bolting connection will call for a structural stress field. The generated stress fields affect the functionality of the component by producing the change in dimensional accuracy. One such space craft component is Multiplexer (MUX) which is an RF (Radio Frequency) filter. This paper deals with identifying the cause and criticality of supporting brackets for multiplexer cavities for thermo structural stress relief. Various modifications in the design of the existing brackets are proposed and evaluated with the help of Finite Element simulations using various CAE tools for the relief of generated thermo structural stresses.**

***Index Terms*-- Thermo structural stresses, Finite Element method, Stress relief design, CAE tools**

I. INTRODUCTION

Use of dissimilar material combination in the space technology when subjected to temperature excursions a thermal stress field is induced within the joint mainly because of the difference in the coefficient of linear thermal expansion "α". This in combination with the elastic constraints may be fastening rivets or bolting connection will call for a structural stress field. Thus the problem becomes now very complex case of the thermo-structural stress fields which gets more complicated when imposed by the constraints like heat transfer, availability of the space, method of production of such components, production difficulties for attaining desired flatness and finally assembly procedure. The induced complex thermo-elastic stress field will cause unwanted deformation which will further affect the functionality of the component. One such space craft component is a Multiplexer (MUX) which is an RF (Radio Frequency) filter. This paper explains the need for the development of the modification of supporting brackets of the component MUX subjected to relieve induced thermo structural stresses during the operation life thus improving functional performance.

II. FUNCTIONAL PERFORMANCE OF MUX

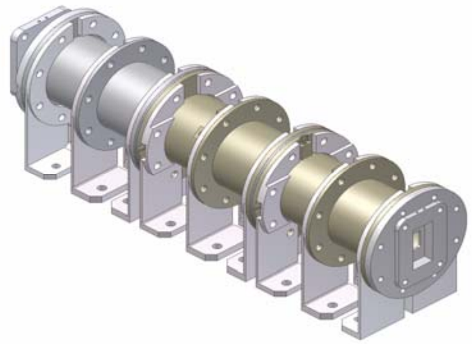

Fig. 1: Single channel of MUX

The function of the multiplexer is to deliver a stable RF frequency over temperature excursions of -40ºC to +120ºC. This frequency depends upon the perfect stable dimension, perfect alignment of central axis, a perfect joint between interfaces without opening joints which may happen due to deformations etc. All these parameter either singly or in combination with each other can affect the end functional performance of the filters by degrading the bandwidth of the filters, losses of filters and offsetting the central frequency.

The input RF energy flows through the input manifold. The input RF energy is distributed through various channels which are basically consists of hollow cavity of inner precise dimensions and iris. The frequency of the RF wave flowing through the channel depends on the volume of the cavity and the dimensions of the iris slots. Every channel of the filter carries particular frequency RF wave and the losses during the filtration of it appears as certain amount of dissipation of heat.

III. CAUSES OF GENERATION OF THERMO STRUCTURAL STRESS AND SELECTION OF COMPONENT FOR MODIFICATION

The RF energy loss dissipates in form of heat during the process of filtration while passing through cavity filter. These in turn raise the temperature of the cavity. Due to raise in the temperature the cavity expands and changes its internal dimensions. To reduce the change in the dimension, the cavity is made of invar which has a linear coefficient of thermal expansion coefficient value about $1.3e^{-6}$ within operating temperature range. This unique property of invar minimizes the expansion and keeps the change in the internal volume of the cavity to the lowest.

Nevertheless Invar material has a drawback. Invar is a bad conductor of heat. So the heat gets accumulated as the filtration process advances. Further to this the satellite operates in outer space (vacuum environment) where the only means of the heat transfer are conduction and radiation only, and in the case of the MUX the heat can be transferred only by means of conduction. So to conduct heat form the cavity to the base plate which is maintained at 60°C, Al Alloy brackets at flanges are provided.

Al alloy (Al 6061 T6) is used because of its good thermal conductivity. Yet, use of aluminum as a thermal sink causes another difficulty. Aluminum has linear coefficient of thermal expansion $23e^{-6}$ and for the purpose of removing accumulated heat from the cavity it comes in the contact with the invar cavity whose linear coefficient of thermal expansion is in order of $1.3e^{-6}$. So contacted mechanically and the difference in the linear coefficient of thermal expansion at the contact is when subjected to temperature excursions cause generation of stresses at joint interface and will cause cavities/iris to deform which affects the performance of filters.

The dimension of the cavity has to be maintained for maintaining its electronic functionality. So the only possible means is to modify the design of the supporting aluminum brackets (cavity filter itself is not considered here as corresponding electrical RF design is to be modified)

The modification in the design of the aluminum brackets includes the design challenge of meeting the imposed thermal and structural constraints. As the main functionality of the aluminum bracket is to form a path of heat transfer for dissipating the heat from cavity to sink. In the existing design of the brackets as shown in the figure 1, the bracket is a full solid bracket which posses the maximum thermal mass for the purpose of transfer of heat. The objective of the bracket as interfacing medium is to extract the heat (forming thermal interface) and at the same time form a supporting medium to withstand environmental loads of launch/ transportation etc. (forming structural interface) and also to de link the cavity from the temperature fluctuation at the base.

IV. BASE LINE DESIGN FOR MODIFICATION

For comparison and the evaluation of various designs of the modified brackets, a base line has to be set. For this, a single invar cavity of existing dimensions with middle flange as shown in the figure 2 has been taken. The flange is supported by pair of rigid brackets for the purpose of maximum heat transfer. The thermal constraints are provided in a way that heat dissipation inside the surface will simulate the condition of loss in the RF energy in terms of heat dissipation. The bases of the brackets are kept at 60ºC which is actually the temperature of the base plate maintained by provisions like heat pipe through out the satellite environment. The thermal analysis is done to find out the temperature distribution after attainment of steady state conduction. The figure shows the base line configurations and the applied thermal constraints in figure 2.

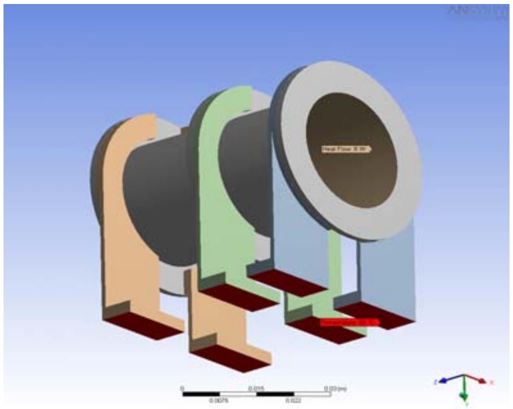

Fig 2.: Baseline configuration

Assumptions

- The heat flow in the channel filter is assumed to be conducted to the base plate.
- The features like holes for the fasteners are neglected in order to facilitate the less time consumption.
- The panel temperature is assumed to be maintained at 60ºC.
- Thermal contact conductance is assumed to be $3000 W/m^{2o}C$

Thermal boundary condition

Dissipation of heat: 8 Watts distributed evenly on the inner surface of the cavity (maximum amount of dissipation in worst case condition)

Temperature: 60º C (on the bases of the brackets)

Temperature result

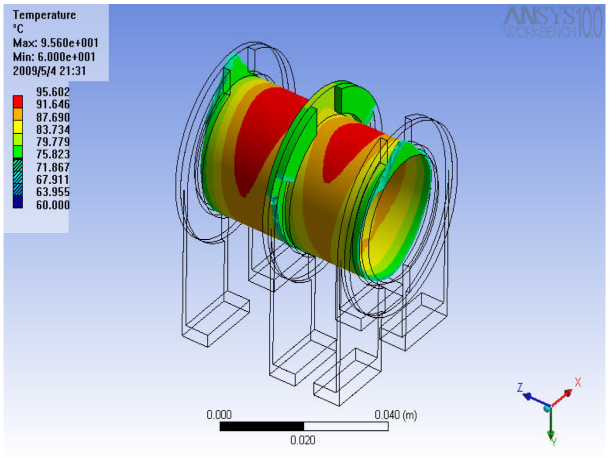

Figure 3.: Temperature profile on cavity

The temperature data are mapped on to the structure to obtain the thermo structural stress profile. Figure 4 shows the deformation profile for the baseline configuration .

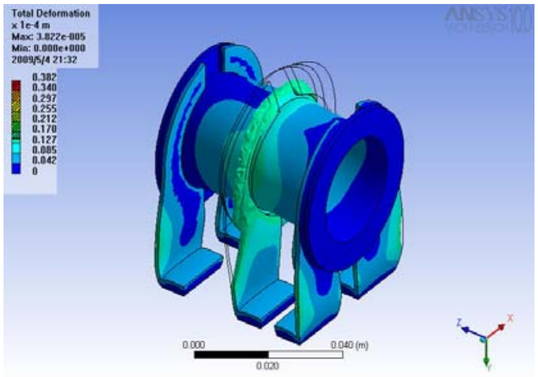

Fig 4.: Deformation profile on cavity

Result summary:
Maximum temperature on cavity: 95.502ºC
Maximum deformation on cavity: 14.1 µ m
Maximum deformation on brackets: 38.2 µ m

1. Design modification 1-Flexible brackets

The concept of reducing the stiffness of the bracket leads to the first modification which is used in the existing assemblies of the Multiplexer. The modification has been done by making the cut outs in the body of the brackets such that the body posses the spring action to give the flexibility in one direction. The second directional flexibility is obtained by providing cutout at the lug bases.

Fig. 5: Flexible brackets

The same thermo structural stress analysis is performed using the same thermal as well as structural boundary conditions that with the baseline design. The result summary for thermo structural stress analysis is as follows.

Result summary:
Maximum temperature on cavity: 106.219ºC
Maximum deformation on cavity: 11.9 µm
Maximum deformation on brackets: 66.4 µm

Advantages:

- Total deformation on the cavity is reduced to 14.9 µ m to 11.9 µ m when compared with the baseline rigid bracket design.
- The total projected foot print area is same as the base line condition
- The cutout in the body of the bracket has reduced the mass of the bracket which will reduce the total mass of the system

Disadvantages:

- The temperature on the cavity has risen to 106.23ºC compared to 95.203ºC of the base line condition. Hence the design shows the loss in the heat transfer capacity
- The raise in the temperature will cause to raise the total deformation of the whole system.

2. Design modification 2- θ brackets

By offsetting the line of application of load from the base will cause the flexure of deformation to move away from the body of the bracket. This will result in the increasing the flexibility of the brackets. The assembly of brackets and cavity with the angled legs are shown in the figure 6. Here the configuration of the angled leg bracket shown for the thermo structural analysis is the out come of the parametric optimization done to find out the suitable parameters of design of bracket which satisfies the maximum condition of optimizations.

Fig. 6: θ brackets

The same thermo structural analysis is done to obtain the various temperature and stress profiles with same thermal and structural boundary conditions

Result summary:
Maximum temperature on cavity: 92.76ºC
Maximum deformation on cavity: 9.06 μ m
Maximum deformation on brackets:41.2 μ m

Advantages:

- Total deformation on the cavity is reduced to 14.9 μ m to 9.06 μ m when compared with the reference rigid bracket design.
- The maximum temperature on the system is 92.76 ºC which is even less than the temperature on the system with rigid brackets.

Disadvantages:

- The design modification has been done in such a way that the total foot print area of the bracket has increased compared to the reference condition. This will affect the design of the base plate and probably will increase its size which will result in to the increase in the total weight of the system
- The thickness of the bracket is 2 mm and the material is distributed maintaining the same thickness throughout the body of the bracket. This will increase the mass of the bracket and finally the total mass of the system.

3. Design modification 3-C brackets

The another mean to introduce the same feature of the moving the flexure point away from the body of the bracket is to modify the body in to the curved shape instead of making the legs of the bracket angled with the main body. Different shapes of the curved brackets are evaluated with the help of thermo structural FE analysis and the best suitable design of the brackets with assemblies is as shown in figure 7. The main motive behind this modification is to keep the foot print area as same as the reference design to save the space and the take the advantage of the bend in the curved portion of the bracket. The bend portion in the bracket itself will act as a medium to transfer the flexure point away from the body of the bracket. The finalized design of bracket is as shown in figure 7

Fig. 7 C brackets

The thermo structural simulation results are as shown below

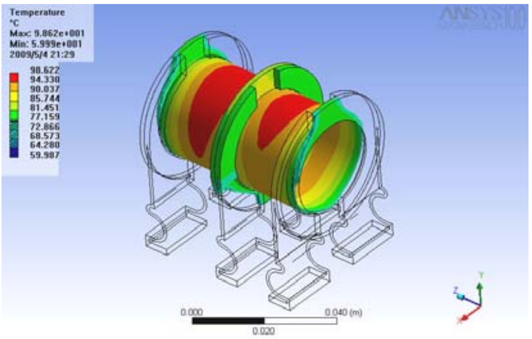

Fig. 8: Temperature profile on cavity

Properties	Invar	Aluminum
Young's modulus (GPa)	141.3	68.3
Poisson's ratio	0.23	0.3
Density (Kg/m3)	8100	2700
Coefficient of thermal expansion (/ºc)	1.6e-6	23e-6
Thermal conductivity (W/mºc)	10.5	220

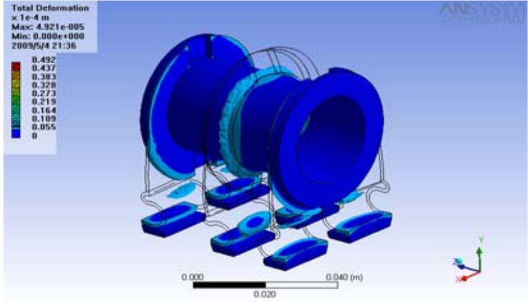

Fig 9.: Deformation profile on cavity

Result summary:
Maximum temperature on cavity: 98.62ºC
Maximum deformation on cavity: 6.89 μ m
Maximum deformation on brackets:49.2 μ m

Advantages:

- Total deformation on the cavity is reduced to 14.9 μ m to 6.89 μ m when compared with the reference solid bracket design.
- The maximum temperature on the system is 98.62 ºC which is even greater than condition with reference condition but still the deformation on the cavity is less compared with the previous design modification.
- The total foot print area is same as that of the design of reference condition

V. RESULT COMPARISION

	Maximum deformation on cavity (μ m)	% reduction in maximum deformation compared to baseline condition
Base line condition	14.9	-
Flexible brackets	11.9	**20.13%**
θ brackets	9.06	**39.19%**
C brackets	6.89	**53.27%**

VI. CONCLUSION

Various modifications in the design of the MUX bracket has been studied and compared using CAE tools from the view point of advantages obtained like improvement of heat transfer, reduction in maximum deformation on the cavity due to thermo structural stresses and space consumed. The final result comparision shows that by replacing the existing brackets with conceptual C brackets, the deformation on the cavity reduced upto 53.27% which shows that the assembly can be made relatively relieved from generated thermo structural stresses.

VII. APPENDIX

Physical properties of Invar and Aluminum

VIII. ACKNOWLEDGEMENT

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