A Study on the Conic Support in the Radiant Cooler

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We have investigated the conic support in the radiant cooler by using finite element method. Results show that the stiffness of the support increases with an increasing of the coning angle in case of launched state, while the situation is reversed in the orbited state. On the other hand, it is also found that the heat loss of the support caused by the thermal conduction decreases with the reduction of the coning angle. Moreover, the optimized coning angle is provided as a function of the length.

INTRUDUCTION

The cryogenic cooler plays an important role in the infrared remote sensing technology. Up to now, the cryogenic cooler widely used in space mainly includes the radiant cooler and the Stirling cooler. Note that the radiant cooler, emitting heat to space to reach the low temperature, has attracted considerable interests, because it exhibits higher stability, long life, no consuming power, no electromagnetic radiation and no moving parts etc.

In the past forty years, several structures of the radiant cooler have been developed, which include W-shaped, L-shaped, conic style and parabolic style [1]. No matter what structure of the radiant cooler is, it is usually organized as the cooler house, the first stage radiator, the second stage radiator and the structural support [2]. Among these the structural support is the crucial mechanical element, which connects the cooler house with the first stage radiator and brings the first stage radiator and the second radiator together. As a result, it should has the excellent rigidity to meet the demands of mechanics. Meanwhile the heat loss of the structural support, results from the temperature difference of the different side, must be as little as possible for insuring the refrigerating capacity of the radiant cooler.

With the development of the cryogenic technology, the radiant cooler should provide lower temperature and more refrigerating output, which certainly will lead to the size of the radiant cooler become larger. Additionally, the stability of the support can be determined by several factors, like its size and shape etc. In order to better develop the radiant cooler along with the infrared remote sensing technology, a detailed consideration for the support is required. In this contribution, we have investigated a conic support that widely used in the radiant cooler by using finite element method. We present a path to improve the performance of the conic support by optimizing its coning angle and height, which can amend the tradeoff between the mechanical stiffness and the heat loss caused by the thermal conduction.

METHOD

All considerations presented below were performed by finite element method (FEM). The FEM is a numerical technique for solving problems, which are described by partial differential equations or can be formulated as functional minimization. A domain of interest is repented as an assembly of finite elements. Approximating functions in finite elements are determined in terms of nodal values of physical field, which is sought. A continuous physical problem is transformed into a discretized finite element problem with certain nodal values [3]. It is one of the most important methods to solve the continuous medium problem and it can adapt to the complex terminal condition. FEM has been widely used in many kinds of fields, like mechanics, thermodynamics and electromagnetic etc.

Here, a short summary of the calculational conditions is given. Figure 1 displays a sketch of the prototypical conic support considered, which is made from the titanium alloy. In Figure 1, α is the coning angle; T is the thickness of the support, given as 0.0005m; ϕ_1 is the upper diameter of the support, given as 0.02m; L is the length of the support varied from 0.05m to 0.08m; ϕ_3 is the bottom inner diameter of the support ranged from 0.025m to 0.05m, which aims to change the coning angle of the support. The magnitude of ϕ_2 is expressed as $\phi_3 + 0.01$m. The thickness of the upper and the bottom are fixed at a constant (0.001m).

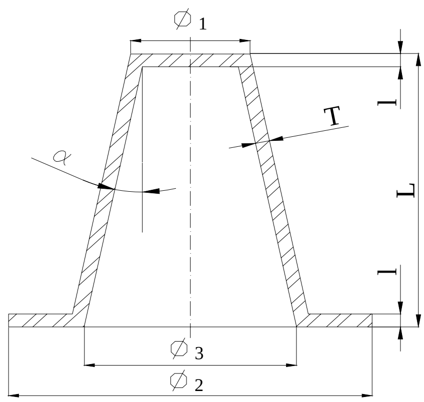

Figure 1 Scheme of the Conic Support

Other necessary parameters are also given. The coefficient of the thermal conductivity is 4.5W/mK, Young's modulus is 100GPa, the thermal expansion coefficient is 1.5e-5K^{-1} and Poisson's ratio is 0.3. Since the temperature-dependence (from 100K to 150K) of the parameters can be neglected, they are adapted as constants for simplifying the computation.

The heat loss of the conic support has two sources. One is the radiant heat loss, which is very little and can be neglected for the conic support locates within the radiant cooler; the other is the heat loss caused by the thermal conduction, which can be written as the following,

$$q = \frac{(\phi_2 - \phi_1)\lambda T \pi}{L \ln\left(\phi_2 / \phi_1 \right)} (T_2 - T_1) \tag{1}$$

where λ is the coefficient of thermal conductivity, T_1 is the temperature of the upper surface of the support, T_2 is the temperature of the bottom surface of the support, T, L, ϕ_1 and ϕ_2 are defined above.

In calculations, two kinds of load are considered in order to simulate the support under different load. One is the load in launched state (replaced by LL) with the pressure 1.25e6Pa and the shear force 3.56N applied to the upper surface of the support; the other is the load in orbited state (replaced by LO) with the temperature 100K and 150K applied to upper and bottom surface of the support, respectively. The bottom surface of the support is restrained under both LL and LO.

Based on the information mentioned above, the solid model is established firstly, and then is meshed to get the discretized equations, which are solved by a computer.

RESULTS AND DISCUSSION

As a starting point in the analysis of the conic support, we study the interrelation between its coning angle and its corresponding stiffness. It is well known that the stiffness can be reduced by its maximal deformation (MD). In generally, the smaller the MD is, the better its corresponding stiffness is. Figure 2 shows the MD of the conic support under the LL as a function of the coning angle. It is clear that the MD for all cases decreases with the increasing of the coning angle, whereas the condition is reversed for the MD under the LO, as shown in Figure 3. For a certain coning angle, the larger the length (L) is, the greater the MD is, which is similar to Figure 3. It’s suggested that a rather short conic support with a larger coning angle is required under the LL, while a shorter conic support with a smaller coning angle is more suitable to the LO.

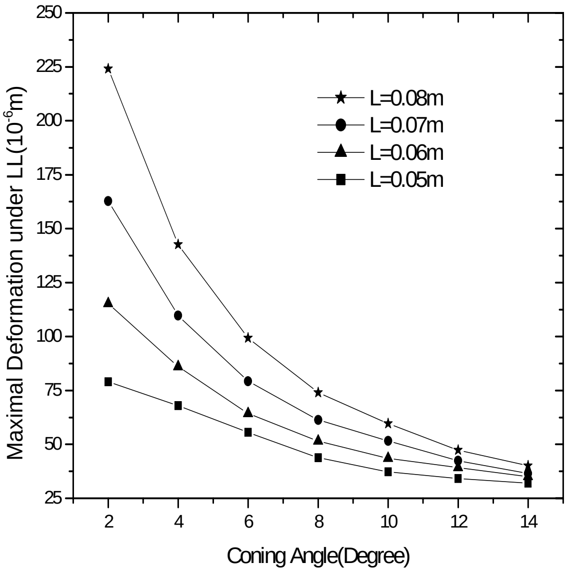

Figure 2 The MD under LL as a function of the coning angle with various length

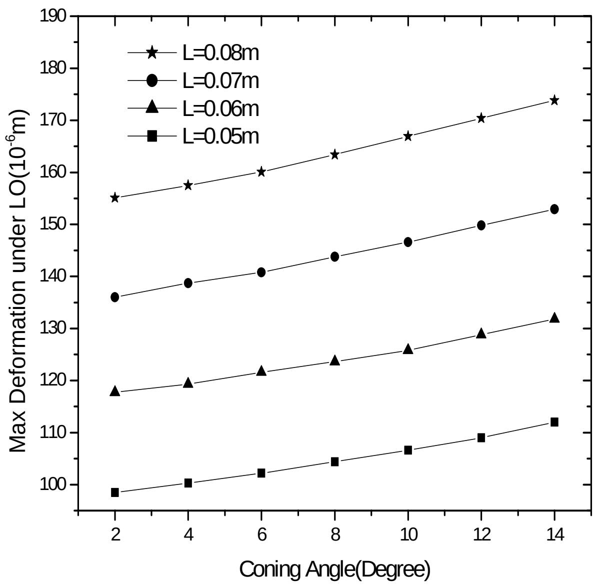

Figure 3 The MD under LO as a function of the coning angle with various length

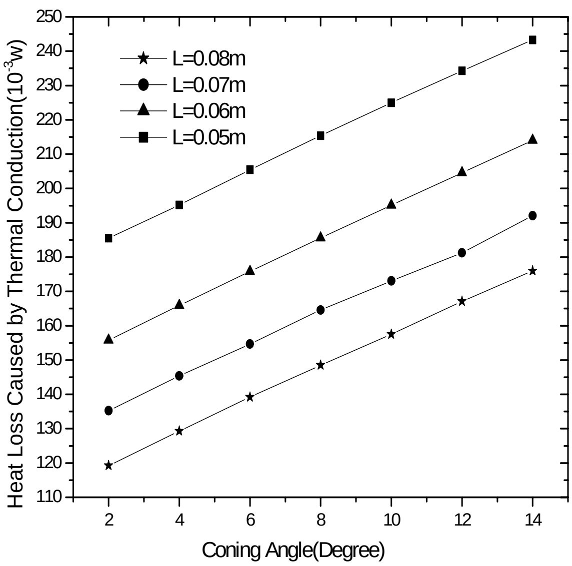

Figure 4 The heat loss caused by the thermal conduction as a function of the coning angle with various length

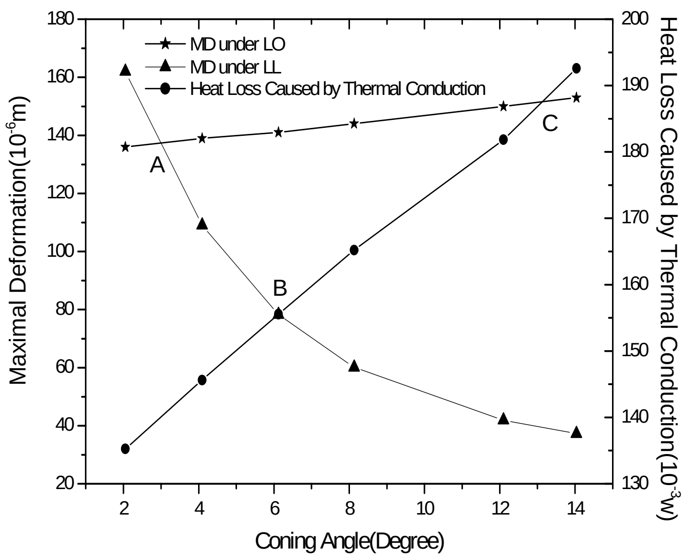

Figure 5 Comparison of MD under LL and LO and the heat loss caused by the thermal conduction as a function of the coning angle with the length being0.07m

Next we focus on the heat loss caused by the thermal conduction. Figure 4 predicts the heat loss caused by the thermal conduction as a function of the coning angle. We found that the heat loss caused by the thermal conduction rises mono-linearly with the increasing of the coning angle. The heat loss caused by the thermal conduction decreases with the length increasing at the same coning degree. Hence, to depress the heat loss caused by the thermal conduction, it is necessary to adopt a way that lengthens the conic support and reduces the coning angle.

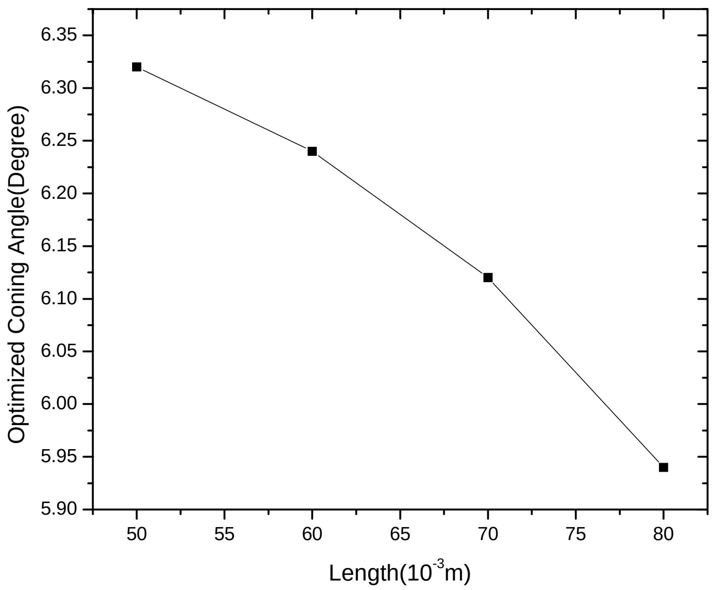

Figure 6 The optimized coning angle as a function of length

However, there is a tradeoff among above obtained results. Taking the length of the conic support being 0.07m for instance, as shown in Figure 5. In Figure 5, it seems that there is no a certain coning angle that can fulfill the requirements of both mechanical and thermal performance at the same time. But note that the MD difference between point A and point C is very small, we can conclude that point B is an approximatively optimized value for the coning degree. According to this, taking varied length into account, an optimized coning angle as a function of the length can be obtained, as shown in Figure 6.

CONCLUSION

In summary, based on finite element method, we have studied the conic support in the radiant cooler. By optimizing the coning angle and the length of the support, we can amend the tradeoff between its mechanical and thermal performance, which presents a possible pass to better develop the radiant cooler.

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