Accelerating Life Test Design on Solid Lubrication of the Bearing Used in the Space

Dong Shu, Zhu Wei, Zhao Wan
China Astronautics Standards Institute
Beijing, 100071, PRC

Abstract—Solid lubrication is widely used in the space mechanical moving components, which are the important parts of spacecrafts or scanning earth sensors. In order to study the failure mode of solid lubricant and evaluate the mechanical system reliability, the Accelerated Life Test (ALT) is developed to accelerate failure by increasing the test stress. An example is given to explain how to do ALT design in this paper. The feasibility, the principle and methods of the ALT for the space mechanical moving components using solid lubricant were discussed. It is pointed out that selecting rotation speed as the accelerating stress of ALT is feasible when using solid lubricant.

Keywords- solid lubrication; accelerated life test; bearing

I. INTRODUCTION

For mechanical system with long life and high reliability, the reliability of bearing is fundamental to life and reliability of the system. Bearing is widely used on satellite, however, it is hard to back up due to various limitations. Thus it will cause single-point failure if the bearing breaks down. With the improving life and reliability experimentations of satellite, it demands more on life of bearing products. Thus, how to evaluate and validate bearing are key issues to be solved. Generally speaking, for long life solid lubrication bearing, we can take 1:1 life test and calculate through its track, which consumes a lot of money and time and is also inapplicable to validate a bearing with very long life requirement. Thus ALT is used to shorten the test cycle and reduce test cost. The paper is to study the ALT design methods and a new approach to be proposed to validate the life of bearing.

II. THE ISSUES TO BE SOLVED

With the increasingly high requirement of bearing, the working environment of bearing is more and more demanding, i.e. low temperature(LT) under -150°C and vacuum degree above 10^-9 Pa, in which traditional grease lubrication bearing cannot be used under this environment but only solid lubrication. Besides, the grease vapor should be kept off optical imaging device on satellite. Thus, solid lubrication bearing is the best substitute. This paper will introduce effects of space environment to solid lubrication bearing and the producing process and failure mode of solid lubrication bearing.

A. Space Vacuum Environment and Its Effects

Space vacuum environment is very special and can affect the life of bearing in the following aspects:

(a) Vacuum environment
   • Under vacuum environment, life of bearings decreases for high vaporizing and loss of grease, while the wear of solid lubrication is much less than in the general environment.
   • Under vacuum environment, absorption film &oxidation film are not easy to form on the friction surface of bearing, while in LT environment, cold welding generates frequently and thus wear of the bearing expands.
   • Under vacuum environment, air-out effect and quality losing effect will decrease the performance of non-metal material and cause early failure of rolling bearing.

(b) Microgravity environment
Under microgravity environment, load and dead weight of bearing decrease dramatically which extend life of solid lubrication material. Therefore, load factor is not considered in ALT of bearings used in space.

(c) High and low temperature shift environment
In space, temperature of satellite surface exposure to the sun can achieve 100°C to 200°C, while temperature of the other surface -100°C to -200°C. This shift of temperature will affect the life of bearing as follows:
   • Grease is consumed rapidly in high temperature and its performance decreases in low temperature., while solid lubrication is applicable in wider temperature range
   • Shift between high and low temperature will probably cause different thermal dilation on inner and outer of bearings, result in stalls of bearings.
   • High and low temperature shift may damage the bearing itself.

(d) Space radiation and elemental oxygen environment
As there are radiations and elemental oxygen environment in the Space, the performance of rolling bearing and grease lubricant will retrogress at different degrees. Generally, solid lubrication has stronger radio resistance, while its lubricity will be reduced, which greatly affect the life of bearing.

978-1-4244-4905-7/09/$25.00©2009 IEEE
B. Introduction of solid lubrication bearings

36018 solid lubrication bearings are widely used in many satellite models characterized with large batch, high-quality requirement, long life and high test cost, etc. The production process is displayed in the figure 1.

![Production process of bearings](image)

**Figure 1. Production process of bearings**

C. Failure modes analysis on bearings

Failure mode is the main mode for product failures. There are several possible failures modes of bearings may occur on satellite orbit.

<table>
<thead>
<tr>
<th>NO.</th>
<th>Failure Mode</th>
<th>Phenomena</th>
<th>Cause</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>High friction drag</td>
<td>rolling imbalance, precision debase stalls</td>
<td>Lubrication failed, improper assemblage deforming</td>
</tr>
<tr>
<td>2</td>
<td>Wear</td>
<td>friction moment, increase, rolling imbalance, precision debase</td>
<td>Lubrication failed, improper assemblage, deforming cold weld</td>
</tr>
<tr>
<td>3</td>
<td>Holder failed</td>
<td>friction moment, increase, noise increase, rolling imbalance, precision debase</td>
<td>Lubrication failed, improper design</td>
</tr>
<tr>
<td>4</td>
<td>Bearing locked</td>
<td>Abnormal rolling</td>
<td>Lubrication failed, improper assemblage, deforming cold weld</td>
</tr>
<tr>
<td>5</td>
<td>Fatigue</td>
<td>vibration noise</td>
<td>Temperature stress, Lubrication failed, improper assemblage</td>
</tr>
</tbody>
</table>

III. TEST DESIGN ANALYSIS

According to the usual process and index of 36018 solid lubrication bearings, we design the test as follows:

A. Choosing test stresses and test environment

Accelerate efficiency is correlated with stress. The test stress should be chosen in accordance with failure mode and failed mechanism. For bearings, as is shown in Chart 1, causes for failure modes vary greatly. Here we will analyze the main failure modes of bearings.

Rotation speed and load, as well as the temperature are the main stresses for bearings. We consider the following factors:

- Gravitation affects less, so the factor of load is ignored in this test.
- Overload may induce failure mechanism change (mainly wear failure on lubricant layer).
- Precision of load in the test is bad with errors often reaching ±50%.
- The effect of load is dispersing.
- Solid lubrication bearing has high thermal stability.
- Failure modes of long life bearing which used in space are mainly lubrication failure caused by lubrication wear.

Based on above analysis, temperature and load are not controlled; it’s under vacuum environment and rotating speed is the only stress used in this test.

A. Choosing life distribution and accelerating equation

Life of bearings is always hypothetically subject to Weibull distribution, and its equation is:

\[ F(t) = 1 - \exp\left(-\left(\frac{t}{\eta}\right)^m\right) \quad t > 0 \]

Here, \( m \) —— Shape parameter
\( \eta \) —— Character parameter
\( t \) —— Life

Now we analyze the wear of lubrication film. At the beginning the MoS\(_2\) film works and wears, subsequently the transferring lubrication film works. The expression of lubrication film is:

\[ \delta = \delta_0 - \frac{W_r}{A} + \frac{W_{br}}{A} - \frac{W_{off}}{A} \]

Here, \( \delta_0 \) —— MoS\(_2\) thickness
\( W_r \) —— MoS\(_2\) Capacity
\( W_{br} \) —— Transfer lubrication film capacity
\( W_{off} \) —— Transfer lubrication film capacity consumed
\( A \) —— Surface area
\( W_{cb} \) —— Transfer lubrication film capacity transferred
Failed Mode of bearings is:

\[ T = k_1 p_0^{-k_2} \omega^{-k_3} \]

Here, \( T \) —— Life of bearings
\( p_0 \) —— Contact stress
\( \omega \) —— Rotating speed
\( k_1, k_2, k_3 > 0 \) —— Undetermined coefficient

With a changeless \( p_0 \), life of bearings decided by \( \omega \) as follows:

\[ T = K \omega^{-k_3} \]

Here, \( K, k_3 \) —— Undetermined coefficient

From the above, we can find that failure mode of bearings subjects to the inverse power model. The accelerating equation is as follows:

\[ \ln \eta = a + b \ln \omega \]

Here, \( a, b \) —— Undetermined coefficient

B. Choosing level

This paper discusses constant stress ALT, and all samples are tested in the 3 stress levels as follows:

- Choosing low stress level

  Low stress level \( N_i \) should be close to normal stress level \( N_0 \), but higher than \( N_0 \), and there should be some failure modes on this level.

- Choosing high stress level

  As the stress level is higher, the time to fail is shorter. But the stress level should be lower than max rotating speed the bearings can endure. High rotating speed may conduct the change of failure mode. So high stress level \( N_i \) should insure the failure mode does not change.

- Choosing intermediate stress level

  As the higher and lower stress levels are chosen, the intermediate stress level should be chosen with appropriate disparity. It can be chosen as follows:

\[ \ln N_i = \ln N_i + (i - 1) \frac{\ln N_N - \ln N_i}{k - 1} \quad (i = 2, \ldots, k - 1) \]

C. Choosing sample

Bearsings used in the test should be chosen from the same batch, and pass performance test. As the cost of bearings is high, and vacuum test is costly, the sample size has to be restricted. According to the requirement of data evaluation, stress levels should be higher than 2, and there should be at least 4 units in each stress level.

D. Choosing test parameters, failure criteria and termination condition

- Test parameters
  - Friction moment
  - Lubrication layer thickness
- Failure criteria
  - Friction moment increase to certain level
  - Termination condition

Reach the required test time or all samples failed.

E. Failure analysis

After the test, causes for the test failure should be analyzed for the benefit of design and production.

IV. CONCLUSION

The ALT design of high reliable, long life space production is still at study stage. Besides, there are several issues should be studied now.

REFERENCES

[3] Todd MJ; Modelling of Ball Bearings in Space Craft; Tribology International;1990, 23(2)
[5] Mike Silverman, QualMark Corporation, Santa Clara ARTC Division Why Halt Cannot Produce A Meaningful Mtbf Number And Why This Should Not Be A Concern.