Study on Unlocking Failure Mode for Mechanical Gyroscope in Spacecraft

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Abstract. Mechanical gyroscope is a single-degree-of-freedom gyroscope used to measure the angular velocity of the carrier. In this paper, in accordance with the problem in the process of producing, based on the analysis of factors that influence the gyroscope’s assembly & debugging precision, through the experiment and analysis, the cause of in the process of producing is found, the technique to solving the problem is presented. The problem of unable to unlock normally is solved. This technique can be used in the producing of gyroscope and can increase passing rate of mechanical gyroscope. The experimentations result indicate that the scheme is in reason. The efficiency of gyroscope assembly is greatly enhanced.

1. Introduction

Mechanical gyroscope is a single-degree-of-freedom gyroscope used to measure the angular velocity of the carrier. The Mechanical gyroscope is mainly composed of gyro motor, a locking mechanism, a float assembly, a housing assembly, an angle sensor, a permanent magnet torque device, etc. The appearance of a gyroscope is shown in Figure 1. The system block diagram of mechanical gyroscope in spacecraft is shown in Figure 2.

![Figure 1. Schematic diagram of rate integration gyroscope](image-url)
Figure 2. Block diagram of gyroscope

The locking mechanism is the core component of the gyroscope, and its performance determines the accuracy of the gyroscope. Unlocking accuracy is the main indicator for measuring the gyroscope. The stability of the working performance of the locking mechanism is directly related to the reliability and service life of the gyroscope.

During the production process, the launch site and the spacecraft flight, this index must be tested to determine the stability of the locking mechanism and confirm the normality of the mechanical gyroscope function. It must be tested during the production process, launch site and spacecraft flight to determine the stability of the motor and confirm the normality of the rate gyroscope function [1]. As shown in Figure 3, it is a schematic diagram of working principle of locking mechanism

Figure 3. Working principle of locking mechanism

During the overall commissioning phase, this type of gyroscope has repeatedly failed to pass inspection and cannot be successfully delivered [2].

Aiming at this problem, through theoretical analysis and a large number of experiments, a set of process methods capable of improving unlocking reliability during the production process have been developed to ensure the quality and reliability of the product.

2. The problem of unlocking

According to the product structure, the assembly process structure and process flow are divided, and the workload of the assembly unit is evenly distributed by taking workload of each unit into consideration [3].

When a gyroscope performs a lock accuracy check outside the factory, the lock is not unlocked properly. Repeated 7 times, 5 of which were unlocked and 2 unlocked normally.

By analyzing the open-close loop of the product, the problem fault tree can be obtained as shown in Figure 4.
3. Failure mode analysis

As shown in Figure 5, it is a schematic diagram of the unlocking operation of the locking mechanism. Under fault tree in Figure 4, unlock failure mode includes four aspects. Contact reed and contact subassembly are used in kinds of mechanical inertial apparatus, and they are is the media between electric signal and mechanical movement. The gyroscope performs lid opening inspection. It focuses on checking the contact gap of the contact components of the program mechanism.

**Figure 4.** The fault tree of the problem of unlocking

**Figure 5.** Schematic of unlocking work of locking mechanism

1) **Power is not applied**

When opening and closing the gyroscope and performing the open-close test, according to the on-site video records, it was clearly observed that the electromagnet has a pull-in action, which proves that the power of the locking mechanism is turned on, and this failure mode can be eliminated.

2) **Unlocking resistance increases**
This model can be divided into the following two factors:

First, Stuck and increased friction of the locking structure: Open the gyroscope cover and observe the state of pulling when the lock is unlocked. The moving parts are flexible, and no stuck phenomenon is found. Further inspection of the gyroscope with a magnifying glass, no extras were found, and it also proved that there were no stuck and increased friction problems in the lock structure, and this failure mode could be eliminated.

Second, the spring tension is increased: using a digital spring scale, the test spring tension is 1.75Kg, which meets the design technical requirements of 0.8Kg to 1.96Kg. According to the characteristics of the spring, during use, the spring force can only be gradually reduced, and will not be increased. This failure mode can be eliminated.

3) Small electromagnet suction

Re-test the resistance of the electromagnet winding coil I, which is 4.1Ω, and the design requirement is 4.1Ω ± 10%, which meets the requirements;

Re-test the resistance of the electromagnet winding coil II, which is 80Ω, and the design requirement is 80Ω ± 10%, which meets the requirements;

The re-testing of the electromagnet's suction force was 8 Kg, and the technical requirements were 6 Kg to 12 Kg, which met the requirements.

These parameters are within the range specified by the technical conditions, which proves that the electromagnet can work normally, and this failure mode can be eliminated.

4) Contact component abnormal

Observation and testing of the contact group found that:

① Contact component surface: ①② There are indentations on the reeds, and there is deformation, and there is ablation on the contacts.

② Due to pressure injury, the pressure of the normally closed contact is 14g, which is significantly less than the specified value of 20 to 30g.

③ The distance between normally open contacts is 0.35mm, which is less than the specified value of 0.5 + 0.1mm.

It can be seen that this contact assembly has not met the technical requirements. Replace the new contact assembly, and then perform the unlocking test. It is found that the unlocking is normal. Therefore, this failure mode cannot be ruled out, so it is thought that the reason that the gyroscope is unlocked abnormally is that the contact component is abnormal.

4. Unlocking work process

When the gyro coil is not powered, the contact reeds ② and ③ form a normally closed contact. When the switch K is closed, the electromagnet coil I works, which generates electromagnetic suction and overcomes the tension of the spring to drive the rocker arm to perform the unlocking action. At this time, the linkage push rod also moves with it. After a certain distance (that is, the distance between the top of the linkage push rod and the contact reed ②), the reed ② is pushed out of the reed ③.

At this time, the solenoid coil II is added to the circuit. The coils I and II work at the same time, so that even if the holding circuit produces a suction force greater than the elastic restoring force, and while ensuring the unlocking, the working current of the coil is also reduced. The linkage push rod pushes the reed ② and then passes a certain distance (the distance between the reeds ② and ①) until the reeds ② and ① are closed, so that the unlocking indicator light is connected to the circuit, the unlocking light is on, and the unlocking process is completed[5].

As shown in Figure 6, the moment when the push rod opens the normally closed contact ② in the unlocking action, it is the switching point of the suction characteristic of the electromagnet. By adjusting the position of the contact assembly relative to the push rod, it is ensured that the switching point is above point b in the figure, so as to ensure that the electromagnetic suction force is greater than the elastic restoring force, and the lock can be unlocked.

At point a, \( F_m > f \) the lock can be unlocked normally.
At point b, $F_m = f$, the unlocking mechanism oscillates, and the contact assembly will generate sparks and ablate the contacts.

At point c, $F_m < f$, cannot be unlocked.

Figure 6. Schematic diagram of electromagnetic suction and spring restoring force

5. Analysis of causes
From the analysis of raw materials, the material of the contact reed is tin bronze. When the parts are processed, they have been heat treated and the elastic properties have reached the requirements. Judging from the retesting of the gyroscope contact assembly, the appearance of the contact assembly was flawed, and both the contact pressure and the distance between the contacts changed: the measured contact pressure was 14g and the distance was 0.35mm. It is thought that the contact damaged the reed during the assembly process. Although the contact assembly met the requirements of contact pressure and spacing at that time, it could be unlocked after adjustment on the instrument base.

Large internal stress, as the stress is released, the reed will produce a large amount of deformation and rebound, which causes the adjusted relative position and the contact pressure of the reed to change (becomes smaller), resulting in the shown in Figure 6. The switching points of $\alpha$ and $\beta$ are advanced, and the electromagnetic suction is not enough to overcome the spring tension and cannot be unlocked[6].

When the amount of elastic jitter is close to or greater than the gap between two contacts, multi-pulse phenomenon will occur. When the amount of elastic jitter is less than the gap between the two contacts, there will be no sudden occurrence of two contacts, that is, no multi-pulse. Although the elastic vibration of the reed cannot be controlled, the contact gap between the two contacts can be prefabricated.

From the analysis of the manufacturing process, during the locking assembly, due to the pollution of the formula glue during the curing process, the local glue solution cannot be cured, which caused the partially incompletely cured glue solution in the mechanism to precipitate out of the gap when it was working on the instrument, and it was covered in a thin film[7]. On the outer circle of the locking mechanism, thereby preventing the contact between the brush and the conductive ring. When there is an excess on the locking mechanism, the contact between the corresponding brush wire and the brush will be affected, resulting in poor contact and increased contact resistance. The contact resistance increases, sparks occur between the contacts, which accelerates the ablation of the contacts, further worsening the working state of the contacts, and eventually leading to unlock failure.

6. Application effects
Based on the experimental analysis conclusions, combined with the actual situation of production, the following measure are proposed: Before the meter is assembled with the contact assembly, check the appearance of the contact assembly with a magnifying glass, and re-measure the contact pressure and
contact gap to ensure that there are no abnormalities. After the meter is assembled with the contact assembly, check the appearance of the contact assembly again with a magnifier to ensure that it meets the technical requirements.

After taking measures, practical test shows the gyro meter inside and outside the plant did not have similar problems.

After adopting the above-mentioned technological measures, stricter process management and quality control have been carried out in each stage of production and use of contact reeds, which strictly guarantees and improves the pass rate of mechanical gyroscope.

7. Conclusion
Aiming at the actual problems in the generation process of the mechanical gyroscope, through theoretical analysis and experimental research, the mode that caused the failure of the unlocking mechanism was found, and a clear, effective and feasible process improvement measure was formulated to avoid similar problems fundamentally Recurrence.

This technique can be used in the producing of gyroscope and can increase passing rate of unlocking normally. The experimentations result indicate that the scheme is in reason. The efficiency of gyroscope assembly is greatly enhanced.

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