Research on the Fast Reset Time of Safety Rod and Implementation

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Abstract. The fast reset time of the safety rod is one of the important parameters for the drive design of space nuclear reactor. In the paper, it analyses the structure, operation process, and fast reset process of the safety rod system, and proposes a measuring method that measures the change of the angular displacement sensor in the drive mechanism during the fast reset process of the safety rod assembly to get the fast reset time of the safety rod. The ground engineering prototype of the safety rod was used to verify the measuring method, by real test environments, such as real high temperature, earthquake. The test results show that the measuring method of the fast reset time is effective on the safety rod, and provides a test basis for the research on the drive design of the safety rod system of the space nuclear reactor.

1. Introduction
The safety rod system is one of the important equipment of the space nuclear reactor. When the reactor is running, the safety rod assembly is pulled out of the core to run to the highest position and maintained. In the case of reactor shutdown normally or accident, the safety rod assembly is released and quickly inserted into the reactor core under the action of the spring acceleration device, to achieve emergency reactor shutdown, and protect the safety of the reactor. The fast reset time of the safety rod is an important parameter of the safe shutdown of a space nuclear reactor, and the fast reset time needs to be measured.

At present, there are very few public research data on the fast shutdown of space nuclear reactor safety rods. In the paper, according to the structural characteristics, operation process, and rapid reset process of the space nuclear reactor safety rod system, it proposes a measuring method that measures the change of the angular displacement sensor during the quick reset process of the safety rod, to verify the design of the space nuclear reactor safety rod system for fast shutdown. The design of fast reset time measurement method is verified under the real test environment such as normal temperature, high temperature and earthquake.

2. Introduction of the safety rod system
The working environment of the safety rod system for the ground nuclear reactors needs to consider the influence of gravity, which is different from nuclear reactors in space. The engineering prototype of safety rod system which is participating in the ground test is completely designed and manufactured according to the real size of the space nuclear reactor safety rod system, in order to verify whether the design and performance of the safety rod system of the space nuclear reactor meet the safety management requirements of the nuclear field.
The safety rod system is mainly composed of a drive mechanism, a transmission mechanism, a distribution mechanism, a safety rod assembly and a locking mechanism, etc. The structure of the safety rod system, as shown in Figure 1.

The driving mechanism is mainly composed of motor, clutch, electromagnetic lock, gear, spring and angular displacement sensor, etc. The drive mechanism drives the motor to rotate, which is transmitted to the transmission mechanism through the pull-in of the clutch. The transmission mechanism drives the safety rod assembly out of the core to move straight up through the rack engagement of the distribution mechanism. During the movement of the safety rod assembly, the spring in the drive mechanism is compressed with the rack bar moving. When the safety rod assembly reaches the highest position, the rack bar is locked by the electromagnetic latch in the drive mechanism, and the clutch in the drive mechanism is powered off, and the safety rod assembly is kept at the highest position. When the safety rod system needs to shut down the reactor, the electromagnetic card lock in the drive mechanism is powered off, and the compressed spring is released instantly. Under the reaction force of the spring, the output shaft of the drive mechanism is quickly reversed, the rack bar is quickly released, and the safety rod assembly is quickly inserted into the core to achieve emergency shutdown.

During the movement of the safety rod system, the spring in the drive mechanism is compressed as the safety rod assembly moves. At the same time, the angular displacement sensor installed at the end of the drive mechanism will change the angular displacement with the spring compressing. Therefore, the change track of the angular displacement sensor in the drive mechanism can be obtained by analysing the change of the spring in the drive mechanism during the quick reset of the safety bar assembly. By measuring the change time of the angular displacement sensor, the fast reset time of the safety rod assembly is calculated.

3. Principle of reset time measurement
Regardless of the influence of friction during the movement, when the electromagnetic latch in the
drive mechanism is de-energized and released, the safety rod assembly begins to fall under the action of the spring reaction force and gravity. At this time, the safety rod assembly bears a downward force \( F \):

\[
F = Kx + G
\]  
(1)

In formula (1), \( K \) is the elastic modulus of the spring; \( x \) is the spring compression, which is the position where the safety rod assembly moves relative to the core; \( G \) is the gravity of the safety rod assembly.

With the falling of the safety rod assembly during the fast reset movement, the position of the safety rod assembly relative to the core becomes smaller, and the compression of the spring becomes smaller, the relative spring force becomes smaller. Because the gravity of the safety rod assembly is a fixed value, it can be considered that the displacement change of the angular displacement sensor in the drive mechanism is proportional to the change in the spring compression, during the resetting process of the safety rod assembly.

This is the simulation results of spring displacement changes during the fast reset, as shown in Figure 2. In Figure 2, the spring constant in the simulation result is the same as the spring constant used in the safety rod system, and the spring compression is the maximum displacement of the safety rod assembly relative to the core. In the first 7 seconds, pressure is applied to make the safety rod assembly run from the core to the highest position, and the spring is compressed to the maximum, at this time, the pressure is released, the spring is released, and a fast reset action is performed. According to the simulation results, the fast reset time of the safety rod assembly is less than 1 second. By analysing the fast reset process of the safety rod assembly, the displacement change of the angular displacement sensor in the drive mechanism is also shown in Figure 2.
4. Reset time measurement design

Based on the analysis of the principle of fast reset time measurement of safety rod assembly, a ground-test equipment specially designed for fast reset time measurement of safety rod assembly is designed, and the software is designed and developed in C++ language. The ground-test equipment is mainly composed of industrial control computer, reset time measurement software and acquisition control module. The acquisition control module mainly completes data acquisition, signal transmission and sending instructions. This is the composition diagram of ground-test equipment, as shown in Figure 3.

![Diagram of ground-test equipment](image)

**Figure 3. Composition diagram of ground-test equipment**

The software mainly completes test information recording, test parameter configuration, safety rod drive control, data acquisition and processing, safety rod status monitoring, fast reset time calculation, data storage, operation log generation and other functions. The functional block diagram of the measurement control software is shown in Figure 4.

![Diagram of measurement control software](image)

**Figure 4. Functional block diagram of the measurement control software**

Fast reset time calculation is the core of the software. In order to verify the correctness of the fast reset time measurement design, the reset time of the angular displacement sensor is verified by comparing the reset time of the optical sensor which is installed at the end of the drive mechanism.

The flow of the fast reset time measurement of the safety rod is shown in Figure 5. When the software sends a fast reset command, it records the current system time t1, and t1 is the start time of the safety rod assembly fast reset. The software collects and processes the values of the angular displacement sensor and the optical sensor in the drive mechanism in real time. When it is detected that the angle is less than 1.5° and the angular speed is less than 0.2, the safety rod assembly is
considered to have completed the reset action, and the software records the current system time \( t_2 \).
Then, the difference \((t_2-t_1)\) is the reset time measured by the angular displacement sensor. When it is detected that the optical coding value is less than 144, records the current system time \( t_3 \), then the difference \((t_3-t_1)\) is the reset time measured by the optical coding sensor.

The judgment threshold in the fast reset process is the actual measured value of the safety rod assembly in the core.

**Figure 5. Flow of the fast reset time measurement**

5. **Reset time measurement verification**

At present, the ground engineering prototype of the safety rod system has participated in normal temperature, high temperature and earthquake tests. During the test, the safety rod engineering prototype was operating normally, and there was no improper operation, accidental rod drops or stick phenomenon. The ground engineering prototype of the safety rod system have completed 30 fast reset operations under normal temperature and high temperature test environments. In the earthquake test environment, the fast reset time of the safety rod assembly is 741ms, which is greater than the average value at normal temperature. The measurement results of fast reset time are shown in Figure 6 and in Figure 7.
The test results show that the fast reset time of the safety rod assembly is less than 1s, under normal temperature, high temperature and earthquake test environment, which meets the design requirements. Because the stiffness and performance of the spring itself decrease to a certain extent under high temperature environment, and the restoring force of the spring becomes worse, the fast reset time in high temperature is longer than in the normal temperature. In the earthquake test environment, the safety rod assembly takes a long time to reset, because of the sloshing of the safety rod system, the increased resistance caused by the friction of the catheter and the deformation of the catheter, but the fast reset time still less than 1 second, which meets system design requirements.

6. Conclusion
In the paper, by analysing the test results of the fast reset time of the safety rod system in the normal temperature, high temperature and earthquake test environment, the fast reset time measurement method of the safety rod is effective and feasible. The emergency shutdown design of the ground engineering prototype of the space nuclear reactor safety rod system meets the requirement of less than 1 second, and provides a test basis for the design and development of the drive mechanism of the safety rod system of a space nuclear reactor.

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