Storage Reliability and Safety Analysis of SLMs

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Abstract. Based on the analysis of the factors of ship storage environment which have adverse effects on the reliability and safety of missile storage, the design scheme of missile storage environment monitoring and control system is put forward. Through on-line monitoring of missile cabin environment monitoring system, the safety of missile and the storage reliability of missile can be guaranteed.

1. Introduction
As a weapon for long-term storage and one-time use, the storage of submarine launched missile(SLM) becomes an important part of their life cycle. In the process of missile storage, its security and reliability are very important. Therefore, it is necessary to establish a safety and reliability evaluation model for missile storage.

In the long-term storage process, SLM weapon system is affected by various environmental stresses, such as mechanical vibration, smoke, water vapor, etc. Its failure mechanism is generally slow chemical and physical processes such as oxidation, aging and performance degradation. In the long-term storage process, especially in the period of important combat training tasks, the contradiction between risk hidden danger and security and stability is particularly prominent. How to effectively identify risk hidden danger, and then take necessary measures to reduce risk and improve the security and reliability of missile storage is a difficult problem for managers.

The purpose of establishing the missile safety and reliability evaluation model is to determine the accident risk affecting the safety of missiles, to scientifically evaluate and predict its reliability, to find out the rules affecting the storage failure of SLMs, and to formulate measures to avoid risks, so as to ensure the safety, reliability and effectiveness of SLMs[1].

No matter how advanced the technical index of a weapon is, its combat effectiveness cannot be fully developed without high reliability as guarantee. SLM is a kind of weapon that can be used once for a long time. The missile should be in combat readiness after being loaded into a ship. Its combat readiness is mainly determined by the storage reliability of the missile. The storage safety of missiles is directly related to the safety and viability of submarines. It is related to the storage environment of missiles and must be considered in the design of submarines and launchers.

2. The missile storage reliability
Missile storage reliability refers to the ability of missile to maintain its performance parameters within the specified range in various storage states, launch states and flight states after experiencing the
environmental conditions specified by various storage states in its life profile. On the premise of certain inherent reliability (reliability after technical preparation), the storage reliability of missile is mainly determined by its storage environment.

2.1. The Storage environment
The inherent reliability of SLMs refers to the reliability of missiles after assembly and testing in technical positions. The missile will enter mooring and navigation storage after docking test. During this period, the storage reliability of missiles is mainly determined by the storage environment in the missile cabin and launcher. The main environmental factors that adversely affect the storage reliability of missiles in the storage environment are the following [3].

2.1.1. High temperature effect. High temperature accelerates the aging of materials and reduces the service life of missile components. Components made of polymer materials are more affected by heat. Environmental high temperature accelerates the decomposition speed of missile propellants, reduces the mechanical properties of engine charges and changes their dynamic characteristics. The alternating changes of high and low temperatures will affect the conductivity of missile control system instruments, capacitors and inductors. The dielectric constant and magnetism affect the accuracy of input and output parameters between missile-borne system and launch control system. The temperature in submarine is very high. In summer, it can reach 30℃ ~ 40℃ or even higher. Because of the air conditioning system failure, missiles are often in high temperature environment, which has a negative impact on their storage reliability.

The missile propellant can keep relatively stable at a certain storage environment temperature, but when the environment temperature rises rapidly, its own decomposition reaction (off-gas) will accelerate under the stimulation of external thermal environment. According to “Arrhenius reaction principle”, the decomposition rate of propellant is [4]

\[ r = k c^n = c^n k_0 \cdot \exp(-E / RT) \]  

In the formula, \( c \) is the concentration of decomposition reactant, \( k \) is the rate constant of chemical reaction, \( n \) is the radix of reaction, \( E \) is the activation energy of propellant, \( R \) is the gas constant, and \( T \) is the reaction temperature. The experimental results show that the rate constant \( k \) of chemical reaction can be increased by 2-4 times with the increase of ambient temperature by 10℃, that is to say, the rate constant \( k \) of chemical reaction can be increased by 2-4 times.

\[ \frac{k_{T+10}}{k_T} = (2 ~ 4)^n \]  

During the storage period, the decomposition reaction of propellant continued and some gas products were released. Some of the decomposed gases are trapped in the propellant grain, and the pressure may exceed its structural strength, resulting in cracks in the propellant grain, changing its original interior ballistic characteristics and mechanical properties; some of them are released to the outer part of the projectile, resulting in an increase in the concentration of flammable and explosive gases in the environment, resulting in potential safety hazards.

2.1.2. Corrosion of Moist Gas. Because of long-term underwater, a small amount of sea water will penetrate into the submarine through the Seaway valve or pressure hull gap, and then form a humid environment with salt fog inside the submarine. Moisture and salt will cause electrochemical corrosion to the missile circuit. Moisture containing salt penetrates into the cracks, thin tubes of missiles or remains on the surface of components, forming an electrolytic layer on the surface of metal materials in the circuit, causing electrochemical corrosion, while causing changes in resistance values of semiconductors and insulating materials and even electricity leakage. Corrosion of metal materials will reduce the working accuracy of equipment and instruments, resulting in signal transmission errors when stored at ambient temperature. When the degree changes greatly, the corrosion degree of the components on the missile will be aggravated.
2.1.3. Corrosion of Fungi and Particles. The ocean atmosphere contains a large number of fine particles (aerosols) with different physical and chemical properties, which will have an impact on missile components. These particles include plant spores, bacteria, microbial flora and so on. At appropriate temperatures, a large number of molds will grow on the surface of devices, producing surface conductivity layer, reducing insulation resistance. In addition, molds will separate organic acids and accelerate circuit corrosion. In the case of high temperature and humidity, the corrosion effect is stronger, and the effect on electronic devices and microcircuits is greater.

2.1.4. Impact Vibration. The Vibration and impact environment is caused by submarine underwater motion, and submarine power plant also generates vibration. The adverse effects of impact vibration on missile are as follows: loose or even shedding of parts and components; poor circuit contact and open circuit; loose and shedding of solder joints and plugs of conductors; vibration breaking of pins and electrodes of electronic components; vibration cracking of solid propellant and debonding of insulating layer. These phenomena will affect the performance of missiles to varying degrees.

2.1.5. Electromagnetic radiation. The electromagnetic radiation of different frequency bands is produced when the equipment in the missile cabin works, which interferes with the electronic, electrical and instrumentation on the missile, and produces erroneous actions, even fails to work normally. Strong electromagnetic radio frequency will also cause misignition of initiating explosive devices on bombs, resulting in potential safety hazards.

2.2. The Storage reliability

The storage reliability of a missile can be expressed by two parameters: one is the time length of keeping its performance parameters within a specified range, which is called storage life; the other is the probability of keeping performance parameters within a specified range within a specified storage time, which is called storage reliability.

The storage reliability of SLM in submarine can be expressed by the following formula

$$R_s(t) = e^{-Z_s(t)}; Z_s(t) = \frac{N(t)}{K(t)}$$

(3)

Where $R_s(t)$ is the missile storage reliability, $Z_s(t)$ is the failure rate or failure rate of missile components, $N(t)$ is the number of failures occurring in components, $K(t)$ is the total number of components stored on the missile[5].

It can be considered that the equipment in a missile is a series system composed of components with different functions. If one or several components fail, the whole series system may fail. The failure of a series system may result in the reduction or failure of the storage reliability of the missile.

If the influence of environmental factors on missile reliability is to be quantitatively analyzed, the empirical data obtained under different environmental conditions can be converted easily, and the concept of environmental factors can be introduced. Storage environment conditions may have two effects on missiles: one is different failure rate during storage; the other is different storage life of missiles. The former is called fault environment factor, and the latter is called life environment factor. Assuming that two groups of missiles with the same intrinsic reliability are stored in two different environments, the storage failure rates $Z_A$ and $Z_B$ of the two groups of missiles are calculated by formula (3) in the same storage time, the storage environment factors can be expressed as

$$K_z = \frac{Z_A}{Z_B}$$

(4)

If the average life of group A missile is known as $T_A$ and that of group B missile is known as $T_B$, then the life environmental factor of the missile is expressed as

$$K_T = \frac{T_A}{T_B}$$

(5)
There are two methods to study the influence of environmental factors on missile storage reliability: one is statistical analysis method, which is to analyze the influence of various environmental factors on missile storage reliability according to the statistical results of past failure rates of missile components, which is commonly used in the United States; the other is accelerated environmental experiment method [6], which is to increase various loops at a certain rate under laboratory conditions. It is a common method adopted by Russia to find out the main factors affecting the reliability of missiles and the weak links of the reliability of missile-borne systems. These two methods are usually used in the reliability growth design of missiles.

2.3. The Reliability Growth Design
Due to the long life cycle of SLMs, which generally need to reach more than 20 years, reliability growth design has become an important part of the development of SLM weapon system. It mainly includes two aspects: one is to improve the storage reliability of missiles by enhancing their environmental adaptability; the other is to improve the storage reliability of missiles by improving their storage environment. The ultimate goal of the storage reliability growth design of SLM is to make the missile in a maintenance-free state after shipment. "Maintenance-free" state means that after the missile is transported from a technical position (or factory) to a ship, the missile-borne system can maintain its inherent reliability for a long time without any detection and maintenance in the environment of the ship. The inherent reliability of missile will be reduced by every function test and inspection. The maintenance-free period of SLMs of US and Russian is over 10 years. Its main approach is also to enhance the missile's environmental adaptability design and improve the missile storage environment to improve the storage reliability.

3. Missile storage safety
SLM is stored in submarine for a long time. The safety of missile is related to the safety of submarine. Therefore, the storage safety of SLM is highly demanded in the design of launching device. The main factors that threaten the safety of missiles are as follows:

3.1. Flammable and explosive gases
The flammable and explosive gases in the missile cabin are mainly formed by the oil mist generated by the decomposition of missile propellant and the operation of electromechanical equipment. When the concentration reaches the ignition-detonation threshold, the explosion will occur in the case of open fire or electrostatic discharge, resulting in serious consequences.

3.2. Electrostatic and Spark
Static electricity and electric sparks are mainly produced by the work of personnel and mechanical and electrical equipment. Static electricity can ignite flammable and explosive gases, and strong static electricity can break down CMOS circuits or ignite pyrotechnics [7].

3.3. Electromagnetic radiation
Electromagnetic radiation is produced when high-power electronic equipment in missile cabin works. Strong electromagnetic radiation will cause accidental initiation and ignition of initiating explosive devices on bombs and launch power systems. From the above analysis, it can be seen that due to the existence of various potential safety hazards, in order to ensure absolute safety, integrated environmental monitoring system must be set up in the missile cabin to ensure the safety and reliability of the missile.

4. Design of Missile Cabin Environmental Monitoring System
There are two main purposes in designing the environmental monitoring system of missile cabin: first, the safety of missile must be guaranteed; secondly, the storage reliability of missile must be guaranteed.
4.1. Monitoring of Missile Storage Environment

The monitoring system should be able to monitor every barrel-missile in the missile cabin on-line. Because of the large number of ammunition stored in the cabin, the distributed measurement and control method can be used for on-line monitoring. The composition of distributed on-line barrel-missile monitoring system is shown in Fig. 1.

![Figure 1. The block diagram of distributed environment measurement and control system for missile cabin.](image)

The signals in the monitoring system are transmitted by serial communication, and each module is used as a node. Each launcher-missile environment measurement and control module is connected to the integrated measurement and control system through the standard interface of the communication bus, forming a multi-node local real-time data communication network (LAN). The monitoring system is controlled by the central measurement and control computer, and real-time display of the missile cabin environment information on the captain display console.

4.2. Environmental Monitoring Module in Launcher

The function of the inner environment monitoring module is to monitor the temperature, humidity and pressure changes in the launching barrel in real time. At the same time, it can monitor the random vibration overload of the missile in navigation on-line. When the inner environment of the launching barrel is abnormal, the monitoring module can send out alarm signals and display the relevant information of the environmental parameters changes in the launching barrel. The basic composition of the inner environment monitoring module of the barrel-missile is shown in Fig. 2.

![Figure 2. The basic composition of environmental monitoring module in launcher.](image)

The environmental monitoring device of the monitoring module consists of temperature sensor array, humidity sensor array, pressure sensor array and vibration sensor array which are set inside and outside the launcher. Temperature, humidity, pressure and vibration overload signals measured on-line are transferred to the central measurement and control computer of the monitoring system through data bus after signal adjustment and conversion circuit modulation.

When the leakage of launching barrel is detected, the inflatable equipment in the launching barrel is automatically activated to supplement the dry gas in the launching barrel; when the pressure in the launching barrel is detected to be higher than the prescribed storage pressure, the pressure relief valve in the launching barrel is automatically activated to reduce the pressure in the barrel; when the temperature in the launching barrel is detected to be higher or lower than the reliable storage...
temperature of the missile, the air conditioning equipment is started to adjust the Active shock absorber of launcher is activated when elastic vibration is abnormal. When the outer temperature of the launcher exceeds the specified ambient temperature in the cabin, the ventilation equipment in the missile cabin can be activated by the central computer to automatically adjust the temperature in the cabin. When abnormal temperature around the missile cabin is detected, the system sends an alarm signal, which can automatically or manually start the spray equipment in the launcher to cool down the spray of the launcher to ensure the safety of the missile in the cabin. The storage reliability of the missile can be improved to the greatest extent by setting up a barrel-missile environment monitoring system, which makes the missile in a "maintenance-free" state.

4.3. Environmental Safety Monitoring System in Missile Cabin

The purpose of the missile cabin safety monitoring system is to monitor the environment of the missile cabin online, eliminate all possible security risks and ensure the safety of the missile in the cabin. When the monitoring system detects that some environmental parameters exceed the specified safety level, the system can send out alarm signals in time and start emergency protection measures according to the scheduled plan. The schematic diagram of the missile cabin safety monitoring system is shown in Fig. 3.

Figure 3. The composition block diagram of missile cabin safety monitoring system.

Its basic functions are as follows:

4.3.1. Temperature and humidity monitoring. Temperature and humidity sensors (located at different locations in the missile cabin) can measure temperature and humidity in the missile cabin on-line and transmit the measured values to the central computer. When the temperature in the cabin exceeds the temperature at which the equipment works reliably, or when the humidity in the cabin exceeds the specified index, the system can send out alarm signals and automatically start the air conditioning equipment.

4.3.2. Flammable and Explosive Gas Monitoring. The purpose of detecting flammable and explosive gases in missile cabin is to prevent accidental explosion accidents caused by electrostatic sparks or circuit sparks when the concentration of flammable and explosive gases exceeds the standard. When the concentration of flammable and explosive gases in the cabin exceeds the specified standard, the system alarms and automatically starts ventilation or spraying equipment to reduce the concentration of flammable and explosive gases.

4.3.3. Electrostatic control. The purpose of detecting electrostatic field in missile cabin is to prevent accidental ignition or explosion of missile caused by electrostatic. When the static electricity of a certain position in the cabin is detected to exceed the standard, the system alarms and automatically starts the spraying equipment or static electricity elimination equipment.
4.3.4. Detection of electromagnetic radiation. The purpose of electromagnetic radio frequency detection is to prevent accidental ignition or explosion of initiating explosive devices caused by electromagnetic radiation. When the monitoring system detects the strong electromagnetic radio frequency, the system can give an alarm and automatically start the electromagnetic shielding equipment to protect the missile.

The design of integrated monitoring and control system for submarine missile cabin environment is an important part of submarine safety design. Through the design of two subsystems, the launcher-missile environment monitoring module and the missile cabin environment safety monitoring system, the design scheme of the missile cabin environment comprehensive monitoring system can be improved.

5. Conclusions

In this paper, based on the analysis of the factors of ship storage environment which have adverse effects on the reliability and safety of missile storage, the design scheme of missile storage environment monitoring and control system in missile cabin is put forward. Through on-line monitoring of missile cabin environment monitoring system, the safety and the storage reliability of missile can be guaranteed.

References

[1] Huo, Y. (2014) The Research of Security Model and Reliability Rate of Spare Parts in Strategic Missile Storage. Xi'an University of Electronic Science and Technology.
[2] Huang, R.S. (2002) Storage reliability of cruise missiles. Beijing: Third Academy Press of Aerospace Science and Technology Group.
[3] Wang, K. (2012) Research on storage environment monitoring and storage reliability evaluation method of missile weapon system. Harbin University of Technology.
[4] Li, B.X. (1990) Properties of solid propellants. Xi'an: Northwest Polytechnic University Press.
[5] Jiang, SH.W., Lu W.M., Wang, L. et al. (2012) Research on the Missiles Storage Reliability Based on Triangular Fuzzy Number”. Journal of Naval Aviation Engineering College, 27: 333-336.
[6] Xie, C.S., Zeng, H.J. (2016) The Method of Storage Reliability Accelerated Test for the Guidance Cabin of Protable Antiaircraft Missile”. Guidance and fuze. 04: 11-16.
[7] Chen, L., Xu, J.G., Jin, C.G., et al. (2012) Study on Test System for Electric-Explosive Initiator Safety”. Journal of Zhongbei University (Natural Science Edition), 33: 288-291.
[8] Li, Z.S. (2011) Monitored Control System of Indoor Environment. Harbin University of Technology.