Research on Reliability Demonstration of Naval Gun Weapon System

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Abstract: Combined with the relevant national military standards, this paper analyzes the problems existing in the selection and determination of the reliability index of naval gun weapon system, and puts forward the determination method of the basic reliability of naval gun equipment and the threshold value and target value of the mission reliability combined with the life profile and mission profile of Naval gun equipment. This method has a certain reference significance for the reliability design of naval gun equipment in the development stage, and the research of this paper has a certain practical value.

1. Introduction

The selection and determination of the reliability index of naval gun weapon system has been widely concerned. At present, the reliability demonstration of naval gun weapon system mainly refers to GJB450a equipment reliability requirements, GJB1909a equipment reliability maintainability supportability requirements demonstration, HJB53 naval ship equipment reliability maintainability parameter selection and index determination principle, GJB z2025 naval gun and naval gun weapon system tactical and technical index demonstration method G GJB 4000, GJB39a and so on. However, there are some problems in the relevant standards, such as the requirements are not unified and the demonstration procedure is not clear. For example, some standards [7] stipulate that the operational availability of naval gun weapon system is 0.95, but in the specific actual operation process, the overall indicators proposed by the ship will be required separately, and there is a certain gap between them; In addition, in the past, the specifications of various types of naval gun development are not consistent, and there is a gap with the requirements of the first level commission reliability team.

In view of the above problems, the paper [2–4] combs the characteristics of the reliability of naval gun weapon system and the problems existing in the process of demonstration; In paper [3], the concept of reliability index of naval gun weapon system and the relationship among the indexes are given; The paper [4] proposes to adopt mission reliability index and fully consider the influence of continuous firing on reliability in the actual use of medium and large caliber naval gun. These ideas and methods are of great significance for reference, but it is still necessary to further study the index system, demonstration method and demonstration process in combination with the equipment characteristics and use characteristics of naval gun weapon system, so as to make it more scientific, reasonable and operable. Therefore, this paper combs and explores several key issues in the process of reliability demonstration.
2. Selection of system reliability index

2.1. Relevant military standard requirements

It is required in many national military standards that the quantitative index of reliability should include mission reliability requirement and basic reliability requirement.

The scope of reliability quantitative requirements specified in GJB450a "equipment reliability requirements" is: "reliability quantitative requirements usually include mission reliability requirements and basic reliability requirements, and reliability quantitative requirements also include storage reliability and durability requirements."

In GJB1909a "equipment reliability maintainability supportability requirement demonstration", it is recommended that the mean time between failures (MTBF) and mean time between serious failures (MTBSF) should be selected as the reliability parameters of artillery. For different mission profiles, the mean time between severe failures can be the number of missiles fired in the mean time between severe failures.

In HJB53 "the principle of reliability and maintainability parameter selection and index determination of naval ship equipment", it is proposed that in the demonstration report, there should be mean time between failures, mean time between serious failures, mean life span, mean number of failures, etc; There should be mean time between failures, mean life, mission reliability, confidence level, risk, etc. in the development mission statement and contract specification. It is also required that there must be detailed mission plan and time requirement to determine the reliability and availability index of naval gun weapon system, otherwise it cannot be determined.

The requirements of GJBz20250 "demonstration method for tactical and technical indexes of naval gun and naval gun weapon system" are as follows: the reliability index of naval gun is usually selected as the number of times between failures, and the reliability index of naval gun servo system is usually selected as the time between failures, the confidence level of reliability test, risk judgment, etc. The reliability, failure rate, probability distribution of system failure, confidence level of reliability test, risk judgment and so on are selected for naval gun weapon system.

2.2. Existing problems

In the past, there were only basic reliability index and mission reliability index in the demonstration of quantitative reliability index of naval gun weapon system. In some cases, there is no clear task profile and failure criteria, no clear verification method and when or at what stage to meet the index requirements.

In addition, in the past, the basic reliability index of naval gun weapon system was emphasized, but the mechanical system was not included in the index calculation. Mean time between failures (MTBF) is a basic reliability index, which refers to the ability of naval gun to work without failures under specified conditions and within specified time. It is related to the environmental conditions, stress conditions and life cycle of the product, that is, the conditions determined by the "Life Profile". It also reflects the requirements of naval gun weapon system for maintenance resources. When evaluating the mean time between failures (MTTR), all associated failures in all life units of products should be counted.

2.3. Selection method of reliability index

In order to improve the reliability quantitative index system of naval gun weapon system, the following methods are recommended for the selection of reliability index.

Firstly, the mission reliability parameters are defined for typical mission profiles. Among them, the task reliability of comprehensive indicators is specified, and the specified value, the minimum acceptable value and the confidence level are specified. At the same time, for electronic equipment, the mean time between serious failures is specified, and the specified value and the minimum acceptable value are specified. For the mechanical equipment of naval gun, the average number of critical failure intervals is specified, and the specified value and the minimum acceptable value are specified.
Secondly, according to the life profile, the basic reliability parameters are defined. Among them, the average failure interval of the mechanical part of the naval gun, the specified value and the minimum acceptable value. The electronic part specifies the mean time between failures, the specified value and the minimum acceptable value.

Finally, the durability index is defined. On the basis of the previous barrel life, it is required to accumulate and determine the life data of the key parts, and put forward the life of the whole gun, barrel, automata and other key parts. The details are shown in Table 1.

| classification | index system              | definition                                                                                     | Suggestion                                |
|----------------|---------------------------|------------------------------------------------------------------------------------------------|-------------------------------------------|
| Mission reliability | Mission reliability        | The probability of the system to complete the task function in the time range and conditions specified by the task profile. | Required. Ammunition can be ignored     |
|                 | Mean time between fatal failures | Within the specified mission profile, the naval gun can complete the specified mission function in the fault free working time. | Optional for electrical and electronic systems |
|                 | Average number of fatal failure intervals | Within the specified mission profile, the number of faultless projectiles that the naval gun can complete the specified mission function. | Optional for mechanical structure system |
| Basic reliability | Basic reliability          | The probability of the system to complete the task function in the time range and conditions specified by the life profile. | Optional                                |
|                 | Mean time between failures | The time of the naval gun working without fault under the specified conditions and within the specified time. | Required for electrical and electronic systems |
|                 | Average number of fault intervals | The number of pellets fired by naval gun without fault under specified conditions and within specified time. | Required for mechanical structure system |
|                 | Reliability of the whole missile | The probability of ammunition hitting the target under specified conditions. | Optional                                |
|                 | Flight reliability         | The probability that the impact point (explosion point) of ammunition is within the specified range under the specified conditions. | Required for guided munitions            |
| Durability index | Service life of full gun   | The time from the use of naval gun to the occurrence of irreparable function failure or failure rate exceeding the acceptable range. | Optional                                |
|                 | Barrel life or automaton life, etc | Under the standard firing conditions, the total number of projectiles with equivalent full charge before the ballistic index of barrel is reduced to the allowable value or fatigue failure. | Required                                |
### 3. System life profile and mission profile

The life profile and mission profile of the system are very important, and they are the basis and input of the system reliability demonstration. In GJB1909a "equipment reliability and maintainability supportability requirements demonstration", it is stipulated that: life profile, mission profile, fault discrimination criteria, verification methods (such as test verification or use verification, including confidence level, acceptance or rejection criteria, etc.), when or at what stage should be achieved, and other assumptions and constraints should be specified. In GJB1909a, examples of mission profile and life profile of Army artillery are also provided as reference. It is stipulated in HJB53 "principles for selection of reliability and maintainability parameters and determination of indexes of naval ship equipment": before putting forward quantitative requirements, the ordering party shall make accurate definition of mission, carry out mission analysis, divide mission stages, make clear mission profile and life profile, give clear definitions of software and hardware operation function, failure criterion and success standard, and make clear the number of mission cycles, the number of mission phases. The quantitative values of environmental stress and time in various environments are given.

According to the demonstration practice in recent years, the specific understanding is as follows.

#### 3.1. Mission profile of naval gun weapon system

(1) Main contents of mission profile

Task profile refers to "the time sequence description of the events and environment that the product experiences during the period of completing the task", including task results and fatal fault judgment criteria. When the same equipment completes different tasks, the task profile is different, including the working state of the equipment, the maintenance scheme (the equipment that can be maintained in the process of the task), the time and sequence of the equipment work, the time and sequence of the equipment environment, and the definition of the success or serious failure of the task.

Using scheme is the premise of drawing up mission profile. The description of operation scheme mainly includes: deployment sea area, operation environment, ship loading platform, operation object, operation mode, system composition, system function and so on.

(2) Key elements of mission profile

Task profile is mainly described from the following aspects: task name, task composition, type and quantity, task proportion, task time sequence and duration, and criteria for defining success and failure. For each task, a corresponding task profile should be made. Combined with the characteristics of naval gun weapon system, the key elements of mission profile are continuous working time and firing ammunition quantity. These two factors reflect the working intensity of equipment, directly affect the connotation of equipment reliability index, and also determine the test quantity of reliability appraisal test, so they are very critical.

The selection of mission profile elements is mainly based on four aspects: similar equipment, operational scenario, historical data and relevant military standards. According to the typical enemy's anti landing operational deployment, a brigade's defense front is about 12 – 16 km, and the defense section is under medium strength defense, with 12 platoon support points in the first line position, 200 blockhouses in the front, 3 howitzer battalions and 1 tank company. The cumulative number of typical targets such as light fortifications and artillery positions that can be hit by naval guns is estimated to be about 200-250. According to four destroyers, four large caliber naval guns and an average of three rounds of ammunition, one target was hit and damaged. A single naval gun fired 32 rounds of land-based missile propellant, and four naval guns fired 128 rounds, which could strike 43 targets, accounting for 17% ~ 21%. According to the "army artillery firing standard", it belongs to medium weak...
strike intensity. When 60 anti-land missile charges (240 in total) are launched respectively, 80 targets can be hit, accounting for 32% - 40%, which belongs to medium strike intensity. When 75 anti-land missile charges (300 in total) are launched respectively, 100 targets can be hit, accounting for 40% ~ 50% of the total, which belongs to relatively strong strike intensity. According to the medium strike intensity, the large caliber naval gun needs to reliably launch 60 guided ammunition [12] ~ [17] for one combat mission.

(3) Main forms of mission profile

As for the form of mission profile, the profile examples given by GJB1909a, HJB53 and other standards are too simple to guide the determination of indicators. The structural modeling methods such as IDEF0, DoDAF and Petri net are used in the literature of optimization of mission profile structure of surface warship combat system (Yong Xu), modeling and simulation method of mission profile oriented to architecture (Xia Chen) and Research on naval gun combat mission profile model (Lei Wang), which are scientific and difficult for non-professionals to master. In contrast, GJB6678 "requirements for combat readiness integrity index of warship combat system" and "analysis, calculation and detection of combat readiness integrity of system" (Bing Xiang Mao) stipulate the compilation requirements of mission profile and life profile, which is more operable.

The naval gun weapon system prepares for war and sailing according to the combat task, arrives at the designated combat sea area with the carrier ship, and carries out operations on the targets assigned by the combat command system. After the end of the battle, check the equipment status, and follow the ship to withdraw from the sea area or return to the base. An example of naval gun weapon system's maritime mission profile with the ship is shown in Figure 1.

![Figure 1. Example of marine mission profile of system (with ship)](image)

The task sequence description of naval gun weapon system mainly refers to the description of the duration and sequence of various events and environmental conditions. An example of task sequence description of naval gun weapon system is shown in Figure 2.
3.2. Life profile of naval gun weapon system

(1) Life profile of surface ship

In principle, the life cycle of naval gun and its weapon system should be consistent with the life of the surface ship, that is to say, at present, destroyers and frigates are generally calculated on the basis of 30 years. Therefore, the life profile of naval gun and weapon system intersects greatly with that of naval platform. The life profile of a typical destroyer is shown in Figure 3.

![Diagram of mission profile](image)

**Figure 2. Example of naval gun equipment firing mission profile on the sea (opposite shore)**

**Figure 3. Life profile of typical destroyer**

| Event                  | Dock repair | Minor repair | Dock repair | Intermediate repair | Dock repair | Minor repair | Dock repair |
|------------------------|-------------|--------------|-------------|---------------------|-------------|--------------|-------------|
| Mission                | 36          | 32           | 32          | 30                  | 34          | 32           | 28          |
| Use(months)            | 30          | 36           | 36          | 36                  | 36          | 36           | 36          |
| Repair(months)         | 12          | 6            | 12          | 6                   | 12          | 6            | 12          |
| Maintenance time allocation of typical destroyer |
| Total                  | 96          | 108          | 108         | 108                 | 108         | 108          | 108         |

Note, in the life profile:
- a. The service life of the ship is 30 years.
- b. During the service life, 4 dock repairs, 3 minor repairs and 1 medium repair are arranged.
- c. The repair interval is about 2.5-3 years.
d. Two dock repairs and one minor repair are arranged before medium repair. Two dock repairs and two minor repairs are arranged after the medium repair.

e. The dock repair time is 6 months, the minor repair time is 12 months, and the medium repair time is 26 months.

(2) Life profile of naval gun weapon system

Life profile is the basis to determine the basic reliability of the system. The life profile of naval gun and its weapon system is "the time sequence description of all the events and environments experienced by the product during the period from manufacture to end of life and out of service" (GJB450-88). It is necessary to describe the events, duration, sequence and working mode of the system in the whole life cycle. According to the use characteristics of naval gun and the article "Research on the concept of reliability index of naval gun weapon system" (Li Ping), the specific form is shown in Figure 4.

Figure 4. example of life profile of naval gun weapon system

Among them, the key event combat task, training task and maintenance in the life profile of naval gun weapon system. The mission profile is determined by the previous section. Maintenance involves planned maintenance, preventive maintenance and wartime emergency repair. The planned maintenance should be carried out along with the ship platform, as shown in the life profile of the surface ship, and undertaken by the base level support force. Preventive maintenance and emergency repair are related to the maintenance system, support facilities and equipment and other support resource requirements. During the implementation of training and combat tasks, it also directly affects the usability, crew level test and maintainability of the system.

4. Determination of system reliability index

4.1. Determine the target value of mission reliability

The main factors to determine the mission reliability of naval gun equipment include the overall requirements of surface ships, operational requirements, comparison of similar systems and reference to relevant standards, and on this basis, comprehensive consideration of funds schedule and other factors to make a comprehensive trade-off.

(1) General requirements for surface vessels

Usually, the surface warship will assign quantitative requirements to all kinds of tasks of combat system, such as sea, air and shore tasks. The single mission involves power, navigation, alert, command and control, weapon system, etc., and there is no clear assignment. There is also no clear distribution of different types of weapons to accomplish the same task. Therefore, the index given by the ship as a whole can only be used as a reference.

(2) Operational use requirement factors

Operational use requirements are the fundamental basis to demonstrate mission reliability, which mainly come from mission time, mission intensity and mission success criteria. Most of the time, naval gun weapon system is in combat preparation or standby stage (from the mission profile), only electrical and electronic equipment start to participate in the work. The amount of ammunition fired in a typical
mission is usually a certain amount, that is, one ammunition base. The mechanical system of naval gun has a greater impact on the reliable launch, and the reliability index proposed is also for mechanical equipment. The task reliability of electrical equipment and mechanical equipment is a series relationship, and the product reflects the task reliability of naval gun weapon system.

\[
R = R_1 \times R_2 = e^{-T/T_m} \sum_{m}^{C_m} p^m (1 - p)
\]

In equation (1), \( R_1 \) is the reliability of electrical equipment and follows normal distribution; \( R_2 \) is the reliability of mechanical equipment and obeys binomial distribution.

3) Comparison of similar system factors

Reference and comparison of similar systems is an important traditional method to determine the reliability index of naval gun weapon system. The first is the similar naval gun system, especially the equipment with certain technology inheritance, which is convenient for comparison and improvement. The second is the artillery system of the same caliber and similar caliber of the army and air force. Third, we can also refer to systems with similar missions, such as anti-ship missile and air defense missile systems. Mainly from the operational use requirements, complexity, use intensity and other aspects of comparison.

4) Refer to relevant standards

In HJB53 "the principle of reliability and maintainability parameter selection and index determination of naval ship equipment", it is proposed that the reliability index of naval gun system should not be lower than 0.95 in order to meet every mission and carry out every battle. This is the only clear mission reliability requirement for naval gun in all current standards. This index is usually quite different from the index issued by the ship as a whole, and can only be used as a reference. For example, in order to complete the sea (or air / shore) mission, the target value of mission reliability issued by a certain destroyer to the combat system is 0.85, not 0.95 of HJB53.

5) How to balance

Comprehensive trade-off refers to the comparison of operational requirements, complexity and operational intensity of comprehensive operations. It should not only meet the overall requirements, but also consider the difficulty of domestic technology implementation, and comprehensively give mission reliability indexes such as mission reliability. In addition, the selection of confidence should also consider the amount of test, test funds and test cycle, so that the index can be operated.

4.2. Determine the target value of basic reliability

The basic reliability reflects the maintenance requirements of the system. When determining the characteristic quantity of basic reliability, all life units and all faults of the system should be counted. The basic reliability of naval gun weapon system refers to the duration and probability of system failure free under the condition of system life profile. The reliability and index should be determined with reference to the following factors: operational requirements, relevant standards and technical specifications of naval gun, comparison of similar equipment and technical development and application.

1) Use requirements

Basic reliability and mission reliability are two aspects of naval gun reliability parameters, which regulate the reliability requirements of naval gun from different aspects and have strong correlation. Therefore, on the basis of mission reliability, the target value of equipment basic reliability can be determined by empirical proportional coefficient method. The basic reliability index of naval gun can be determined by the following formula:

\[
MRBF = K_1K_2K_3 \times MRBCF
\]

\[
MTBF = K_1K_2K_3 \times MTBCF
\]

\( K_1 \) is the serious fault coefficient, which is determined according to the proportion of serious faults in the naval gun test. \( K_2 \) is the system complexity factor which is determined by considering the
complexity and redundancy of the equipment. $K_i$ is the technology maturity coefficient which is determined according to the proportion of new technology used by equipment.

(2) Relevant standard requirements
For example, GJB4000 general specification for ships "chapter 711 naval gun" puts forward the corresponding requirements for the number of average failure intervals of the mechanical part of naval gun according to the caliber: not less than 300 for large caliber naval gun, not less than 500 for medium caliber naval gun, not less than 1000 for small caliber naval gun, but it is not clear whether this is the specified value or the minimum acceptable value. However, in the standard "chapter 710 naval gun and support system", the requirement that the mean time between failures of the control part is not less than 150h is specified, but there is no minimum acceptable value.

(3) Comparison of similar equipment and technology development and application
The basic reliability of equipment reflects the characteristic quantity of reliability in the whole life cycle of equipment. It is difficult to describe it accurately by theoretical calculation method, but it is difficult to operate the test method because of its high cost and long cycle. The use of other similar equipment can reflect the basic reliability of the equipment to a certain extent, so the "analogy method" can be used to compare and analyze the basic reliability indexes of similar equipment at home and abroad, and the basic reliability of the equipment can be determined by comprehensively weighing the factors such as the differences in use environment and technology application between similar equipment.

4.3. Determine the threshold value of reliability index
The target value of reliability refers to the expected service index, which can not only meet the service requirements of naval gun weapon system, but also make the system achieve the best efficiency cost ratio. It is the basis for determining the specified value of reliability. According to the determined target value of naval gun reliability and considering the possible growth potential of naval gun reliability, the threshold value of equipment reliability can be determined by using empirical discrimination, model prediction and other methods.

1. Empirical method
The threshold value of equipment reliability is obtained by multiplying the reliability target value by the proportional coefficient $K$. The proportional coefficient $K$ is generally obtained by referring to the development law of naval gun reliability in recent years, and comprehensively measuring the conditions of equipment use, complexity and new technology application. According to the current technical level of equipment design, production and reliability growth, the proportion coefficient is generally taken as 0.6.

2. Forecast method
According to the target value of naval gun reliability and considering the growth potential of naval gun reliability, the threshold value can be determined by means of Duane model. The main steps of threshold prediction method based on Duane model are as follows

(1) Determine the mature period of new naval gun
Assuming that a certain type of naval gun has $n$ gun in service in the early stage, the naval gun will enter the mature stage when each gun has fired $s$ times, that is to say, when it reaches the mature stage, the cumulative number of shots fired is $n \times s$.

(2) Various factors affecting the reliability growth of naval gun are given
The influencing factors of naval gun reliability growth rate include complexity, schedule requirements, technical level, research and development funding, army use frequency, fracas (fault reporting, analysis and corrective action system) operation effectiveness and so on.

(3) The weight coefficient of each factor for reliability growth is calculated.
If analytic hierarchy process (AHP) is used to calculate the weight of each influencing factor

\[
W = \left( w_1, w_2, w_3, w_4, w_5 \right)
\]  \hspace{1cm} (4)

(4) Comprehensive evaluation of influencing factors and calculation of growth rate.
The fuzzy comprehensive judgment method is used to calculate, and the evaluation matrix $R$ and the evaluation set $V$ are obtained.

$$m = w RV^T$$  \hspace{1cm} (5)

(5) The threshold value is obtained by Duane model formula.

$$MRBF_l^* = MRBF_m^* \times \left( \frac{R_0}{R} \right)^m$$  \hspace{1cm} (6)

$$MRBCF_l^* = MRBCF_m^* \times \left( \frac{R_0}{R} \right)^m$$  \hspace{1cm} (7)

$MRBF_l^*$, $MRBCF_l^*$ are the reliability threshold values, $MRBF_m^*$, $MRBCF_m^*$ are the reliability target values, $R_0$ is the number of military test shells before the design finalization, $R$ is the cumulative number of used shells from the end of the design finalization to the maturity period, and $m$ is the reliability growth rate.

5. Reliability index demonstration process
Index demonstration includes the selection of index parameters and the quantification and trade-off of index parameters. The demonstration process is a series of trade-offs. The complete index demonstration procedure can be shown in Figure 5.

![Figure 5. Flow chart of index demonstration procedure](image)

The basis of index quantification and trade-off is the mathematical model of system effectiveness or availability, the mathematical model of life cycle cost, the index level of similar equipment and the domestic design level constraints. In the process of quantification and trade-off, mathematical analysis, computer simulation and optimization are usually used. According to the mathematical model and logical relationship of each reliability index, a digital simulation platform is established to conduct repeated experiments on the operation status and process of the equipment, and the large amount of data generated from the simulation is statistically analyzed to obtain the required characteristic parameters. The reliability of the simulation results, the fidelity of the simulation results and the appropriateness of the input data.

6. Concluding Remarks
Based on the relevant standards, this paper expounds the meaning of the reliability index of naval gun, and analyzes the selection and determination method of the reliability index parameters of naval gun. With the development of the research on combat readiness, the reliability index has become an index that users and contractors pay more and more attention to. It is also an index that must be implemented and realized in equipment. The main aspects to be further studied are as follows:
1. Calculation method of target value and threshold value of naval gun reliability index. It is necessary to make a comprehensive analysis and research according to the data of domestic and foreign service equipment, and reasonably determine the proportional relationship between the target value and the threshold value.

2. Service life index of naval gun. Naval gun weapon system has its own use environment and mission characteristics, so it is necessary to explore the calculation method of equipment service life in line with the characteristics of naval gun weapon system.

3. The reliability index prediction and allocation criteria of naval gun subsystem need to be further studied. The complexity of naval gun weapon system is much higher than that of other similar equipment. Making reasonable reliability prediction and allocation standard is an important premise to promote equipment reliability research and improve equipment research efficiency and economy.

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