Maintainability Distribution Model for Laser Inertial Navigation System

Yun Fu*, Jin'e Huang and Zhe He

P.O.BOX 1303, Beijing, CHINA

*Corresponding author

Keywords: Laser inertial navigation, Maintainability distribution model, System level, Device level.

Abstract. This study builds a maintainability distribution model suitable for laser inertial navigation system beginning with the description of the maintainability index and combining with the characteristics of the system. To enhance the system-level products, the failure rate distribution model is applied, while the weighting factor distribution model of failure rate and design characteristic is applied to the device-level products. Accordingly, these factors providing the basis for the reasonable distribution of maintainability.

Introduction

Maintainability is a type of quality characteristic of an equipment and the attribute provided by the design to make the equipment maintenance simple, rapid, and economical^[1-2]. The laser inertial navigation system ensures safe navigation during long voyage, dynamic alignment of weapon systems, and stability control of various combat task sensors, thereby making maintainability an important quality characteristic of systems^[3-4].

To control the maintainability of the system, the contents of the reliability indexes should be maintained at all levels, while the top-level reliability index should be assigned from top to bottom to each key subsystem. The existing reliability index distribution method is unable to combine the characteristics of the entire subsystem to proceed with a scientific and reasonable index distribution, while the distribution result is difficult to realize in the actual production design or the completed product effect is unable to meet the expected requirements^[5-6]. This study uses the system-level and device-level maintainability characteristics of an inertial navigation system to introduce different maintainability distribution models and develop a new maintainability distribution method to enhance the existing single distribution method.

Maintainability Distribution Indicator

The maintainability design and evaluation of a system is an entire and multi-statistic evaluation process. This process means that the evaluation of reliability should undergo product definition, design, development, production, use, and maintenance. Multi-statistic refers to the variety of indicators used to measure and evaluate the reliability of automobiles. Accordingly, many varying statistics can be evaluated. This study evaluates the convenience of statistical indicators and the accuracy of statistical data by mainly using mean time between failure (MTBF) as distribution indicator.

In the prototype stage, the characteristics of a laser inertial navigation system are combined to build a maintainability distribution model that is suitable for this is constructed.

Maintainability Distribution Model

The maintainability distribution of a laser inertial navigation system is mainly divided into two stages.

First, the laser inertial navigation system maintainability indicators for the system-level distribution are assigned to the three sub-systems of inertial, explicit control transmitter, and power supply devices, which often use the failure rate distribution method.

Second, the distribution value of each sub-system for the device-level distribution is assigned to

the basic level unit, which often uses the weighted factor distribution method on the basis of the failure rate and design characteristics.

Distribution Model by Failure Rate

The specific steps of distribution by failure rate are as follows:

- 1) Determine the failure rate of the J^{th} sub-system λ_j ;
- 2) Determine the percentage of the impact of the failure rate of each sub-system on the total failure rate; that is, determine the failure rate weighting factor for each sub-system W_j as follows:

$$W_j = \frac{\lambda_j}{\sum_{j=1}^n \lambda_j},$$

where λ_j is the failure rate of unit J and n is the number of unit types.

- 3) Calculate the mean time to repair for each sub-system $\bar{M}_{ctj}$ as follows:

$$\bar{M}_{ctj} = \frac{\bar{M}_{ct}}{nW_j}$$

Weighting Factor Distribution Model by Failure Rate and Design Characteristics

The specific steps of the weighting factor distribution method by failure rate and design characteristics are as follows:

- 1) Analyze the type of product and design characteristics of the product, determine the weighting factors of each unit of the product on the basis of the reference value of the maintainability weighting factor in Table 2, and determine the sum of the K_{ij} weighting factors of each unit on the basis of the following formula K_i :

$$K_i = \sum_{j=1}^m k_{ij},$$

where K_{ij} is the weighting factor of the i^{th} and j^{th} units and m is the number of weighting factor types.

- 2) Determine the failure rate of each unit of product λ_i .
- 3) Calculate the mean time to repair unit i as follows:

$$\bar{M}_{cti} = \frac{k_i \sum_{i=1}^n \lambda_i}{\lambda_i \sum_{i=1}^n k_i} \bar{M}_{ct}$$

where n is the number of unit types.

Table 1. Reference values of four maintainability weighting factors

Failure detection and isolation factor (k_{i1})			Accessibility factor (k_{i2})		
Types		Description	Types		Description
Automatically	1	Automatically detect the failure part using internal device of the equipment	Good	1	No need to remove coverings when replacing fault units
Semi-automatically	3	Fault location of the detection circuit in the manual control machine or detection of the detection hole set in the machine by the automatic detection equipment outside the machine	Ok	2	Can quickly remove coverings
Manually	5	Detect hole detection in machine with off-machine lightweight instrument	Poor	4	When removing blocks or coverings, screw on and screw out the screws
Manually	10	Set detection hole with machine, and it must trace manually point-by-point	Very poor	8	In addition to screwing on and screwing out the screws, more than two people should move the block and coverings
Changeability factor (k_{i3})			Adjustability factor (k_{i4})		
Type		Description	Type		Description
Plug and unplug	1	Replaceable units are plug-ins	No adjustment	1	No adjustment required after the replacement of the fault unit
Buckle	2	The replaceable unit is a module, while the buckle opens when replacing	Fine adjustment	3	Adjust using internal adjustment components
Screw	4	Replace the unit to screw on and screw out the screws	Joint adjustment	5	Must be adjusted jointly with other components
Weld	6	Weld when replacing			

In the prototype stage, the data source is defined, while a comprehensive and detailed maintainability distribution endeavor is conducted at the system and device levels, respectively.

Case Application

Data Sources

The failure rate data required in the maintainability distribution are determined on the basis of the relevant reliability analysis data of the inertial navigation system. Table 3 shows the failure rate data of each LRU, in which the power control module temporarily lacks an accurate failure rate data, the failure rate range of the related reference modules is between $5 \times 10^{-6}/h$ and $10 \times 10^{-6}/h$, and the boundary failure rate data is considered a $10 \times 10^{-6}/h$ processing.

In addition, the failure rate data of the inertial device should include the failure rate of the biaxial modulation mechanism and failure rate data of the explicit control transmitter. However, the power supply device should include the failure rate of the internal radiator of the device. The *Reliability Analysis Technical Report of the Laser Inertial Navigation System* shows that the failure rate of the biaxial modulation mechanism is $37 \times 10^{-6}/h$. We obtain the radiator failure rate of $2 \times 10^{-6}/h$ from the electronic system failure rate data in GJB1909.10-1998 *Equipment Reliability Maintainability Parameter Selection and Indicator Determination Requirements*.

The failure rate of each device is calculated through cumulative correction on the basis of the failure rate data of the LRU component unit.

Table 2. LRU failure rate data of a laser inertial navigation system

No.	Sub-system	Sub-system failure rate data	LRU name	Number n	λ_i (10 ⁻⁶ /h)
1	Inertial device	120.6880a	IMU	1	58.6098
2			Angle Measurement Control Module	1	7.5235
3			Navigation Calculation Module	1	10.0313
4			Servo Drive Module	1	5.0156
5			Power Control Module	1	10
6	Display control transmitter	17.0000b	Hard Disk Board	1	3
7			CPU Motherboard	1	1.5
8			CAN module	1	1.5
9			Dual redundant network communication module	1	1.5
10			Serial port control module	1	1.5
11			Data Synchronism Forwarding Module	1	1.5
12			Reinforcement of computer power supply	1	1.5
13			Display panel	1	3
14	Power supply unit	30.5074 ^c 37.0091d	24V redundant power supply	1	6.0016
15			60V redundant power supply	1	6.5017
16			Excitation power supply	1	7.0018
17			Programmable power supply (initial prototype stage)	1	6.5017
18			UPS power supply	1	9.0023

The weighting factor data of the LRU product is determined on the basis of the design scheme of a product combined with the reference value table of the factor. The quantitative analysis of the principle prototype stage is as follows.

Maintainability Distribution

System-level Distribution. System-level distribution aims to allocate the maintainability index ($MTTR \leq 0.5h$) of the laser inertial navigation system to three devices, namely, inertial device, explicit control transmitter, and power supply device, on the basis of the failure rate. The distribution is based on the distribution model by failure rate. Table 3 shows the results of the failure rate data and maintainability distribution.

Table 3. MTTR distribution value of each subsystem of the laser inertial navigation system

No.	Sub-system	Number	Failure rate λ_j (10 ⁻⁶ /h)	$\bar{M}_{ctj}$ (min)
1	Inertial device	1	120.6880	14
2	Display control transmitter	1	17.0000	103
3	Power supply unit	1	30.5074	57

Device-level distribution

(1) Inertial device

Table 4 shows the failure rate data and weighting factor values of each LRU of the inertial device. The distribution results of inertial devices can be obtained on the basis of the failure rate and design characteristic weighting factor distribution method.

Table 4. Inertial device LRU distribution results

No	Name	LRU name	Number n	λ_i (10 ⁻⁶ /h)	Weighting factor k_{i1}	Weighting factor k_{i2}	Weighting factor k_{i3}	Weighting factor k_{i4}	Total K_i	$\bar{M}_{ctij}$ (min)
1	Inertial device	IMU	1	58.609 8	1	7	6	3	17	15
2		Angle Measure ment Control Module	1	7.5235	1	4	3	1	9	61
3		Navigation Calculatio n Module	1	10.031 3	1	7	5	1	14	71
4		Servo Drive Module	1	5.0156	1	4	3	1	9	91
5		Power Control Module	1	10.000 0	1	7	5	1	14	71

(2) Display control transmitter

Table 5 shows the failure rate data and weighting factor values of each LRU of the display control transmitter. The distribution results of the display control transmitter can be obtained on the basis of the failure rate and design characteristic weighting factor distribution method.

Table 5. Individual LRU distribution result of the display control transmitter

No	Name	LRU name	Numbe r n	λ_i (10 ⁻⁶ /h)	Weight ing factor k_{i1}	Weight ing factor k_{i2}	Weight ing factor k_{i3}	Weight ing factor k_{i4}	To tal K_i	$\bar{M}_{ctij}$ (min)
1	Display control transmi tter	Hard disk board	1	3	1	2	1	1	5	6
2		CPU motherboard	1	1.5	1	2	1	1	5	11
3		CAN module	1	1.5	1	2	1	1	5	11
4		Dual redundant network communicati on module	1	1.5	1	2	1	1	5	11
5		Serial port control module	1	1.5	1	2	1	1	5	11
6		Data synchronism Forwarding module	1	1.5	1	2	1	1	5	11
7		Reinforceme nt of computer power supply	1	1.5	1	2	1	1	5	11
8		Display panel	1	3	1	2	6	1	10	11

(3) Power supply unit

Table 6 shows the failure rate data and weighting factor values of each LRU of the power supply unit. The distribution results of the power supply unit can be obtained on the basis of the failure rate and design characteristic weighting factor distribution method.

Table 6. Individual LRU failure rate data of the power supply unit

No.	Name	LRU name	Number n	λ_i (10 ⁻⁶ /h)	Weighting factor k_{i1}	Weighting factor k_{i2}	Weighting factor k_{i3}	Weighting factor k_{i4}	Total K_i	$\bar{M}_{ctij}$ (min)
1	Power supply unit	24 V redundant power supply	1	6.0016	1	5	5	1	12	30
2		60 V redundant power supply	1	6.5017	1	5	5	1	12	27
3		Excitation power supply	1	7.0018	1	5	4	1	11	23
4		UPS power supply	1	9.0023	1	5	6	1	13	21

MTBF, which is a system-level maintainability indicator, is reasonably assigned to each device to clearly evaluate the maintainability of a system. This method is also feasible in engineering applications.

Conclusion

This study uses the average fault interval MTBF as the maintainability distribution index of a laser inertial navigation system. Accordingly, the use of this index clearly and intuitively reflects the maintainability level of each subsystem and even the unit level products at a certain stage. The reliability distribution method of system-level and device-grade products reasonably and comprehensively distributes the system-level reliability index to the subsystem and unit levels. The result can reflect the importance of a key subsystem to the maintainability of a system and make the maintainability index considerably intuitive in device-level products. These results provide a scientific basis for the evaluation of maintainability.

References

- [1] Gan Maozhi, Fu guangfu, Wang Linshu, et al. GJB2072-94 Maintainability Test and Evaluation [S]. Beijing: Standards Press of China, 1994:10-15.
- [2] Lv Chuan. Maintainability Design Analysis and Verification [M]. Beijing: Distribution Department of National Defense Industry Press, 2012:150-160.
- [3] Wang Jiachao, Chang Tianqing, Zhu Bin, Wang Yuhao. Maintainability Information Analysis of Strapdown Inertial Navigation System
em Based on FMECA [J]. JOURNAL OF PROJECTILES, ROCKETS, MISSILES AND GUIDANCE, 2011,31(01):29-32.
- [4] Che Guolun. Research on State Monitoring Technology of Laser Gyro Strapdown Inertial Navigation System [D]. National University of Defense Technology, 2002.
- [5] He Zhongwu. Research and Application of RCM Technology at Home and Abroad [J]. Aeronautic Standardization & Quality, 2006(03):38-40.
- [6] Wang Changgao. Research on Reliability-centered Maintenance Thought [J]. Journal f Beijing University of Aeronautics and Astronautics (Social Sciences Editon), 1999(01):36-39.