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Qualitative Maintainability Evaluation of a Laser Inertial Navigation System

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***Abstract*—In this work, a qualitative analysis of maintainability is performed on the basis of a general and specially designed criteria in the early stage of equipment development. A qualitative evaluation system of maintainability is constructed by defining the design criteria of maintainability and combining it with the development stage of the current equipment. This system provides a comprehensive, objective, and systematic basis for the maintainability analysis of a laser inertial navigation system at the present stage of equipment development.**

***Keywords*—laser inertial navigation system;maintainability qualitative analysis; general and special design criteria**

I. INTRODUCTION

Maintainability is the ability of equipment to perform maintenance activities according to prescribed procedures and methods for maintaining or restoring its specified state under certain conditions within a specific period of time [1]. Qualitative and quantitative evaluation of maintainability are an important means to achieve good product maintenance [3]. A laser inertial navigation system provides position, orientation, speed information, and calibration functions for its equipment or platform and plays an important role in actual operations [4]. However, existing maintainability evaluation techniques fail to cover most qualitative design criteria, especially when special criteria are not combined with the characteristics of the laser inertial navigation system. Thus, an actual production design is hardly achieved, or the finished product effect cannot meet expected requirements [6]. On this basis, this work performs maintainability qualitative analysis on the subordinate devices of a laser inertial navigation system. This approach aims to guide a reasonable and comprehensive design of maintainability in the early stage of equipment development.

II. QUALITATIVE REQUIREMENTS FOR THE MAINTAINABILITY OF A LASER INERTIAL NAVIGATION SYSTEM

Maintainability analysis and engineering design are systematically performed in accordance with some related national standards to ensure that the maintenance time can be reduced under the same guarantee conditions.

III. GENERAL DESIGN CRITERIA FOR MAINTAINABILITY

This work proposes a general design criteria for maintainability (41 items in seven categories) and special design guidelines (36 items in system systems). Such approach aims to provide a comprehensive and targeted basis for the maintainability qualitative analysis of a laser inertial navigation system.

A. *Simple Design*

The functional integration and structural simplification of a laser inertial navigation system are satisfied under function and use requirements.

Fast unloading and locking structures are used to simplify disassembly and assembly operations.

B. *Design of Accessibility and Operability*

The route for the disassembly and assembly of parts should be a straight line or a gentle curve, which should not be bent or inverted and then removed.

Checkpoints, test points, and inspection windows of products should be laid out in an accessible position.

When checking or disassembling a part, other parts should not be disassembled and moved, or such operations should be reduced as much as possible.

Parts that need to be repaired and disassembled must have enough space around them for testing or disassembly.

During repair, the passageway should have a proper space for observation besides that for holding the maintenance personnel's hands or arms.

The operation force required in maintenance should be within the limit of human physical strength and must not easily cause fatigue to ensure operation efficiency.

The structure of the parts should be convenient for hand grasping.

Maintenance devices, such as fuses and indicator lights, should be installed in exposed positions for easy replacement.

C. *Generalized, Serialized, and Combined Design*

The use of universal parts should be maximized, and variety should be reduced.

Critical components with high failure rate and easy damage should have good interchangeability and necessary versatility.

Parts, groups, and components with the same function and symmetrical installation should be universally designed.

The mounting holes and brackets should adapt to the same type of finished parts and accessories produced by different factories.

The individual modules of the system should be easy to test separately after their removal.

Off-the-shelf components, tools, and test equipment should be used as much as possible.

Low-cost devices should be fabricated and labeled.

D. *Safety Design*

Maintenance signs, symbols, or instructional signs should be set in places where maintenance personnel must pay attention or maintenance errors often occur.

Striking signs and text warnings should be set up in locations where dangers might occur to prevent accidents that would endanger personnel and equipment safety.

Equipment should be properly arranged to avoid danger during operation, maintenance, repair, or adjustment. Such risks include dangerous chemicals, high-voltage electricity, electromagnetic radiation, cutting edges, and sharp parts.

The power supply, control devices, and critical components of redundant subsystems should be protected by isolation or shielding.

Hazardous materials, components, and operations should be isolated from other activities, areas, personnel, and incompatible equipment.

The risk of Levels I and II must be eliminated, and associated risks should be reduced to an acceptable level for the subscriber.

Safety measures, such as minimum risk design, safety and alarm devices, special procedures, and training, are used in sequence.

E. *Human Factor Engineering Design*

The component layout should ensure that maintenance personnel are in a comfortable position and posture during maintenance work.

Appropriate natural or artificial lighting conditions should be provided for the repair site.

The work of maintenance personnel should be consistent, and work difficulty should be appropriate.

The physical limits during raising, pulling, lifting, and rotating should be considered in maintenance operation.

F. *Error-preventive Design*

Parts with similar shapes and functions, important connecting parts, and those that are prone to errors during installation should be structurally distinguished or clearly marked.

The product should have necessary signs for error prevention and maintenance efficiency improvement.

Special designs, such as thread design in different directions, are used to avoid component reversal or misassembly.

Unified methods are adopted to simplify the coding and numbering of parts.

Design measures should be considered to prevent human error during connection and installation and ensure the immediate detection of connection and installation errors.

The external electrical connector should be marked.

G. *Test and Diagnosis Design*

Functional units should be reasonably divided.

Internal and external test equipment should be provided for the diagnostic object, and they should be repaired and calibrated for OnboardE (internal test set) performance.

Test of procedures (process) and external sources of excitation have no detrimental effects on the overall system.

All bus systems are accessible to various measurements.

Diagnostic applications should be designed and written for common functions to ensure that service personnel can quickly detect them.

The external equipment required for maintenance and its measurement process should be considered. Compatibility with external equipment and necessary test points should be considered.

The diagnostic system should be able to evaluate product use, state of the design unit, and output characteristics through appropriate measurements.

IV. Special Design Criteria for the Maintenance of a Laser Inertial Navigation System

Specific design guidelines (36 items for three systems) are developed for the characteristics of the system, in addition to the design according to the abovementioned eight qualitative requirements. This task aims to provide a comprehensive and targeted basis for the maintainability qualitative analysis of a laser inertial navigation system

A. *Display Control Transmitter*

1) Display and control panel: Names, numbers, or functions should be indicated on or near each function key, display, and numeric keypad.

The font color should complement the background for maximum visibility.

The signs used should be read horizontally, not vertically.

The marking of each button or knob should be in the same relative position.

Signs should be placed in a location that is not contaminated by grease, rubbing, dirt, or moisture.

2) Reinforcement of computers: Each processing module should use a quick-release device for easy installation and disassembly.

Each processing module can be independently tested after disassembly.

A free card slot should be reserved for the installation of redundant backup modules.

The reinforcement machine in the display control device should have good accessibility.

B. Power Supply Unit

1) Locking pins: The number should be strictly minimized, and the number of locking pins on one part should not exceed four. The volume can be large, but installing numerous locking pins with poor tightening ability is not advisable.

Standard parts are selected.

The locking pins should be equipped with torque protection to prevent excessive torque and damage.

Such pins should be regularly maintained to prevent rust.

Maintenance space should be as adequate as possible to improve accessibility.

The holes left in the installation should be slightly larger in diameter, thus facilitating the insertion of the locking pins and not requiring initial complete alignment.

2) Power supply: The power supply should be designed in an environment away from hazardous features and properly protected to ensure proper operation under any temperature.

The fixing device of the power supply should be firm and reliable and convenient for battery disassembly and repair, thereby preventing shocks during the working process of the ship.

Ventilation and cooling should be performed.

C. Inertial Device

The inertial device should be installed in a position that is easy to reach after the casing has been opened.

A modular design should be adopted for inertial devices.

1) Inertial measurement components: Inertial measurement components should be divided into several module units according to the actual electricity and machinery needs.

All modules should be as small and uniform as possible to facilitate assembly. The module design should be tested after removal from the equipment, and almost no calibration is required after replacement on the equipment.

Maximum functional independence and minimal interference between modules are required.

Each module can be independently inspected as much as possible.

The laser gyro inertial measurement unit should be close to the housing position.

The relevant processing circuit in the laser gyro inertial measurement unit should be modularized and installed and repaired in the form of modules.

2) *Lubrication of the double-axis rotating mechanism:* Structure design must not require lubrication, especially for parts where lubrication is inconvenient.

If lubrication maintenance procedures have to be adopted, then lubrication maintenance interfaces should be concentrated as far as possible to reduce lubrication time.

Protective measures should be formulated for certain oil injection nozzles. Such measures should be indirectly exposed to air, or they will be prone to pollution.

The interface for lubrication and maintenance should be easily accessible for maintenance.

Tools used for lubrication should be standardized as much as possible.

Lubrication interfaces must have clear instructions or color warnings.

Lubrication procedures, diagrams, and types of lubricants to be added should be included in the lubrication area.

The lubrication interface should not be protruded as far as possible to reduce the possibility of damage.

Lubrication port accessories must have warning signs and safety equipment.

3) *Hydraulic device:* The hydraulic device should be designed for lubrication, maintenance, inspection, and replacement.

V. MAINTAINABILITY QUALITATIVE ANALYSIS

A. Overview of Maintainability Qualitative Analysis

A qualitative analysis of the product's maintainability is conducted to determine whether the product design meets the specified maintainability qualitative requirements. Maintenance qualitative analysis aims to analyze the degree to which the developed product meets the qualitative requirements for maintainability. During the analytical process, the design defects related to the maintainability of equipment are found and identified. Accordingly, corrective measures can be taken to improve design and achieve maintainability growth.

The following maintenance qualitative analysis work is performed during the laser inertial navigation system program:

1) Design of accessibility: The reinforcement machine in the display control device is a product of a navy standard setting series, which has good accessibility.

The inertial device is modular in design and mounted in an accessible position after the shell has been opened.

The relevant processing circuits in the laser gyro inertial measurement unit are modularized, and the mounting box is repaired and replaced in the form of a module close to the shell.

Repair devices, such as fuses and indicator lights, are installed in a clearly exposed position for easy replacement. All electrical stand-alone thicknesses are designed to provide service access.

2) Standardized, interchangeable, and modularized design: In the equipment design, a “Standardization Outline” is formulated to guide the standardization design. For example, the display control and power supply devices, keyboard, and power module have adopted the standardized products. The boards in the chassis have the same structure and connector standards, and the electrical singles of each device are modularly designed, installed, and repaired in modules. The printed boards are distributed in accordance with the function modules, and the printed boards are not replaced using special tools but with a plug-in type.

3) Antierror measures and identification design: The device connector is printed with a clear logo, and the connector uses different keys to prevent misinsertion.

All cables and transmission wires identify cable and line numbers.

A protective cover is designed for the AC power switch.

Power-on protection design measures are made for the electrical single unit to prevent the power-on error from burning the circuit.

The software is designed to be robust against maloperation.

4) Maintenance safety design: The power module of the equipment is designed for overcurrent protection and will be automatically protected in case of short circuit during maintenance. The transmission and control of an AC 220 V and a servo drive 28 V power supply adopt strict insulation protection measures to protect maintenance safety.

In the equipment design, each single electrical machine performs self-inspection and fault diagnosis design. The software design can perform real-time online detection when necessary. Each single machine is also powered with evident indication design, which is convenient for the maintenance personnel when conducting visual tests.

The qualitative analysis of the maintainability of the inertial and power supply devices and the display and control devices are performed in combination with the disassembly of the LRU in the laser inertial navigation system, mainly analyzing the following: whether the modular setting of the laser inertial navigation system is reasonable; accessibility of personnel during maintenance operation; whether the product error prevention measures and identification mark design meet the requirements; degree of interchangeability and standardization of spare parts; safety of personnel during maintenance operation; whether the maintenance operation meets the requirements of human engineering; operability of the maintenance of components and parts; and whether the testing and diagnosis methods of products, applicability of maintenance tools, and preventive maintenance design of products are reasonable. Lastly, the identified maintainability problems are classified into Levels I, II, and III, and the corresponding improvement suggestions are provided.

B. *Summary of Maintainability Qualitative Problems*

In view of the analysis of the maintenance problem, the problems are classified into Levels I, II, and III considering the degree of influence of each maintenance problem on the product and improving the possibility and economy of the design. Level I consists of serious problems, which greatly affects maintainability in practical use and must be improved. Level II includes important problems, which have a relatively great effect on maintainability in practical use and should be improved in accordance with the actual situation. Level III is composed of minor problems, which have a certain effect on maintainability in practical use, and improvement can be decided in accordance with the actual situation. Suggestions are then proposed for the improvement of each problem, as shown inTable **2**.

The accessibility, error preventive measure and maintenance mark, modularity, interchangeability and standardization, maintenance safety, human factor engineering, operability, test diagnosis, maintenance tools, and preventive maintenance are systematically analyzed for the three devices of the inertial system. Few maintainability problems are found, with proposed suggestions for improvement. Analysis results show that the modular design of the inertial system is reasonable. Various qualitative aspects of maintenance are considered to meet the qualitative requirements of maintainability.

TABLE I. DEFINITIONS OF THE THREE LEVELS OF MAINTAINABILITY PROBLEMS

Level	**Definitions**
I	Serious problems have a great effect on maintainability in practical use and must be improved.
II	Important problems have a relatively great effect on maintainability in practical use and should be improved in accordance with the actual situation.
III	Minor problems have a certain effect on maintainability in practical use, and the improvement can be decided in accordance with the actual situation.

TABLE II. SUMMARY OF MAINTAINABILITY QUALITATIVE PROBLEMS

No.	Problem description	Types involved	The system where the problem is located	Level of problem	Suggestions for improvement
1	The three modules of the calculation circuit control component are evenly distributed outside the inertial device, and the shape and size of the module are similar, with no evident identification. Misassembly might occur during installation.	Error prevention and identification mark	Inertial device	Class I	The three modules are identified by text or color.
2	Seven pluggable circuit board modules are installed side by side in the ruggedized computer. The power modules are similar in shape and size with no evident identification. Misassembly might occur during installation.	Error prevention and identification mark	Display control device	Class I	The corresponding slots of the seven modules are identified by text or color.
3	Approximately 24 and 60 V redundant power supplies must be regularly charged, but the charging interval is uncertain and cannot guide preventive maintenance work.	Preventive maintenance	Power supply unit	Class II	Clarify the charging period of redundant power supply
4	The three modules of the calculation circuit control component are evenly distributed at the bottom of the inertial device. After the inertial device has loaded, the inner module may be blocked depending on the installation position.	Accessibility	Inertial device	Class II	Do not block when installing
…	…	…	…	…	…

VI. CONCLUSION

In this work, systematic analysis of ten aspects is performed on the basis of the general and special design criteria for maintenance qualitative analysis. These aspects include modularization, accessibility, error-preventive measure and maintenance mark, interchangeability and standardization, maintenance safety, human factor engineering, operability, test diagnosis, maintenance tools, and preventive maintenance. Few maintenance problems are found, and suggestions for improvement are proposed. Analysis results show that the modular design of the laser inertial navigation system is reasonable, and the maintenance qualitative aspects are considered comprehensive to meet the maintainability qualitative requirements. In each iteration, the subsequent stages can be designed in accordance with the maintainability qualitative problems found in the previous stage, thus effectively improving the maintainability design level of the system.

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