CHINA CLASSIFICATION SOCIETY

# RULES FOR INTELLIGENT SHIPS

# 2015

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# CONTENTS

# Chapter 1 General

## 1.1 General requirements

1.1.1 The Rules apply to ships for which CCS Intelligent Ship class notation is requested.

1.1.2 Intelligentization means applications specific to certain object which are integrated by means of modern communication and information technology, computer network technology and intelligent control technology. Such applications generally include, but not limited to, assessment, diagnosis, prediction and decision making. Intelligentization is generally characterized by:

(1) Perception, i.e. the ability to perceive the outside world and obtain outside information;

(2) Memory and thinking, i.e. the ability to store perceived outside information and knowledge arising from thinking, and at the same time analyze, calculate, compare, judge, associate and make decisions on information by making use of available knowledge;

(3) Learning and self-adaptability, i.e. the ability to continuously learn and accumulate knowledge by interacting with the environment so as to be adaptable to environmental changes;

(4) Behavioral decision making, i.e. the ability to respond to external stimulus, make decisions and convey relevant information.

1.1.3 Intelligent ships are those ships which automatically perceive and obtain information and data on ship itself, marine environment, logistics and port by making use of sensors, communication, the Internet of Things, the Internet and other technical means, and achieve intelligent operation in terms of ship navigation, management, maintenance and cargo transportation based on computer technology, automatic control technology and big data processing and analyzing technology, so that ships can become safer, more environmentally friendly, economical and reliable.

1.1.4 The functions of intelligent ships consist of intelligent navigation, intelligent hull, intelligent machinery, intelligent energy efficiency management, intelligent cargo management and intelligent integration platform.

1.1.5 Ships, for which an Intelligent Ship class notation is requested, are also to comply with the relevant requirements of CCS rules and those of the Administration of the flag State.

## 1.2 Application of new technology

1.2.1 The intelligent ship technology is developing continuously. Where the application of CCS rules hinders the application of new technologies, the design of system and equipment adopting the new technology may deviate from the requirements of CCS rules provided that such system and equipment can provide an equivalent level of safety to that required by CCS rules subject to risk assessment and test.

1.2.2 The risk assessment may be carried out in accordance with CCS Guidelines for Application of Formal Safety Assessment of Ships (2015) or a method given in relevant national or international standards.

1.2.3 The new technology may be approved by referring to the Guidelines for the Approval of Alternatives and Equivalents as provided for in Various IMO Instruments (MSC/Circ.1455).

## 1.3 Alterations and repairs

1.3.1 For a ship assigned Intelligent Ship class notation, which has undergone any alteration or repair of its equipment or system in association with intelligent ship functions, is to be subject to a survey, as appropriate, for confirming compliance with the technical requirements for the existing notation.

## 1.4 Class notation for intelligent ships

1.4.1 A ship, which has, upon its request, undergone plan approval and surveys by CCS and its compliance with the requirements of the Rules in terms of intelligent navigation, intelligent hull, intelligent machinery, intelligent energy efficiency management, intelligent cargo management and intelligent integration platform is confirmed, may be assigned the following Intelligent Ship class notation:

**i-Ship (Nx, Hx, Mx, Ex, Cx, Ix)**

where the letters in the parentheses stand for functional notations of intelligent ships, which may be assigned in accordance with the functions possessed by the ship. Functional notations can be added based on the development of technology.

1.4.2 Functional notations are defined as follows:

N – functional notation for intelligent navigation, for which the requirements of Chapter 2 of the Rules are to be satisfied;

H – functional notation for intelligent hull, for which the requirements of Chapter 3 of the Rules are to be satisfied;

M – functional notation for intelligent machinery, for which the requirements of Chapter 4 of the Rules are to be satisfied;

E – functional notation for intelligent energy efficiency management, for which the requirements of Chapter 5 of the Rules are to be satisfied;

C – functional notation for intelligent cargo management, for which the requirements of Chapter 6 of the Rules are to be satisfied;

I – functional notation for intelligent integration platform, for which the requirements of Chapter 7 of the Rules are to be satisfied;

x – additional notation for optional function. One small letter stands for one additional notation for function and a functional notation may have multiple additional notations for function. Detailed requirements are given in Chapters 2 to 7.

1.4.3 The assignment, maintenance, suspension, cancellation and reinstatement of Intelligent Ship class notation are to be in accordance with the requirements of Section 9, Chapter 2 of PART ONE of CCS Rules for Classification of Sea-Going Steel Ships.

## 1.5 Computer systems

1.5.1 Relevant hardware and software of intelligent systems covered by the Rules are to satisfy the relevant requirements of Section 6, Chapter 2, PART SEVEN of CCS Rules for Classification of Sea-Going Steel Ships and to be subject to plan approval and survey by CCS.

1.5.2 Software development is to satisfy the requirements of CCS Guidelines for Assessment of Security and Reliability of Marine Software (GD11-2015).

1.5.3 Risk assessment is to be carried out to the system. During system design and analysis, relevant failure conditions and system response to such failure conditions are to be determined. The interaction between faults is to be eliminated or restricted by means of design of software and hardware of relevant equipment while fault detection and tolerance are to be provided. In addition to the software testing within the normal range, the testing in abnormal range is also to be carried out, in order to ensure correct response ability of equipment and software under abnormal input and condition.

### 1.6 Personnel requirements

1.6.1 The owner or ship management company is to develop corresponding management regulations, training plans and operational procedures for intelligent systems, in order to specify requirements such as responsibilities, qualifications and training of personnel operating and using intelligent systems.

1.6.2 Relevant personnel are to receive pre-post training, obtain qualification, and be familiar with the operation of intelligent system.

# Chapter 2 Intelligent Navigation

## 2.1 General requirements

2.1.1 The requirements of this Chapter apply to ships for which the functional notation for intelligent navigation is requested.

2.1.2 Intelligent navigation makes use of computer technology and control technology to carry out analysis and processing of information that is perceived and obtained, as well as design and optimization of ship's route and speed; if feasible, the ship can prevent collision automatically in open water, narrow channel and complex environmental condition and realize autonomous navigation.

2.1.3 The basic function of intelligent navigation is route design and optimization.

2.1.4 In addition to the basic function of 2.1.3, intelligent navigation may also have the following additional functions:

(1) Autonomous navigation;

(2) Advanced autonomous navigation.

## 2.2 Functional notation for intelligent navigation

2.2.1 Upon request, the following functional notation for intelligent navigation may be assigned subject to satisfactory plan approval and survey by CCS:

Nx

where: N – the ship with the basic function of intelligent navigation;
x – notation for additional function, expressed by the following small letters:
o – the ship with function of autonomous navigation;
n – the ship with function of advanced autonomous navigation; in this case, the assignment of notation for additional function of autonomous navigation o is not necessary.

## 2.3 Plans and documents submitted for approval

2.3.1 For route design and optimization, the following plans and documents are to be submitted to CCS:

(1) System composition diagram;

(2) Software functions of route design and optimization;

(3) Mooring test and sea trial programme.

2.3.2 For autonomous navigation and advanced autonomous navigation, the following plans and documents are to be submitted to CCS:

(1) Description on composition and function of shore-based supporting center, navigation system in severe weather, emergency handling, automatic collision prevention system and track monitoring system;

(2) Risk analysis of autonomous navigation and advanced autonomous navigation, including failure mode and effect analysis of propulsion system, ship's steering gear system, navigation system and auxiliary system;

(3) Mooring test and sea trial programme.

## 2.4 Route design and optimization

2.4.1 For route design and optimization, the route and ship speed are designed and optimized to minimize the fuel consumption, which is continuously optimized throughout the navigation period, in accordance with the technical condition and performance of ship, specific navigation task, draft, cargo characteristics and sailing schedule and by taking into full consideration such factors as wind, wave, current and swell, provided that the safety of ship, personnel and cargo is guaranteed.

2.4.2 Route design and optimization generally consist of shipborne systems and shore-based supporting center.

2.4.3 Ship performance calculation model is to be available for route design and optimization. The following data (if available) is in general to be considered:

(1) Ship general arrangement drawing;

(2) Ship lines plan and midship section with bilge keel details;

(3) Hydrostatic curves;

(4) Main engine particulars and shaft generator details;

(5) Main engine shop test results;

(6) Model test or ship trial reports;

(7) Typical past voyage reports showing ship speed, rate of revolution, power and fuel oil consumption (such data may be obtained from relevant systems of Chapter 5);

(8) Ship's performance of resistance against wind and wave.

Where such data is unavailable, the model may be established by means of theoretical analysis and empirical curves. Improvement is made continuously by data obtained from real ship.

2.4.4 The short-term and long-term weather data is to be considered and updated for route design and optimization. The following data is to be obtained periodically:

(1) Wind speed and direction;

(2) Wave height and mean period;

(3) Swell height, direction and mean period;

(4) Current speed and direction;

(5) Tropical cyclone (or typhoon): maximum wind speed, gust speed, radius etc.;

(6) Extratropical cyclone: central pressure, moving path and speed, cold/warm front etc.;

(7) Warning of strong cold high pressure (cold wave and gale);

(8) Ice condition (where applicable).

2.4.5 The following optimized functions are in general to be available for route design and optimization:

(1) Determined time of arrival;

(2) Shortest navigation period;

(3) Minimum fuel oil consumption;

(4) Minimum total cost;

(5) Highest wind and wave scale the ship withstands.

2.4.6 The ship is to be provided with:

(1) Data communication equipment: communication connection is to be established to the shore base to facilitate exchange of information;

(2) Electronic chart display and information system;

(3) Electronic positioning equipment;

(4) Anemorumbometer;

(5) Gyro-compass;

(6) Speed and distance measuring device.

2.4.7 Route design and optimization systems are to comply with the requirements for category I computer systems.

**2.5 Autonomous navigation**

2.5.1 The ship has the ability of autonomous navigation in open water.

2.5.2 The ship is provided with integrated navigation system①, as well as shore-based supporting center, navigation system in severe weather and emergency handling system etc.

2.5.3 The ship is provided with automatic collision prevention system in open water, which can realize automatic collision prevention in accordance with intended route and conduct autonomous navigation.

2.5.4 For ships applying for autonomous navigation, any foreseeable risk due to autonomous navigation in open water is to be considered and comprehensive risk assessment is to be carried out.

2.5.5 Autonomous navigation systems are to comply with the requirements for category III computer systems.

**2.6 Advanced autonomous navigation**

2.6.1 The ship is to have the ability of autonomous navigation.

2.6.2 The ship is provided with automatic collision prevention system for narrow channel and has the ability of realizing autonomous navigation in complex environmental conditions.

2.6.3 The ship can realize automatic approaching and leaving docks.

2.6.4 For ships applying for advanced autonomous navigation, any foreseeable risk due to autonomous navigation in open water and narrow channel and during the process of automatic approaching and leaving docks is to be considered and comprehensive risk assessment is to be carried out.

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① The requirements of performance standards for Integrated Navigation Systems (INS) as amended by resolution MSC.252(83) are to be complied with.

2.6.5 Advanced autonomous navigation systems are to comply with the requirements for category III computer systems.

## 2.7 Survey and test

### 2.7.1 Initial survey

2.7.1.1 Relevant plans have been examined.

2.7.1.2 Confirming that the system is furnished with relevant certificate.

2.7.1.3 Confirming the input, output and communication functions of intelligent navigation system.

2.7.1.4 Based on different input conditions, route simulation as well as ship speed design and optimization are carried out, and software function is verified.

2.7.1.5 Confirming that relevant charts have been updated as appropriate.

2.7.1.6 Verifying the function of autonomous navigation and advanced autonomous navigation (where applicable) as well as the ability to handle severe weather and emergency at sea trial.

### 2.7.2 Survey after construction

2.7.2.1 Previous service condition of systems are reviewed at annual, intermediate and special surveys to confirm that they are in normal condition.

2.7.2.2 Functions of the equipment and system are to be re-verified after their repair and renewal. Sea trial is to be carried out after repair or renewal of the automatic collision prevention system and autonomous navigation system.

# Chapter 3 Intelligent Hull

## 3.1 General requirements

3.1.1 The requirements of this Chapter apply to ships for which the functional notation for intelligent hull is requested.

3.1.2 Intelligent hull provides assistant decision-making on safety and structural maintenance within the lifecycle of hull based on the establishment and maintenance of hull database; Meanwhile it provides assistant decision-making on ship manoeuvring by means of automatic acquisition and monitoring of data related to hull.

3.1.3 Hull lifecycle management includes the following functions:

(1) Hull construction monitoring and management;

(2) Thickness monitoring and strength assessment of hull structures;

(3) Hull inspection and maintenance scheme;

(4) Damage stability and residual strength assessment of structure.

3.1.4 Hull monitoring and assistant decision-making system includes the following functions:

(1) Hull monitoring system;

(2) Assistant decision-making system of navigation.

3.1.5 System software covered by this Chapter is to satisfy the requirements for category II computer software.

## 3.2 Functional notation for intelligent hull

3.2.1 Upon request, the following functional notation for intelligent hull may be assigned subject to satisfactory plan approval and survey by CCS:

Hx

where: H – the ship with the function of hull lifecycle management;
x – notation for additional function, expressed by the following small letter:
m – the ship with hull monitoring and assistant decision-making system.

## 3.3 Hull lifecycle management

3.3.1 General requirements

3.3.1.1 Hull database for the hull lifecycle management is to be established, where the data generated by various stages of hull design, construction and service is stored and transmitted in the form of standardized electronic data, and maintained and updated timely within the lifecycle of ship. Meanwhile digital transmission technology is used to integrate hull monitoring data with inspection and maintenance data of hull structures, providing technical safeguard for effective structural inspection, maintenance and repair. The condition of hull structures is known on real-time basis and the maintenance plan is developed in advance for the purpose of implementing lifecycle management of hull from construction to service, in order to achieve the objective of reducing maintenance cost of structures and prolonging service life of structures.

3.3.1.2 Hull database for the lifecycle management is to include geometric model of hull structures, structural strength analysis model and calculation model of hull performance. The requirements for structural strength analysis and hull performance models are as follows:

(1) The structural strength analysis model is to comply with the requirements of relevant CCS rules/guidelines, including FE model of cargo tank and/or ship and calculation model of hull girder longitudinal strength and local strength of structural members. The calculation and analysis related to yielding, buckling, fatigue strength, ultimate strength and residual strength are realized based on the applicable requirements of relevant CCS rules/guidelines.

(2) The calculation model of hull performance is to comply with statutory requirements, realizing calculation and analysis of intact stability and damage stability.

3.3.1.3 The electronic files of ship construction management are established based on geometric model of hull structures at construction stage, including critical location/precision of structures and record of process of survey during construction.

3.3.1.4 The structural thickness measurement database is to be established based on geometric model of hull structures at in-service stage, in order to monitor change of thickness of hull structures, predict trend of corrosion and conduct assessment of hull structural strength. A periodical inspection and maintenance scheme specific to hull structures is to be developed, in order to provide guidance to crew on routine inspection and maintenance.

3.3.1.5 Calculation and analysis of damage stability and residual strength are to be provided, in order to provide technical assessment for the ship in emergency.

### 3.3.2 Plans and documents

3.3.2.1 For the lifecycle management, the following information is to be submitted to CCS:

(1) Instruction of design of hull database;

(2) Hull construction monitoring plan;

(3) Relevant information on computer systems of hull construction monitoring and management;

(4) Relevant information on computer systems of hull inspection and maintenance scheme;

(5) Relevant information on shore-based organization for calculation and analysis of damage stability and residual strength.

3.3.2.2 The following information is to be readily available on board the ship:

(1) Hull thickness measurement report for the last 5 years;

(2) Analysis report of hull thickness measurement data for the last 5 years;

(3) Assessment report of longitudinal strength for the last 5 years (where applicable);

(4) Assessment report of fatigue strength (where applicable);

(5) Relevant information on hull inspection and maintenance scheme.

### 3.3.3 Hull construction monitoring and management

3.3.3.1 Hull construction monitoring and management carry out monitoring and management of hull construction process by using computer systems, maintain records and documents of surveys of newbuildings and form electronic files of hull construction and monitoring, in order to provide basis for routine maintenance and repair in shipyard of hull in service. The system is to satisfy the requirements of 3.3.3.2 and 3.3.3.3.

3.3.3.2 All hull survey items in the survey checklist jointly developed by the owner, shipyard and classification society are covered. Based on the geometric model of hull structures, the hull block, block assembly and survey history of compartments during construction process are recorded, and the comments, conclusions, photos and electronic files during survey process are recorded.

3.3.3.3 In accordance with CCS Guidelines for Construction Monitoring of Hull Structures, monitoring is carried out to alignment, fit-up, groove preparation and workmanship of the critical locations of the relevant hull structures, to ensure that the critical locations are built to both an acceptable quality standard and approved construction procedures. Construction monitoring of hull structures is to satisfy the requirements of CCS Guidelines for Construction Monitoring of Hull Structures.

### 3.3.4 Thickness monitoring and strength assessment of hull structures

3.3.4.1 For thickness monitoring and strength assessment of hull structures, the database of structural thickness is established within the in-service period of ship from completion of construction to decommissioning by using computer systems and based on the geometric model of hull structures, for which the requirements of 3.3.4.2 to 3.3.4.4 are to be satisfied.

3.3.4.2 Previous thickness measurement data and renewal history of structural members are recorded. Statistical analysis is carried out to previous thickness measurement data. Corrosion condition of hull structures is shown intuitively and the trend of corrosion is predicted based on the change of thickness of structural members and the environment.

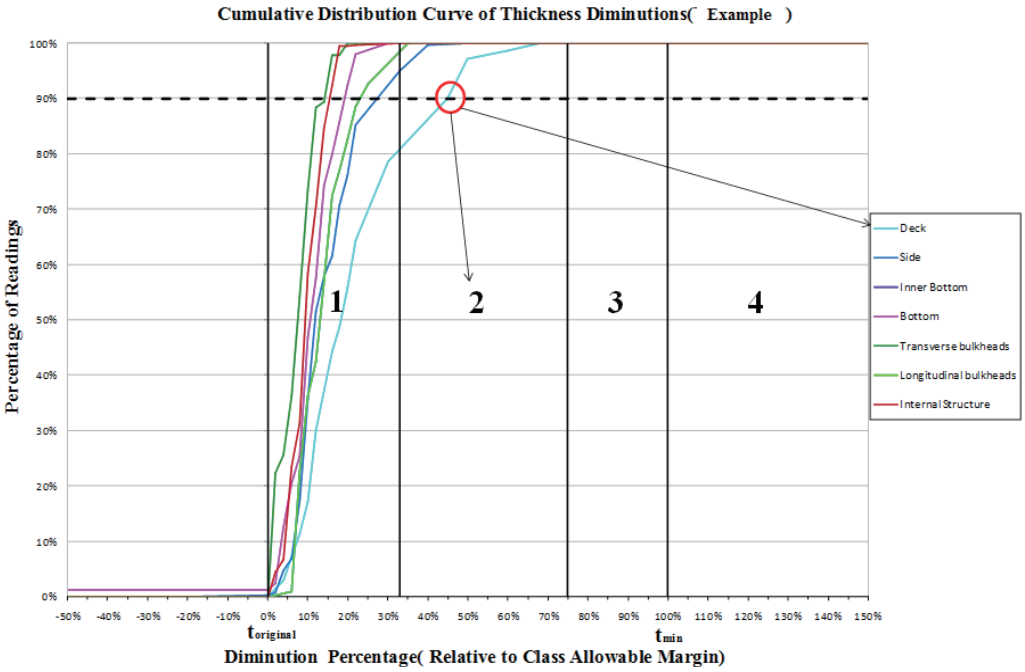
3.3.4.3 The thickness measurement data is analyzed and graded in accordance with the following requirements based on collected thickness measurement data:

(1) The hull structure is divided into several compartments/spaces/areas, e.g. ballast tanks, cargo tanks (including void spaces, pump rooms etc.) and external structures (exposed strength deck and shell plating). For the thickness measurement data of each compartment/space/area, the statistical analysis method of 90% reliability (S-Curve method) is used for analysis.

(2) For the boundary and structural members of each compartment/space/area, they are in general divided into several structural elements (including plates and attached stiffeners): deck structure, side structure, bottom structure, inner bottom structure, transverse bulkhead structure, longitudinal bulkhead structure and internal structure (hatch cover and coaming are also to be included where applicable). Each structural element is divided into grade 1 to 4 as follows:

| | Grade | | | |
|---|---|---|---|---|
| | 1 | 2 | 3 | 4 |
| Diminution percentage, $r$ | $r \leq 33\%$ | $33\% < r \leq 75\%$ | $75\% < r \leq 100\%$ | $r > 100\%$ |

(3) The grading result of thickness measurement is determined based on the grading section where the intersection point of 90% horizontal line (e.g. the horizontal dotted line in the figure below) and thickness measurement curve is located (e.g. the thickness measurement of deck is assessed as grade 2 in the figure below).




(4) For compartments/spaces with common boundaries, the thickness measurement data of the common boundary is to be included in the compartment/space on both sides respectively.

3.3.4.4 The strength assessment of hull structures may be carried out as necessary based on the hull database.

### 3.3.5 Hull inspection and maintenance scheme

3.3.5.1 For hull inspection and maintenance scheme, a periodical inspection and maintenance scheme of hull structures is developed based on the geometric model of hull structures, in connection with the characteristics of hull structures and survey records of newbuildings and in accordance with class/statutory survey requirements and the needs of ship companies during the service life by using computer systems, for the purpose of providing guidance to crew on routine inspection and maintenance. The system is to satisfy the requirements of 3.3.5.2 to 3.3.5.6.

3.3.5.2 General inspection items, critical area and typical defect diagram are to be developed in accordance with the characteristics of hull structures, ship design, construction, plan approval and calculation and guidelines for survey of ships in service as well as strength assessment during the service life.

3.3.5.3 The inspection results of coating and structure as well as structural defects in each structural area of ship compartments are to be recorded. The inspection results of coating and structure, structural corrosion condition, defects and repair history are to be shown intuitively, including the following:

(1) Inspection standards and grading principle are to be established for “coating, average corrosion, pitting corrosion, grooving corrosion, deformation and crack”, generally consisting of GOOD, FAIR and POOR.

(2) In accordance with the inspection results of each structural area of ship compartments, the condition of each structural area and the compartment as a whole is to be graded, generally consisting of GOOD, FAIR and POOR.

(3) For structural areas graded as FAIR or POOR, the system is to provide necessary reminder and follow up.

3.3.5.4 The survey history of construction of hull structures, information on the size of structural members of hull structures, historical data of thickness measurement, defect and repair history are reviewed.

3.3.5.5 The coating area and the weight of structural members during ship repair are calculated. The repair work amount is assessed.

3.3.5.6 In addition to the periodical inspection and maintenance scheme, the hull monitoring system is integrated with the hull inspection and maintenance scheme by digital transmission technology. In connection with the thickness monitoring and strength assessment of hull structures, the practical condition and reliability of ship are analyzed comprehensively and an interim inspection and maintenance scheme of hull structures is developed.

### 3.3.6 Survey

3.3.6.1 Prior to completion of construction of ship, the initial survey is at least to include the following items:

(1) The geometric model of hull structures, structural strength analysis model and calculation model of hull performance specified in the design instruction of hull database satisfy relevant requirements of this Chapter.

(2) Examining the approval certificate of system software.

(3) The hull construction monitoring plan is implemented satisfactorily.

(4) The survey items in the computer system of hull construction monitoring and management are complete; system records are complete and consistent with practical conditions.

(5) The computer system of hull inspection and maintenance scheme has been installed on board the ship and operates normally.

(6) General inspection items, critical areas and inspection interval of hull inspection and maintenance scheme satisfy requirements.

(7) Personnel carrying out hull inspection and maintenance on board the ship have been trained by CCS or an organization accepted by CCS.

3.3.6.2 The annual/intermediate/special survey is at least to include the following items:

(1) The information specified by 3.3.2.2 is to be readily available on board the ship.

(2) The thickness data of structural members and renewal history recorded in the structural thickness database are consistent with practical conditions.

(3) The analysis report of hull thickness measurement data satisfies the requirements of 3.3.4.3.

(4) Personnel carrying out hull inspection and maintenance on board the ship have been trained by CCS or an organization accepted by CCS.

(5) Witnessed by the surveyor, inspectors on board the ship randomly select at least two ballast tanks for internal inspection, correctly determine the coating and structural conditions of the structural area under inspection and correctly enter the identified problem and assessed grade into the computer system.

(6) The records in the computer system of hull inspection and maintenance scheme are complete and consistent with practical conditions.

## 3.4 Hull monitoring and assistant decision-making system

### 3.4.1 General requirements

3.4.1.1 The hull monitoring and assistant decision-making system collects, stores, analyzes and displays data such as hull structural stress, ship motion, ship loading, sea state, course and speed, which gives warning in case the change of such data exceeds the preset critical value and provides assistant decision making on guiding navigation and operation of ship.

3.4.1.2 The hull monitoring and assistant decision-making system is to satisfy the following requirements:

(1) Collecting and monitoring important parameters related to the safety of hull structures;

(2) Storing collected data;

(3) Carrying out calculation and abnormal analysis in accordance with the data collected by the monitoring system;

(4) Capable of giving alarms in a timely manner in case the analytical result is abnormal;

(5) Providing decision-making suggestions on ship operation in accordance with alarm parameters;

(6) Analyzing and recording sea state information and navigation parameters by online link to the loading computer, navigation sensors (GPS, speed log, gyro compass, rudder angle etc.) and wind sensor.

### 3.4.2 Plans and documents

3.4.2.1 For hull monitoring and assistant decision-making system, the following information is to be submitted to CCS:

(1) System diagram;

(2) System operating manual;

(3) System hardware specification;

(4) System instructions;

(5) System testing procedure.

### 3.4.3 Hull monitoring system

3.4.3.1 The hull monitoring system is to comply with the relevant requirements of Chapter 21 Hull Monitoring Systems, PART EIGHT of CCS Rules for Classification of Sea-Going Steel Ships.

3.4.3.2 In connection with the distribution characteristics of hull structural stress of various ship types, the hull monitoring system is to monitor important parameters related to the safety of hull structures and parameters related to the sea state, generally including:

(1) Longitudinal strength of hull structures;

(2) Critical areas of hull structures, e.g. cargo hatch corner of large container ships;

(3) Ship motion, e.g. rolling angle and pitching angle;

(4) Acceleration of ship motion, e.g. vertical acceleration and transverse acceleration;

(5) Bow slamming;

(6) Sloshing in the tank (for tankers);

(7) Structural temperature (for tankers carrying liquid cargo of high or low temperature);

(8) Sea state, e.g. wind force, wind direction and sea wave;

(9) Navigation parameters, e.g. course and speed;

(10) Relevant monitoring parameters may be determined or further added in accordance with practical conditions of ship and safety needs.

**3.4.4 Assistant decision-making system**

3.4.4.1 In order to realize the assistant decision-making function of system, sufficient sensors are to be fitted in accordance with the needs of ship type to guarantee the assistant decision-making ability of system.

3.4.4.2 In accordance with the monitoring and alarm given by the monitoring system with regard to ship navigation, loading and unloading in port and docking condition, the assistant decision-making system is to be capable of providing assistant decision making on relevant operations. In general the following requirements are to be considered:

(1) In case an alarm is given with regard to parameters such as hull structural stress, ship motion and acceleration, bow slamming pressure and tank sloshing pressure during navigation, the system is to be capable of carrying out general calculation, analysis and assessment of hull structure in accordance with current sea state, course and speed, and giving operating instructions on whether to change course, speed and ship motion.

(2) In case an alarm is given with regard to hull structural stress during loading and unloading in port, the system is to be capable of providing guidance on whether to continue loading and unloading, adjusting cargo tanks for loading and unloading as well as speed of loading and unloading.

(3) In case an alarm is given with regard to hull longitudinal deformation when the ship is docked and repaired, the system is to be capable of providing measures of adjusting the arrangement of docking block.

(4) Relevant assistant decision-making functions may be determined or further added in accordance with practical conditions of ship and safety needs.

**3.4.5 Survey**

3.4.5.1 The initial survey is at least to include the following items:

(1) Confirming that relevant plans and documents have been examined;

(2) Confirming that system hardware products (including sensors) are furnished with relevant certificates;

(3) Confirming that system software has been approved in accordance with category II software;

(4) After completion of installation of equipment, survey and test are carried out in accordance with testing procedures and calibration procedures for monitoring devices to verify system function.

3.4.5.2 Previous service conditions of the following systems are to be reviewed at annual/intermediate/special surveys to confirm that the hull monitoring and assistant decision-making system operates in normal condition:

(1) Maintenance record of hull monitoring and assistant decision-making system;

(2) General operating condition of hull monitoring and assistant decision-making system;

(3) Details and cause analysis of system fault/failure;

(4) Repair record and replacement of spare parts.

3.4.5.3 In addition to the contents of 3.4.5.2, the following items are also to be examined:

(1) Examining whether the hull monitoring and assistant decision-making system operates effectively;

(2) Examining the detailed working record of hull monitoring and assistant decision-making system;

(3) Examining the repair record of system equipment;

(4) Confirming that the historical and analytical data of the hull monitoring and assistant decision-making system is complete and carrying out random examination of report contents;

(5) Confirming that operators are familiar with the hull monitoring and assistant decision-making system and confirming the implementation condition;

(6) Some testing and analysis processes need to be verified if deemed necessary by the surveyor;

(7) Examining and confirming that relevant instrumentation of the hull monitoring and assistant decision-making system has been calibrated in accordance with specified procedures and plans.

3.4.5.4 In case of any fault of the hull monitoring and assistant decision-making system, or any damage, repair or renewal of equipment, or any major change to the means of monitoring, the owner or ship management company is to apply for an occasional survey.

# Chapter 4 Intelligent Machinery

## 4.1 General requirements

4.1.1 The requirements of this Chapter apply to ships for which the functional notation for intelligent machinery is requested.

4.1.2 Intelligent machinery is capable of carrying out analysis and assessment of the operating condition and health condition of machinery installations in machinery space by comprehensively using various information and data collected by the condition monitoring system, which is used for decision making on operating machinery installations and developing maintenance plan.

4.1.3 Intelligent machinery is to have the following basic functions:

(1) Carrying out monitoring of the operating condition of main propulsion engine(s), engines used for auxiliary power generation and shafting;

(2) Carrying out analysis and assessment of the operating condition and health condition of machinery installations based on data collected by the condition monitoring system;

(3) Providing suggestions on correction based on the result of analysis and assessment, in order to provide suggestions for decision making on ship operation.

4.1.4 In addition to the basic functions of 4.1.3, relevant condition-based maintenance plan may be developed in accordance with the result of analysis and assessment of the operating condition and health condition of machinery installations, which is used as the additional function of intelligent machinery .

4.1.5 For condition monitoring carried out to main propulsion engine(s) and its parts, the following parts/performance are at least to be included:

(1) Combustion condition of cylinders;

(2) Relevant parts of combustion chamber, e.g. cylinder liner, piston head (including piston ring), cylinder cover (including inlet and exhaust valves) and fuel nozzles/valves;

(3) Friction parts, e.g. main bearings, crankpin bearings, crosshead bearings and camshaft bearings;

(4) Explosion proof of crankcase;

(5) Performance of turbocharger.

4.1.6 For condition monitoring carried out to engines used for auxiliary power generation and its parts, the following parts/performance are at least to be included:

(1) Relevant parts of combustion chamber, e.g. cylinder cover (including inlet and exhaust valves), cylinder liner and fuel nozzles/valves;

(2) Friction parts, e.g. main bearings, crankpin bearings and camshaft bearings;

(3) Performance of turbocharger.

4.1.7 For condition monitoring carried out to propulsion shafting, the following are at least to be included:

(1) Gearbox (if any), e.g. bearings;

(2) Shaft and bearings, e.g. bush and sealing performance.

4.1.8 The condition monitoring system used for assistant decision-making and condition-based maintenance is to be approved by CCS.

4.1.9 Where the condition monitoring and fault diagnosis system is capable of carrying out health assessment of working condition of machinery installations and parts, demonstrating that the condition determined by condition monitoring is equivalent to that determined by direct inspection, the implementation of condition-based maintenance may be approved by CCS.

4.1.10 The overhaul items of machinery installations and parts, which are covered by the condition-based maintenance, can be implemented in accordance with the condition-based maintenance plan. For equipment and parts not included in the condition-based maintenance system, maintenance and survey are still to be carried out in accordance with PMS.

4.1.11 Upon completion of installation of the condition monitoring system on board the ship, an initial survey is to be carried out in accordance with the requirements of 4.5.1 of this Chapter to verify that the condition monitoring of machinery installations and systems is carried out in accordance with approved procedures and plans, and that the monitoring system can operate effectively as intended.

4.1.12 For the purpose of this Chapter:

(1) *Planned maintenance scheme* (*PMS*) means a detailed periodical maintenance plan for machinery (including electrical installations) onboard made by the owner or the ship management company in accordance with the relevant requirements of the Rules and the specifications of manufacturers. Through the implementation on board, the machinery will be always kept in good technical condition. Such planned management of periodical maintenance for machinery is called planned maintenance scheme.

(2) *Condition-based maintenance system* means a system for development of condition-based maintenance plan in accordance with the analysis and assessment results of operating condition and health condition of machinery installations.

(3) *Assistant decision-making* means proposing corrective actions based on the analysis and assessment results of operating condition and health condition of machinery installations, in order to provide suggestions for decision making on ship operation.

(4) *Condition monitoring and health assessment system* means a system carrying out monitoring of working condition of machinery installations by means of sensors, and carrying out analysis and assessment of operating condition and health condition of machinery installations based on monitoring data, mainly including sensors, acquisition, processing, analysis and storage of data, as well as output of analysis and assessment results.

(5) *Baseline data* means the data measured and obtained when the performance of machinery installations and their parts reaches or at the initial condition, which is used as the baseline for the analysis and comparison of health condition of machinery installations and their parts, and which is generally measured during operation on board the ship.

(6) *Reference conditions* means the conditions specified for acquisition of condition monitoring data, including the operating conditions of monitored machinery installations (e.g. temperature, pressure, rate of revolution etc.), the working conditions of the related systems, the operating conditions of ship (e.g. ship speed and draft) and relevant environmental conditions (e.g. temperature, pressure, sea state, wind speed etc.).

### 4.2 Functional notation for intelligent machinery

4.2.1 Upon request, the following functional notation for intelligent machinery may be assigned subject to satisfactory plan approval and survey by CCS:

Mx

where: M – the ship with the basic function of intelligent machinery specified by 4.1.3;
x – notation for additional function, expressed by the following small letters:
m – the condition-based maintenance based on condition monitoring is implemented for main propulsion engine(s) and parts;
a – the condition-based maintenance based on condition monitoring is implemented for engines used for auxiliary power generation and its parts;
p – the condition-based maintenance based on condition monitoring is implemented for propulsion shafting.

4.2.2 For ships applying for intelligent machinery notation M, the following prerequisites are to be satisfied:

(1) Relevant requirements for AUT-0 notation are satisfied;

(2) Assistant decision-making system based on condition monitoring is provided.

4.2.3 For ships applying for intelligent machinery notation Mx, in addition to complying with the requirements of 4.2.2, the following prerequisites are also to be satisfied:

(1) Relevant requirements for PMS notation are satisfied;

(2) Condition-based maintenance system based on condition monitoring is provided.

**4.3 Plans and documents**

4.3.1 For ships applying for intelligent machinery notation, the following applicable plans and documents are to be submitted:

(1) List and description of monitored machinery installations, at least including the following information of each equipment and part:

① monitoring condition and/or fault, e.g. combustion condition in the cylinder, wear condition of bearing and performance of turbocharger;

② monitoring parameters and normal range, e.g. temperature, pressure, flow and vibration;

③ monitoring devices/sensors;

④ monitoring procedures;

⑤ condition analysis/assessment method;

⑥ acceptance criteria.

(2) Detailed information on condition monitoring and fault diagnosis system, generally including the following:

① system principle, functions, operating and maintenance description;

② system hardware description, e.g. sensor, data acquisition device, data storage/backup device;

③ software description, e.g. data processing and analysis method, fault diagnosis method and condition assessment method;

④ type and content of output data/information.

(3) Relevant information on condition-based maintenance system, including:

① system functions, use and maintenance description;

② list and description of equipment and parts included in the condition-based maintenance system;

③ content and plan of condition-based maintenance;

④ procedures for development and implementation of condition-based maintenance plan.

(4) Relevant information on assistant decision-making system, including:

① system functions, use and maintenance description;

② list and description of equipment and system included in Assistant decision making;

③ implementation procedures.

(5) Procedures and schedules, including:

① onboard testing procedures;

② procedures and schedules for data collection;

③ procedures and schedules for data storage/backup;

④ procedures and schedules for data analysis;

⑤ output of assessment result/report;

⑥ procedures and schedules for calibration of monitoring devices.

(6) Relevant information on the company, at least including:

① structure diagram of relevant posts (responsibilities) of company;

② working flow, including goal, method and strategy;

③ training plan and qualification requirements for relevant personnel carrying out Assistant decision making and condition-based maintenance.

### 4.4 System requirements

#### 4.4.1 General requirements

4.4.1.1 Computer systems covered by this Chapter are to be designed, manufactured, surveyed and tested in accordance with the requirements for category II computer systems.

4.4.1.2 Relevant parameters necessary for condition assessment of machinery installations are to be collected by selecting appropriate measurement technology/method. Such parameters are to be appropriate for displaying the trend of condition change of machinery installations and their parts within a period of time. The measurement data is to be documented in a standard format to be suitable for read and use.

4.4.1.3 The trend analysis of condition monitoring data is to be carried out conveniently and easily. The trend data is to display condition change in a convenient way. The analysis and assessment result is to be described intuitively.

4.4.1.4 Sensors used by the system are in general to be a fixed type. Where it is impracticable to fit fixed sensors, other equivalent means of measurement may be used subject to the agreement of classification society. Where portable instruments are used, the position of relevant measurement points and the direction of measurement (measurement of parameters related to direction) are to be permanently marked. For the connection of sensors to measurement points, the influences of any human factor are to be excluded. The measurement results are to be entered into the condition monitoring system periodically for health assessment.

4.4.1.5 The condition monitoring data may be collected via the monitoring and alarm system of machinery installations on board the ship provided that the normal function of the monitoring and safety system is not affected.

4.4.1.6 The data of condition monitoring is to be stored periodically, which may be replayed and displayed at any time as necessary.

4.4.1.7 The system is to be provided with means required for database backup.

4.4.1.8 For a condition monitoring and health assessment system of novel design, the designer may consult with CCS to determine the requirements for system design, installation, parameter measurement, test and survey.

### 4.4.2 Assistant decision making

4.4.2.1 The assistant decision making system is to be capable of putting forward corrective actions and providing basis for decision making on operation and management of machinery installations, based on the analysis and assessment result of operating condition of machinery installations and in connection with the knowledge base and expert database that have been established for the system as well as monitoring parameters of relevant auxiliary systems.

4.4.2.2 The knowledge base and expert database of the assistant decision making system are to be updated and improved continuously with the accumulation of experience in system operation and the update of knowledge.

4.4.2.3 The assistant decision making system is to be capable of outputting the analysis and assessment report of operating and health condition of machinery installations as well as suggestions on decision making.

4.4.2.4 The assistant decision making system is to be capable of making historical data query conveniently and outputting relevant records required for survey.

4.4.2.5 Where the shore-based supporting method is used for assistant decision making, the shore-based system is be considered as part of the assistant decision-making system，and the submitted plans and documents are to include information on the function, design, operation and maintenance of shore-based system.

### 4.4.3 Condition-based maintenance system

4.4.3.1 The condition-based maintenance system is to be capable of developing the condition-based maintenance plan of monitored machinery installations and parts based on the health assessment results.

4.4.3.2 The condition-based maintenance system is to be capable of updating the maintenance plan continuously bases on the information of condition monitoring.

4.4.3.3 Spare parts on board the ship are to consider the needs of the condition-based maintenance plan.

4.4.3.4 The condition-based maintenance system is to be capable of producing the following records:

(1) List of check items of equipment conducting condition-based maintenance;

(2) Records of condition-based maintenance service, examination and repair of fault.

4.4.3.5 The condition-based maintenance system is to be capable of storing and managing the information on condition monitoring and health assessment, and outputting examination results, monitoring data and various information required for initial survey.

4.4.3.6 The historical data of condition-based maintenance plan can be queried at any time as necessary.

4.4.3.7 Where the shore-based supporting method is used for condition-based maintenance of equipment, relevant plans and procedures are to be submitted to CCS and satisfy the relevant requirements for the goal of condition-based maintenance.

**4.4.4 Monitoring and measurement**

4.4.4.1 One or more applicable monitoring techniques are to be selected based on the monitoring object, goal and purpose. Detailed instructions are to be provided for each monitoring technique that is selected. Common monitoring techniques are listed in Appendix 1 of the Rules for reference.

4.4.4.2 Where the oil analysis technique is used for condition monitoring and health assessment of diesel engines and screwshafts, the requirements of Appendix 15 Guidelines for Lubricating Oil Condition Monitoring System of Diesel Engines and Appendix 14 Guidelines for Screwshaft Condition Monitoring System, Chapter 5 of PART ONE of CCS Rules for Classification of Sea-going Steel Ships are to be satisfied respectively.

Where the oil analysis technique is used for condition monitoring of other equipment, the implementation may refer to the requirements of the guidelines above and the following requirements are at least to be considered:

(1) Sampling personnel: specialized personnel are to be designated to take oil samples on board the ship.

(2) In order to ensure that the oil sample is representative, it is best to take samples during normal operation period of equipment.

(3) Sampling period: the sampling period of oil analysis is developed in accordance with type, rate of revolution, working condition and performance of equipment.

(4) Sampling points are to be clearly identified and permanently marked.

(5) The oil analysis report is to be provided by a company approved by CCS. In case the analytical result exceeds the range allowed by standards, the ship company is obligated to report to CCS in a timely manner.

4.4.4.3 In order to ensure the normal function of monitoring equipment and correct measurement result, functional test and periodical calibration are to be carried out in accordance with approved procedures and plans. Test and calibration are to be recorded.

4.4.4.4 The monitoring data is to be measured in accordance with specified time internal. Parameters are in general to be measured in the reference condition. Where the reference condition cannot be met during measurement, the measured value is to be corrected to the value in the reference condition. The correction method and other related information are to be submitted to CCS for approval.

4.4.4.5 The record of monitoring parameters is at least to include the following information:

(1) General data describing machinery installations;

(2) Measurement position;

(3) Method of processing measurement data;

(4) Information on measurement date and time.

4.4.4.6 The baseline data of condition monitoring is to be measured or obtained when the machinery installations are in initial conditions. The reference condition during measurement is to be documented.

4.4.4.7 The baseline data is in general to be measured during testing on board the ship, which is to satisfy the following requirements:

(1) The measurement personnel are to have relevant qualifications.

(2) Representative baseline data in various operating conditions is to be measured.

(3) The effectiveness of measurement results of baseline data used for fault diagnosis and health analysis is to be assessed.

(4) For new equipment or equipment subject to major conversion, the baseline data is to be measured after a period of running in.

4.4.4.8 The maintenance and/or repair of machinery installations are to be recorded and identified on the condition trend curve. After the repair of equipment, relevant monitoring parameters are to be measured, and the newly measured data is to be compared with the historical data (before repair) for examination of any deviation. The measurement data and deviation are to be documented.

4.4.4.9 Any fault/failure of the condition monitoring system is to be recorded in the annual report specified in 4.5.2.2 of this Chapter. Any major fault /failure which affects the trend analysis of measurement data is to be repaired immediately. In case monitoring parameters cannot be measured as planned due to such fault/failure, CCS is to be notified.

### 4.5 Survey and test

#### 4.5.1 Initial survey

4.5.1.1 The initial survey is at least to include the following items:

(1) Plans and documents have been examined.

(2) The condition monitoring and health assessment system has been approved.

(3) Confirming that the designated operating personnel have completed relevant training as required and are able to perform duties correctly.

(4) After completion of installation of relevant equipment, survey and test are carried out in accordance the the testing procedures on board the ship and calibration procedures for monitoring devices.

(5) Checking the condition-based maintenance plan and implementation procedures to ensure that the contents are consistent with real ship.

(6) Confirming that relevant plans and documents, manuals, procedures and relevant records are kept on board the ship.

#### 4.5.2 Survey after construction

4.5.2.1 For ships which are assigned the notation for intelligent machinery , the annual survey is to be carried out in connection with the annual/intermediate/special survey of ship, in order to verify the normal function of condition monitoring, assistant decision-making and condition-based maintenance systems related to intelligent machinery.

4.5.2.2 Prior to the annual survey, the owner or ship management company is to submit to the local survey offices of CCS an annual report on condition monitoring, assistant decision-making and condition-based maintenance systems, which at least is to include the following items from last annual survey:

(1) Maintenance records of condition monitoring, assistant decision-making and condition-based maintenance systems of intelligent machinery;

(2) General operating condition of condition monitoring, assistant decision-making and condition-based maintenance systems of intelligent machinery;

(3) Fault/failure conditions and cause analysis of the monitored machinery installations;

(4) Repair records and replacement of spare parts of the monitored machinery installations.

4.5.2.3 At annual survey, in addition to examining the annual report submitted by the owner (ship), the surveyor is also to examine the following items on board the ship:

(1) Examining whether condition monitoring, assistant decision-making and condition-based maintenance systems of intelligent machinery operate effectively;

(2) Examining detailed working records of condition monitoring, assistant decision-making and condition-based maintenance systems of intelligent machinery;

(3) Examining repair records of machinery installations which are monitored. For replacement of important components and parts, the spare parts are to satisfy the certification requirements of CCS rules. The part or equipment being replaced is to be checked;

(4) Confirming that the historical data, trend analysis data, lubricating oil analysis report and vibration analysis report of condition monitoring, assistant decision-making and condition-based maintenance systems are complete and carrying out random examination of report contents;

(5) Confirming that operators are familiar with condition monitoring, assistant decision-making and condition-based maintenance systems and confirming the implementation condition;

(6) Some testing and analysis processes need to be verified if deemed necessary by the surveyor;

(7) Examining and confirming that the condition monitoring system and relevant instrumentation have been calibrated in accordance with specified procedures and plans;

(8) The maintenance of equipment included in the condition-based maintenance system is to be confirmed.

# Chapter 5 Intelligent Energy Efficiency Management

## 5.1 General requirements

5.1.1 The requirements of this Chapter apply to ships for which the functional notation for intelligent energy efficiency management is requested.

5.1.2 Intelligent energy efficiency management is capable of evaluating ship energy efficiency condition, navigation and loading condition by online monitoring of ship navigational condition and energy-consuming condition as well as automatic collection of data, and providing data evaluation and analysis results as well as assistant decision-making recommendations for ships, and solutions for speed optimization and optimal stowage based on trim optimization, so as to realize real-time monitoring of ship energy efficiency as well as intelligence evaluation and optimization, and improve level of energy efficiency management of ship.

5.1.3 Intelligent energy efficiency management is to have following basic functions:

5.1.3.1 Online monitoring of ship navigational condition, energy efficiency and energy-consuming condition, automatic collection of data and obtaining meteorological and environmental data;

5.1.3.2 Providing evaluation, report and alarm on ship energy efficiency and energy-consuming condition;

5.1.3.3 Providing assistant decision-making recommendations for ship energy efficiency management according to analysis and evaluation results.

5.1.4 In addition to basic functions specified in 5.1.3, intelligent energy efficiency management may also have following additional functions:

5.1.4.1 Providing speed optimization plan based on different objectives and in combination with evaluation results of route characteristics, fuel consumption and cost effectiveness;

5.1.4.2 Providing optimal stowage plan based on trim optimization according to initial loading and ship's optimal navigation state analysis.

5.1.5 Functional notation for intelligent energy efficiency management

5.1.5.1 Upon request, the following functional notation for intelligent energy efficiency management may be assigned subject to satisfactory plan approval and survey by CCS:

Ex

Where: E — the ship with basic functions of intelligent energy efficiency management;
x — notation for additional function, expressed by the following small letters:
s — speed optimization;
t — optical stowage based on trim optimization.

5.1.5.2 Ships applying for the functional notation for intelligent energy efficiency management are to satisfy requirements for basic functions required by 5.1.3 of this Chapter. If relevant requirements for speed optimization or optimal stowage based on trim optimization are satisfied, corresponding supplementary functional notations may be assigned.

5.1.6 Definitions and abbreviations

5.1.6.1 Relevant definitions and abbreviations in this Chapter are as follows:

(1) *EEOI* means ship's energy efficiency operation index, i.e. the ratio of mass of $CO_2$ emitted per unit of transport work.

(2) *MRV* means monitoring, reporting and verification of $CO_2$ emissions from maritime transport.

(3) *Emission control area* (*ECA*) means the area requiring special compulsory measures to be taken to ship emission so as to prevent, reduce and control atmospheric pollution due to $NO_x$ or $SO_x$ and particulate matters or all three emission types, which will then cause adverse effect on human health and environment. Emission control area mentioned in this Chapter is to include area listed or specified in Regulations 13 and 14 of MARPOL Annex VI.

(4) *Main energy-consuming equipment* means main energy-consuming equipment including main engine, auxiliary engine, boiler and inert gas generator, etc.

(5) *Transportation work* means product by multiplying the distance travelled with the amount of cargo carried.

5.1.7 Plans and documents

5.1.7.1 The following plans and documents are to be submitted to CCS:

(1) Composition and explanation of energy efficiency on-line monitoring system, at least including following information:

① explanation of equipment composition;

② monitoring method and parameters;

③ special explanation on installation processes and positions of monitoring equipment (if necessary);

④ method for analyzing and evaluating energy efficiency/energy consumption;

⑤ (initial) set value of energy efficiency/energy consumption evaluation criteria;

⑥ type and contents of output data/information;

(2) Electrical system plan of energy efficiency on-line monitoring system (including system power supply, system input and output signal circuit and parameter list);

(3) Electrical system plan and arrangement plan of shaft power monitoring equipment;

(4) Arrangement plan of fuel metering device for main energy-consuming equipment;

(5) Procedure and plan, including:

① Procedure and plan for data collection/storage;

② Procedure and plan for relevant evaluation results/report output;

③ Plan for calibration of monitoring device;

(6) Basic principle, function and instructions of speed optimization system;

(7) Basic principle, function and instructions of optimal stowage system based on trim optimization;

(8) Test program of energy efficiency management system.

## 5.2 Ship energy efficiency on-line intelligent monitoring

### 5.2.1 General requirements

5.2.1.1 Energy efficiency on-line intelligent monitoring is to be able to monitor main energy-consuming equipment and ship navigational condition, collect, transmit, store and analyze data, and carry out evaluation and alarm on relevant technical index such as ship's energy efficiency and energy consumption.

5.2.1.2 It is to be able to carry out periodic general evaluation on ship's energy efficiency condition and provide assistant decision-making recommendations on energy efficiency optimization and improvement.

5.2.1.3 It is to be able to provide relevant data or analysis evaluation report according to demand and based on the results of monitoring, analysis and evaluation of energy efficiency and energy consumption data.

5.2.1.4 Computer system of energy efficiency on-line intelligence monitoring is to satisfy requirements for category I computer system, and monitoring equipment or system is to be approved by CCS.

### 5.2.2 Data monitoring and collection

5.2.2.1 It is to be able to carry out real-time collection of relevant data of following equipment: main energy-consuming equipment, shaft power monitoring equipment, fuel metering device for main energy-consuming equipment, wind speed and direction indicator, global positioning system, log, electronic clinometer, sounding instrument and ship draft measuring equipment.

5.2.2.2 Monitoring parameters of ship's main energy-consuming equipment, metering equipment and navigational equipment include, but not limited to:

(1) parameters of power, pressure and temperature of main energy-consuming equipment;

(2) parameter of fuel consumption of main energy-consuming equipment;

(3) parameter of main engine shaft power;

(4) parameter of wind speed and direction;

(5) parameters of ship position, course and speed;

(6) parameter of speed through the water;

(7) ship inclination angle;

(8) water depth value;

(9) ship draft value;

(10) surge parameter (when practicable, ship is able to obtain marine meteorological data).

### 5.2.3 Data transmission and storage

5.2.3.1 The system may receive and store equipment parameter data periodically, and the receiving period may be adjusted according to minimum period set of the equipment and management demands.

### 5.2.4 Energy efficiency/energy consumption and emission data analysis

5.2.4.1 The system is to be at least able to calculate following energy efficiency and emission index automatically:

(1) EEOI;

(2) fuel consumption per distance;

(3) fuel consumption per transport work;

(4) $CO_2$ emission per distance;

(5) $CO_2$ emission per transport work.

5.2.4.2 The system is to be at least able to calculate following index of main energy-consuming equipment automatically:

(1) fuel consumption per hour;

(2) fuel consumption per day;

(3) summary of fuel consumption per voyage (leg).

**5.2.5 Energy efficiency and energy consumption evaluation**

5.2.5.1 Real-time evaluation of energy consumption of main energy-consuming equipment

(1) Automatically judging ship's navigational status such as mooring, maneuvering navigation and constant speed navigation according to actual operational condition of ship equipment;

(2) Using real-time data of ship's energy consumption, carrying out comparison and analysis according to set energy consumption evaluation method and criteria, automatically judging energy-consuming condition and outputting evaluation conclusion.

5.2.5.2 Evaluation of ship energy efficiency and emission index

(1) It is to be able to carry out automatic real-time monitoring of energy efficiency and emission evaluation index, at least including $CO_2$ emission for transportation work per unit (EEOI), fuel consumption per transport work, $CO_2$ emission per distance, fuel consumption per distance and $CO_2$ emission per transport work, and carry out comparison and analysis with energy efficiency evaluation criteria;

(2) It is to be able to automatically generate yearly, quarterly, monthly and voyage-related index data report according to demands and carry out inquiry when necessary.

5.2.5.3 Ship's energy consumption distribution analysis

(1) It is to be able to obtain energy consumption distribution proportion and energy utilization efficiency of main energy-consuming equipment under ship's design speed by analysis and according to ship's design parameters and relevant plans and information (e.g. estimation of ship's machinery equipment, calculation of power load);

(2) It is to be able to obtain ship's dynamic energy consumption distribution proportion and energy utilization efficiency by real-time analysis according to real-time data of ship's energy consumption;

(3) It is to be able to output static and dynamic energy consumption distribution data and analysis result of energy utilization efficiency.

5.2.5.4 Reminding that index exceeds limit

(1) If real-time value of ship's energy efficiency and energy consumption index exceeds set value, the system is to give alarm.

**5.2.6 Assistant decision-making on energy efficiency management**

5.2.6.1 General evaluation on ship's energy efficiency and energy consumption condition may be carried out according to voyage and natural period (not exceeding one year).

5.2.6.2 It is to be able to provide assistant decision-making recommendations on energy efficiency optimization and improvement according to results of general evaluation on ship's energy efficiency and energy consumption.

**5.2.7 Assistant management of energy efficiency**

5.2.7.1 Carbon emission monitoring and reporting required by MRV: system is able to monitor carbon emission data required by MRV, and generate relevant report and evidence satisfying verification requirements.

5.2.7.2 Emission control area (ECA) early warning: system is able to provide early warning for residual nautical miles and residual time within certain area away from ECA according to current ship course and speed to ensure that emission within ECA complies with requirements.

5.2.7.3 Fuel information management: information management for fuel transfer during fuel bunkering and navigation, including information management for fuel bunkering type and fuel information before and after fuel transfer.

**5.3 Speed optimization**

**5.3.1 General requirements**

5.3.1.1 It is to be able to provide speed optimization plan based on different objectives according to voyage plan, fuel consumption and general cost effectiveness analysis.

5.3.1.2 Speed optimization analysis is to generate speed optimization plan according to ship's navigational data and in combination with voyage plan, route characteristics, ship efficiency, fuel consumption evaluation and navigational cost analysis.

5.3.1.3 Speed optimization function based on different objectives is to include speed optimization based on voyage plan and speed optimization based on cost effectiveness.

5.3.1.4 Computer system of speed optimization is to satisfy requirements for Category I computer system.

**5.3.2 Speed optimization based on voyage plan**

5.3.2.1 It is to predict information such as navigation distance based on voyage and leg management and according to ship's department port, destination port and departure time. It is to automatically calculate navigated distance and navigated time, and forecast arrival time according to residual voyage and current speed.

5.3.2.2 It is to automatically calculate specific fuel consumption under current speed according to parameters such as speed, main propulsion equipment power and fuel consumption, calculate oil consumption according to current speed and residual navigation distance and calculate fuel consumption for navigated miles and fuel necessary for residual miles.

5.3.2.3 It is to evaluate effect on speed according to set factors such as ship efficiency index which can reflect ship performance and efficiency during operation as well as weather and sea conditions, and based on historical data analysis (relationship among factors such as speed, cargo capacity, oil consumption as well as weather and sea conditions).

5.3.2.4 During navigation, the system is able to provide speed optimization plan based on voyage plan by integrating above analysis.

### 5.3.3 Speed optimization based on cost effectiveness

5.3.3.1 Cost management and benefit index evaluation

(1) The system is to provide management functions for all cost involved in ship operation, including freight charge, port charge, fuel price, ship depreciation, material input, crew wages, shore-based personnel wages and management charges;

(2) The system may check each cost during ship operation and evaluate voyage benefits.

5.3.3.2 It is to be able to provide speed optimization plan based on cost effectiveness according to evaluation results of benefit index.

## 5.4 Optimal stowage based on trim optimization

### 5.4.1 General requirements

5.4.1.1 Optimal stowage system based on trim optimization is to have functions such as trim optimization and automatic stowage optimization, and can be used for calculating optimal trim condition under each loading condition.

5.4.1.2 Optimal stowage system is to firstly satisfy relevant requirements for loading instruments in Chapter 2, PART TWO of CCS Rules for Classification of Seagoing Steel Ships.

5.4.1.3 Optimal stowage system may provide optimal energy-saving stowage plan according to initial loading and target trim by adjusting cargo and ballast water with computer simulating automatic iteration.

5.4.1.4 Optimal stowage computer system based on trim optimization is to satisfy requirements for Category I computer system.

### 5.4.2 Requirements for trim optimization and stowage optimization

5.4.2.1 Trim optimization system usually includes device collecting voyage data, basic database for trim performance and analysis system which can carry out trim optimization.

5.4.2.2 Database for trim performance can be established by means of model test and numerical calculation, or by model analysis on serial data obtained from real-time voyage data collected from ship.

5.4.2.3 Database for trim performance established by means of model test and numerical calculation is to at least cover conditions included in loading manual, and each condition is to include draft, speed and trim. Database for trim performance established by means of collecting ship's real-time voyage data is to include operational and navigational condition data such as trim, draft, speed, propulsive power and speed of main propulsion plant, wind speed and wind direction.

5.4.2.4 It is to be at least able to carry out optimal trim optimization calculation under any condition included in loading manual, and output optimized trim range which can be used for adjusting navigational floating condition.

5.4.2.5 When optimizing loading plan based on target trim , operation is to be simple and convenient, and calculation efficiency can be accepted.

5.4.2.6 When optimal energy-saving loading plan is outputted automatically, the plan is to comply with objective of optimal navigational state and satisfy requirements for hull strength, intact stability, grain stability, damaged stability and serial safety index of initial navigation.

5.4.2.7 It is to be able to set several target trim for loading plan optimization according to user demand.

5.4.2.8 It is to fit optimal navigational state target selected by users as far as possible. The user is to be notified if data exceed limit and fitting is impossible, and output plan which is nearest to the target.

## 5.5 Survey and test

### 5.5.1 Initial survey

5.5.1.1 For ships intending to apply for the functional notation for intelligent energy efficiency management, it is to be confirmed that plans and information specified in 5.1.6 have been examined.

5.5.1.2 It is to confirm that computer system of intelligent energy efficiency management has been issued relevant certificates.

5.5.1.3 It is to confirm that system hardware has been approved by CCS.

5.5.1.4 Installation and inspection of relevant signal-collecting equipment

In addition to satisfying statutory and class inspection requirements, following equipment within statutory and class range is to be inspected according to following requirements:

(1) Shaft power monitoring equipment

① Carrying out installation and inspection according to approved plans and manufacturer's instructions;

② Considering the effect of ship deformation and local vibration on performance of shaft power monitoring equipment, the stator installation foundation for shaft power monitoring equipment is to be welded tight, generally welded on ship's strong components, and welding on hull plating is not allowed;

③ Witnessing check process and result of shaft power monitoring equipment.

(2) Fuel metering device for main energy-consuming equipment

① Checking qualification report of fuel metering device;

② Inspecting the installation according to approved plans and manufacturer's instructions;

(3) Electronic clinometer

① Inspecting the installation according to approved plans and manufacturer's instructions;

② Confirming electronic clinometer has been calibrated during function test and output results of inclination angle.

(4) Wind speed and direction indicator, sounding instrument, global positioning system, log, remotely draft measuring equipment

① Inspecting the installation according to approved plans and manufacturer's instructions;

② Inspection on function test.

5.5.1.5 Checking signal output and input of signal-collecting equipment

(1) Checking integrity of parameter input to system;

(2) Checking consistency of parameter data of software system receiving end and parameter data of sending end of signal-collecting equipment.

5.5.1.6 Test and inspection are to be carried out according to test program.

5.5.1.7 User manual as well as maintenance and calibration log have been kept on board.

**5.5.2 Survey after construction**

5.5.2.1 For ships assigned with the functional notation for intelligent energy efficiency management, previous service condition of systems are to be reviewed at annual, intermediate and special surveys to confirm that they are in normal condition.

5.5.2.2 Equipment calibration depends on calibration interval specified in manufacturer's instructions, and it is to be confirmed that calibration is carried out according to instructions at annual/intermediate/special survey.

# Chapter 6 Intelligent Cargo Management

## 6.1 General requirements

6.1.1 The requirements of this Chapter apply to ships for which the functional notation for CCS intelligent cargo management is requested.

6.1.2 Intelligent cargo management carries out automatic collection of parameters of cargo, cargo hold and cargo protection system by using sensing equipment such as sensors, and based on computer technology, automatic control technology and big data processing and analysis, to realize monitoring, alarm, assistant decision-making and control of cargo hold, cargo and cargo protection system conditions, and at the same time, carry out cargo optimized stowage and automatic loading and unloading based on monitoring and obtained data to realize intelligent management of ship cargo.

6.1.3 Intelligent cargo management is to have following basic functions:

(1) Monitoring alarm and assistant decision-making for cargo hold and cargo;

(2) Monitoring alarm and assistant decision-making for cargo protection system;

(3) Cargo stowage system.

6.1.4 Intelligent cargo management may also have following supplementary functions:

(1) Automatic loading and unloading system.

6.1.5 Intelligent cargo management system computer is to satisfy the requirements for category II computer system.

## 6.2 Functional notation for intelligent cargo management

6.2.1 Upon request, the following functional notation for intelligent cargo management may be assigned subject to satisfactory plan approval and survey by CCS:

Cx

where: C — ship has monitoring alarm and auxiliary systems for cargo hold, cargo and cargo protection system as well as cargo stowage system;
x — notation for additional function, expressed by the following small letter:
l — ship with automatic cargo loading and unloading system.

## 6.3 Plans and documents

6.3.1 For intelligent cargo management, following plans and documents are to be submitted to CCS:

(1) Arrangement plan of sensors;

(2) System composition and function explanation;

(3) System hardware specifications;

(4) System test procedure.

## 6.4 Cargo and cargo hold monitoring alarm and assistant decision-making systems

6.4.1 Cargo and cargo hold monitoring alarm system is to be able to monitor state parameters of cargo and cargo hold on board ship according to cargo property and state, and provide operational condition by analyzing and identifying monitored state parameters. When monitoring parameters exceed the threshold value and alarm is activated for system failure, if applicable, following parameters are usually monitored:

(1) water ingress within cargo hold;

(2) temperature and pressure within cargo hold;

(3) combustible, explosive and toxic gas within cargo hold;

(4) liquid level of tanker;

(5) cargo shift;

(6) relevant monitoring parameters may be determined or further added in accordance with practical conditions of ship and safety needs.

6.4.2 When alarm is given due to abnormal monitoring data of cargo or cargo hold, assistant decision-making system is to have data analyzing and handling capacity, and give recommendation on operational handling.

### 6.5 Cargo protection system monitoring alarm and assistant decision-making systems

6.5.1 Cargo protection system is to be able to monitor structure, equipment and system relating to cargo safety protection. When monitored parameters are abnormal, the system is to be able to give alarm as well as failure position, possible cause and countermeasures, and crew can carry out inspection and maintenance to cargo protection system in time. When applicable, following parameters are usually monitored:

(1) structural stress of critical area of tanker containment system;

(2) temperature and pressure of tanker containment system;

(3) cargo and container securing load;

(4) watertightness of hatch cover;

(5) relevant monitoring parameters may be determined or further added in accordance with practical conditions of ship and safety needs.

### 6.6 Cargo stowage system

6.6.1 Cargo stowage system is stowage instrument carrying out automatic optimization by general consideration of various constraints, it collects data relating to cargo loading and unloading by using equipment such as sensor and provide optimal stowage and operation plan after calculation and analysis. Following factors are usually to be considered:

(1) safety, environmental protection and energy efficiency;

(2) ship’s floating state, stability and strength;

(3) cargo hold capacity and stowage factor;

(4) cargo loading and unloading sequence, speed and time;

(5) ballast water operation;

(6) emergency stop procedure;

(7) cargo hazard property;

(8) ship maneuvering, charter contract, port and dock;

(9) cargo long-distance identification and tracking;

(10) route, weather and hydrology.

6.6.2 For tanker cargo stowage system, following factors are usually also to be considered:

(1) quantity and grade of each kind of cargo;

(2) density, temperature and other relevant performance;

(3) stowage plan, pipes and pumps to be used;

(4) maximum allowable pressure;

(5) ventilation requirements;

(6) emergency procedure for SOPEP;

(7) preventing static electricity;

(8) initial loading and unloading rates;

(9) temperature control procedure;

(10) stripping;

(11) crude oil tank cleaning procedure;

(12) residual water depth limit;

(13) special precaution against cargo.

**6.7 Automatic cargo loading and unloading system**

6.7.1 Automatic cargo loading and unloading system is to meet the requirements of 6.6.

6.7.2 Automatic cargo loading and unloading system provides optimal loading and unloading plan by carrying out monitoring as well as calculation and analysis to relevant factors during cargo loading and unloading to realize automatic cargo loading and unloading.

6.7.3 Automatic cargo loading and unloading system includes control of loading and unloading process, control of loading and unloading equipment as well as treatment and control of abnormal conditions, usually including:

(1) operation of cargo loading and unloading equipment;

(2) operation of cargo hold ventilation, tightness, cargo hold switch, cargo pump and stripping;

(3) control of cargo loading and unloading process, generally including:

① cargo hold capacity;

② ballast water in ballast tank;

③ maximum still water bending moment and shearing force;

④ ship trim and draft condition as well as stability;

(4) prompt treatment and control of factors such as sudden equipment failure and external environment change.

**6.8 Survey**

**6.8.1 Initial survey**

6.8.1.1 Relevant plans have been examined.

6.8.1.2 It is to be confirmed that the system has relevant certificate.

6.8.1.3 System design, system input and output as well as communication function are to be confirmed.

6.8.1.4 According to application for different intelligent cargo control notations, different conditions are inputted for simulation operation to verify software function.

6.8.1.5 Capability of treating emergency situation is to be verified.

**6.8.2 Survey after construction**

6.8.2.1 Previous service condition of systems are reviewed at annual, intermediate and special surveys to confirm that they are in normal condition.

6.8.2.2 Functions of the equipment and system are to be re-verified after their repair and renewal. Test is to be carried out after repair or renewal of the intelligent cargo management system.

# Chapter 7 Intelligent Integration Platform

## 7.1 General requirement

7.1.1 The requirements of this Chapter apply to ships for which the functional notation for CCS intelligent integration platform is requested.

7.1.2 If a ship is assigned with the functional notation for intelligent integration platform, at least data of three systems (i.e. intelligent navigation, intelligent engine room and intelligent energy efficiency management) are to be integrated to form unified integration platform with data and application on board ship. Integration platform is to be open and be cable to integrate existing information management system on board ship and subsequent newly-added system to realize all-round control and intelligent management for ship as well as data exchange with shore base.

7.1.3 By general application of integrated data resource, intelligent integration platform is to have following basic functions:

(1) statistical analysis and general evaluation, capable of providing automatic and standardized customized analysis;

(2) providing general forecast and early warning for relevant index such as navigation, safety and economy according to multi-dimensional boundary conditions set by the user;

(3) providing trend prediction for current ship operation and management plan by using ship's historical operation condition and relevant parameters;

(4) supporting good assistant decision-making, improving ship performance and decreasing error due to human factors. Capable of providing general management and operation plan for accident response, risk reaction plan, environmental protection measures, accident detection and prevention, economic performance promotion, resource management and communication according to evaluation and prediction results;

(5) capable of realizing ship-shore data exchange.

## 7.2 Functional notation for intelligent integration platform

7.2.1 Upon request, the following functional notation for intelligent integration platform may be assigned subject to satisfactory plan approval and survey by CCS:

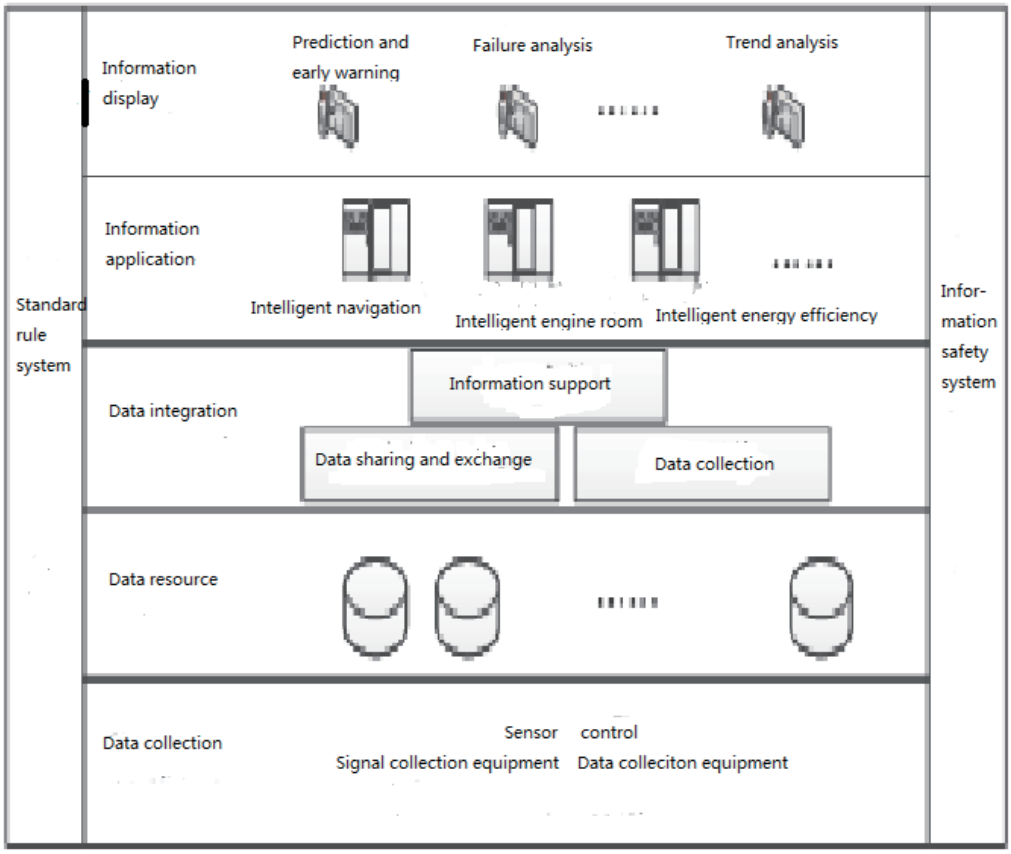
I

where: I represents that the ship can at least integrate data of three systems (i.e. intelligent navigation, intelligent engine room and intelligent energy efficiency management) and has basic functions for intelligent integration platform specified in 7.1.3; Be capable of integrating functions of existing application system on board ship to form highly integrated web application platform which is open, having capability of accessing newly-added system.

7.2.2 Ships applying for functional notation I for intelligent integration platform are to have functional notations N, M and E.

## 7.3 System layer

7.3.1 Overall structure of system




(1) Data collection, i.e. using sensing equipment such as sensor, control, signal collecting equipment and data collecting equipment to collect required data, collecting data, defining data standard, including standard relating to data definition, data description, data quality, data transmission and data handling, and realizing data traceability;

(2) Data storage, i.e. establishing subject-oriented, integrated and stable data set supporting decision-making and management process and reflecting historical change, carrying out storage as well as safety and evaluation management for data collected to ensure accuracy, integrity and availability of data;

(3) Data integration, i.e. carrying out system processing, aggregation, analysis integration and exchange based on necessary selection and cleaning of existing data, using multi-dimensional analysis method, analyzing and comparing from different angle, and extracting information hidden within data to provide information support for service application and assistant decision-making as well as play a role of information integration;

(4) Information application, i.e. providing relevant integration service application based on integrated data resource, aiming at customized subject, excavating data, and obtaining but not limited to capability of failure analysis, forecast and early warning as well as assistant decision-making;

(5) Information display, i.e. by means of human-computer interaction and according to customization, providing excavating results of relevant data, expressing failure cause in proper form and providing prediction and early warning for user operational decision-making by using data trend;

(6) Standard rule system, which is to be observed during system integration process;

(7) Information safety system, i.e. based on requirements for information safety (information confidentiality, authenticity, integrity, unauthorized copy and safety of parasitic system) and from computer operation system, security agreement and mechanism (digital signature, message authentication and data encryption) to safety system, proposing design thinking and protection strategy to ensure continuous, reliable and normal operation of system and uninterrupted information service as well as final continuous service.

### 7.4 System requirements

#### 7.4.1 General requirements

7.4.1.1 The reliability and security of intelligent integration platform are to satisfy CCS requirements for category III software.

7.4.1.2 System integration is to adopt unified input and output standard.

7.4.1.3 Database is to have backup and disaster recovery mechanism to ensure data integrity and consistency.

7.4.1.4 Stable and reliable communication agreement and system data transmission mechanism is to be adopted between ship and shore.

7.4.1.5 Data collection is to have fault-tolerant mechanism.

7.4.1.6 Database of integration platform is to have valid integration process, i.e. screening necessary data according to data quality of each system and functional requirements for integration platform.

7.4.1.7 The system supports multi-terminal (PC and mobile device) access.

7.4.1.8 When necessary, the system is to provide external data transmission interface and have capability of sharing data with relevant parties.

7.4.1.9 The system is to realize multi-department and multi-user cooperative management according to company's relevant requirements for management system.

#### 7.4.2 System integration requirements

7.4.2.1 Intelligent integration platform is to integrate existing information resource of intelligent system on board ship. Data collected through intelligent system can be stored in integration platform database, or establish effective call relation with it.

7.4.2.2 Intelligent integration platform can integrate functions relating to ship information management system and realize management for relevant ship information by ship and company, e.g. equipment maintenance management, crew delivery and basic information management, security management, system management, cost management and electronic management of maritime information.

7.4.2.3 Intelligent integration platform is to be able to integrate newly-added system (e.g. video monitoring system, consolidated navigation system) according to conventions, rules as well as company management and operation needs. The system is to have certain expandability and complete data interface plan to facilitate access of other newly-added system. Data collected through newly-added system may be stored in intelligent integration platform database, or establish effective call relation with it.

### 7.5 Survey

#### 7.5.1 Initial survey

7.5.1.1 It is to be confirmed that plans have been examined.

7.5.1.2 Ships applying for the functional notation for intelligent integration platform is to be subject to initial survey to verify following items:

(1) confirming that intelligent integration platform has relevant certificates;

(2) confirming that process of data collection, storage, transmission, display and application of intelligent integration platform is implemented properly;

(3) inspecting functions of intelligent navigation, intelligent engine room and intelligent energy efficiency management according to requirements for each integration system.

### 7.5.2 Survey after construction

7.5.2.1 Following items are to be examined at annual survey, intermediate survey and special survey:

(1) examining former service condition record of intelligent integration platform and confirming normal operation of intelligent integration platform;

(2) system data can be exchanged normally between ship and shore, and conforming historical record of data exchange;

(3) checking system backup record randomly and confirming system has implemented effective backup;

(4) inspecting functions of intelligent navigation, intelligent engine room and intelligent energy efficiency management according to requirements for each integration system.

# Appendix 1 Common Condition Monitoring Techniques

## 1.1 Vibration monitoring techniques

1.1.1 General requirements

1.1.1.1 Vibration measurement for condition monitoring may be in various forms from simple to complex, including continuous measurement and periodical measurement, in order to evaluate machinery conditions precisely and reliably through vibration monitoring.

If vibration monitoring technique is adopted, applicable monitoring procedures are to be established, at least including following elements:

(1) detailed description of condition monitoring technique used;

(2) selection of vibration monitoring points;

(3) description of vibration monitoring equipment, including user's manual, technical index and applicable environmental condition;

(4) methods and standards for evaluating vibration data.

1.1.2 Overall evaluation on vibration of ship's auxiliary machinery equipment

1.1.2.1 Machinery equipment is divided into 5 categories according to power and rotation mode:

(1) category 1: rotating machinery with power below 15 kW;

(2) category 2: rotating machinery with power between 15 kW and 75 kW;

(3) category 3: rotating machinery with power above 75 kW;

(4) category 4: reciprocating machinery with power not above 75 kW;

(5) category 5: reciprocating machinery with power above 75 kW.

1.1.2.2 Evaluation on vibration intensity of ship machinery equipment is divided into following 4 grades:

(1) Grade A: good;

(2) Grade B: acceptable;

(3) Grade C: still acceptable, but improvements desirable;

(4) Grade D: risk of breakdown.

1.1.2.3 For machinery equipment installed by flexible support, vibration intensity grade may be determined according to Table 1. For machinery equipment installed by rigid support, vibration intensity grade may be determined according to Table 2. For details, refer to GB/T 16301 standard.

**Determination of vibration intensity grade under installation method of flexible support Table 1**

<table>
<tr><td rowspan="2">Vibration intensity limit mm/s</td><td colspan="5">Category of machinery equipment</td></tr>
<tr><td>Category 1</td><td>Category 2</td><td>Category 3</td><td>Category 4</td><td>Category 5</td></tr>
<tr><td>0.28</td><td rowspan="4">A</td><td rowspan="5">A</td><td rowspan="6">A</td><td rowspan="7">A</td><td rowspan="8">A</td></tr>
<tr><td>0.45</td></tr>
<tr><td>0.71</td></tr>
<tr><td>1.12</td></tr>
<tr><td>1.8</td><td rowspan="2">B</td></tr>
<tr><td>2.8</td><td rowspan="2">B</td></tr>
<tr><td>4.5</td><td rowspan="2">C</td><td rowspan="2">B</td></tr>
<tr><td>7.1</td><td rowspan="2">C</td><td rowspan="2">B</td></tr>
<tr><td>11.2</td><td rowspan="5">D</td><td rowspan="2">C</td><td rowspan="2">B</td></tr>
<tr><td>18</td><td rowspan="4">D</td><td rowspan="2">C</td></tr>
<tr><td>28</td><td rowspan="3">D</td><td rowspan="2">C</td></tr>
<tr><td>45</td><td rowspan="3">D</td></tr>
<tr><td>71</td><td rowspan="2">D</td></tr>
<tr><td>112</td></tr>
</table>

**Determination of vibration intensity grade under installation method of rigid support Table 2**

<table>
<tr><td rowspan="2">Vibration intensity limit mm/s</td><td colspan="5">Category of machinery equipment</td></tr>
<tr><td>Category 1</td><td>Category 2</td><td>Category 3</td><td>Category 4</td><td>Category 5</td></tr>
<tr><td>0.28</td><td rowspan="3">A</td><td rowspan="4">A</td><td rowspan="6">A</td><td rowspan="8">A</td><td rowspan="10">A</td></tr>
<tr><td>0.45</td></tr>
<tr><td>0.71</td></tr>
<tr><td>1.12</td><td rowspan="2">B</td></tr>
<tr><td>1.8</td><td rowspan="3">B</td></tr>
<tr><td>2.8</td><td rowspan="2">C</td><td rowspan="2">B</td></tr>
<tr><td>4.5</td><td rowspan="3">C</td><td rowspan="3">B</td></tr>
<tr><td>7.1</td><td rowspan="8">D</td><td rowspan="2">C</td><td rowspan="2">B</td></tr>
<tr><td>11.2</td><td rowspan="7">D</td><td rowspan="2">C</td></tr>
<tr><td>18</td><td rowspan="6">D</td><td rowspan="2">C</td></tr>
<tr><td>28</td><td rowspan="5">D</td></tr>
<tr><td>45</td><td rowspan="3">D</td></tr>
<tr><td>71</td></tr>
<tr><td>112</td></tr>
</table>

1.1.3 Common failure and cause analysis of vibration monitoring

Machinery vibration is due to various causes, e.g. deterioration, abrasion, abnormal operation, poor installation as well as maintenance and design defects of machinery components. Rotor unbalance is normal cause for machinery vibration, which will cause vibration of rotor and fixed parts of machinery. Another normal cause for rotating machinery vibration is misalignment of shaft or bearing. Table 3 lists normal cause for transverse vibration of machinery, vibration frequency characteristics information and recommendation on vibration assessment. Vibration spectrum analysis is an effective method for assisting vibration evaluation. Other determining factors include vibration phase difference due to rotating speed change or other reasons as well as machinery positions with most obvious vibration.

**Most common cause and vibration characteristics of transverse vibration Table 3**

| Cause | Vibration frequency | Remarks |
|---|---|---|
| Unbalance | 1X (e.g. 1 x r.p.m) | Balance change will cause 1X vector changes. The vibration is maximum when rotating speed coincides with critical rotating speed of rotor system. Obvious phase change will occur when passing through critical rotating speed. Vibration amplitude is constant under fixed rotating speed. |
| Bearing misalignment | 1X or higher-order harmonics | Parallel or angular bearing misalignment generally caused by basic motion. Bearing misalignment is not the direct cause for vibration excitation, but misalignment changes dynamic properties of supporting system. |
| Rolling bearing abrasion | High-frequency wideband acceleration | It is required to detect by means of sensors with high-frequency response. Vibration tends to be limited within area with defective bearings. Vibration readings are usually unstable and increase along with time. It may be necessary to represent failure of this kind by other technique. |
| Rotor bending | 1X, 2X or higher-order harmonics | The most popular is change of 1X. If rotor is bent in the vicinity of coupling, high 2X axial vibration is often observed, and vibration amplitude is constant under fixed rotating speed. |
| Cracked rotor | 1X, 2X or higher-order harmonics | 2X vector increase indicates growth of transverse crack towards threshold, and change of 1X or higher-order harmonics vector may also occur. |
| Looseness of rotor components | 1X or rotating speed frequency harmonics | Vibration amplitude may be unstable and inconsistent at each start-stop. Sometimes subharmonic frequency can be observed. |
| Shaft neck eccentricity or out-of-roundness | 1X, but for non-circular shaft neck, with rotating speed frequency harmonics | Vibration amplitude may be abnormal or excessive at low rotating speed and rotor critical rotating speed, and vibration amplitude is constant under fixed rotating speed. |
| Gear defects | High frequency corresponding to gear engagement/rotating frequency harmonics and relevant side band | It is required to detect by means of sensors with corresponding high-frequency. If one tooth has defect, it is 1X and frequency multiplication. If several teeth wear, it is gear engagement frequency and with side band and frequency multiplication. |
| Resonance | Vibration with excitation frequency, e.g. rotating speed is equal to one of inherent frequency of rotor/supporting system | Vibration amplifies at rotating speed of resonance of each machinery, and there is significant change for phase angle in 1X response when rotors passing through critical rotating speed. Rotor unbalance is also common excitation, which can generate machinery resonance response in unrotating system. For electric motor, another main excitation is 2X, which is caused by electromagnetic force inducted on stator by rotor. |
| Friction | Most common is 1X, but with 1X frequency multiplication, subharmonic frequency and inherent frequency | Minor friction can make it run in at low speed. However, friction may cause vibration mutation at high speed, and then increase rapidly to amplitude for stop. Sometimes friction is due to rapid loading of machinery or sudden change of thermal condition of machinery. In addition, in other conditions, friction may also be caused by small gap between rotating parts and fixed parts or part movement during operation. |

1.1.4 Sensors and measuring positions

1.1.4.1 Sensors are selected according to detailed application. Sensors for condition monitoring generally include:

(1) acceleration meter, any one of three parameters (acceleration, speed and displacement) can be obtained by its output;

(2) speed sensor, displacement can be obtained by its integration;

(3) non-contact type sensor, its output is directly proportional to relative displacement between rotating parts and non-rotating parts of machinery.

Relationship between dynamic range and frequency is to be taken into account for sensor selection. At present, application scope of vibration sensor includes most application of condition monitoring. Under special conditions, scope may be enlarged after evaluation by CCS.

1.1.4.2 Measurement is to be carried out at position where failure may be most likely detected. Measuring points are to have unique identification, and it is recommended that installation be carried out by professional engineer or vibration monitoring company. Following factors are to be considered for sensor installation:

(1) safety;

(2) high sensitivity of fault condition change;

(3) repeatability of measure;

(4) accessibility;

(5) environmental condition;

(6) cost.

**1.2 Oil analysis technique**

1.2.1 Oil analysis items

(1) Oil physical and chemical performance analysis

Normal physical and chemical performance analysis is judging abrasion condition of machinery according to performance change of oil itself, which may prevent failure due to poor lubrication. There is close relationship between oil performance and abrasion condition and service life of machinery equipment. The objective of monitoring abrasion condition indirectly can be achieved by monitoring physical and chemical performance index of lubricant.

(2) Spectrum analysis

Spectrum analysis of lubricating oil is identifying pollutant in the oil as well as its composition and amount by mean of spectrum analysis to predict conditions of condition monitoring equipment and oil. Spectrum analysis mainly applies launching spectrum analysis method and infrared spectrum analysis method.

(3) Ferrographic analysis

Ferrographic technique is also called iron physiognomy, which makes lubricating oil with debris pass through a magnetic field with high strength and high gradient, separates magnetic debris from lubricating oil by magnetic force, and produces spectrum piece by deposit debris particle on the substrate according to its size for observation and analysis. Observation can be made by ferrous spectrum microscope, and quantitative determination can be made for debris distribution condition by optical densitometer. Observation can also be made by electronic microscope and accurate determination can be made for each element in the debris by X-ray energy spectrometer or X-ray wave spectrometer. The contents of determination include:

① debris concentration and particle size, reflecting severity of abrasion;

② debris size and shape, reflecting debris cause;

③ debris composition, reflecting debris position.

### 1.3 Noise monitoring techniques

1.3.1 One of the first symptoms of mechanical or electrical fault is the increase of noise generated by machinery parts. These sonic signatures can be defined and recognized, while changes in these signatures can be also identified as components begin to wear or deteriorate. Noise monitoring technique can detect following faults:

(1) bearing deterioration;

(2) compressed air or hydraulic fluid leaks;

(3) vacuum leaks;

(4) tank leaks.

1.3.2 Noise detection scope depends on sound pressure level and background noise level. Table 4 shows coverage distance for different type of noise areas. The trigger will be set as 6dB above the average background noise.

**Coverage distance for different type of noise areas** **Table 4**

| Type of area | Background noise level/trigger | Coverage distance |
|---|---|---|
| Low noise area | 58dB/64dB | 15-20m |
| Average noise area | 68dB/74dB | 9-12m |
| High noise area | 78dB/84dB | 5-8m |

### 1.4 Thermography technique

Infrared thermography is a kind of science which detects and measures radiation with photoelectric equipment and establishes relationship between radiation and surface temperature. Radiation is heat movement due to movement of radiation energy of optical figure of infrared thermography (electromagnetic wave) without direct transmission media. The operating principle of modern infrared thermography is detecting and measuring radiation with photoelectric equipment as well as establishing relationship between radiation and surface temperature. All objects higher than absolute zero (-273$^{o}$C) can emit infrared radiation. Infrared thermography obtains infrared thermogram by receiving infrared radiation energy distribution of the measured target with infrared detector and optical imaging objective lens and reflecting on light sensor. Such thermogram is corresponding to heat distribution field of object surface. In general, infrared thermography changes invisible infrared energy sent by the object to visible thermal image. Different colors in thermal image represent different temperature of measured object. By reviewing thermal image, overall temperature distribution condition of measured target can be observed for studying heating condition of target so as to carry out further judgement.

Thermography can measure temperature in any part of machinery and equipment so as to detect any change in the operating temperature thus indicating fault development. Due to the non-contact function, it is suitable for structural, machinery, electrical and material detection malfunctions. The key advantage of thermal imaging technique compared to other monitoring techniques is the real-time representation of thermal image.

### 1.5 Electrical signal analysis technique

Electrical signal analysis technique can detect faults and information that are not easy to detect with other monitoring techniques. The most common faults are summarized as follows:

(1) insulation detection;

(2) stator electrical imbalance checking;

(3) short circuit caused by stator winding faults;

(4) harmonic change;

(5) rotor faults detection.