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Metrological Data Application Solutions in the Field of Marine Power

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***Abstract* –This paper addresses critical metrological challenges in marine power systems—including measurement deficiencies for 23 key parameters, digital fragmentation hindering cross-system data integration, and inconsistent standardization across lifecycle phases. This paper propose a Cloud-Edge-Device Integrated Architecture with five functional strata: the Data Layer consolidating laboratory/vessel datasets, the Perception Layer enabling edge-computing acquisition via adaptive tools, the Platform Layer standardizing metadata through API services, and the Application Layer deploying predictive maintenance and lifecycle simulation. This framework establishes closed-loop data management for 53 critical parameters, resolving "unmeasurable/ inaccurate/ incomplete" data issues while implementing robust security via national encryption algorithms, RBAC/ABAC access controls, and blockchain-anchored trusted timestamps. Implementation demonstrates reliability improvement and accelerated design iteration, providing end-to-end metrological support compliant with international maritime standards.**

I. INTRODUCTION

Marine power systems serve as the "heart" of offshore engineering equipment, directly determining operational safety and economic efficiency. As complex coupled systems, the development, testing, and operation of marine power equipment require comprehensive support from metrological testing data throughout their lifecycle. To address the urgent demands of marine equipment advancement, it is imperative to strengthen the construction, aggregation, analysis, application, and governance of marine power metrological data, enhance data security management, and improve data governance capabilities and application effectiveness.

Under the driving force of new-generation technological revolution and industrial transformation [1-3], the global marine power equipment industry is experiencing rapid digital and intelligent transformation. Over the past decade, while significant progress has been made in metrological testing data for marine power systems, three critical challenges persist:

A. Critical Parameter Measurement Deficiencies

Current measurement capabilities remain limited to conventional instruments (pressure gauges, thermocouples, flow meters) under static laboratory conditions and normal measurement ranges. Significant gaps exist in dynamic parameter measurement, extreme environment testing, peak value detection, and online monitoring capabilities. These limitations result in unmeasurable, inaccurately measured or incomplete critical data, severely constraining scientific management of marine power systems and even leading to operational accidents.

B. Digital Fragmentation and Data Utilization Barriers

Despite the accumulation of substantial metrological testing data, low digitalization levels have created isolated data silos across different measurement devices. The strong correlation between operational parameters in marine power systems is hindered by this fragmentation, preventing comprehensive data integration and effective utilization for industrial upgrading.

C. Inconsistent Data Standardization Practices

The value transmission chain in marine power systems involves multiple components (calibration devices, sensors, dynamometers) with diverse measurement methodologies across different design phases and application scenarios. Lack of unified evaluation criteria frequently causes data inconsistency between design stages, posing significant challenges to equipment safety.

These metrological data challenges in acquisition, analysis, and application have created critical bottlenecks in marine power system development. Addressing these priorities through comprehensive metrological data system construction will fundamentally improve the reliability, safety and performance of next-generation marine power systems.

II. FRAMEWORK OF THE SOLUTIONS

The system adopts a Cloud-Edge-Device Integrated Data Circulation Architecture as illustrated, comprising five functional strata: Data Layer (Source Scenarios), Perception Layer, Network Layer, Platform Layer, and Application Layer.

A. Data Layer (Foundational Data Repository)

Serves as the multi-source data ecosystem encompassing:

- Laboratory metrological datasets
- Power equipment design verification data
- Operational performance metrics
- Marine vessel operational records

Data acquisition channels include experimental setups, sensing devices, sensor arrays, information systems, and physical/digital documentation.

B. Perception Layer (Intelligent Acquisition Gateway)

Implements edge computing-enabled data ingestion through:

- Multi-protocol edge data terminals
- Adaptive data collection tools

Key functionalities:

- Unified collection from heterogeneous sources
- Context-aware preprocessing
- QoS-guaranteed data transmission

C. Platform Layer (Data Middleware Infrastructure)

Operates as the distributed data orchestration hub featuring:

- Scalable storage architecture
- Data asset lifecycle management
- API-driven service provisioning

Core capabilities:

- Metadata standardization
- Multi-dimensional data modeling
- Secure service publication

D. Application Layer (Value-Creation Ecosystem)

Delivers intelligent analytics services through:

- Predictive maintenance models
- Operational diagnostics frameworks
- Lifecycle performance simulation

Implementation outcomes:

- Enhanced equipment reliability
- Optimized maintenance planning
- Data-driven design iteration acceleration

This framework establishes an industrial-grade metrological data value chain, delivering reliable and precise metrological support for the full lifecycle management of marine power systems - from conceptual design through operational deployment to predictive maintenance.

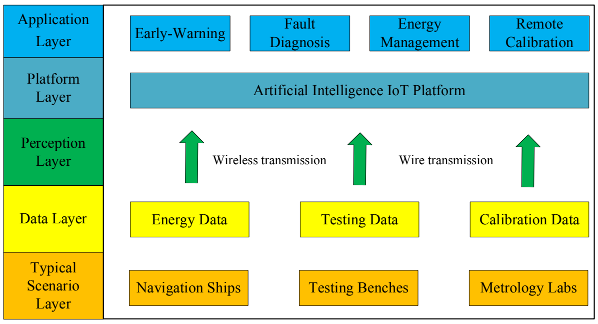

Fig. 1. Framework of the data application.

III. PARAMETER SYSTEM

In response to the problems of "inability to measure, inaccurate measurement, and incomplete measurement" of key parameters of marine power equipment, "data silos", and standardized management, we will investigate the mainstream testing and measurement technology requirements for marine strategic power equipment, strengthen top-level planning, establish a measurement and testing technology system that complements the commonality and individuality of marine power equipment, and support the systematic technological development of marine power equipment.

Preliminary research was conducted on the faults and measurement testing issues of the ship's power system in the early stage, and 53 parameters were sorted and summarized. 23 key parameters lacked testing capabilities, and 42 parameters lacked calibration capabilities.

IV. DATA MANAGEMENT ARCHITECTURE

The established measurement data platform promotes the classification, grading, and full lifecycle management of marine power equipment measurement data and resources. The data platform realizes the acquisition, aggregation, and development of measurement data throughout the entire chain, forming data assets and providing data services. It forms a data closed-loop management system from data collection and aggregation, data storage and integration, data processing and cleaning, data update and maintenance, data ownership and release, data service and use, data archiving and destruction. The data management architecture of the data center is shown in Figure 2.

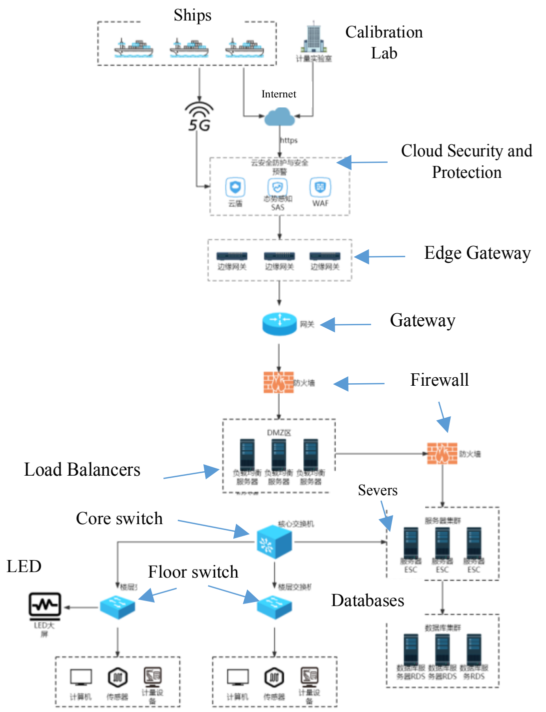

Fig. 2. Data management architecture.

V. MEASUREMENT DATA SECURITY AND COMPLIANCE

Encryption mechanism. Encrypt important and sensitive data using national encryption algorithms during storage and transmission to ensure data security.

A. Digital signature

Digitally sign measurement data, reports, certificates, etc. to ensure the integrity and authenticity of the data during transmission and storage.

B. Access control

Role based access control (RBAC) and attribute-based access control (ABAC) ensure that only authorized users and systems can access specific data.

C. Security audit

All data access operations require recording audit logs to ensure the traceability of data access, and regularly auditing the security and compliance of the system.

D. Data desensitization.

For sensitive data, anonymization and data perturbation techniques are used to ensure that personal privacy and sensitive information are not exposed during the data flow process.

E. Data compliance.

Ensure that data processing and storage comply with relevant international and national standards, especially in cross-border marine equipment metrology scenarios, and ensure the legality of data transmission and sharing

F. Electronic signature.

Verify the identity and protect the integrity of circulation documents such as testing reports, inspection reports, calibration certificates, etc. It includes digital signatures, encryption techniques, and authentication mechanisms to ensure the authenticity and immutability of files during the signing process.

G. Data trusted timestamp.

Generate a unique timestamp for each data record, identifying the time of data generation or modification. Verify the authenticity of timestamps through digital signatures and encryption techniques to ensure that data has not been tampered with.

VI. CONCLUSIONS

This article proposes a digital solution for measuring marine power equipment. By constructing a marine power measurement testing system, the data acquisition capability is systematically improved. Based on the data management architecture and data security scheme of the data platform, reliable data support is provided for marine power equipment.

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