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Integration and Management of Gear Quality Information Based on Cloud Services

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Abstract: In order to overcome the challenges associated with the disorderly formatting, dispersion, and inadequate traceability of gear quality data, a research study was undertaken to explore methods for managing such data. The study focused on constructing a gear quality data model using GXML and investigating techniques for mapping this model to a gear quality database. As a result, a gear quality cloud evaluation system was developed, offering valuable data support for the efficient management and exchange of gear quality information.

Keywords: GXML; gear quality; data model; data mapping; database

I. Introduction

As gear trade becomes increasingly globalized and gear manufacturing enterprises continue to embrace digital transformation, the demand for gear quality information from gear customers, suppliers, and metrology institutions has been growing steadily. To facilitate the smooth flow of gear quality information among all stakeholders within the enterprise, it is essential to effectively express and integrate gear quality data throughout the entire lifecycle of gears.

In recent years, there has been extensive research by scholars worldwide on the intelligentization of gears in various stages such as design, manufacturing, and measurement. The Gleason-developed Gleason bevel gear manufacturing expert system has seamlessly connected the design and manufacturing phases, to a certain extent achieving automated tooth surface design [1]. Klingelnberg has developed the Klingelnberg Gear Engine cloud computing system to manage equipment related to gear production, control the production process, and ensure complete product quality traceability [2]. Hexagon's Q-DAS quality data system integration solution has streamlined the entire process of quality data, from collection to upload, statistical analysis, and reporting, thus achieving comprehensive lifecycle management of quality data [3]. Moreover, in the field of gear measurement, the German Engineering Association has released the XML-based Gear Data Exchange Format (VDI-2610)[4], which includes not only gear parameter information but also manufacturing tool data, manufacturing process and process chain data, gear measurement process data, and customer information. Chinese scholars, including Wang Yu, have proposed a cloud-based gear measurement standard language called GXML (gear extensible markup language) and studied the exchange process system between the cloud platform and gear measurement data, effectively addressing data exchange issues within and between enterprises [5].

The research described has made significant strides in applying digitalization and data exchange to gear design, manufacturing, and measurement, resulting in improved production efficiency for gears. Nonetheless, practical applications still face challenges with gear measurement instruments from different manufacturers due to inconsistencies in standards, protocols, and interfaces, leading to the problem of "data islands."[6] Consequently, integrating and sharing gear quality data using scientific management methods and tools has become an urgent necessity for gear manufacturing enterprises seeking to enhance gear quality evaluation efficiency amidst the rise and advancement of cloud computing and cloud measurement models. Thus, this paper focuses on researching a cloud-based gear quality information integration method to address issues such as the confusion, dispersion, and poor traceability of gear quality data formats.

II. Gear Quality Infomation Modeling

The main goal of modeling gear quality data is to investigate the formatting and data definition rules, ensuring that gear measurement data adheres to international and national standards while enabling swift retrieval and matching within extensive datasets. This guarantees efficient storage and analytical capabilities for voluminous data. To fulfill the requirements of modeling and managing gear quality data, this section constructs a gear quality information model based on the extension and referencing of elements and attributes from GXML [5].

2.1 Organizational structure for the gear quality information model

The main purpose of presenting gear quality data in this study is to facilitate data exchange during the evaluation process and manage information related to the quality of gear products. Gear quality data, relevant to quality assessment in gear manufacturing, can be categorized into different parts based on their respective functions. These include gear accuracy standards, gear standard tolerances, gear measurement information, gear evaluation parameters, gear evaluation results, and gear quality certification information, as outlined in Figure 1. Furthermore, it is important to determine the interrelationships between various data elements to meet the requirements of gear quality evaluation, such as the correspondence between gear accuracy standards and gear standard tolerances, or the association between gear evaluation parameters and gear evaluation results.

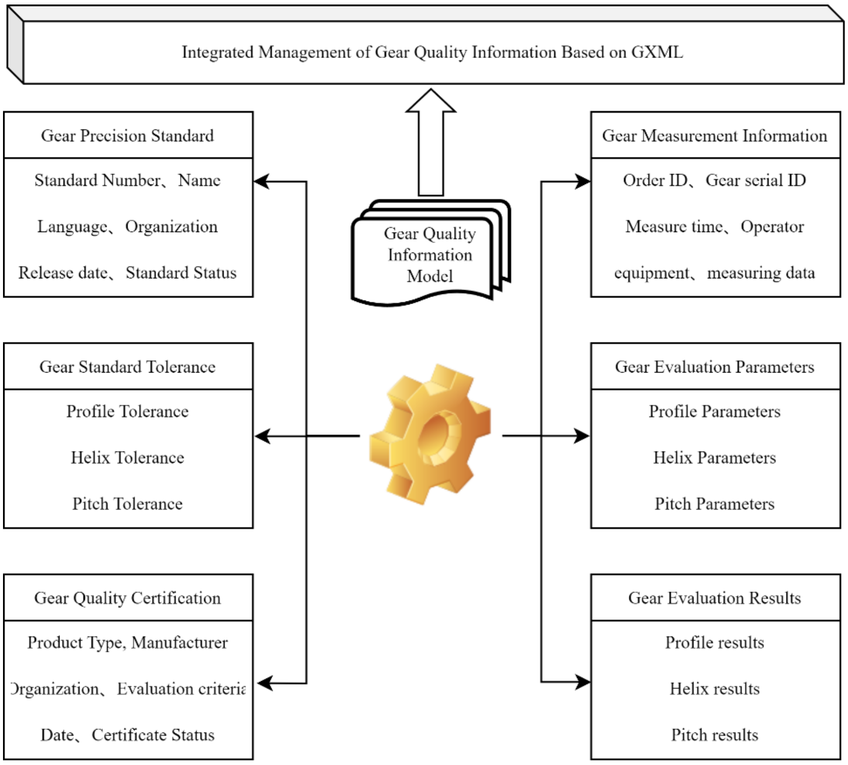

Fig.1. Organizational structure for the gear quality information model

According to the organizational structure, the fundamental element of this model is the "gear_quality_model," within which the nested element "gear_measurement" is equipped with a "serial_number" attribute serving as the unique identifier for gear products. It is further divided into six main parts, encompassing gear_measurement, gear_accuracy_standard, gear_standard_tolerance, evaluation_parameters, evaluation_results, and quality_certificates. The Schema structure of its XML document is depicted in Figure 2.

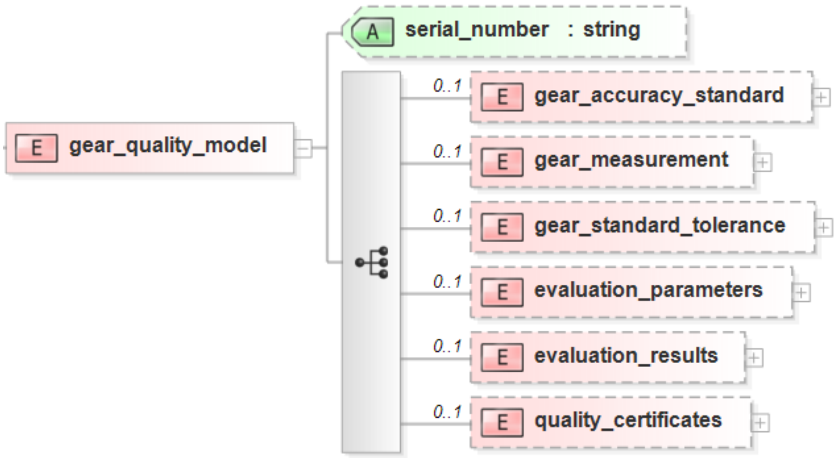

Fig.2. The schema structure of gear quality information model

2.2 Constructing the Model for Gear Quality Information

In order to clearly illustrate the construction method of the gear quality information model, a tree diagram can be utilized to systematically classify it, providing a lucid depiction of the content and relationships between various data categories. The GXML format standard for gear measurement data represents an application and extension of XML technology in the realm of describing and exchanging gear data. This paper expands upon the GXML data model within the domain of gear quality information and utilizes Schema to enforce constraints on the format and content of gear quality data. Subsequently, the expression method for gear quality information is exemplified using gear evaluation results as a case study.

The assessment of gears typically involves describing profile deviation, helix deviation, pitch deviation, and their associated precision grades. As the new standard ISO 1328-1:2013 gradually replaces the old standard, it allows for the specification of identical tolerance grades for tooth surfaces with varying load requirements or different assessment criteria for the same tooth surface, as well as the specification of diverse tolerance grades.[7] Hence, when structuring the organization of gear evaluation result information, consideration must be given to its compatibility with the new standard. Each "evaluation_results" element encompasses multiple evaluation results and their corresponding precision grades, identified by the "toothNum" attribute. Table 1 outlines the format template for profile evaluation results, while Table 2 presents an example of corresponding profile evaluation results.

Table 1: Fragment of an XML schema definition

```
<xs:element name="profile_results" minOccurs="0" maxOccurs="unbounded">
        <xs:complexType>
        <xs:sequence>
                <xs:element name="total_actual" type="xs:double" minOccurs="0" maxOccurs="1"/>
                <xs:element name="slope_actual" type="xs:double" minOccurs="0" maxOccurs="1"/>
                <xs:element name="form_actual" type="xs:double" minOccurs="0" maxOccurs="1"/>
                <xs:element name="profile_grade" type="xs:integer" minOccurs="0" maxOccurs="1"/>
        </xs:sequence>
        <xs:attribute name="toothNum" type="integer" use="optional"/>
        </xs:complexType>
</xs:element>
```

Table 2: Resulting XML file instance

```
<profile_resultstoothnum="L1">
        <total_actual>3.8</total_actual>
        <slope_actual>0.6</slope_actual>
        <form_actual>3.7</form_actual>
        <profile_grade>5</profile_grade>
</profile_results>
```

2.3 Mapping the GXML Data Model to the Database

Within the gear cloud measurement system, the GXML model adheres to XML syntax specifications, enabling data exchange and web operations. To facilitate the integration and sharing of gear quality data, it is essential to establish a mapping and conversion relationship between the gear quality information model and the database. An XML document can be visualized as a hierarchical structure, with the root node corresponding to the root element, and each child node representing an element, attribute, or text node. In the context of a relational database, objects, sub-objects, object properties, and object relationships align with elements, sub-elements, element attributes, and element relationships in an XML document [8]. For example, nodes in the GXML model document can be mapped to tables in the database model, attributes and elements can be translated into fields in the database table, and the relationships within the GXML model can be reflected as associations in the database model.

2.4 Designing the Structure of the Database

The purpose of database design is to convert entities and relationships from the real world into tables and relationships within the database, enabling efficient storage and management of data. The distinctive characteristics of gear quality data dictate the presence of significant associations between various data modules in the gear quality database.[9] Thus, establishing correlations among the entire quality data resources is of utmost importance. A database model is built for entities such as gear measurement equipment, gear basic parameters, gear measurement results, and gear quality statistical results, using the MySQL database management software for modeling purposes. Relationships between tables are established using primary and foreign keys. For example, the evaluation parameter number can serve as the primary key of the evaluation parameter table and be stored as a foreign key in the evaluation results table, thus linking evaluation parameters to gear evaluation results. Similarly, the primary key of the gear evaluation results table can be used as a foreign key to associate the gear product table with the gear evaluation results table, and the primary key of the measurement results table can be used as a foreign key to connect the quality statistical information table to the measurement results table. The resulting database model is depicted in Figure 3.

Fig.3. Database model of gear quality evaluation database

III. The System Architecture of the Gear Quality Evaluation System

In a cloud measurement environment, one of the pathways for gear users to effectively utilize gear quality information is by establishing a gear quality cloud evaluation system. This system leverages cloud services to provide gear quality evaluation services to users. The method proposed in this article is based on cloud services and involves integrating gear quality information by connecting the gear measurement system and the cloud server using a gear quality information model. The cloud server transmits the quality data collected from the measurement system to a web-based quality evaluation platform, enabling dynamic evaluation and analysis of gear quality data. The entire process is depicted in the in Figure 4. The GXML gear quality data model is employed to facilitate the binding and data exchange between the measurement system and the evaluation platform.

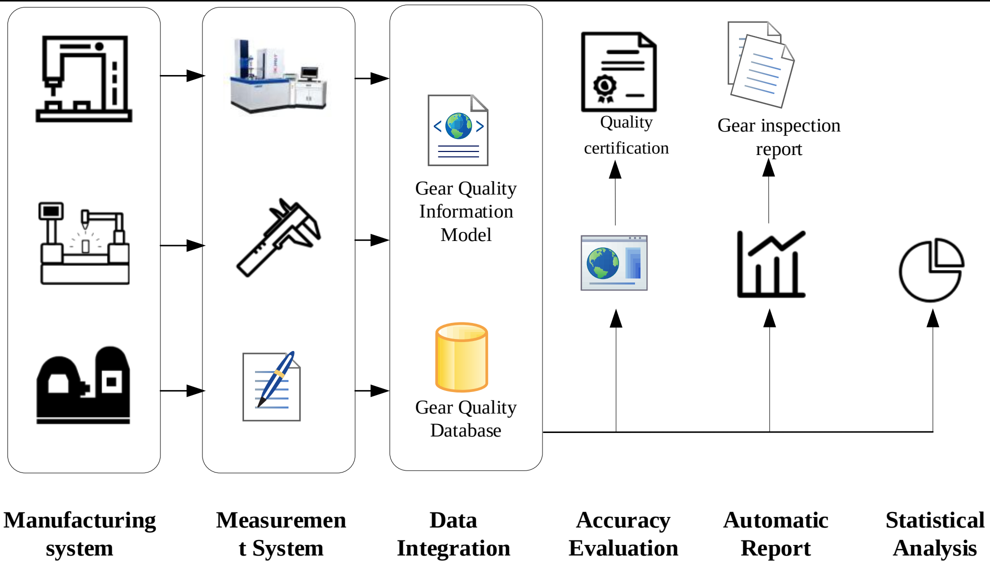

Fig.4. Gear quality evaluation cloud service process

The framework of the gear quality evaluation system proposed in this article under the cloud architecture is illustrated in Figures 5. It facilitates the interconnected sharing of the entire gear quality evaluation data through data integration and cloud service programs. Within this framework, the system is divided into four layers: the data storage layer, the business logic layer, the presentation layer, and the user layer. The data storage layer is responsible for secure data storage, while the business logic layer handles data analysis and decision-making logic. The presentation layer visualizes the evaluation results for users, and the user layer provides user interfaces and system management functionalities. Collaboratively, these layers form a comprehensive gear quality cloud evaluation system, enabling the integration and sharing of gear quality data.

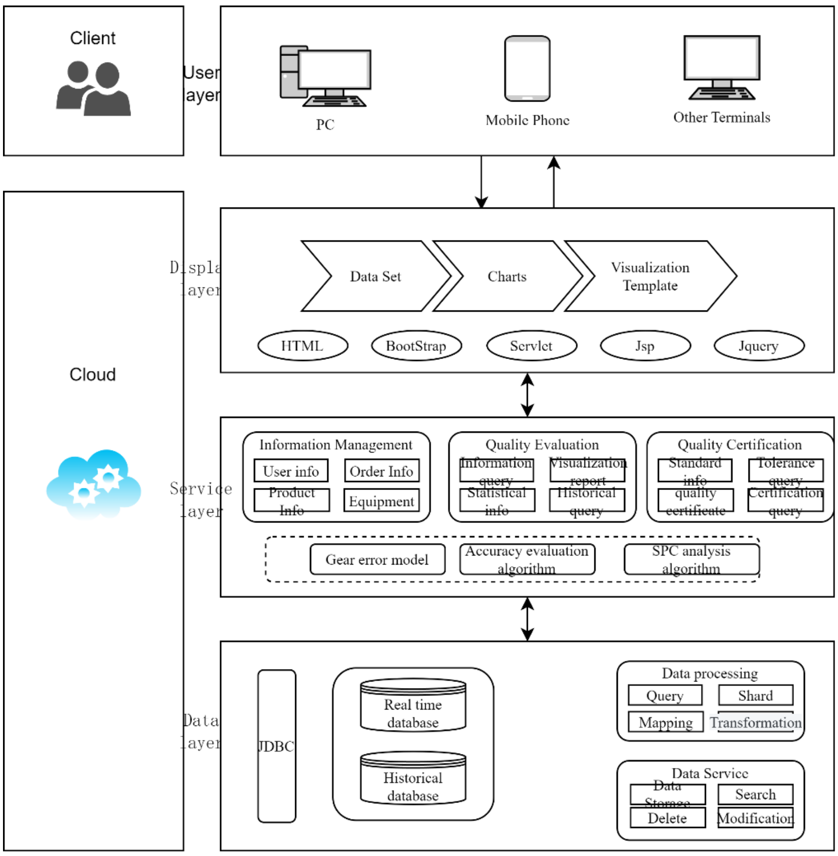

Fig.4. Cloud-based Architecture for Gear Quality Evaluation System

IV. Instances of System Applications

Based on the Gear Quality Information Model, this paper develops a Gear Quality Cloud Evaluation System. The system adopts the MySQL relational database as the system database and is developed based on the B/S architecture. In the system development process, ECLIPSE serves as the main development platform, and programming languages such as Java, HTML, and JavaScript are employed for front-end and back-end development. The following section presents application cases of the Gear Quality Information Model in gear accuracy evaluation and SPC statistical analysis.

4.1 Gear Precision Evaluation

After the measuring instrument is connected to the Gear Cloud evaluation system, it transmits data to the cloud in the form of GXML documents. Users can then centrally manage the data through the information management module upon logging into the system, as depicted in Figure 5. The gear quality evaluation module provides precise assessments of gear profile deviation, tooth pitch deviation, helix deviation, and more, while also visualizing the measurement results of the gears. Users have the capability to query gear order information based on the gear's unique identifier. The server processes the request, retrieves gear quality data based on the gear's unique identifier, performs gear error analysis and accuracy evaluation according to the selected standard, and subsequently stores the results in the database. The gear quality evaluation results page features interactive charts based on ECharts, facilitating user interaction through hover, click, and dialogue boxes, thereby emphasizing key indicator data of gear deviations. This approach offers a clear hierarchy, intuitive information, and rich charts, ultimately enhancing users' efficiency in information acquisition.

Fig.5. Gear Precision Evaluation Interface

4.2 Statistical Process Control analysis

The system depicted in Figure 6 represents an application of the gear quality data model, resulting in a statistical analysis system for gear quality information. This system includes features such as gear quality data management, historical data tracing, SPC statistical analysis, and control chart generation. By utilizing the SPC statistical analysis system, gear users can gain a holistic understanding of the overall quality condition and distribution of different quality grades for a specific batch of gear products, thus providing decision-making support for gear trading. Furthermore, the efficient management and organization of extensive historical data by the gear quality information model leads to improved statistical analysis and enhances the effectiveness and reliability of gear quality information.

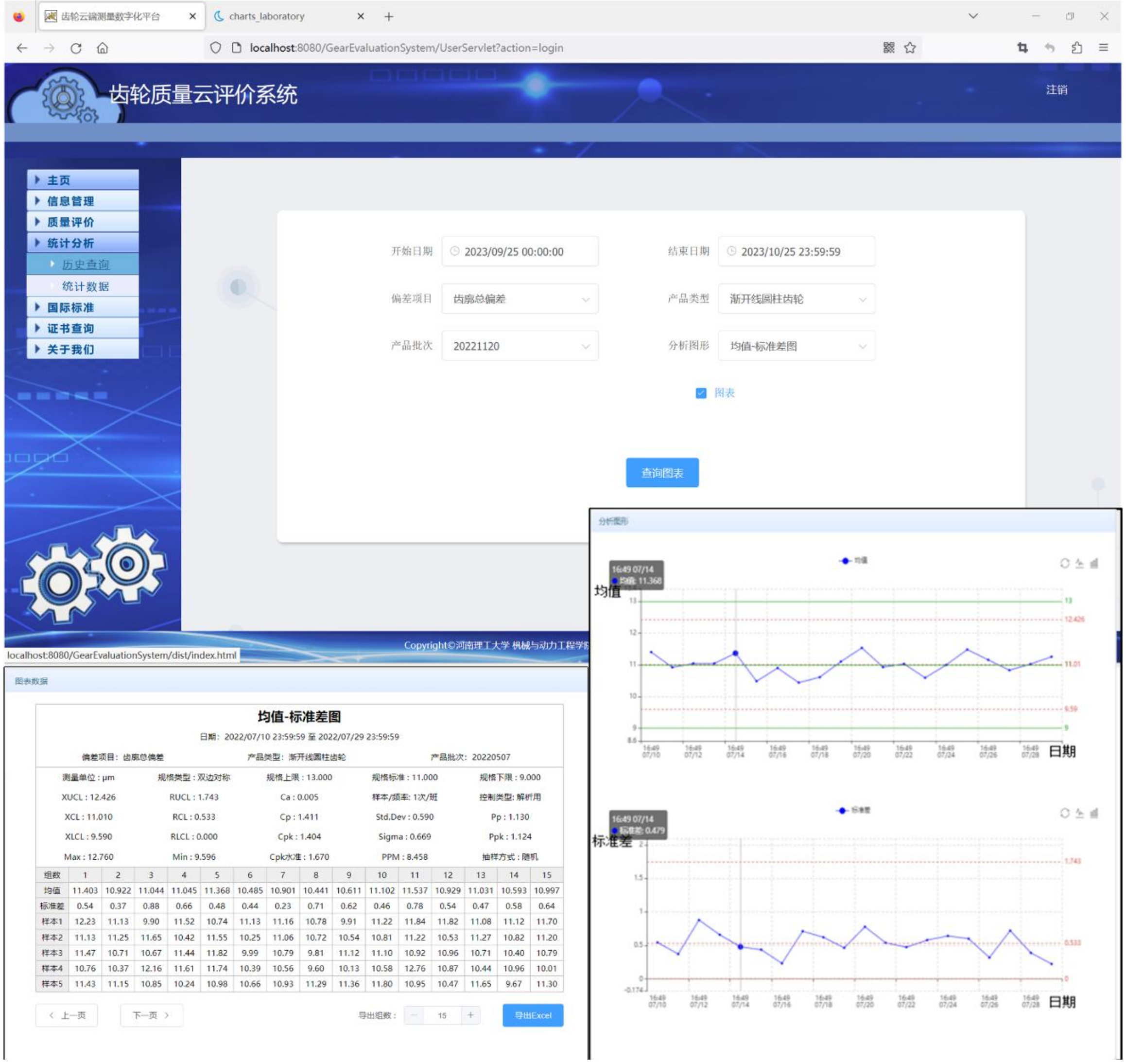

Fig. 6 Gear quality control diagram interface

V. Conclusion

The objective of gear quality information modeling is to define and articulate the quality assessment data generated during the manufacturing process of gear products, while establishing interconnections among these data. Through an analysis of the gear quality assessment workflow, information sources, and heterogeneity, this study employs GXML to develop a gear quality information model comprising various modules, including standard information, measurement information, evaluation information, and statistical information. Additionally, a mapping approach between the gear quality information model and the quality database is proposed, along with the design of the gear quality database model. Leveraging the gear quality information model, a gear quality cloud evaluation system is constructed, facilitating the integration and sharing of gear quality information in the cloud.

VI. Acknowledgements

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