

Overview of Mainstream Turbine Fault Detection Technologies and Development Prospects

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Abstract: The turbine is the ‘heart’ of the ship, and its fault detection technology is of great significance. The technology has gone through the transformation from artificial experience detection to modern intelligent detection. The current mainstream technology is based on vibration analysis, oil analysis, infrared thermal imaging and expert systems, each with its own principles, application scenarios, advantages and disadvantages. However, they face challenges such as complex detection environment, data accuracy and technology applicability. Emerging trends such as big data, artificial intelligence and fault detection fusion and multi-technology fusion, to solve the challenge of providing new ideas, various types of technology needs to be optimised towards multi-technology fusion, intelligent direction to adapt to the industry's development needs.

Keywords: Turbine faults; Detection techniques; Mainstream technologies; Emerging trends.

1. Introduction

From the theoretical level, the research can help improve the theoretical system of fault detection, integrate new technologies, discover deficiencies, and lay the foundation for innovation; in practice, the results can guide the detection work, help maintenance personnel to quickly locate faults, improve efficiency, reduce costs, and safeguard the operation of the ship, but also improve the safety and reliability of shipping, enhance the competitiveness of enterprises, and promote the sustainable development of the shipping industry.

The purpose of this thesis is to analyse the engine fault detection technology, systematically sort out its theory and method, provide researchers with the basic knowledge of the field and the development of the status quo, help grasp the direction of the research, and provide support for the safe and efficient operation of the shipping industry.

2. Main Theoretical Support for Turbine Fault Detection Technology

The core theoretical system of turbine fault detection technology consists of fault diagnosis and signal processing theory. Fault diagnosis is based on the construction of system state model, real-time analysis of equipment operating parameters (such as vibration, temperature, pressure, etc.) to achieve fault identification and accurate positioning, the core of which is to analyze the mechanism of abnormal state through mathematical modeling and logical reasoning; signal processing technology focuses on the feature extraction of multi-dimensional signals, such as vibration, oil, fluid, etc., and extracts key information from complex signals through time-domain statistics, frequency-domain transformation and time-frequency analysis to provide data support for diagnostic decision-making. Signal processing technology focuses on feature extraction of multi-dimensional signals such as vibration, oil and fluid through time-domain statistics, frequency-domain transformation, and time-frequency analysis, etc., which can isolate key information characterising faults from complex signals and provide data support for diagnostic decisions. [1]

The development of this technology has gone through three typical stages: early artificial detection relies on the sensory

experience of maintenance personnel (such as auscultation, tactile measurement), subjective judgement and detection means of limitation, it is difficult to find early weak faults; the application of sensor technology to promote the detection of the automation stage, various types of vibration, speed, oil sensors to achieve real-time collection of operating parameters, but the early analysis of the data only stays in the threshold comparison of simple processing level, the identification of complex faults, and so on. With the development of artificial intelligence and big data technology, modern intelligent detection technology through machine learning algorithms to automatically mine the deep characteristics of the signal, to achieve automatic fault identification, location and prediction in a strong noise environment, significantly improving the level of intelligent detection.

The main problems faced by the current research include: the application limitations of a single detection technology, such as vibration analysis method is highly sensitive to mechanical faults, but the diagnostic ability of the lubrication system faults is weak; the depth of multi-source data fusion is insufficient, and the synergistic diagnostic advantages of multi-dimensional signals, such as vibration, oil, temperature, etc., have not yet been given full play to; the noise interference in complex industrial environments (e.g., high temperature, electromagnetic interference) can easily lead to signal distortion and affect the feature extraction accuracy. In this regard, the focus of research is shifting to the organic integration of traditional detection technology and emerging intelligent algorithms to optimise the detection model through technological complementation, with the aim of improving the system's detection accuracy, reliability and environmental adaptability under complex working conditions.

3. Analysis of Mainstream Turbine Fault Detection Techniques

3.1. Inspection Techniques Based on Vibration Analysis

Detection technology based on vibration analysis is one of the core means of turbine condition monitoring, which collects vibration signals generated during operation in real

time by arranging acceleration sensors or piezoelectric sensors in key parts of the equipment (e.g., bearing housings and rotor housings). The technology constructs a characteristic map corresponding to the operating state of the equipment by analysing the frequency components, amplitude distribution and phase relationship of the signals: when the bearing raceway has spalling, wear and other faults, its characteristic frequency will stimulate the vibration components in a specific frequency band; and rotor imbalance faults are manifested in the fact that the amplitude of the working frequency (rotational speed frequency) shows a significant increase in the periodicity with the increase in rotational speed. increase [2].

The method is widely used in the detection of mechanical faults such as bearing failure, rotor imbalance, gear mesh abnormality, etc. It can capture the weak vibration anomalies caused by wear and tear of components and gap changes during the early stage of equipment operation. Its significant advantage lies in its sensitivity to early faults - it can detect subtle changes in vibration energy at the incipient stage of a fault, and it supports real-time on-line monitoring, and realises rapid identification and positioning of fault signals through the embedded processing unit to satisfy the demand for dynamic monitoring of the equipment's health status in the industrial field.

However, in practical application, the complex operating environment of the turbine poses a challenge to this technology: the structural vibration coupling under high temperature and high pressure conditions, as well as electromagnetic interference, pipeline rheological vibration and other multi-source noise can easily lead to signal distortion, which makes it more difficult to extract effective features; when there is a composite fault of bearing wear and rotor misalignment, the modulation and superposition of the different fault characteristic frequencies form a complex vibration signal mode, which makes it difficult for the traditional Fourier analysis method to accurately identify and locate the fault signals. Fourier analysis method is difficult to accurately decouple, need to combine wavelet transform, empirical modal decomposition and other time-frequency analysis techniques to improve the diagnostic accuracy.

3.2. Fluid Analysis Technology

As an important means of equipment condition monitoring, oil analysis technology realises the assessment of equipment wear state by detecting the physicochemical properties of lubricant (such as viscosity, acid value, moisture content, etc.) and the abrasive characteristics carried in it (including the morphology, size and composition of abrasive particles, etc.). This technology is widely used in the fault diagnosis of key transmission components such as internal combustion engines, gearboxes, hydraulic systems, etc. It can effectively capture early abnormal signals such as bearing wear, gear gluing, parts corrosion, etc., and reflect the overall wear condition of the equipment from the global perspective of the lubrication system.

Its core advantage lies in its ability to predict potential failures through gradual changes in the fluid, which has unique diagnostic value, especially for the slow development of wear loss patterns. However, there are inherent limitations in this technology: the detection period is long, which is difficult to meet the real-time monitoring requirements; the oil sample collection process is easily affected by the sampling location, frequency and operation specifications,

which may lead to bias in the analysis results if the samples fail to accurately reflect the real state of the lubrication system; and at the same time, the comprehensive interpretation of the physical and chemical indexes of the oil and the characteristics of abrasive particles relies on professional experience, which needs to be combined with the systematic study of the equipment's operating conditions.

3.3. Infrared Thermography

Infrared thermal imaging technology uses the temperature difference of the object to generate thermal images to detect faults, through the reception of infrared converted to visual images to locate temperature anomalies in the region, such as electrical faults localised overheating, pipeline blockage temperature difference. [3] Applied to ship turbine electrical faults, pipe blockage detection, the advantage is non-contact, fast detection, intuitive; shortcomings are subject to ambient temperature interference, limited ability to detect internal faults.

4. Challenges and Strategies for Turbine Fault Detection Technology

4.1. Challenges Faced

The high temperature, high humidity and strong vibration environment of ship turbine operation significantly affects the fault detection technology: high temperature causes changes in the performance of electronic components, changes in the physical properties of the detection object, reducing the accuracy; high humidity is easy to cause circuit short-circuiting, component damage and corrosion of the metal, which interferes with the signal acquisition; strong vibration causes the sensor to be displaced, generating signal noise, which affects the identification of weak faults.

Detection data accuracy is affected by data noise (electromagnetic, mechanical interference, etc.) and sensor errors (manufacturing, aging, installation factors), resulting in signal feature extraction difficulties. Different turbines and failure modes have different requirements for the applicability of the technology: vibration analysis is applicable to bearings and other faults, with limited ability to detect complex electrical faults; oil analysis is good at wear and tear monitoring, and is difficult to cope with sudden structural failures; infrared thermography is good for surface fault detection, but is limited to detecting deep internal faults.

4.2. Response Measures

To deal with the complexity of the testing environment, anti-interference equipment (heat insulation, moisture-proof, shock absorption) can be developed and signal processing algorithms can be optimised; to improve data accuracy, noise reduction algorithms such as wavelet transforms need to be adopted, and sensors need to be regularly calibrated and maintained; to deal with the applicability of the technology, a guide to the selection of the technology should be established, technical principles and advantages and disadvantages should be analysed in conjunction with case studies, and training for testing personnel should be strengthened [4].

5. Emerging Turbine Fault Detection Technology Trends

In the field of steam turbine fault detection, big data technology has built a full-dimensional condition monitoring

system. By deploying a high-density sensor network, multi-modal operation data such as vibration acceleration, temperature gradient, pressure pulsation, speed fluctuation, etc. can be collected in real time, and the average daily data collection volume reaches GB level. These heterogeneous data are initially cleaned by the edge computing platform, and then converged into the central analysis system for spatial and temporal correlation modelling: the equipment health benchmark model is constructed based on the historical data, the deviation analysis between the real-time data and the benchmark model is realized through the dynamic time adjustment algorithm, and a multi-level warning mechanism is constructed by combining with the statistical process control, which is capable of capturing the trend of the early failures, such as the bearing clearance increasing by 0.05mm and the slight corrosion of the blades, and providing data for predictive maintenance. changes, providing data support for predictive maintenance.

The deep integration of artificial intelligence technology promotes fault detection from threshold judgement to intelligent diagnosis. Deep learning algorithms show unique advantages in feature engineering: convolutional neural network (CNN) automatically extracts the time-frequency domain layered features of vibration signals through multi-layer convolutional kernel, and effectively identifies the 1/2-frequency modulation phenomenon triggered by the failure of the outer ring of the bearing; recurrent neural network (RNN) combines with the long and short-term memory unit (LSTM) to deal with the temperature time-series data, and achieves the trend prediction of rotor thermal bending failure. Machine learning algorithms play a key role in classification decision-making: Support Vector Machine (SVM) solves the problem of fault classification in high-dimensional feature space through kernel function mapping, and the accuracy rate is increased by 25% compared with the traditional method in the diagnosis of compound faults in gearboxes; Decision Tree Algorithm combines the experience of experts to build a fault rule base, and achieves fast logical reasoning for complex faults such as shaft misalignment and steam excitation, which significantly shortens the diagnosis cycle. cycle.

In the face of the complex working conditions of steam turbine coupled with multiple physical fields, the detection technology is showing the development trend of multimodal fusion. Vibration analysis technology is good at capturing high-frequency dynamic features, providing micro-scale signal details for precision diagnosis; oil analysis reveals the progressive wear state of the lubrication system through spectral analysis of abrasive grain composition; infrared thermal imaging technology locates the temperature anomaly area at the 0.1°C level in non-contact manner, and accurately identifies the hidden dangers of thermal faults such as valve leakage and poor lubrication of bearings. Through the dual integration of the data layer (feature level fusion) and the decision-making layer (evidence theory fusion), these technologies, combined with the fault knowledge base constructed by the expert system for comprehensive reasoning, form a three-dimensional diagnostic system of 'macroscopic positioning - microscopic verification - trend prediction', which effectively solves the problem of the detection blind area of a single technology and raises the accuracy rate of fault identification under complex working conditions to more than 95%, and provides a technical guarantee for the reliable operation of the turbine in long term under high parameters. It provides technical guarantee for the

long term and reliable operation of high parameter turbines.

6. Conclusion

Engine fault detection technology is crucial to the safe, reliable and economic operation of ships. The principles, application scenarios, advantages and disadvantages of each technology are different: vibration analysis monitors the characteristics of vibration signals, applicable to bearings and other faults, sensitive, fast, but prone to interference; oil analysis through physical and chemical and abrasive grain analysis to determine wear, applicable to diesel engines, etc., to detect hidden dangers in advance, but the cycle is long; infrared thermography using temperature differences in the detection of faults, applicable to electrical and other faults, non-contact, intuitive, but subject to the environmental impact of the big; expert system based on the The expert system is based on knowledge diagnosis, applicable to complex systems but difficult to update the knowledge base [6].

Facing the challenges of detection environment, data accuracy and technology applicability, anti-interference equipment can be researched and developed, data processing can be improved, and selection guidelines can be established. Big data, artificial intelligence and fault detection fusion and multi-technology fusion become emerging trends [7].

Future technology will develop towards multi-technology fusion and intelligence, with complementary advantages, intelligence and efficiency. In this paper, there is insufficient research on the application of emerging technologies, so we can dig deeper into the potential of emerging technologies, explore the multi-technology fusion mode, and improve the technology selection guide under different working conditions.

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