Research on Health Management Technology and Application of Lifting Machinery

Guansi Liu \textsuperscript{1,2}, Keqin Ding \textsuperscript{1,2}, Hui Jin \textsuperscript{1,2} and Li Chen \textsuperscript{2}

\textsuperscript{1} Jiangsu Key Laboratory of Engineering Mechanics, School of Civil Engineering, Southeast University, 211189, China
\textsuperscript{2} China Special Equipment Inspection Institute, Beijing 100029, China

Keqin Ding, e-mail: kqding@sina.com; Hui Jin, e-mail: jinhui@seu.edu.cn

Abstract. Lifting machinery is a key facility for the development of modern industry. It’s not only an important support for the construction of major national projects but also one of the core competitiveness of China’s equipment manufacturing industry. With the development of large-scale, high-parameterization and intelligentization of lifting appliances, technologies such as safety monitoring and health monitoring have been gradually applied to industrial fields such as ports and metallurgy. In order to further develop the data-driven health management technology and engineering application of cranes, on the basis of elaborating the health management needs of cranes, the current status and development trends at home and abroad, we explored and proposed a technical framework for health management of cranes, and analyzed the lifting Key technologies such as machinery safety monitoring, health monitoring, health status diagnosis, failure trend prediction, and predictive maintenance decisions. Finally combined with a 200t casting crane in a steel plant, carried out safety monitoring and data-driven diagnosis, prediction and system visualization management. The results show that: the hoisting machinery health management system can monitor and forecast in real time and carry out early warning and forecasting to avoid the occurrence of unexpected accidents; based on predictive maintenance decisions, it helps enterprises to reasonably arrange maintenance cycles and maintenance methods to reduce the maintenance cost of the enterprise; reduce hoisting machinery downtime Time to enhance the effective value of assets; and enhance the level of enterprise information management.

1. Preface
Lifting machinery is widely used in metallurgy, chemical industry, power, port, construction, manufacturing and other industries. It is a key facility for the development of modern industry, an important support for the construction of major national projects, and one of the core competitiveness of China’s equipment manufacturing industry.

In China, the hoisting machinery industry has been established and gradually developed from 1950s to 1960s. It has formed a wide range of products and a large group of enterprises, serving all walks of life in the national economy. Since 2002, lifting industry has developed rapidly, and by 2004, all indicators of the whole industry have reached a record. During the 11th Five Year Plan period, the state focused on the development of energy, power, petrochemical, metallurgy, shipbuilding, transportation and other industrial fields, driving the continuous prosperity of the lifting industry. During the 12th Five Year Plan period, the gross industrial product and sales revenue of hoisting...
machinery products increased by 30% each year. During the 13th Five Year Plan period, efforts were made to improve the reliability, durability and safety of hoisting machinery products, improve the level of industrial monitoring and test verification, and speed up the technology of product life cycle management and online monitoring.

China has 2.4401 million cranes, and the cranes manufactured by ZPMC have been exported to 103 countries and regions. Under the new normal of economic development, the hoisting machinery is developing towards large-scale, high parameter. For example, the lifting capacity of a single bridge crane in the Three Gorges power station is 1200 tons, the lifting capacity of a single shipbuilding gantry crane is 1600 tons, the lifting capacity of the third generation nuclear power crawler crane is 3600 tons, and the lifting torque is 86000 tons. The structure of hoisting machinery is more and more complex, the potential risks and hidden dangers are increasing gradually, which makes the accidents of hoisting machinery easy to happen and frequent. In 2017, 94 crane accidents occurred nationwide, in 2018, 100 crane accidents occurred nationwide, and in 2019, 26 crane accidents occurred nationwide. The number of accidents accounted for three consecutive years in the forefront of eight types of special equipment, which not only caused huge economic losses and casualties to enterprises, but also had a bad social impact. The lack of highly reliable monitoring equipment, diagnosis and prediction methods, and health management theory and system has seriously restricted the development of intelligent and intelligent hoisting machinery in China.

2. Research status of health management of hoisting machinery

2.1. Health management requirements for lifting equipment

(1) The after-sales service with health diagnosis and remote maintenance as the core is an important way to realize service-oriented manufacturing.

Under the background of globalization, equipment users are distributed in all corners of the world, which brings great difficulties and challenges to the operation and maintenance of equipment. Under the background of service, equipment manufacturing and service infiltrate and integrate with each other. The traditional "manufacturing + sales" manufacturing one-way business began to transform to the "technology + Management + service" service-oriented manufacturing complex business. From production-oriented manufacturing to service-oriented manufacturing has become the main trend of the development of manufacturing industry. Therefore, it is necessary to shift from the low end of the value chain with significant production ratio to the high end of the value chain with significant service ratio and high added value. The development of after-sales service with health diagnosis and remote maintenance as the core as a high value-added product business will become an important way to promote the transformation and upgrading of the manufacturing industry and move towards the high end of the industrial chain.

(2) The traditional "post maintenance" and "planned maintenance" are difficult to meet the needs, which urgently need the technical support of health diagnosis and health management.

With the development of science and technology, hoisting equipment is developing towards large-scale and automation. The structure and function of hoisting machinery are becoming more and more complex, and the difficulty of maintenance and management is increasing. Once an accident occurs, it often causes huge losses, even catastrophic consequences. Traditional "fault maintenance", "planned maintenance" and "post maintenance" are passive or experience-based, which can not be combined with the current state of the equipment for reasonable maintenance. It will inevitably cause problems such as inadequate equipment maintenance and excessive maintenance, which will affect the safe use of the equipment.

2.2. Health management of hoisting equipment at home and abroad

In 1998, the United States first proposed the concept of health management, and developed systems using health management technology. Hale et al. Studied the fatigue crack monitoring technology of crane metal structure; Lee et al. Carried out the fatigue crack growth monitoring research of steel
plate under cyclic load, which proved that the change of stiffness can reflect the crack growth of structure and can be used for crack growth monitoring. Crane monitoring system developed by Yaskawa company of Japan System, through intelligent sensor technology to collect real-time production site related data, and then through wireless communication technology to remotely monitor container handling equipment, to achieve remote fault diagnosis; Sumitomo crane monitoring system, developed by Japan, can real-time monitor the metal structure stress of the crane, and through ultra-high speed exchange routing technology to achieve its own brand machinery production in the world Real time online health monitoring of the product. Based on wireless technology, a complex health monitoring system is developed in the port of Johor, Malaysia. The special software is used to realize the unified scheduling of port operations and the automation of port operations. In addition, Kony, Demag, Liebherr, manitowak and other enterprises have developed safety monitoring and management systems for corresponding equipment types to monitor the operation parameters and operation instructions of hoisting machinery in real time [1].

Xu Changsheng and others of Wuhan University of science and technology carried out research on structural stress diagnosis based on Improved BP neural network for port quayside bridge structure, and developed online monitoring system based on GPRS wireless network [2] Xu Huping and others designed and developed a safety monitoring system for portal crane [3], Jia minping, et al. Of Southeast University collected the operation data of the unit in real time by arranging vibration sensor and pressure sensor, and added relevant algorithm analysis to the fault diagnosis system, which can provide general solutions for specific faults [4]. Based on configuration software and wireless network, the design and development of crane remote monitoring system has been completed [5]. Wang Quanwei, Xu Geling, et al. Of Taiyuan University of science and technology carried out the theoretical and Application Research on the health monitoring system of hoisting machinery, and developed a comprehensive evaluation system for the health monitoring of hoisting machinery based on VC [6]. During the 13th Five Year Plan period, China Academy of special equipment inspection and research respectively undertook 863 subjects "Research on the integration and application of life cycle data of large complex lifting equipment" and the national key research and development program "research and development of health monitoring and diagnosis technology and equipment of lifting machinery", developed and completed the life cycle data integration management system of lifting machinery, safety monitoring and airborne early warning system of lifting machinery Unified and crane health monitoring and prediction management system and other management systems realize the whole life cycle management, operation parameter monitoring management and operation state monitoring management of crane, and provide a large number of data support for crane health management [7 ~ 10].

2.3. Development trend of health management of hoisting equipment
The current development trend of health management technology research is mainly reflected in the following aspects:

(1) Networking. With the development of information technology, the development of Web-based remote fault diagnosis and health management system can improve the coordination and accuracy of fault diagnosis of complex equipment, reduce the operation cost of complex equipment, and improve the economic efficiency of enterprises.

(2) Service oriented. Service encapsulates and uses fault diagnosis resources in the form of services, and exchanges and shares services in the health management platform, which is conducive to enriching knowledge resources, diagnosis methods and other contents of the platform, improving resource utilization, and promoting in-depth research and application of health management technology.

(3) Intelligent. Knowledge will play a more important role in the health management system, and knowledge and intelligence will become the development trend of health management technology. The equipment system will have the functions of self-diagnosis and remote maintenance. The corresponding health management system is required to have the ability to learn and update
knowledge, and be able to complete the equipment diagnosis and operation and maintenance guidance by self-learning.

3. Health management technology of hoisting machinery

3.1. Health management framework of hoisting machinery
The health management of hoisting machinery combines advanced means and technologies such as intelligent sensor technology, Internet of things technology, database storage technology, signal processing technology, artificial intelligence technology and visualization technology. Firstly, the key characteristic parameters of crane structure, mechanism, electric control and environment are sensed by intelligent sensor technology; secondly, the monitoring parameters are sent to remote center by Internet of things technology; secondly, the unstructured data is structured by database interface, analysis and fast storage technology; thirdly, the unstructured data is realized by signal processing technology, feature extraction technology and data fusion technology Processing and analysis of characteristic parameters; thirdly, through artificial intelligence, deep learning and other technologies to achieve crane diagnosis and prediction; finally, through visualization technology to achieve crane health management visualization. The health management structure of hoisting machinery is figure1.

![Figure 1. System design architecture](image)

3.2. Key technology of health management of hoisting machinery

3.2.1. Safety monitoring technology
According to the requirements of GB/T 28264 crane safety monitoring management system, based on weight, displacement, limit switch, video and other sensing monitoring means, using industrial bus and wireless network technology, and based on OPC technology. 14 monitoring parameters and 9 monitoring states of crane are recorded and managed. Safety monitoring technology is figure2.
3.2.2. Health monitoring technology

Based on vibration, temperature, rotation speed, fiber Bragg grating strain and other sensing monitoring means, using field bus and wireless network technology, real-time online monitoring and storage are carried out for the main load-bearing parts of crane structure, high-speed shaft and low-speed shaft of reducer, brake torque state and brake displacement, so as to realize the all-weather monitoring and early warning function of crane parameters. Health monitoring technology is figure 3.

3.2.3. Health status diagnosis technology

Analyze the stress monitoring data of the key parts of the hoisting machinery structure, diagnose the structural bearing capacity of the hoisting machinery under the specified conditions and the worst dynamic conditions, and analyze the structural health level. The vibration monitoring data of high-speed shaft, low-speed shaft and other parts of the reducer are collected, and the time-frequency characteristic parameters of the vibration signal are extracted by using the correlation analysis of time-domain and frequency-domain to diagnose the healthy state of the reducer. Based on the data collection of brake torque scale, the image feature extraction and time history correlation analysis are used to diagnose the brake health. Finally, based on fuzzy evaluation method, extension
evaluation method and other methods, the health diagnosis of the whole system is carried out. Health status diagnosis technology is Figure 4.

![Figure 4. Health status diagnosis technology](image)

3.2.4. **Damage trend prediction technology**

The rain flow counting method is used to predict the fatigue life of each measuring point. The fault state of the reducer is predicted by time-domain, spectrum correlation analysis and time series prediction model. Based on image feature extraction and time history correlation analysis, the performance degradation state of brake is predicted, and the fault trend of brake is predicted based on neural network. Damage trend prediction technology is Figure 5.

![Figure 5. Damage trend prediction technology](image)

3.2.5. **Predictive maintenance decision technology**

Based on the real-time monitoring data, historical status data, fault maintenance data and other information, aiming at the minimum maintenance downtime loss and the minimum maintenance resource consumption, the maintenance strategy of quantitative system for important functional components of hoisting machinery is formulated, and the maintenance cycle of functional components of hoisting machinery system is determined based on the technical means of field fault data statistics, expert evaluation, quantitative modeling, etc; Combined with monitoring technology, information management, grey prediction, multi-objective theory, reliability modeling, dynamic decision-making, opportunity maintenance and other technical methods of cross and coupling, the predictive maintenance decision-making of hoisting machinery is finally obtained.
4. Application of health management system for hoisting machinery

4.1. Basic information of hoisting machinery
The four beam six rail casting crane of a steel plant has been put into use since 2000, with main lifting capacity of 200t, auxiliary lifting capacity of 63T, crane running speed of 9.8m/min, main trolley running speed of 42.8m/min, auxiliary trolley running speed of 41.7m/min and main beam span of 23.5m. The physical drawing of crane is shown in Figure 6 below.

4.2. Application of safety monitoring and health monitoring
According to GB / T 28264, real-time monitoring of operation parameters and operation status of hoisting machinery is carried out. At the same time, the strain of the main beam, the connection part of the main beam end beam and the end beam are monitored by optical fiber strain; the vibration of the high-speed shaft, the low-speed shaft and the end bearing of the drum of the reducer of the main hoisting mechanism is monitored by piezoelectric diagnosis; the brake moment scale of the main hoisting mechanism is monitored by video by machine vision. Data collection is sent to the remote management platform through the security monitoring and health monitoring system of the lower computer. Field installation is as follows Figure 7.

4.3. Application of data driven diagnosis and prediction
According to GB/T 33218, the monitoring data of stress state are analyzed by rain flow counting method.

\[
\log_{10} N_i = \log_{10} C_0 - d \cdot SD - m \cdot \log_{10} Sa
\]

(1)

Calculate the cumulative fatigue damage of each measuring point:

\[
D_i = \frac{n_i}{N_i}, \quad D = \sum_{i=1}^{n} D_i \quad (n = 1, 2, 3, \ldots)
\]

(2)

Calculate the effective value of vibration in time domain:

\[
V_{rms} = \sqrt{\frac{1}{N} \sum_{t=1}^{N} \chi^2(t)}
\]

(3)

At present, the most widely used standards for equipment vibration state diagnosis are ISO2372 and ISO 3945. According to the standards, the RMS value of speed of medium-sized machinery (class II) should be less than 7.1 mm/s. The diagnosis results show that the motor and reducer work normally.

4.4. Application of system platform
The system adopts Net as the development platform, establishes communication through standard industrial protocol and Ethernet, and adopts the current popular interface. The system platform includes three parts: basic platform, application system and database. All monitoring data are transmitted to the remote cloud computing center, which can sort out and analyze the massive monitoring data and present the analysis results to users in the form of cloud platform. The functions of cloud platform include user-friendly login interface, system alarm, monitoring data history curve view, health status diagnosis, damage trend prediction, predictive decision maintenance and other functions. Structural stress and vibration data analysis of reducer are shown in Figure 8 to Figure 11.

\[ \log_{10} C_0 = 14.034, \ SD = 0.204, \ m = 3.5 \ \text{and} \ d = 0.2. \] 

According to formula (1) and formula (2), the fatigue damage of point 1 is \(2.9218 \times 10^{-7}\). Since the damage value is far less than 1, it can be judged that there will be no fatigue cracks at these two measuring points, The structure is in a healthy state.

According to the formula (3), the maximum vibration value of the measuring point of the reducer is \(23.9226 \text{mm/s}^2\), and the effective value of the speed is \(0.0038 \text{mm/s}\). Referring to ISO2372 and ISO 3945, the reducer is in a healthy state.

5. conclusion

With the development of information, intelligence and automation of hoisting machinery, the health management of hoisting machinery will go deep into port, metallurgy, major engineering and other fields.

(1) Five key technologies of crane safety monitoring, health monitoring, health status diagnosis, fault trend prediction and predictive maintenance decision-making were analyzed, which laid a foundation for the application of crane health management technology.

(2) The technical framework of crane health management is proposed, and the application demonstration of a metallurgical crane is carried out. The application results show that the stress...
value of each stress measuring point is in the safe range, the cumulative damage value of the structure is far less than 1, and the structure will not appear fatigue cracks.

(2) Reduce maintenance costs. The predictive maintenance decision-making of equipment based on monitoring big data is adopted to change the traditional regular maintenance and post maintenance mode, optimize the maintenance cycle and maintenance mode, and reduce the cost of personnel and materials.

(3) With the development of sensor technology, Internet technology and big data processing technology, crane health monitoring will focus on solving the key problems such as sensor point selection, structural health status representation and diagnosis prediction, mechanism health status representation and diagnosis prediction, and electrical control system health status characterization and diagnosis prediction.

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References
[1] Liang Kai 2012 Research and development of tower crane monitoring system based on arm D. Shenyang University of technology
[2] Chang Song 2009 Research on wireless data transmission of on-line stress monitoring of mechanical equipment structure D. Wuhan University of technology
[3] Feng Kai 2015 Design and implementation of safety monitoring system for gantry crane D. Wuhan University of technology
[4] Hu Jingbo, Luo Cheng, Jia minping and Feng Yuegui 2019 Research on maintenance strategy system of gantry crane based on RCM J. Hoisting and transportation machinery (02) 121-5
[5] Bikai 2014 Design of crane remote monitoring system based on configuration software and wireless network D. Dalian University of technology
[6] Wang Quanwei 2018 Research on theory and application of health monitoring system of hoisting machinery D. Taiyuan University of science and technology
[7] Chen Li, Liu Guansi and Ding Keqin. 2018 Safety evaluation method of hoisting machinery system based on membership function model J. Hoisting and transportation machinery (12) 87-94
[8] Chen Li, Liu Guansi and Ding Keqin 2016 Development and engineering application of fatigue life analysis and prediction software for hoisting machinery J. China work safety science and technology 12 (09) 138-45
[9] Liu Guansi, Ding Keqin and Chen Li 2015 Stress state monitoring technology and application of metallurgical lifting machinery C. (Beijing University of technology 2015 Far East NDT New Technology Forum) a collection of NDT papers based on big data. (Beijing University of Technology: Far East NDT new technology forum) 571-4
[10] Tang Fangxiong 2015 RCM analysis and Application Research of port gantry crane D. Wuhan University of engineering
[11] Liu Guansi, Ding Keqin, sun Baozhan and Ge Changqing 2019 Applied research on health monitoring and diagnosis technology of rail container gantry crane J. Engineering machinery 50 (05) 17-21 + 6-7