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OPTIMIZATION MEASURES OF AUTOMATED CONTROL IN CHEMICAL PRODUCTION SAFETY

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Abstract: Electronic technology has advanced significantly, leading to the widespread application of automation across multiple industries. This integration has resulted in a substantial liberation of the workforce, enhancing both operational efficiency and financial profitability for enterprises. However, the chemical industry poses inherent dangers, necessitating careful consideration of the associated risks when introducing automated control systems. To ensure the effective and safe utilization of automation in chemical production, it is imperative to establish clear operational guidelines and safety measures.
Keywords: Automation control; Chemical industry; Safety production; Optimization measures

1 THE IMPORTANCE OF AUTOMATED CONTROL

Accidents such as explosions, fires and unavoidable corrosion are prone to occur during the chemical production process. In order for the chemical industry to operate normally in society, it is necessary to find more ways to avoid hidden dangers that threaten personal safety. The use of automated control will greatly improve the efficiency of enterprises, but in this process, enterprises must have more safety awareness and increase the safety inspection of equipment in chemical production [1-2]. In order to more accurately predict accidents in the chemical production process, users and enterprises need to have certain scientific management and control knowledge and capabilities, conduct regular equipment safety inspections during the work process, and always update precautions and possible occurrences during the use of the equipment. Hidden dangers should be prevented to ensure the safe operation of automated control.

1.1 The Importance of Automated Control

The application of automation control technology provides hardware conditions for the development of the chemical industry. The chemical industry is a high-risk profession, and the use of automation has inevitably increased the risk factor of the profession to a certain extent. In addition to bringing safety risks to workers, it also brings risks to the reputation of the company. If the lives and safety of employees are threatened, the reputation of the company and its development in society will end in failure. Safety measures cannot just rely on the employees' experience in daily work. The company itself should also pay attention to the inspection and elimination of equipment safety hazards[3]. If necessary, it is necessary to train company employees on the safe use of equipment, and strive to improve the chemical production process. The risk factor is reduced to a minimum, allowing employees to feel at ease at work, better serving the company, and maximizing the company's interests while working with peace of mind.

1.2 Risk parameters

How to estimate risk in an event that never happened? How to calculate the result parameters in an already happened event? These are all security issues that an enterprise should consider during its operations [4]. Avoidance parameter: It is the probability that workers can avoid the danger when a danger occurs. However, this depends on the professionalism of the staff, whether they have sufficient awareness of safety hazards, awareness and theoretical knowledge of safety measures to avoid dangers. Here the author will give a hierarchical classification to avoid parameters[5]. Consequence parameter: refers to the proportion of the number of people who died in the accident or who were killed or seriously injured as a result of the accident to the total number of people in the factory (Table 1-2). N is the number of casualties that may be caused by the accident, A is the ratio of the total factory area occupied by the accident, and V is the fatality rate.

Table 1 Avoid parameter hierarchies

parameter	Divide the scope
P1	May be avoided under certain conditions
P2	almost impossible to avoid

Table 2 Fatal rate values and hazard descriptions

Fatal rate V	describe
0.01	small scale hazard
0.10	massive harm
0.50	Large-scale hazards, but can cause larger disasters such as fires
1.00	More serious explosions and other accidents

2 AUTOMATION CONTROL TECHNOLOGY AND EXPLORATION USED IN THE PROCESS OF CHEMICAL PRODUCTION SAFETY

2.1 Automation Control Technology Used in the Process of Chemical Safety Production

2.1.1 Process monitoring and fault diagnosis system

In the chemical production process, it is unrealistic to use simulated safety inspections to check safety everywhere [6]. Therefore, this requires enterprises to put some expert predictions into a designated database. Once the database is activated by background operations, the database will automatically process the information layer by layer to detect equipment and make security prevention strategies, effectively avoiding detected potential safety hazards. In addition to safety hazards that are easily encountered in the chemical production process, the machinery and equipment used by employees have caused wear and tear due to long-term use. In the long run, the safety performance of the equipment itself also affects the personal safety of users. Therefore, equipment failure monitoring is very important. The use of automation technology to discover safety problems such as long-term disrepair in equipment in a short period of time provides a certain basis for timely maintenance of enterprises, ensures equipment safety and work efficiency, and improves the personal safety factor of employees.

2.1.2 Application of emergency stop system (ESD)

Process monitoring can achieve continuous and stable safety monitoring, but if an emergency hazard is discovered that is too late for human control, it will also cause an irreversible situation. The application of emergency stop system gives the equipment the final safety guarantee in crisis situations. When an emergency occurs and there is no time for human rescue, the emergency parking system will automatically cut off all running machinery and equipment to ensure the safety of people present. With the development of the chemical industry, the requirements for safety monitoring are becoming higher and higher. The emergency stop system was originally based on relays and evolved into the emergence of PLC technology. The original PLC technology was widely used because it relied on programming for accurate monitoring. However, it had certain limitations, so it was only used in safety applications. Projects with lower requirements.

3 IMPROVE MANAGERS' AWARENESS OF EMERGENCY MANAGEMENT

Through the analysis of hazardous chemical accidents, it can be seen that most hazardous chemical accidents are caused by human behavior, and most units have insufficient efforts in emergency management of hazardous chemicals and only focus on the understanding and learning of theoretical knowledge and related technologies. , lack of popularization of safety knowledge and prevention awareness. In this case, once a hazardous chemical accident occurs, there are limited methods during the handling process, making it difficult to effectively control the spread of the accident and the danger. Therefore, relevant administrative departments should do a good job in enterprise execution qualification training, formulate good training plans, and adopt professional training and management training methods to improve the business knowledge level of relevant personnel. In addition, all hazardous chemical companies have the risk of emergencies. Therefore, all companies and departments should develop early warning mechanisms and implement specific training based on the characteristics of chemicals, do preventive work before accidents occur, and be able to prevent accidents after they occur. Provide timely rescue and treatment to reduce property losses and casualties.

4 DO A GOOD JOB IN FIRE SAFETY CONSTRUCTION

In the emergency management of hazardous chemicals storage, fire safety construction work should also be done to provide a corresponding safety environment foundation for the use and management of hazardous chemicals, ensure the adequacy of safety facilities and related configurations, and ensure the effective implementation of hazardous chemicals safety work. , and at the same time improve the safety protection capabilities of warehousing management by drawing on advanced experience in related fields. Carry out regular inspections of safety management equipment and related facilities to ensure that all equipment has good performance and status and can play a stable role in the application process. In addition, ensure that all staff understand the operating methods and procedures of these safety facilities.

5 STRENGTHEN GOVERNMENT SUPERVISION OF EMERGENCY MANAGEMENT

When carrying out emergency management of hazardous chemicals, it is necessary to analyze the potential hazards of hazardous chemicals. The state can promulgate relevant legal systems based on the hazard levels of hazardous chemicals and do a good job in emergency management legislation. At the same time, government departments also need to do a good job in supervising hazardous chemical companies in accordance with relevant laws and regulations, so that the emergency management work of chemical companies can develop reasonably under the constraints of legal regulations. Through regular or irregular spot inspections and supervision, it attracts the attention of relevant enterprises and ensures the effective implementation of the emergency management safety system.

6 CONCLUSION

To sum up, hazardous chemicals themselves have inherent risks. If not properly managed, they can easily lead to serious safety accidents, resulting in property losses and casualties. However, these hazardous chemicals play an important role in the development of the chemical industry, and it is impossible to cancel production. The only way to ensure the quality of hazardous chemicals management can only be to strengthen prevention, early warning and the formulation of emergency measures. In the formulation of emergency measures and safety warning measures, it is necessary to improve relevant legal systems to provide effective basis for the development of relevant policies. At the same time, we must do a good job in internal management and training of the enterprise, enhance the responsibility awareness and emergency response capabilities of relevant managers, and improve safety facilities. construction work to ensure the implementation of the emergency management system and improve the efficiency of emergency management through the synergy between the government and enterprises.

COMPETING INTERESTS

The authors have no relevant financial or non-financial interests to disclose.

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ADVANCEMENTS IN THE DEVELOPMENT OF ELECTRO-HYDRAULIC COMPOSITE BRAKING SYSTEMS FOR ELECTRIC VEHICLES

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Abstract: This paper meticulously categorizes, hones, and summarizes pertinent technical matterspertinent technical matters both domestically and internationally, focusing on the optimal design, system control, and testing platform of the electro-hydraulic composite braking system. It also presents a comprehensive review of the advancement of electro-hydraulic composite braking systems for electric vehicles, offering a future perspective. Research indicates that the integration, reliability, and robustness of electro-hydraulic composite braking systems are crucial areas for further improvement, as they emerge as a significant development trajectory for braking systems in electric vehicles.
Keywords: Electro-hydraulic composite braking; Optimized design; System control; Test platform

1 OPTIMIZED DESIGN

As people pay more and more attention to energy and environmental protection issues, the regenerative braking technology of electric vehicles has become a hot research issue and has been implemented in engineering applications. The regenerative braking force of the motor can be divided into three types: front axle compound braking, front and rear axle compound braking, and rear axle compound braking according to the location of the braking force. form. The regenerative braking torque and hydraulic braking torque on each wheel can be adjusted in real time. When the car is braking, the electric drive system is used to convert kinetic energy into electrical energy and is stored in the battery energy storage system. The sensor detects the driver's braking signal and transmits it to the controller, which distributes the braking force to meet the vehicle's braking requirements and achieve energy recovery at the same time. Regenerative braking has become a key technology for electric vehicles to save energy and improve their cruising range. The system should meet the following points: comply with braking safety regulations, meet braking safety and robustness requirements, effectively recover braking energy, provide driver braking comfort, and have effective fault tolerance mode.

In order to study the issues of electric vehicle electro-hydraulic composite braking system more deeply, based on the development of related technologies, the existing related research and technological progress will be studied and reviewed focusing on optimization design, system control and test platform.

Domestic and foreign scholars have achieved rich research results in the optimization design of electro-hydraulic composite braking systems. Literature [1] based on the constraints of braking regulations, motor characteristics, braking stability and braking comfort, ideally designs the electric vehicle motor braking/electronic hydraulic brake (EHB) composite braking system. For power distribution control optimization, a multi-boundary condition optimization design method for the electro-hydraulic composite braking system control algorithm is proposed, and the front and rear axle braking force distribution coefficients are determined based on factors such as braking intensity requirements and the frequency of use of roads with different adhesion coefficients. Yu Zhuoping [2] studied the matching method of the electro-hydraulic composite braking system of wheel-driven electric vehicles, and optimized the electro-hydraulic composite braking parameters of an electric vehicle. Liu Qinghe et al. [3] proposed an electro-hydraulic parallel braking system structure suitable for electric vehicles and designed a parallel braking force distribution scheme. Literature [4] simulates and analyzes the impact of the main parameters of the solenoid valve and accumulator on the dynamic characteristics of EHB, which provides a basis for the optimal design of the EHB system. Song Shigang et al. [5] determined the safe operating range of series electro-hydraulic composite regenerative braking of electric vehicles, established a mathematical model for the regenerative braking optimization problem, and improved the recovery rate of vehicle braking energy.

The ideal relationship curve between front and rear wheel ground braking force distribution is expressed by the formula:

$$Fxb_2 = \frac{1}{2}\left[\frac{G}{h_g}\sqrt{b^2 + \frac{4h_g L}{G}F_{xb1}} - 2Fxb1\frac{Gb}{h_g}\right], (1)$$

In the formula: Fxb_1 and Fxb_2 are the ground braking forces of the front and rear wheels, N; G is the gravity of the car, N; b is the distance from the center of mass of the car to the center line of the rear axle, m; hg is the height of the center of mass of the car, m; L is the axle of the car. Distance, m.

On the basis of the above, Lan Fengchong et al. [6] used a hierarchical control method to control the stability of dual-motor four-wheel drive electric vehicles, and obtained the optimal control through coordinated control of the output torque of the front and rear axle motors and the hydraulic braking torque of the wheels. It optimizes the yaw moment and increases the vehicle speed while ensuring the stability of the vehicle. The control objective is in the form of standard quadratic programming:

$$f(x) = \frac{1}{2} xTHx + CTx, (2)$$

satisfies biTx=vci, i = 1, 2,...; ci is a vector; F1, F2, F3, and F4 are the braking forces of the left front wheel, right front wheel, left rear wheel, and right rear wheel respectively.

Yang Pengfei et al. [7] designed a joint control strategy for the wheel hub motor and hydraulic braking system of a four-wheel hub-driven electric vehicle. The upper layer of the controller uses a sliding mode variable structure to obtain the generalized force, and the lower layer uses the quadratic programming method for optimal torque distribution. Taking the overall road load status of the vehicle as the optimization goal:

$$\min J=\sum_{i=1}^{4} \frac{F_{xi}^2 + F_{yi}^2}{(\mu F_{zi})^2}, i = fl, fr, rl, rr, (3)$$

In the formula: μ is the road adhesion coefficient, which can be obtained through identification; Fxi and Fyi are the longitudinal and lateral forces of each wheel respectively; Fzi is the vertical load of each wheel; fl, fr, rl, rr are the left front wheel, Right front wheel, left rear wheel, right rear wheel.

Zhou Lei et al.[8] ensured braking performance while taking into account energy recovery and reducing brake pad wear. Literature [9] established mathematical models of brake wheel cylinders, solenoid valves, DC motors, hydraulic pumps, etc. based on AMEsim, and carried out optimized designs. Gao et al. [10] optimized the braking force distribution control model and energy feedback system, and realized the anti-locking function of electric vehicles by setting the threshold value of the motor's regenerative braking force. Lee et al. [11-12] designed an EMB approximate time-optimal tracking controller and designed a high-bandwidth controller based on the time-optimal switching surface. Han et al. [13] designed a constraint function to ensure the optimal distribution of regenerative braking torque and improve vehicle lateral stability and braking energy recovery.

2 SYSTEM CONTROL

2.1 Braking Dynamics Control

In view of the shortcoming of poor braking feeling in the research on braking dynamics control, some scholars have conducted in-depth research on this issue. Li Shoutao et al. [14] analyzed the pedal force transmission path, pedal feel and its influencing factors under normal working conditions and oil leakage conditions in the front and rear chambers respectively, and used fuzzy adaptive PID control solenoid valve to establish a good simulated braking feeling. . EHB electro-hydraulic coordinated control includes regenerative braking and hydraulic pressure

move.

Pan Ning et al. [15] proposed a braking intention classification method and online identification method for the purpose of improving comfort, and controlled the hydraulic actuator based on the classification results; using multi-sensor data fusion, using neural networks to identify braking intentions , improve braking comfort and safety. Solenoid valve control is essentially flow control. Literature [16] analyzed the transmission path of pedal force in the normal and failure modes of the electro-hydraulic composite braking system, and studied the pedal feel and its influencing factors in different modes. Literature [17] proposed a wheel slip rate control method based on EHB. The superimposed braking energy feedback system directly superimposes the motor feedback braking force on the friction braking force. This control strategy has poor braking feeling and low feedback efficiency [18-20]. Ko et al. [21] pointed out that the performance of regenerative braking control can be improved by improving the accuracy of hydraulic control of electric vehicles. Amodeo et al. [22] used a high-order sliding mode controller to suppress chatter during the control process. Ivanov et al. [23] verified through experiments the coordinated control algorithm of electro-hydraulic composite braking and ABS on low-adhesion road surfaces, which improved braking comfort.

Compared with traditional braking systems, active control in EHB systems appears more and more frequently in braking conditions. The quality of the braking dynamics control algorithm has become a key factor in whether the EHB system can achieve real-time and accurate pressure control. It is also the key to achieving a good match with the entire vehicle.

2.2 Vehicle Control Strategy

In terms of research on vehicle control strategies, Liu Shunan et al. [24] proposed using a digital high-speed switching valve and a single-chip microcomputer to form a braking force electro-hydraulic proportional distribution device to achieve proportional distribution of the pressure of the front and rear brake cylinders to meet different working conditions and road surfaces. requirements. Literature [25] conducts anti-lock control considering comfort for the electro-hydraulic composite braking system of distributed electric vehicles. On the basis of the above research, in order to improve the control accuracy of hydraulic brake pressure in electro-hydraulic composite braking of electric vehicles, literature [26] designed an electro-hydraulic composite braking ABS control method based on wheel speed error. Jin Liqiang et al. [27] proposed a new configuration of electromechanical composite regenerative braking system and control strategy suitable for electric vehicles. Considering the impact of battery SOC value and braking intensity on the motor regenerative braking torque, a dual-input single-output fuzzy control was designed. The device realizes the recovery of regenerative braking energy while ensuring braking efficiency. Yuan Xiwen et al. [28] aimed to achieve vehicle active safety and braking energy recovery, and proposed a control strategy integrating AFS and electro-hydraulic composite braking of distributed electric drive vehicles. Jo et al. [29-30] considered static friction and

Stribeck effect, established an EMB planetary gear model, developed two coordinated control strategies of friction braking force and feedback braking force suitable for electric cars, and achieved good control effects. Literature [31] proposed a hierarchical control strategy for electro-hydraulic composite braking direction stability of electric wheel vehicles. Literature [32] designed a series electro-hydraulic composite braking structure that can realize electro-hydraulic braking.

In addition to the above control strategies, some scholars also study the control issues of electro-hydraulic composite braking systems from other perspectives. The driver's braking feeling and vehicle braking comfort are improved through the braking force distribution correction module and motor force compensation module [33]. Xie Shaobo et al. [34] analyzed the relationship between the front and rear axle braking forces during the braking process of an electric car and its impact on stability. Liu Yang et al. [35] defined feedback energy efficiency and driver driving interpretation consistency as quantitative evaluation indicators for different solutions. The coordinated braking energy feedback system has good braking feeling and high feedback efficiency [36-37]. Cikanek et al. [38] rationally distribute the motor braking torque and mechanical braking torque, and perform as much regenerative braking as possible to improve energy utilization under the premise of meeting braking regulations and safety. Ko et al. [39] considered factors such as system response, wheel speed, road adhesion coefficient, and motor rotation angle, and proposed a collaborative control strategy for motor braking and mechanical braking. Novellis et al. [40] adjusted the yaw moment of the vehicle through coordinated control of the electric motor braking force and the mechanical braking force, thereby improving the active safety of the vehicle under extreme working conditions.

A large number of studies have shown that there are many control methods for the existing electric vehicle electro-hydraulic composite braking system, but a systematic system has not yet been formed, and the evaluation method is not perfect enough. Although a mathematical model has been established, the definition of the input quantity is not clear enough. These issues remain to be further resolved.

2.3 Wheel Cylinder Pressure Control

Many scholars have conducted research on wheel cylinder pressure control, which has greatly improved the accuracy of pressure control, as shown in Table 1.

Table 1 Wheel cylinder pressure control

Method	Research Content	In Conclusion
Number table interpolation algorithm [41]	Build a hydraulic brake system model and analyze the braking force adjustment characteristics	Achieve fast and fine adjustment
Dynamic coordinated control [42]	Summarizes the key technologies of electromechanical composite braking coordination control	Coordinated control and parameter matching of electromechanical composite braking system
Serial compound brake control [43]	Developed wire-operated hydraulic brake valve	Realize the serial application of motor regenerative braking and friction braking
Energy flow method [44-45]	Designed an electro-hydraulic composite braking system with an integrated brake master cylinder assembly	Recover more braking energy and improve braking stability
PID control strategy [46-47]	Established EHB model	Achieve precise pressure control and improve vehicle handling stability
PID linear control [48]	Current controlled linear solenoid valve opened by solenoid valve	Real-time control of wheel cylinder pressure

2.4 Estimation and Identification

There are few literatures on the estimation and identification of electro-hydraulic composite braking systems of electric vehicles. Zhang Houzhong et al. [49] developed an electro-hydraulic composite braking vehicle control algorithm based on road surface recognition. Literature [50] analyzed the braking intention and evaluated the consistency of the integrated electro-hydraulic composite braking system, analyzed the driver action signal change mechanism during the braking process, built a simplified model of the integrated master cylinder and conducted parameter identification. Literature [51] proposed a driving state parameter estimation algorithm based on a composite braking system structure and a maximum energy recovery control strategy optimization algorithm based on driving state estimation to prevent premature wheel locking. Sun Daxu et al.[52] used a radial basis function neural network system to conduct online identification of the electro-hydraulic composite braking system of electric vehicles, and used the sensitivity information of wheel slip rate to changes in motor braking torque to roll the PID control parameters. Optimized to achieve adaptive composite anti-lock braking control, improving the response speed and accuracy of anti-lock braking control for dual-motor four-wheel drive electric vehicles. Li Yufang et al. [53] proposed the definition of braking feeling consistency of electric vehicle electro-hydraulic composite braking system and analyzed its influencing factors. Literature [54] uses EHB hardware-in-the-loop simulation to evaluate its dynamic characteristics and estimate the performance of each component of the hydraulic regulator. Literature [55] proposed a regenerative braking neural network control strategy and performed system state estimation. Paul et al. [56] used the estimated values of slip rate and road adhesion coefficient to propose a braking force distribution strategy for electric vehicles to improve the lateral stability of the vehicle.

From the above summary, it can be seen that adaptive parameter estimation in the estimation process is an effective means to improve estimation and identification accuracy. Especially when there are system model errors and parameter perturbations, how to improve the estimation accuracy of the algorithm is the next step that should be focused on. The problem.

3 TEST PLATFORM

In order to solve the problem of test verification in the product development process and reduce the cycle cost of the R&D process, Yan Weiguang et al. [57] developed an electric vehicle electro-hydraulic hybrid braking system test bench. Sun Zechang et al. [58] used MATLAB/Simulink to establish a vehicle model and a braking energy recovery strategy model, implemented a rapid prototype of the controller based on Moto Hawk, and built an xPC Target hardware-in-the-loop platform. Gao Feng et al. [59] developed an integrated electro-hydraulic braking system and formed a prototype. The prototype is composed of a hollow motor, a ball screw pair, a three-cavity master cylinder, a human cylinder and a pedal stroke simulator. It integrates functions such as brake assist, brake-by-wire and regenerative braking. Luo Yugong et al. [60] developed equipment with hydraulic braking and motor braking execution.

Mechanism, and a hardware-in-the-loop test bed that can simulate dynamic changes in road braking force in real time. Introduce components such as hydraulic brakes, motors, speed and pressure sensors, and comprehensively consider the dynamic response characteristics of the interaction between wheels, hydraulic braking systems and motor braking systems during the braking process, and measure the key parameters of the test bench and the electrohydraulics of electric vehicles. The slip rate coordinated control test of compound braking verified the effectiveness of the test bench. Gao Guotian et al. [61] proposed an electro-hydraulic composite control strategy based on multi-objective dynamic coordination, built a test platform, and compared and analyzed the control test results under the two conditions. Literature [62] designed an electro-hydraulic composite feedback braking simulation test bench to verify the feasibility of the proposed electro-hydraulic composite braking force coordinated control strategy based on maximizing braking energy recovery. Han Yunwu et al. [63] verified the electro-hydraulic composite braking control algorithm that comprehensively considers vehicle safety and economy through simulation and test platforms. Literature [64] used xPC target to build an integrated electro-hydraulic composite braking system hardware-in-the-loop simulation test bench, and conducted tests on non-emergency and emergency braking conditions and driver braking intention analysis and braking force application consistency. Test, it can meet the needs of energy recovery and coordinated control with anti-lock braking. The German Bosch Company has developed a composite braking system. It starts the motor braking first, and then starts the electro-hydraulic composite braking system after the idle stroke, and conducted a bench test [65]. In summary, the existing electro-hydraulic composite braking system pressure control algorithm verification mostly uses test benches, which lack real vehicle test verification. The real-time performance and robustness of the test bench under complex working conditions need to be further improved.

4 CONCLUSION

Conduct a systematic study on the structural characteristics and research progress of electro-hydraulic composite braking systems at home and abroad from three aspects: optimal design, system control, and test platform, and subdivide the core issue system control into braking dynamics control and vehicle control Four topics including strategy, wheel cylinder pressure control, estimation and identification were discussed. The study concluded that:

1) Electro-hydraulic composite braking can prevent wheel locking and recover braking energy, but it requires the motor to continuously switch working modes and is still insufficient in terms of control accuracy and stability.

2) Batteries and motors participate in the energy conversion of electric vehicles. Their operating conditions are dynamic and changeable, and working modes switch frequently, which affects the braking performance of electric vehicles and has obvious nonlinear coupling system characteristics.

3) Compared with pure hydraulic control, electro-hydraulic composite braking maximizes the braking energy recovery efficiency of electric vehicles and greatly optimizes braking stability and braking feel.

4) The hydraulic control algorithm is the key to achieving accurate real-time pressure regulation in the electro-hydraulic composite braking system. The accuracy of hydraulic pressure control and the robustness of the control algorithm must be further improved. There is a lack of in-depth discussion on the impact of the algorithm on the braking comfort and handling stability of the vehicle. The reliability of the algorithm in engineering practice should be verified by real vehicle tests. This will be an important development direction of electro-hydraulic composite braking systems.

COMPETING INTERESTS

The authors have no relevant financial or non-financial interests to disclose.

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ANALYSIS OF MEASUREMENT TECHNOLOGY AND ITS EVOLUTION IN SURVEYING AND MAPPING ENGINEERING

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Abstract: Surveying and mapping engineering measurement technology is the direct application of surveying and mapping technology in the process of social construction and development. The application scope of traditional surveying and mapping engineering measurement technology is relatively narrow, limited to the fields of water conservancy, construction and transportation, and its main content is as follows Two aspects: mapping and setting out. With the continuous development of surveying and mapping engineering measurement technology, its application fields are becoming more and more extensive. At present, the relatively mature and widely used surveying and mapping engineering measurement technologies mainly include global positioning technology, remote sensing technology and geographical information system technology. The advantages of these three methods are relatively obvious, and in the actual application process, the accuracy of measurement work will be greatly improved. and efficiency, effectively saving the cost investment in surveying and mapping work, and playing a huge role in promoting the development of the surveying and mapping industry.
Keywords: Surveying technology; Mapping engineering; Measurement technology; Engineering

1 MEASUREMENT TECHNOLOGY IN THE SURVEYING AND MAPPING PROCESS

1.1 Global Positioning Technology

Global positioning technology (GPS) first appeared in the 1970s. The United States successfully built a navigation and positioning system that has all-round three-dimensional navigation and positioning capabilities on land, sea, and air, and can use navigation satellites to measure time and distance. In the following decades, the horizontal positioning accuracy of the global positioning system continued to improve, the software and hardware features were continuously improved, and the application fields became wider and wider[1-2]. GPS technology can work around the clock and is not affected by external factors such as weather, with a coverage rate of 98%. The accuracy of its three-dimensional fixed-point and speed-fixing function is very high, so it can accurately position objects that need to be positioned. During the measurement process, GPS technology is less restricted and can accurately obtain measurement results without having to see clearly[3]. GPS technology mainly consists of three parts: space constellation, user equipment and ground monitoring: the space constellation is composed of 24 satellites, forming a honeycomb structure, with directional solar cells installed on both sides; the user equipment refers to the GPS receiver, which uses the The signals received are used to calculate the three-dimensional coordinates of the location; ground monitoring is mainly composed of ground antenna stations, main control stations and monitoring stations, which implement comprehensive monitoring of various locations on the ground[4].

1.2 Remote Sensing Technology

Remote sensing technology is a deep sounding technology based on electromagnetic wave theory. During the actual measurement process, sensing instruments are used to collect and process electromagnetic wave information reflected or radiated by distant targets, and then imaging is performed based on the obtained data, thereby achieving Depth testing of targets. Remote sensing technology has the following advantages: First, it has a wide detection range. During aerial photography, the flying height of the aircraft can reach about 10 km, and the orbit of the Land Satellite can also reach about 910 km; secondly, the acquisition speed of information is fast[5-6]. Land satellites can cover the earth once every 16 days, the cycle is very short, and the data acquisition speed is very fast; third, there are fewer restrictions. Remote sensing technology will not be affected by environments such as glaciers, mountains, and deserts, nor will it be affected by factors such as temperature and pressure; fourth, it has a large amount of information. The information obtained by the remote sensor is closely related to the difference between the remote sensor and the band. Each band contains 7.6 million pixels. Remote sensing technology mainly consists of remote sensors, receiving devices, image processing equipment, information transmission equipment, and remote sensing platforms. It has been used in many fields such as agriculture, environmental protection, geology, oceans, forestry, surveying, geography, hydrology, meteorology, and military reconnaissance. widely used in the field.

1.3 Geographic Information System Technology

Geographic information system technology (GIS) is a spatial information analysis technology that has only been developed in recent years. Its application in the field of environment and resources can effectively manage various resources and environmental information, and can also dynamically monitor multiple periods of time. Production activities, significantly improving work efficiency and economic benefits. Geographic information system technology is mainly used in agriculture, forestry, land resources, ecological environment, disaster warning and environmental resources, etc., and has achieved good application results. In terms of environmental resources, GIS technology is mainly applied through the establishment of information management systems. In terms of land resources, GIS technology can be applied to land use status surveys, land evaluations, land use planning, and dynamic monitoring of land cover, etc. aspect.

2 FUTURE DEVELOPMENT OF SURVEYING TECHNOLOGY IN SURVEYING AND MAPPING ENGINEERING

As the demand for engineering measurement technology continues to increase, various measurement technologies will achieve greater development in the future. The following analyzes the future development direction of surveying and mapping engineering measurement technology from four aspects.

2.1 The Data Collection and Processing Process will become more Real-time, Automated and Digital

Taking GPS technology as an example, GPS technology receivers are improving in the direction of being lightweight and portable, while wide-area and real-time differential technology and CCD technology can better meet the dynamic, static and high-precision needs of positioning technology. , and the receiver will also be lighter. As the scope of land use continues to expand, land surveying and mapping technology will gradually expand to more remote areas. This development trend determines the real-time, automation and digitalization of GPS technology. Only by making GPS technology unrestricted by geography and all-weather By controlling all areas within the measurement range, engineering measurement technology can have a wider application space.

2.2 The Management of Measurement Data will be more Standardized, Scientific and Information-based

Monitoring network optimization software will gradually be used between the engineering measurement control network and the city to realize intelligent management of measurement data. It can also make the observation and processing of control network data more standardized, scientific and information-based. 2.3 Surveying and mapping hardware facilities will become more domestic, user-friendly and intelligent. Most of the surveying and mapping technology equipment currently used in our country are imported. With the continuous advancement of surveying and mapping technology, the country's research on surveying and mapping equipment will also increase accordingly. Realize the localization of surveying and mapping hardware facilities. In addition, the overall development trend of society will also have a certain impact on the development direction of surveying and mapping technology, such as humanization and intelligence. Under the influence of the entire society pursuing humanization and intelligence, the development of the surveying and mapping industry will naturally follow this trend. This trend realizes the humanization and intelligence of surveying and mapping hardware facilities.

2.4 "3S" Integration Technology

Global positioning system technology, remote sensing technology and geographical information system technology are the three most important technologies in surveying and mapping engineering. Each of these three technologies has its own advantages and disadvantages. In actual application, just choose the most appropriate one according to the actual situation. Future surveying and mapping engineering measurement technology will realize "3S" integrated technology - bringing together the advantages of three different surveying and mapping technologies and establishing a complementary relationship based on their common theoretical basis. Integrated technology can simultaneously cover information collection, processing and The entire process, including analysis, makes the measurement technology of surveying and mapping projects more efficient and more widely used.

3 CONCLUSION

To sum up, among the three measurement technologies commonly used in surveying and mapping projects, global positioning technology can work around the clock and is not affected by external factors such as weather. It has very high coverage and accuracy, and can accurately measure without having to see through. Results: Remote sensing technology has the advantages of wide detection range, fast information acquisition, few restrictions and large amount of information. It is widely used in agriculture, environmental protection, geology, ocean, forestry, surveying and mapping, geography, hydrology, meteorology and military reconnaissance. It has been widely used in many fields; geographic information system technology can significantly improve work efficiency and economic benefits, and is mainly used in agriculture, forestry, land resources, ecological environment, disaster warning, and environmental resources. With the continuous development of society, the data collection and processing process of measurement technology will become more real-time, automated and digital, the management of measurement data will become more standardized, scientific and information-based, and the surveying and mapping hardware facilities will become more domestic, humane and intelligent. ization, and will also integrate “3S” technology to promote the development of China’s surveying and mapping undertakings.

COMPETING INTERESTS

The authors have no relevant financial or non-financial interests to disclose.

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RESEARCH ON THE APPLICATION OF INTELLIGENT CONTROL SYSTEM IN URBAN LANDSCAPE LIGHTING

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Abstract: This article studies the application of intelligent control systems in urban landscape lighting. With the further integration of Internet technology and LED chip technology, urban landscape lighting has entered the era of intelligence. Traditional switching control methods can no longer meet the needs of modern urban landscape lighting, and the development of intelligent control systems provides a new solution for urban landscape lighting. This article analyzes the advantages and application cases of intelligent control systems in urban landscape lighting, and explores the future development trends of intelligent control systems. Intelligent control systems can achieve remote control, real-time monitoring, and data analysis and other functions, providing more refined management methods for urban management departments. In the future, with the continuous advancement of technology and the continuous expansion of application scenarios, intelligent control systems will play a more important role in urban landscape lighting.
Keywords: Intelligent control system; Landscape lighting; Urban space

1. INTRODUCTION

With the development of The Times, the Internet technology and LED chip technology are further integrated. With the combination of Internet technology and LED chip technology, the 2013 Nanchang Ganjiang River Light Exhibition in Taiwan took the lead in setting the national trend and became the driving force of the growth of urban night view economy. Various places have followed suit, such as the Hangzhou G20, Qingdao Shanghai Cooperation Summit and other projects, beautify the city night scene, but also drive the development of related industries. These projects not only demonstrate the combination of technology and art, but also become a new driving force for urban economic development.

In the early stage, the landscape lighting in many cities adopts the traditional clock-controlled switch mode. In this way, the switch time is already set during the project acceptance or handover. If it needs to be adjusted, a lot of manual operation is required, which is both time-consuming and laborious. Moreover, the adjustment of the real time cannot be synchronized with the cycle change, it cannot be flexibly and quickly adjusted and controlled during holidays or major activities, and it is more difficult to achieve remote control and fault detection, resulting in landscape lighting management difficulties.

After nearly 20 years of development, the urban landscape intelligent control system has experienced the evolution from the traditional clock control to the "three remote" and "five remote" control mode, and then to the intelligent remote table reading and real-time data upload function. In recent years, the system is moving towards the direction of intelligence, and significant progress is being made in remote control, optical remote control, portable operation, multi-screen collaboration, video surveillance and security protection interconnection mode. However, due to historical, technical and economic reasons, there is a large gap in the construction schedule of the urban landscape lighting control system, with some common problems. From all the studies above, the conclusion of construction problems of urban landscape lighting control system can be listed as Table 1.

Table 1 Table of the construction problems of urban landscape lighting control system

Rank	The sorting table of the construction of urban landscape lighting control system
1	Lack of overall planning, disorderly construction time, and independent regional governance, resulting in decentralized management, delayed response, and difficult coordination between departments
2	Simple functions, traditional scenes, lack of fine management, failed to make full use of the new technology to update.
3	Not effectively connected with the smart city big data platform, and the phenomenon of information island is serious.
4	Network and security system operation and maintenance management standards are not unified, which increases the difficulty of management.

2. CURRENT STATUS OF DOMESTIC AND INTERNATIONAL RESEARCH

2.1 Domestic Research Status

2.1.1 2016 "G20 Summit" Hangzhou Landscape Lighting Performance Project.

In order to welcome the "G20 Summit" in Hangzhou, in 2016, the highlight of the new round of Hangzhou landscape lighting improvement project lies in the control system integration and centralized management platform "single knife switch control system". In the same year, the world-famous Hangzhou G20 Summit " was successfully held, and the Qianjiang New City Media Facade Lighting Performance Project also achieved great success, which was highly praised by the leaders and the masses. The project shows the beautiful scenery of the Qianjiang New City business district, making it a new cultural name card of Chinese culture. The project installed 700,000 LED point light sources on the facades of 38 high-rise buildings more than 100 meters high, showing superscale images 2 km long and 100 meters high. The main visual observation points are the city balcony and the Olympic Stadium. At the same time, nearly 200 buildings along the Qiantang River have also lit up the atmosphere circle.

"Impression West Lake G20 version" is a large-scale waterscape performance symphony concert directed by Zhang Yimou. The centralized control system platform of the project is very advanced, including the main core control system, 8 sub-regional control centers, 7 sub-electronic touch points, etc. In addition, there are 15,000 sets of LED light source lights, with a color temperature tone, dual control system and other integrated functions. The equipment adopts special optical fiber and cable as the main optical cable signal transmission mode, and the wireless signal transmission serves as the auxiliary, which improves the signal smoothness, technical reliability and timeliness of activity. The system also combines "unified control" and "independent subsystem control", and adopts RDM system and GIS system, with the function of online state monitoring, data feedback and abnormal data alarm, and can quickly locate the data address. This system has become a complete, ecological, two-way feedback intelligent system, providing strong technical support for the activities [1].

2.1.2 Light Show case of the 40th Anniversary of reform and Opening up.

The light show project of Futian Civic Center for the 40th anniversary of Shenzhen's reform and opening up takes the civic Square and 43 surrounding buildings and green belts on both sides as the carrier, and adopts centralized intelligent control to form the media facade linkage. Different from the night views of the G20 Summit in Hangzhou, Xiamen Wuyuan Bay and Qingdao Fushan Bay, the space is arranged in a "U" shape, most of which are super high-rise buildings, including one building of 600 meters and 6 buildings over 280 meters, which brings challenges to the distribution of point light sources of media facades. To this end, the combination of large and small point light source technology is adopted to enhance the hierarchical sense of media facade.

The control system of Shenzhen project adopts the international brand Osram control system, which is stable, reliable and flexible, and can centrally control the lighting facilities of the first and second bid sections of Futian Central District, including lighting, electrical, linkage control and cloud platform system. The communication mode is 4G + optical fiber + Internet of Things, and the network and communication terminal are provided by Huawei and Unicom. The control platform is compatible with multiple sets of subsystems, realizing centralized control and management, and providing a reliable platform for project operation and management [2].

2.1.3 Shanghai Hongkou North Bund City Lighting Linkage Control Case in 2019.

Taking the North Bund landscape lighting improvement project in Shanghai Hongkou District as an example, the project is divided into four layers: "cloud, pipe, edge and end", which is conducive to the joint control effect and meets the requirements of intelligent detection and detailed management. The North Bund of Hongkou District is the core area of Shanghai, which has transformed the riverside night view of 2.5 kilometers away, with the theme of "The Bund heading north, sailing a new Shanghai", to ensure the harmony and unity of the connected area. According to the time and use needs, the mode is divided into normal mode, weekend mode, holiday mode and late night mode. The project makes full use of the old equipment, connects through the control system, and retains the lighting screens of multiple media facades to form a large-scale linkage scene. In the process of control system compatibility, the original control equipment has many brands and poor compatibility, which becomes the difficult pain point of the change.

The system combines the Internet + Internet of Things, cloud data analysis and other technologies to realize the intelligent and integrated management of lighting scenarios. The system is divided into four levels: "cloud, pipe, edge and end", where "cloud" is the control core, analyzing, managing and making decision on uploaded data, and establishing visual management center; "tube" is the network transmission layer, responsible for transmission from the cloud to the gateway; "edge" has preliminary computing power, screen and report abnormal information, and save network resources; "end" is the terminal, responsible for data collection, including lighting product control terminal, and light source and induction collector. The system also sets up three-level authority management: municipal, district and node control, and municipal institutions have unified and absolute command. The system is compatible with other smart platforms, such as traffic lights, cameras, urban environmental noise monitoring, etc. [3].

2.2 International Research Status

2.2.1 US City feel Wireless Sensor Network Project.

Foreign smart lighting systems gradually evolve to the direction of open carriers, massive sensors and big data. In recent years, the NSFC has funded Harvard University and BBN to jointly develop a "city feel" wireless sensor network system based on municipal street lights. The system was first used in a lighting system in Kamanbridge, Massachusetts, with sensors on street lights and a street light power supply system to power the operation of the sensors. These sensors form nodes in the city to send the detection content back to the detection center and provide massive data for experts and scholars[4].

2.2.2 Dutch "Twilight" adaptive lighting system project.

The Dutch Twilight adaptive lighting system uses a similar intelligent lighting scheme to the "city feel" system. The "Twilight" system instsensors on the dense municipal lighting in the city, collects a large amount of mobile information from pedestrians, cyclists and cars, and automatically and flexibly adjusts the lighting brightness of pedestrians or vehicles, so as to achieve the goal of environmental protection and energy saving. Today, the installation of the "Twilight" adaptive lighting system has spread from several towns in the Netherlands to many cities in Ireland and India, integrating the concept of improving functional lighting quality, energy saving and emission reduction into the local lighting aesthetics [4]. (See Figure 1 and Figure 2)

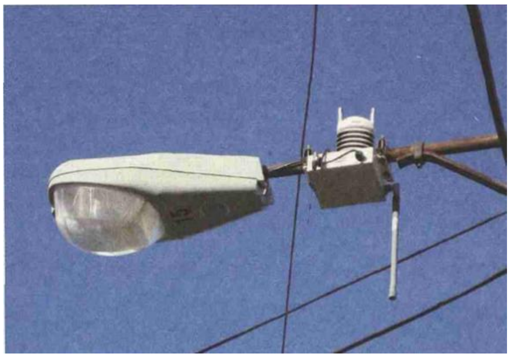

Figure 1 "City feel" street lamp in the United States[4]

Figure 2 The Dutch Twilight adaptive lighting system[4]

2.3 Comparison Of Intelligent Control Systems Domestic And International

The development of lighting systems at home and abroad shows that the development process of functional lighting, landscape and art decoration lighting, indoor and outdoor space special lighting, green and energy-saving lighting to "light + N" breakthrough lighting engineering and application development, light and lighting is a history of technological innovation [5].

At present, the LED lighting market at home and abroad has entered a relatively mature stage, the future development trend is through the Internet +, big data, new technology applications such as artificial intelligence, form wisdom interconnection, wisdom lighting upgrade iteration and data driven, the whole chain of scientific lighting control system, strengthen the construction of urban lighting organic, fine management and industry high quality development.

2.3.1 There are different application areas of intelligent control system.

Compared with foreign countries, China's current DMX512 control system is mainly used in urban landscape lighting, with large media facade linkage to show the city reputation, and is not used in the field of urban functional lighting. In foreign countries, due to the influence of political system and other factors, urban intelligent control system is mainly used in urban functional lighting, with linkage control of municipal street lights, emphasizing lighting function and other factors.

2.3.2 Intelligent control from the traditional SPI serial protocol to the unification of the DMX512 protocol. In this regard, there is a trend of replacing SPI serial interface technology with DMX512 protocol at home and abroad, which has great research value. Compared with the traditional SPI serial interface technology at home and abroad, DMX512 protocol is more widely used in the light control system at home and abroad. This protocol adopts point-to-point master-slave control system, and adopts multi-point bus structure in the interconnection form, there is no problem of information channel obstruction, and has high reliability [6].

The comparison between DMX512 protocol control system and SPI serial interface control system is shown in the following table 2.

Table 2 Analysis and comparison of SPI SACS to DMX512 protocol control system

	Benefits	Defects
DMX512 protocol control system	1. Parallel structure of lamps, the damage of a single lamp will not affect the use of other lamps; 2. Simple implementation, do not need special hardware equipment support; 3. International standards are widely used abroad.	Single hole and single point design, the cost is relatively high.

SPI SACS	1. occupying less port, allowing one main device to start one slave device, saving cost and space; 2. Is mature and widely used in China.	1. The semiconductor components must comply with the original controller; 2. In the series system, the damage of one lamp will affect the use of subsequent lamps.
Trend summary	At present, DMX512 protocol control system is replacing SPI serial interface control system, and obtaining more and more application scenarios at home and abroad.	

3. ARCHITECTURE OF THE URBAN LANDSCAPE LIGHTING CONTROL SYSTEM

Reviewing the development process of urban landscape lighting and media facade lighting, in view of the difficulties in the development of intelligent control system, it is necessary to improve the system architecture to make it more adapt to the needs of smart city. This paper summarizes the idea of system architecture and improves, combined with the actual case problem, puts forward the thinking of urban landscape lighting control system architecture.

3.1 Three Main Functional Structures

From the perspective of the internal operation function of the system, the system consists of three parts: operation hardware and software entities, management behavior authority allocation and management behavior function. The operating hardware and software entities account for 40% of the total architecture, mainly including electrical facilities and equipment, application and maintenance technology, network functional equipment and software, etc. Electrical facilities and equipment include monitoring equipment and alarm equipment, application technologies include matrix soft jumper technology and self-start technology, etc. Each functional equipment is signal network construction facilities, including router, optical fiber network, Ethernet, wireless network, etc. Data function devices include data integration programs and data logging programs [7].

From the perspective of the internal operation function of the system, the system consists of three parts: operation hardware and software entities, management behavior authority allocation and management behavior function. The operating hardware and software entities account for 40% of the total architecture, mainly including electrical facilities and equipment, application and maintenance technology, network functional equipment and software, etc. The allocation of management behavior authority accounts for about 35% of the whole structure, mainly including management elements, management mode and the evaluation of management results. Management elements include landscape lighting, road lighting, building lighting and other contents that need to be managed. The management methods include multi-level management, authority management, etc., and the evaluation results include terminal big data analysis, asset analysis, etc. Functional components account for about 25% of the system share, with independent authority, scalability capabilities, and portable compatibility. The main contents include single light / single point independent control, loop switching function, light source dimming and other comprehensive control functions, and third-party port protocol control function [8].

3.2 Ecosystem Architecture

From the perspective of longitudinal extension, the management platform is an intelligent landscape lighting system based on computer, Ethernet, optical fiber and 5G networks. It goes from the link control center at the top to the touch device, light source lamp and other execution devices at the bottom, using various interface protocols such as DMX512, RDM and RS485.

From the perspective of horizontal extension, the execution equipment can realize the interactive synchronous operation and coordination of media laser performance, music fountain and media facade lighting show. It mainly uses 5G broadband network and dedicated optical fiber transmission equipment to coordinate the execution of each bottom terminal to realize the synchronous control of ultra-remote space. It is required that the feedback data signal should be transmitted to the control center platform to realize cloud synchronous coordination and synchronous execution.

At present, the multi-terminal management center platform has tablet computers and smartphones, real-time on-site monitoring and management functions. Fixed centralized control center equipment, portable platform and fixed management center constitute a centralized + marginalized collaboration mode, which helps to solve emergency problems at any time.

In the ecological control system, executive equipment such as street lighting, landscape lighting, multimedia lighting, laser projection and artistic water le face compatibility problems due to diversity, large number, environmental differences and technical obstacles. To solve this problem, protocols with strong general compatibility and easy expansion and upgrading, such as DMX512, C-BUS and DALI, are usually selected.

The system coordination function is completed by the management center, and its complexity depends on the difference and compatibility of the regional lighting system managed and controlled. For example, the core area of the city takes the basic control unit as the urban lighting system, including multiple lighting scenes, landscape scenes, street scenes and nodes, forming a large-scale comprehensive and complex scene. Therefore, the data information is huge in terms of transmission and feedback. According to the field application, weather change and activity requirements, data need to be processed in coordinated operation to realize dynamic changes, such as peak and valley changes of electricity consumption, network signal congestion degree and data transmission rate, etc. The intelligent control management center is in the core position in the joint operation of the system, which not only involves the operation of large system, but also has problems such as data processing, abnormal feedback, synchronous monitoring information processing, abnormal alarm response mechanism, scheduling processing mechanism and routine data analysis, test and analysis.

3.3 Network, Security Technology System And Emergency Plan Framework

3.3.1 Platform information and technology security.

The management unit shall abide by network security laws and regulations, formulate / revise security plans, implement confidentiality responsibility, and ensure that each post has a clear person in charge. For the system to establish a hardware firewall and software antivirus program double guarantee. Establish the backup mechanism of multiple machines and devices to ensure that when the host encounters a fault, attack or threat, the backup device can be replaced in time and provide operation guarantee. Set centralized hierarchical authority management, and set operation authority according to job responsibilities.

3.3.2 Early warning.

Through the abnormal feedback system, the remote investigation of the involved area points, forming the abnormal document classification report, automatically repaired or reported to the management unit for on-site investigation. Quick response: Field patrol personnel can quickly determine the fault. Quick repair: repair the site problems in time.

4. OPERATION AND MAINTENANCE SYSTEM PLANNING

4.1 Daily Strategy of System Operation And Maintenance

Develop the information collaborative management and data exchange strategy of the control system to ensure the project stability. Record the fault items in the operation and maintenance management, and take the responsibility to the person in the form of work order. The data sources include the control platform software, audio and video monitoring platform and on-site inspection personnel, etc.

1.Confirm the equipment and software models, specifications and technical parameters with the owner unit, implementation unit, design unit, quality inspection unit and other related units. Coordinate with suppliers to conduct equipment commissioning, acceptance, training and maintenance.

2.Dynamic setting and preservation system management and equipment confidentiality password, timely report, not adjusted at will, quarterly / monthly update.

3.Regular data statistical report: summarize and analyze the platform data at monthly, quarterly and annual levels, and report to the management unit.

4.2 Safe And Environment Support

1.Network environment: To ensure the interconnection between the server and the terminal buildings of the urban landscape lighting project, the fiber optic network with sufficient bandwidth is used. At the same time, equipped with enough office space and computer equipment to ensure the communication between audio and video monitoring stations and monitoring server, and daily management of office station control center and terminal control carrier interconnection.

2.Software environment: According to the management requirements, it is necessary to install intelligent lighting intelligent control platform software and intelligent lighting video monitoring platform software on the computer in the operation and maintenance station, and conduct debugging and operation.

3.Management documents and operation and maintenance documents: The goal of management documents is to achieve controllable data analysis and improve the quality of management through storing and calling documents. Operation and maintenance documents include software and hardware specification documents, system management documents, feedback data storage documents, operation log documents, service quality control documents, etc. In addition, other documents and materials, such as fax, documents and external materials, are required.

5. SUMMARY

This paper studies the development history of urban intelligent control system, the application status at home and abroad, and the functions of urban landscape lighting control system architecture and operation and maintenance system planning and so on. On the one hand, based on literature research method, investigation comparison method and case study method, the comparison study of urban lighting control system at home and abroad, the development process of urban lighting control system is summarized, and the application comparison conclusion of urban lighting control system at home and abroad is put forward. On the other hand, by summarizing the problems existing in the urban lighting control system, and putting forward optimization measures, it provides cases and literature reference for the future application research of the urban lighting control system [9].

COMPETING INTERESTS

The authors have no relevant financial or non-financial interests to disclose.

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INVESTIGATE THE PERFORMANCE OF NONLINEAR BIPOLAR TRANSISTOR AT HIGH TEMPERATURE

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Abstract: An increase in the board temperature can have an effect on the basic characteristics of electronic elements which may influence the performance of the circuit. The objective of this paper is to investigate the influence of thermal rise on some characteristics of Bipolar junction transistor. Some static and dynamic characteristics have been experimentally measured and analyzed of a transistor type 2SC2120 at high temperatures. The obtained results indicate that with an increase in temperature over the range 30-90 °C, a collector current will increase by about 0.04 A, whereas the current will be around 0.12 A. The applied threshold voltage has been droped from 0.63 V to 0.45 V. The obtained results also illustrate that the reverse breakdown of emitter-to-base transition capacitance has been increased from 41 pF to 47 pF.
Keywords: BJT; Temperature; Performance; Static and dynamic characteristics

1 INTRODUCTION

The global demand for high stability integrated circuits with environmental sensors was increased in modern electronic devices in a wide range of applications. From the first transistors to the modern complicated integrated circuits, semiconductor parts play an essential role in such diverse fields as for information technology, electronic communications, medical and energy [1].
Major changes in the design of electronic components starting in the 1970s have resulted in the design and fabrication of highly complex, integrated, high-powered devices [2]. Much effort has been made by the researchers to develop new building alloys to enhance the lifetime of semiconductor components [3]. Since the majority of semiconductor components operate together in an electronic circuit, there is excessive heat generated. Such heat or retained heat can cause damage or decrease the capacity of the system [4]. However, thermal heat is at all times represent a hazard to semiconductors. Often, coolers and blowers were very often the first defense used against extreme heat and humidity [5]. A lot of industries require an electrical utility that can hold up well to challenging conditions and temperatures. Professionals typically propose devices to measure temperature, investigate motor temperature variations, and to ensure that the system is operating properly while keeping its performance unchanged [6].
Although many of our electronic equipment can withstand high temperatures, the operating systems are unable to withstand impacts and vibrations. The amount of heat treatment time is defined by the heat treatment processing unit [7]. All the products have to be stable to be dependable. However, their design is limited and cannot withstand high temperatures [8].
In the present time, in which nuclear technology, space technology and satellite industry play an essential role, the need for the use of high-temperature solid-state components has considerably increased. A lot of studies have been conducted to solve this important necessity. Bipolar junction transistors (BJT) have proved to be suitable candidates for such applications thanks to their utility in a variety of circuits [9]. As the NPN transistor is a component of modern electronics, a particular attention has been given to the analyzing the emitter-base connection of the silicon NPN transistor [10]. It is essential to fully understand the silicon-based BJT parameters under thermal conditions [11].
The performance of BJT at higher temperatures has been closely studied in a lot of literatures, it is obvious that the researchers are focusing on the material properties analysis under overloading and under electrostatic charging. Others are to optimize, design optimization, dynamic and steady-state behavior, and non-linear behavior.
Kozmic et al. [13] have proposed a new HEMT electrical thermal characterization method. By combining this method with an interferometry mapping (TIM) approach, a baseline understanding of the temperature distribution over time in HEMTs is obtained. Following pulse initiation, the heating time is held constant at 200 ns and the heat resistance of the AlGaN/GaN/Si HEMT is 70 K/W for 400 ns [14].
Gutierrez et al [15], investigated the influence of thermal looping on the electrical breakdown. By using high ambient temperature to manage the heating performance of the electrical equipment. characterizing and analyzing thermal data for failure modes and damage mechanisms of the electrical systems [16]. The characteristics of tunnel field-effect transistor (TFET) under high voltage and discharge current were studied and analyzed by using numerical simulation. The influence of surrounding temperature, variation of rising and falling times, and the power system conditions on the operational and non-operational voltages were considered. The simulation results indicate that TFET perform better than the isolated diodes in the protection of the complete chip circuit [17].

The physical properties of the semiconductor materials can be changed by the temperature. The thermal characteristics of the transistors must be taking into account during the design process for a particular application. The present paper investigates the BJT performance under temperature degree fluctuations.

2 METHOD

In the present study, electric performance of 2SC2120 (BJT) at different temperatures (30, 45, 75 and 90 ^{o}C) have been tested. This investigation was conducted in the electrical lab using Tektronix 370A line monitor and RCL Fluke PM6306 for precise measurements on variety of products. Figure 1 presents the schematic of bipolar junction transistor [18]. Table 1 presents the main characteristics of 2SC2120 transistor.

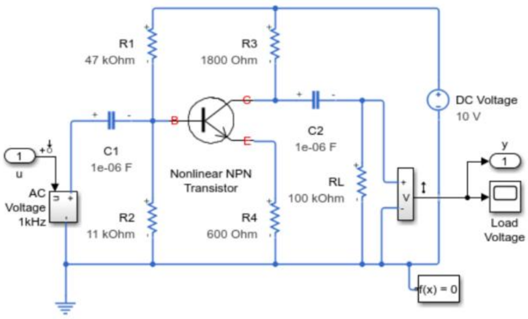

Figure 1 Nonlinear BJT circuit [18]

Table 1 The basic parameters of the 2SC2120 transistor being tested [20-23]

Parameter	Value
Power Dissipation of collector	0.60 Watt
Collector-Base Voltage	30.4 Volt
Voltage of Collector-Emitter	32 Volt
Voltage of Emitter-Base	5.4 Volt
Junction Temp.	153 °C
Current Transfer Ratio (h_{FE})	11

3 RESULTS AND DISCUSSION

The obtained results are listed in Tables 2 and 3 and the graphical representation is shown in figures 2-8. The measurements of collector current depending on the collector voltage V_{CE} and emitter supply voltage for transistor under testing for various temperatures with I_B baseline value being 1 mA is shown in Table 2. A graph of the results is presented in Figure 2.

Table 2 Collector current at testing temperature

	Collector current, Ic(A)			
VCE (V)	30 OC	45 OC	75 OC	90 OC
1	0.135	0.45	0.62	0.84
2	0.136	0.46	0.63	0.85
4	0.141	0.48	0.66	0.91
6	0.143	0.49	0.75	0.99
8	0.150	0.51	0.78	1.03

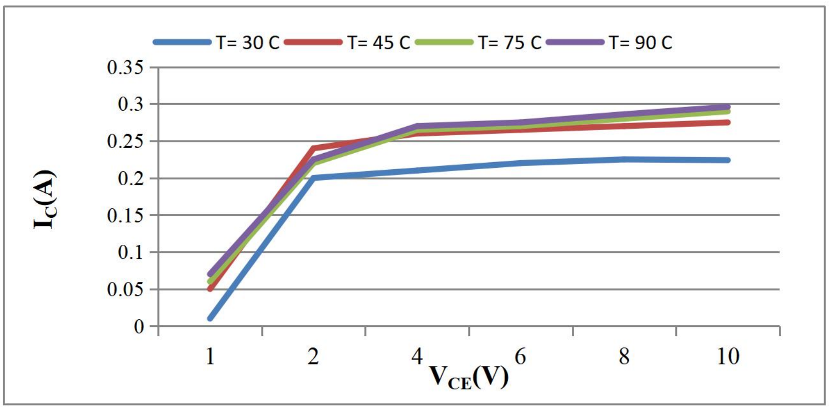

Figure 2 Collector current at rising temperature degrees.

It can be seen from Figure 2 that there is a rise in IC with increasing temperature. At V_{CE} = 2 V (measured at 90 °C), the value is 1.0 A compared to 0.18 A (measured at 30 °C).
The bipolar junction transistor currents under different temperatures may be calculated as follows [2].

$$R_{out} = \frac{\Delta V_{CE}}{\Delta I_C} \tag{1}$$

ΔV_{CE}: change of collector-emitter voltage, ΔIC indicates change of collector current. The changes in the transition resistance value is illustrated in Figure 3.

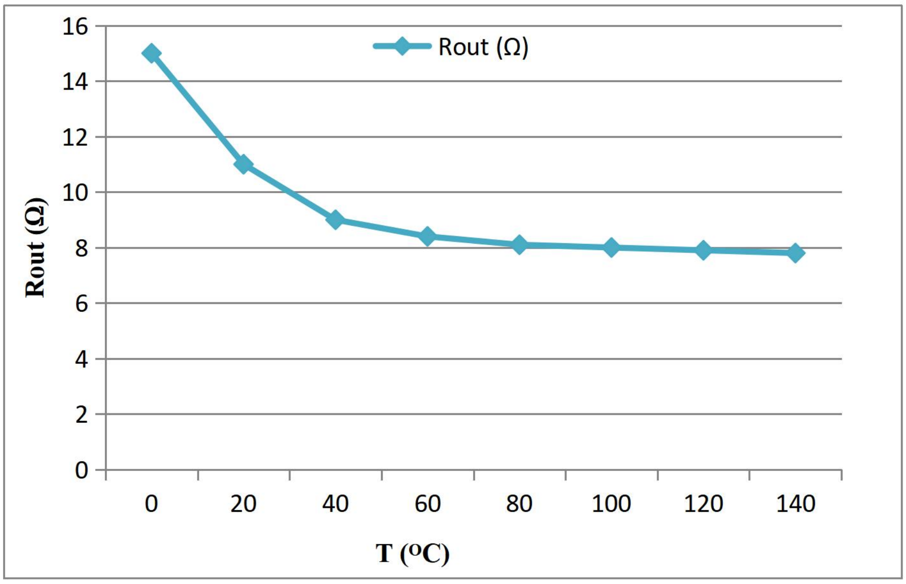

Figure 3 Transition output resistance values under temperature degrees fluctuations

However, Figure 3 demonstrates the capacitance value dropping from 15Ω at 30 °C to 8.54Ω at 90 °C. This indicates that an increasing in temperature will affect the transistor output resistance of the tested transistor.
The DC gain of h_{FE} can be calculated using equation (2) The plot shows the increment of DC gain of H_{FE} versus temperature [24].

$$h_{FE} = \frac{\Delta I_C}{\Delta I_B} \tag{2}$$

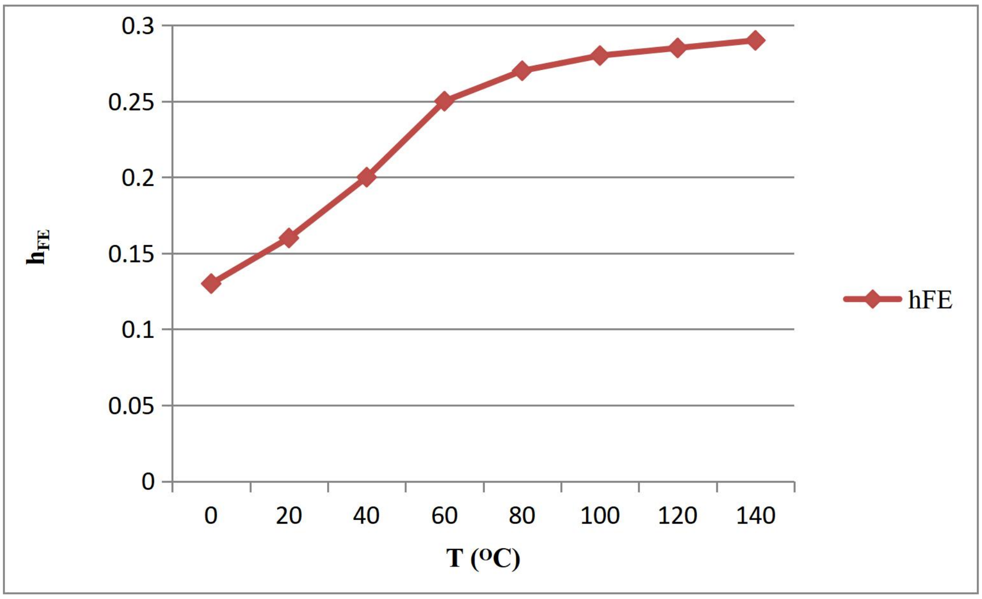

Figure 4 Current gain h_{FE} value due to temperature degrees fluctuations

Figure 4 gives an indication of the increase in h_{FE} going from 0.13 (at 20 °C) to 0.23 (at 125 °C). This indicates that when the supply current increases as a consequence of temperature, then the h_{FE} value also increases.
The taken at room temperature can be obtained by the following formula [26]:

$$V_{Th}(T) = V_{Th}(0) - AT \tag{3}$$

$V_{Th}(T)$ and $V_{Th}(0)$ are the initial voltages recorded at room temperature, respectively. Figure 5 illustrates the change of threshold voltage V_{Th} as a functions of the temperature.

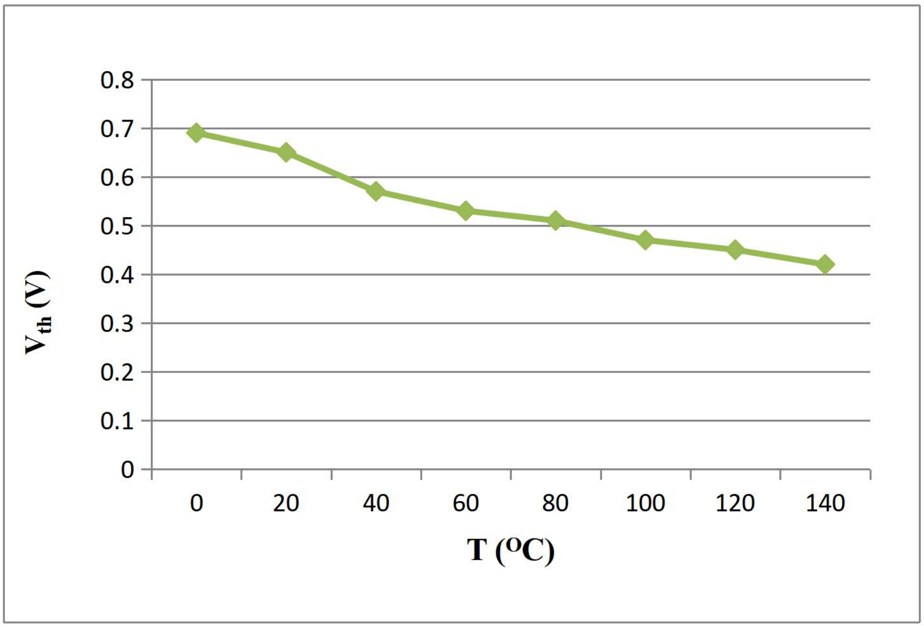

Figure 5 The threshold voltage drop with temperature rising

From Figure 5, it can be noted that the magnitude of V_{Th} drops from 0.66 V to 0.41 V with temperature increase. This causes the electrons within the valence band to be excited and migrate to the conduction band, resulting in a larger current.

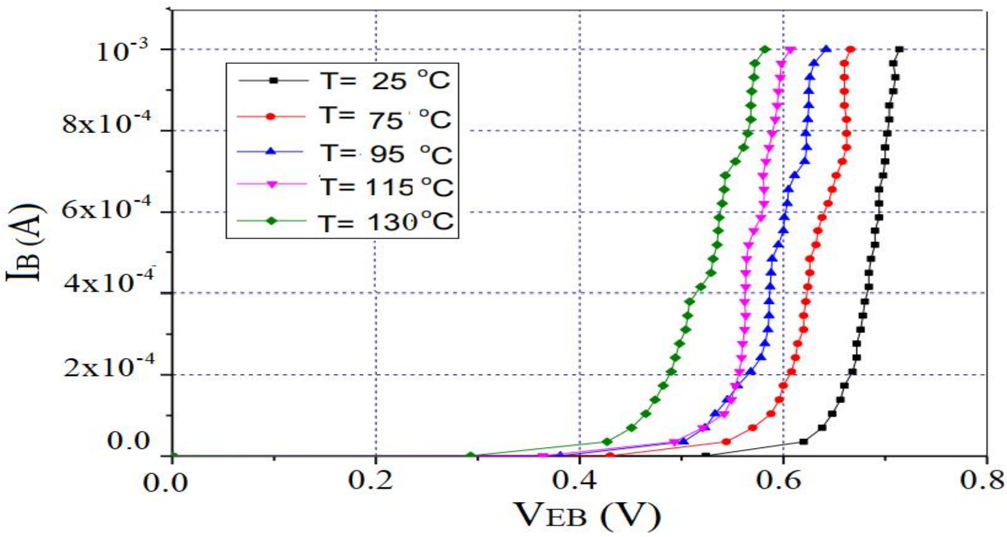

Figure 6 I_B-V_{BE} value changing at temperature rising

Figure 6 indicates that as V_{EB} is greater than 0.5 V, current of the base will increase with increasing temperature. This suggests that the current through the base is influenced by the temperature rise.
Table 3 provides a representation of the C_T and C_d Capacitors values. Changes of C_T as a function of the temperature rises (25 °C) is shown in Figure 7, the C_T change is given in Figure 8.

Table 3 C_T and C_d Capacitors changing values

Capacitance (nF)	Collector - base				Emitter - base			
Temp. (°C)	30	45	75	90	30	45	75	90
C_T (nF)	178	35	49	54	61	12	3	8
C_d (nF)	24	34	44	57	68	16	10	7

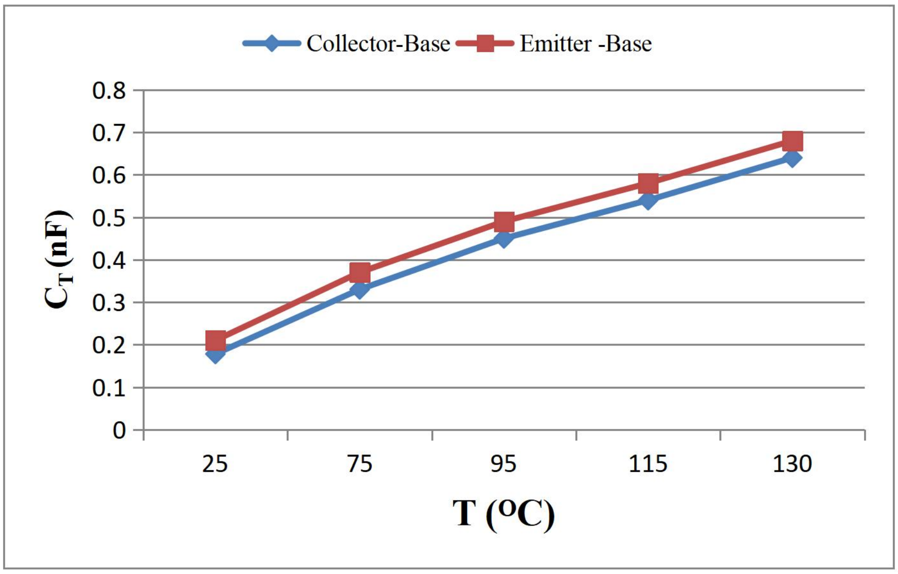

Figure 7 The (C_T) values as a function of the temperature change

Figure 7 illustrates that C_T gradually rises from 0.22 nF to 0.68 nF and Cd from 0.179 nF to 0.69 nF. This means that the C_d value is influenced by the increasing of temperature.

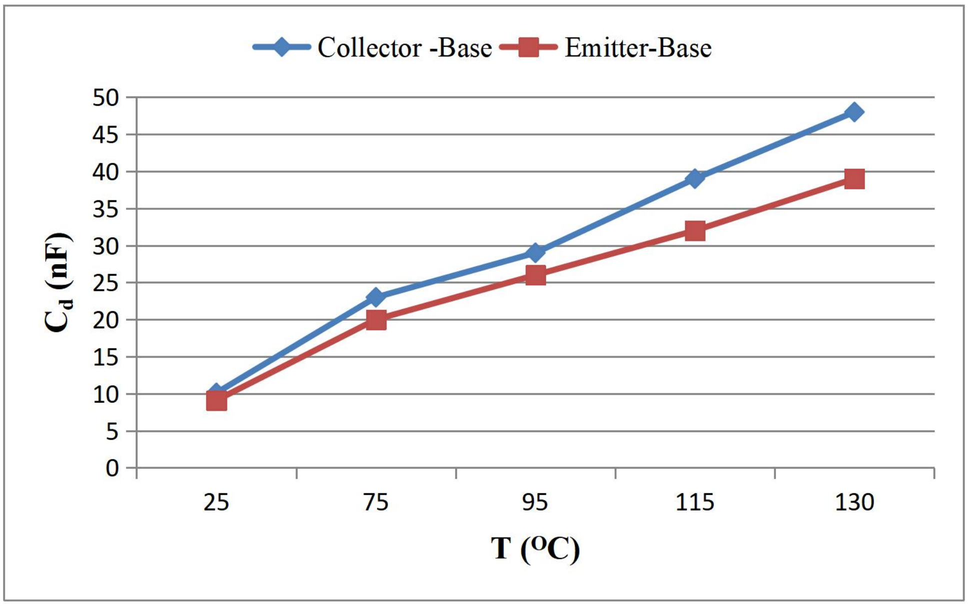

Figure 8 C_d value as a result of temperature rising.

4 CONCLUSION

The high development of the electronics industry nowadays has resulted in the emergence of a higher number of high temperature and high cool electronic products, such as facilities for heat monitoring or controlling many associated processes. Such devices may involve high-temperature facilities as well as nuclear power reactors used to produce nuclear energy. These application and facilities requires steady operation under high temperatures, need air conditioning for temperature reduction, and add to size and cost. One solution to these challenges is through the use of silicon carbide electronic devices. In this paper, the influence of the high temperature on the BJT- 2SC2120 performance has been experimentally investigated and analyzed. on some parameters of a bipolar junction transistor type 2SC2120 at high temperatures. The experimental results indicate that in case of an increase in temperature over the range 30-90 °C, a collector current has been increased by about 0.045 A, whereas the current raised for 0.122 A. The applied threshold voltage has been decreased from 0.65 V to 0.47 V. The obtained results also illustrate that the reverse breakdown of emitter-to-base transition capacitance has been increased from 40 pF to 46 pF. From the obtained results, it can be conclude that the rising of temperature will results in some changes in the transistor parameters such as output current, output voltage and output resistance.

COMPETING INTERESTS

The authors have no relevant financial or non-financial interests to disclose.

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HIGH-PRECISION CONSTRUCTION TECHNOLOGY FOR LARGE-AREA SANDWICH-TYPE LIGHTWEIGHT AND HEAVY-LOAD FLOORING

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Abstract: In view of the shortcomings of traditional large-area floors in terms of bearing capacity, deadweight, cost and crack control, this paper proposes a sandwich-type lightweight and heavy-load flooring construction technology. This technology combines solid waste slag concrete cushion layer, film sliding layer, steel fiber concrete and diamond wear-resistant surface layer to ensure that the bearing capacity reaches 5 t/m², effectively solving the problems of high bearing capacity, heavy deadweight and crack prevention. At the same time, the structure saves costs, improves the utilization of solid waste materials, meets the requirements of green buildings, and provides an important reference for the construction of lightweight and heavy-load wear-resistant floors in China.
Keywords: Sandwich type; Light and heavy load; Solid waste slag; Green and low carbon

INTRODUCTION

With the rapid development of global industry, the construction demand of factories and exhibition halls is increasing. As an important component, the floor has put forward higher requirements on construction area, bearing capacity, flatness, crack control and use environment [1-3]. In order to meet the social needs of energy saving, environmental protection and high precision, the floor construction process needs to be optimized and innovated. Traditional large-area floors are usually composed of concrete cushion layers and reinforced concrete surface layers, but when meeting heavy load requirements, there are problems such as heavy weight, high construction cost, high crack risk and difficulty in flatness control [4]. To solve these problems, this paper proposes a sandwich type lightweight heavy load floor construction technology based on the design concept of high load and low bulk density to achieve the advantages of light weight, high flatness, high crack resistance, low cost and green and low carbon.

1 PROCESS PRINCIPLE

Based on the design concept of high load and low bulk density, solid waste slag concrete cushion layer, film sliding layer, steel fiber concrete and corundum wear-resistant surface layer are used (Figure 1). By optimizing the mix ratio of lightweight slag concrete, it replaces traditional plain concrete as cushion backfill; pouring steel fiber concrete to reduce the use of steel bars, and using the excellent properties of steel fibers to improve tensile strength. A double-layer sliding film is added between the slag cushion layer and the steel fiber concrete to reduce shrinkage cracks. At the same time, a leveling robot is used to ensure the high-precision flatness of the large-area surface layer.

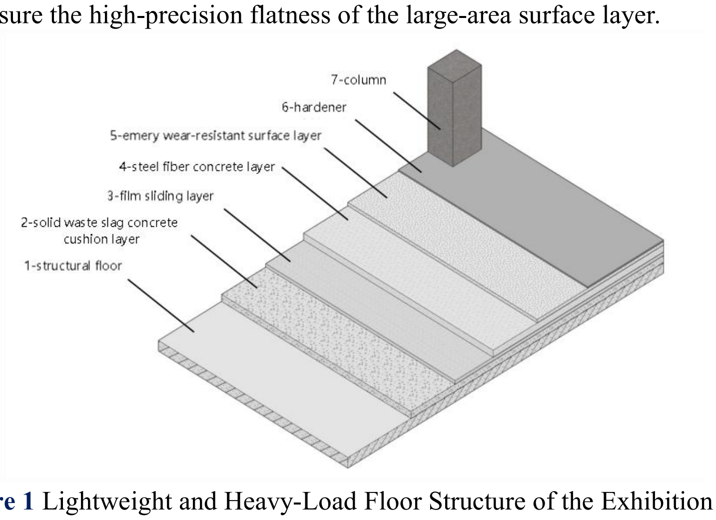

Figure 1 Lightweight and Heavy-Load Floor Structure of the Exhibition Hall

2 PROCESS FLOW AND KEY POINTS OF OPERATION

2.1 Process Flow

Technical preparation → Construction of lightweight slag cushion layer → Laying of film sliding layer → Setting of trench Z-shaped steel, isolation around columns, etc. → Casting of steel fiber concrete → Spreading and finishing of corundum wear-resistant aggregate → Cutting seams → Spraying of hardener → Grinding (Figure 2).

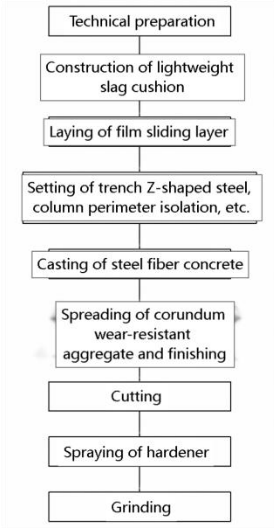

Figure 2 Construction Process Flow Chart

2.2 Technical Preparation

Based on the green building design concept, the lightweight slag cushion layer is optimized in mix ratio design. To ensure that the strength of lightweight aggregate concrete meets the design requirements, 13 groups of standard concrete test blocks are prepared according to different mix ratios, 3 blocks in each group, with specifications of 100mm×100mm×100mm. The mix ratio of lightweight aggregate slag concrete is shown in the table below.

Table 1 Slag Concrete Mix Ratio (0.003m3)

Group Cement	cement（g）	Slag（g）	quicklime（g）	Yellow sand（g）	Stone powder（g）	Crushed stone（g）	Water（g）
1#	471	3000	366	441	-	-	1050
2#	501	3000	366	441	-	-	1050
3#	531	3000	366	441	-	-	1050
4#	561	3000	366	441	-	-	1050
5#	471	3000	366	-	441	-	1050
6#	501	3000	366	-	441	-	1050
7#	531	3000	366	-	441	-	1050
8#	561	3000	366	-	441	-	1050
9#	471	3000	366	-	-	441	1050
10#	501	3000	366	-	-	441	1050
11#	531	3000	366	-	-	441	1050
12#	561	3000	366	-	-	441	1050
13#	621	3000	366	-	-	-	1050

After the test block reaches 28d curing age, the compressive strength test is carried out. The compressive strength of the 8#, 11#, 12#, and 13# test blocks meets the design requirements (≥7.5MPa), as shown in the following table. Finally, considering the low bulk density requirement, on-site construction conditions, and the influence of workers' operation deviation on the strength of slag concrete, the 13# mix ratio was determined as the optimal mix ratio of slag concrete.

Table 2 Comparison of Bulk Density of Slag Concrete with Different Proportions (1m3)

Serial number	42.5Cement（kg）	Slag（kg）	Quicklime（kg）	Stone powder（kg）	Crushed stone（kg）	Water（kg）	Density（kg/m^3）	Compressive strength（MPa）
8#	187	1000	122	147	-	350	1800	7.7
11#	177	1000	122	-	147	350	1800	7.6
12#	187	1000	122	-	147	350	1800	8
13#	207	1000	122	-	-	350	1680	8.2

Figure 3 Optimization of Lightweight Slag Concrete Mix Ratio

2.3 Construction of Lightweight Slag Cushion

The design thickness of the lightweight slag concrete cushion is 250mm, and it is laid in layers, with a ratio of virtual laying to compacted thickness of 1.3:1. Before laying, the surface of the base layer needs to be sprinkled with water to moisten it, and 1:0.5 cement slurry is evenly applied to form a bonding layer. The mixing, laying and compaction of the slag cushion layer must be closely combined to ensure that all operations are completed within 2 hours. For construction joints, a cement slurry bonding layer is applied at the interface when joining to ensure good bonding between different slag cushions and ensure the stability of the overall structure. As shown in Figure 4.

Figure 4 Construction of Slag Concrete Cushion Layer

Figure 5 Laying of Sliding Layer

2.4 Laying of Film Sliding Layer

The sliding layer is set between the cushion layer and the upper concrete. After the slag cushion layer reaches the design strength, two layers of 0.3mm thick PE film are laid perpendicular to each other on it. The PE film must be laid with overlap, and the overlap width is not less than 200mm. As shown in Figure 5.

2.5 Z-Shaped Steel in Trenches, Isolation around Columns, etc.

During trench construction, Z-shaped steel should be welded and fixed on the reserved steel bars on the anti-slope on both sides as the side formwork and finished surface control line of the floor surface. A single-layer bidirectional steel mesh of Φ6@150 is arranged on the surface of the slip layer. The thickness of the protective layer must meet the design requirements to enhance the crack resistance of the upper steel fiber concrete. At the same time, anti-crack reinforcement steel bars are arranged at a 45° angle at the stress concentration parts of the floor (such as the positive corners of the columns), and isolation measures are set around the columns to prevent cracks caused by the restraint of the columns. As shown in Figure 6.

Figure 6 Anti-Crack Reinforcement Setting around Trench and Column

2.6 Steel Fiber Concrete Pouring

Add 10-15 kg of steel fiber into the concrete, with about 4,600 fibers per kg, to enhance the bonding and bite force between the concrete and the aggregate, improve the anti-cracking ability of the floor, and ensure integrity. In addition, a trench is set every 6 meters to realize the compartment pouring of steel fiber concrete. After the concrete is poured, it is first leveled with a vibrating beam, and then leveled with a robot to ensure uniform density of the concrete, and the surface flatness is controlled within the range of 3mm/2m. As shown in Figure 7-8.

Figure 7 Steel Fiber Concrete

Figure 8 Robot Leveling

2.7 Spreading and Finishing of Diamond Wear-Resistant Surface Layer

Before the initial setting of the concrete, mechanical spreading is used instead of manual work to ensure uniform spreading of aggregates. Spread 2/3 of the diamond wear-resistant surface layer on the concrete surface for the first time. After it absorbs water and shows a damp color, use a disc polisher to compact and rub it. The operation should be performed at least 3 times. Then, spread the remaining 1/3 of the diamond sand, with the spreading direction perpendicular to the first time, and smooth it immediately after spreading. Work at least 3 times, and the polishing machine should be operated in a crisscross manner to ensure uniformity and order. As shown in Figure 9-10.

Figure 9 Mechanical Spreading

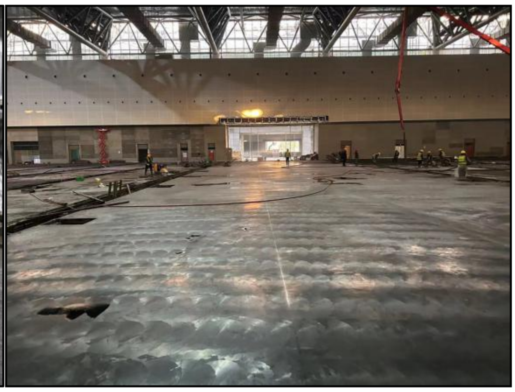

Figure 10 Surface Finishing

2.8 Cutting

Within 48 hours after the floor surface is finished, the cutting should be done with a spacing of 6 meters, a width of 3-5 mm, a depth of 1/2, and staggered arrangement. Before filling the joints, it is necessary to clean up the debris in the joints to ensure that the gaps are clean, and then fill the joints according to the design requirements.

2.9 Hardener Spraying

After the floor has been maintained for 21 days, the surface hardener should be sprayed, and the surface dust should be removed before spraying. On the premise of ensuring that the ground is dry, use a low-pressure spray pot to evenly spray the hardener on the floor surface according to the design dosage of 0.3 kg/m², and keep it wet for at least 40 minutes to penetrate, so as to improve the strength and hardness of the concrete surface and meet the requirements of heavy-duty use.

2.10 Grinding

After the hardener penetration construction is completed, 400# grinding disc should be used for water grinding to remove the residual hardener. After the ground is dry, 800# and 1500# resin sheets are used in combination with grinding equipment for fine grinding to further improve the surface density and ensure that the floor has stronger impact resistance, anti-fouling and anti-seepage capabilities. As shown in Figure 11.

Figure 11 Grinding

3 BENEFIT ANALYSIS

3.1 Economic Benefit

Compared with traditional floor construction methods, this technology uses lightweight slag concrete instead of ordinary plain concrete for cushion backfill; a sliding layer is added between the cushion and the upper surface layer; steel fibers are used instead of the upper steel mesh in the floor surface concrete, which reduces the project cost and saves project costs. The cost comparison between this method and traditional construction is shown in the following table.

Table 3 Cost Comparison (yuan/m^2)

Traditional method (price per square meter)				
Item	Material	Unit price	Quantity	Unit cost (yuan)

1	Plain concrete cushion	580yuan/ m³	0.25m³	145
2	φ6@150steel mesh	5500yuan/ton	12.4kg	68.2
Total				213.2
This process (price per square meter)				
1	Lightweight slag concrete	229.4yuan/ m³	0.25m³	57.3
2	PE film	3yuan/㎡	2 ㎡	6
3	φ6 steel bar	5500yuan/ton	6.2kg	34.1
4	Steel fiber	12000yuan/ton	2.5kg	30
Total				127.4
Comparison results: Compared with the traditional floor method, this process can save about 86 yuan/m^2 (corresponding to the thickness of the cushion layer 250mm).				

3.2 Environmental Benefits

Based on the concept of green building, this method uses industrial solid waste slag, and optimizes the slag concrete ratio to make its corresponding strength reach 8.2MPa (design strength 7.5MPa), and the density is only 1680kg/m3, which effectively solves the problem of solid waste utilization and has good environmental benefits.

4 CONCLUSION

Lightweight and heavy-load floor is an important part of factory and exhibition hall buildings. According to the requirements of construction area, bearing capacity, flatness, crack control, etc., an effective technical solution is proposed. Based on the design concept of high load and low bulk density, this technology adopts solid waste slag concrete cushion layer, sliding layer, steel fiber concrete and diamond wear-resistant surface layer to achieve a bearing capacity of 5 t/m², effectively solving the high load, heavy weight and crack prevention problems of large-area floor. In addition, compared with traditional construction technology, this method saves costs, improves the utilization of solid waste materials, meets the requirements of green and low-carbon buildings, and provides a useful reference for the construction of lightweight and heavy-load wear-resistant floor in China.

COMPETING INTERESTS

The authors have no relevant financial or non-financial interests to disclose.

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STABILITY AND UNLOADING CALCULATION ANALYSIS OF TEMPORARY SUPPORT FRAME OF RING-LAYERED HOLIER-WEB TRUSS

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Abstract: This paper takes the Beijing-Hangzhou Grand Canal Museum project in China as the background, introduces the stress characteristics of the ring-layered holier-web truss of the project, and designs a temporary support frame structure based on its stress characteristics to ensure the safe construction of the project. Yingjianke software is used to verify the overall stability and floor shear bearing capacity of the temporary support frame, and the support frame during the construction process is subjected to stress analysis. In addition, the active control method is used for unloading to realize the conversion of the force system, and the stress and strain measurement points are arranged in the key sections to monitor the stress and strain in real time during the structure construction and unloading process. The construction method of this project can provide a technical reference for the construction of similar projects.
Keywords: Annular laminated holier-web truss; Temporary support frame; Yingjianke software; Force analysis

INTRODUCTION

The holier-web truss consists of upper and lower chords and vertical webs. It is evenly stressed, has good lateral stiffness, and has a high energy dissipation capacity. In recent years, for buildings with large-span discontinuous vertical components and high requirements for facade effects, holier-web trusses have been widely selected [1-3].
The laminated holier-web truss can further reduce the internal force of the rod, reduce the cross-section of the rod, and make the force more uniform, effectively solving the problem of weak layers and weak layers [4-5]. Sun Yongzhi [6]'s research shows that the overall bending of the large-span laminated holier-web truss structure system causes the plate grid at the end of the floor slab to produce a large negative bending moment, and the plate grid at the middle of the floor slab to produce a large positive bending moment. This additional stress cannot be ignored. Li Yuying[7] and Wang Hongchang[8] believed that when the constraint of the truss column on the truss beam is very small, the truss column mainly transmits axial force, and the upper and lower truss beams work independently and mainly bear bending moment; when the constraint of the truss column on the truss beam gradually increases, the truss effect is obvious. At this time, the truss beam not only bears bending moment, but also bears tension (lower truss beam) and compression (upper truss beam); when the constraint of the truss column on the truss beam is extremely large, the stress characteristics of the laminated hollow truss are mainly bending deformation, reflecting the stress characteristics of the beam and the stress characteristics of the truss, that is, in addition to bearing bending moment and shear force, it also bears axial force. The upper chord is a compression, bending and shearing member, and the lower chord is a tension, bending and shearing member.
For large-span laminated hollow trusses, Duan Yongfei[9] believed that the hollow truss beam needs to be supported at the bottom during construction. When the upper and lower chords and vertical bars of the hollow truss reach the design strength, the vertical support can be removed.
Based on the Grand Canal Museum project in Hangzhou, Zhejiang Province, this paper uses YJK (5.2.1) software to study the stability of the temporary support frame of the annular laminated pierced truss, and gives the unloading construction method, which can provide a design basis for similar projects.

1 PROJECT OVERVIEW

This project is located on the bank of the Grand Canal in Hangzhou. It adopts the form of "one museum and multiple museums", covering multiple functions such as museums, conference centers, and the Grand Canal International Exchange Center, creating a new world-class cultural landmark.
This project has 2 underground floors and 15 above-ground floors, of which floors 1-8 are podiums and floors 9-15 are towers. The total height of the building is 73.5m and the total construction area is about 175650m^2. The project effect is shown in Figure 1.

Figure 1 Project Effect Diagram

2 STRUCTURAL SYSTEM

The tower is a frame-shear wall system, mainly composed of an outer "mountain"-shaped column tube, an inner "mountain"-shaped column tube, and a concrete core tube. The "mountain"-shaped column tube is a frame structure composed of folded beams and stepped lap columns. Among them, the beams and columns of the inner "mountain"-shaped column tube (9F-15F) are all supported on the 9F conversion ring beam, and the conversion ring beam is supported on the cantilever wall (7F-8F) at the core tube through four conversion columns (8F floor-9F floor). The structure is converted layer by layer, the force transmission is complex, and the overall redundancy of the structure is small.

In order to improve the integrity and safety of the inner courtyard structure and reduce the bending moment of the conversion ring beam, the inner courtyard is considered as a hollow truss structure system during the design, that is, the roof ring wall is used as the upper chord, the 9F conversion ring beam is used as the lower chord, the 10-15F floor frame beam is used as the middle chord, and the 9-roof layer lap columns are used as vertical webs to form a spatial structure system. Therefore, during the construction process layer by layer, the hollow truss cannot be stressed as a whole, and the conversion ring beam bears the load transmitted by the upper columns, and each side under the ring beam is supported by only 2 conversion columns, with a maximum span of 20m.

In order to ensure the safe construction of the ring-layered hollow truss structure and effectively control its mid-span deflection, ensure the flatness of the finished surface of the building and do not affect the use effect of the building. A concrete frame structure is set up from the negative second floor to the eighth floor below the ring-layered hollow truss as its temporary support until the hollow truss structure is completed and the overall force is applied, and then the temporary support frame is removed. The force transmission path of the ring-layered hollow truss is shown in Figure 2.

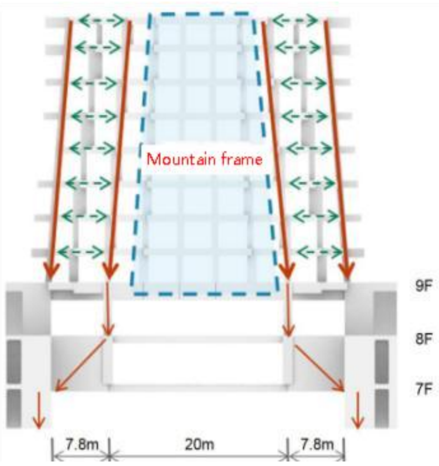

Figure 2 Force Transmission Path of Annular Laminated Open-Web Truss

3 SUPPORT STRUCTURE DESIGN AND FORCE ANALYSIS

3.1 Support Frame Design

The support frame is equipped with 12 frame columns, of which: 4 are set under the conversion ring beams on the east and west sides, a total of 8 as the main load-bearing frame columns (the cross-sectional dimensions of frame columns below the elevation of 31.355m are all 900mm×900mm, and above the elevation of 31.355m, the cross-sectional dimensions of corner columns are 900mm×1125mm, and the cross-sectional dimensions of side columns are 900mm×1070mm); 4 frame columns with a cross-sectional dimension of 700mm×700mm are set in the middle, which mainly play a role in tensioning. The 12 frame columns are connected together by frame beams to ensure the overall stability of the support frame. There are 9 frame beams in total, which are located at elevations of -5.500m, 0.850m, 5.940m, 11.290m, 16.805m, 21.855m, 26.955m, 32.155m, and 37.832m. The frame columns of the support frame are only connected to the floor beams and slabs of the first and second floors of the main structure, and are separated from the floor beams and slabs of the other floors of the main structure. The relative relationship between the support frame and the main structure is shown in Figure 3.

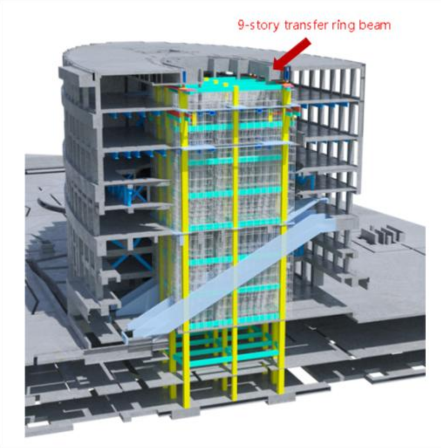

Figure 3 Relative Relationship between the Support Frame and the Main Structure

3.2 Force Analysis of the Support Frame

3.2.1 Establishment of the support frame model

The structural calculation program of this project uses Yingjianke Building Structure Design Software (YJK5.2.1) to analyze the support frame. Among them: wind load is calculated according to the windproof area of the component, and the corrected basic wind pressure is 0.45kN/m^2; seismic action is not considered; the structural importance coefficient is 1.0; the self-weight of the cast-in-place slab is automatically calculated.

Load value: The constant load is 2kN/m^2; the live load is 2kN/m^2; the upper hollow truss load is converted into a concentrated force and acts on the top of the support frame column. The load arrangement diagram and the support frame model diagram are shown in Figures 4 and 5.

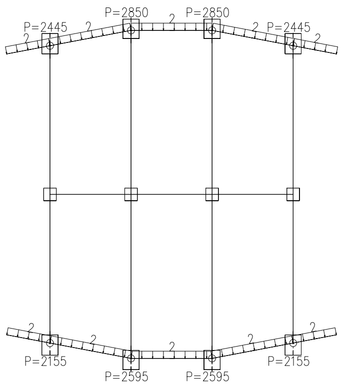

Figure 4 Load Arrangement Diagram

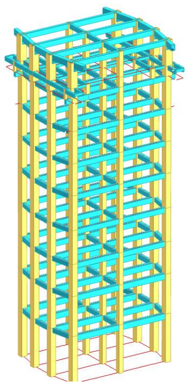

Figure 5 Support Frame Model Diagram

3.2.2 Overall stability verification of the support frame structure

The overall stability calculation results of the support frame structure are shown in Table 1.

Table 1 Stability of Supporting Frame Structure

Layer number	X-direction Stiffness/10^5	Y-direction Stiffness/10^5	Floor height	Upper part Weight	X-stiffness to weight ratio	Y-stiffness to weight ratio
3	2.78	2.25	5.090	48201	29	24
4	2.33	1.86	5.350	45848	27	22
5	2.13	1.74	5.515	43559	27	22
6	2.40	1.95	5.050	41098	29	24
7	2.20	1.96	5.100	38886	28	25
8	2.17	1.91	5.200	36615	30	27
9	1.86	1.48	5.677	31824	33	26

It can be seen from Table 2 that the rigidity-to-weight ratio of the support frame structure Di×Hi/Gi＞20, which meets the requirements of the "High Code", can pass the overall stability verification and can ignore the second-order effect of gravity.

3.2.3 Verification of shear bearing capacity of support frame floors

The calculation results of the shear bearing capacity of the support frame structure floors are shown in Table 2.

Table 2 Shear Bearing Capacity of Supported Frame Floors

Layer number	X-axis bearing capacity	Y-axis bearing capacity	Ratio_X	Ratio_Y
9	7.17×10^3	8.46×10^3	1.00	1.00
8	7.67×10^3	7.84×10^3	1.07	0.93
7	8.13×10^3	8.33×10^3	1.06	1.06
6	8.32×10^3	8.72×10^3	1.02	1.05
5	7.97×10^3	8.14×10^3	0.96	0.93
4	8.34×10^3	8.71×10^3	1.05	1.07
3	9.32×10^3	9.53×10^3	1.12	1.09
2	7.48×10^3	7.75×10^3	0.80	0.81
1	6.25×10^3	6.43×10^3	0.84	0.83

Ratio_X, Ratio_Y: represents the ratio of the bearing capacity of the current layer to the previous layer.

Table 2 shows that the interlayer shear bearing capacity of the floor lateral force resistance structure and the shear bearing capacity of the adjacent previous layer are both ≥0.8, which meets the provisions of Article 3.5.3 of the Technical Code for High-rise Concrete Structures JGJ3-2010.

3.3 Construction Condition Analysis

Due to the large stiffness of the cantilever wall under the conversion column, in order to prevent the conversion beam from arching during the construction process, which affects the open-web truss structure, Yingjianke software (YJK5.2.1) is used to perform layer-by-layer construction simulation analysis, mainly analyzing the column top reaction force and compressive deformation of the conversion column and supporting frame column.

The floor load values for 9 floors (transfer floors) and above are: additional dead load 1kN/m^2, construction live load 2kN/m^2, and concrete pouring live load 4kN/m^2. Beam and wall loads: except for the core tube, which is the original design load, others: 0kN/m. The compressive deformation of the top of the supporting frame column and the column top reaction force are shown in Figures 6 and 7.

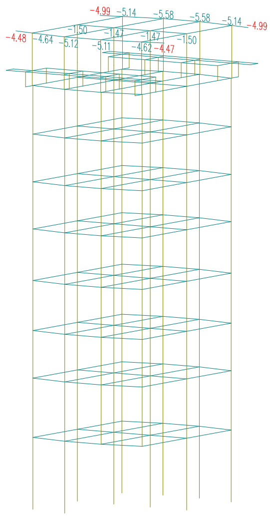

Figure 6 Compressive Deformation Diagram of the Top of the Supporting Frame Column

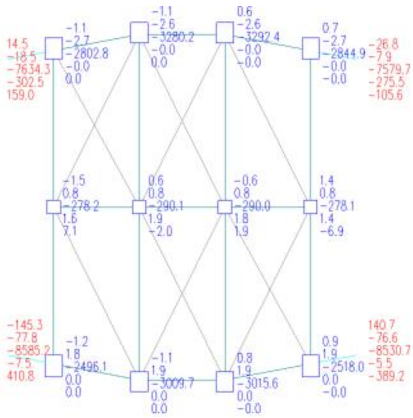

Figure 7 Reaction Diagram of the Top of the Supporting Frame Column

It can be seen from Figures 8 that during the loading process, the column top reaction force of the conversion column is greater than that of the adjacent frame column, and the compressive deformation of the conversion column is less than that of the frame column. Therefore, the conversion beam will not produce an upward arch phenomenon during the loading process, which is consistent with the design intention of the main structure and meets the design requirements.

4 UNLOADING OF THE SUPPORTING FRAME

The unloading process of the supporting frame is to gradually transfer the load borne by the temporary support to the structure, realize the self-stressing of the hollow truss structure, and finally the temporary support withdraws from work. In this project, sand boxes are used as temporary supports, which are set at the top of the east-west frame columns (columns A-H), with a total of 8 groups. 300t hydraulic jacks are set on the top of the axil beams on both sides of the sand box to cooperate with unloading. See Figure 8 for details of the unloading support.

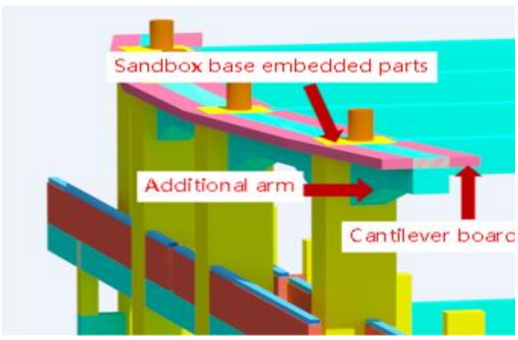

Figure 8 Sectional View of Unloading Support

Unloading adopts the principle of grading and symmetry. When unloading, first apply a top force to the jacks on both sides (the top force value on each side is 1/2 of the residual load value after unloading at this level). At this time, the entire load after unloading at this level is actively borne by the jacks, and then the sand is released by turning the sand box nut to separate the sand box from the conversion ring beam. The unloaded load is borne by the hollow truss itself. Finally, the lifting force of the jacks on both sides is slowly unloaded, so that the unloaded load is transferred to the sand box again. At this time, the first level of unloading is completed. Unloading is carried out step by step in this way until the hollow truss structure is self-stressed. Finally, the sand box and the jack are removed, and the unloading is completed. Unloading is divided into five levels, and the graded unloading amount is shown in Table 3.

Table 3 Gradual Unloading Amount

Unloading grade	Unloading amount
First-level unloading	Support columns B, C, F, G unload 30% of the reaction force FN; support columns A, D, E, H unload 20% of the reaction force FN.
Second-level unloading	Support columns B, C, F, G unload 50% of the reaction force FN; support columns A, D, E, H unload 50% of the reaction force FN.
Third-level unloading	Support columns B, C, F, G unload 70% of the reaction force FN; support columns A, D, E, H unload 65% of the reaction force FN.
Fourth-level unloading	Support columns B, C, F, G unload 90% of the reaction force FN; support columns A, D, E, H unload 80% of the reaction force FN.
Fifth-level unloading	Support columns B, C, F, G unload 100% of the reaction force FN; support columns A, D, E, H unload 100% of the reaction force FN.

4.1 Monitoring Frequency

Loading condition monitoring frequency: Monitor and collect data once 30 minutes before each concrete pouring of the AH-AK axis atrium area of the 9th floor and above, monitor in real time during the pouring process and collect data every 15 minutes, monitor and collect data once 30 minutes after the concrete pouring is completed; monitor and collect data every 2 days for the rest of the time.

Unloading condition monitoring frequency: Monitor and collect data once 10 minutes before each level of unloading, monitor in real time during the current level of unloading and collect data every 5 minutes, collect data at the 5th minute, 15th minute, 30th minute, 45th minute, and 60th minute after each level of unloading is completed, and collect data every 30 minutes thereafter, until the last level of unloading is completed and all monitoring data are stable for 24 hours, then the monitoring can be ended.

5 CONCLUSION

This paper takes the Beijing-Hangzhou Grand Canal Museum project in China as the background, introduces the stress characteristics of the ring-laminated venter truss of the project, and designs a temporary support frame structure based on its stress characteristics to ensure the safe construction of the project. Yingjianke software is used to verify the overall stability and floor shear bearing capacity of the temporary support frame. In addition, the active control method is used for unloading to realize the transformation of the force system, which can provide technical support and reference for the construction of similar projects.

COMPETING INTERESTS

The authors have no relevant financial or non-financial interests to disclose.

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ENERGY CONSUMPTION IN MANUFACTURING SYSTEMS

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Abstract: Green manufacturing represents a paradigm shift towards sustainable production processes that minimize environmental impact by reducing energy consumption and conserving natural resources. This paper explores green manufacturing strategies, focusing on the adoption of energy-efficient technologies, the use of recycled materials, and the redesign of manufacturing processes to minimize waste and emissions. The research highlights the importance of energy reduction at multiple system levels—process, equipment, facility, and supply chain—demonstrating how dynamic scheduling and modern technologies can lead to significant energy savings. The study emphasizes the growing need for industries to adopt green manufacturing practices as a response to global warming and environmental degradation, while also recognizing the financial benefits of reduced energy consumption. The integration of environmentally friendly designs, sustainable materials, and optimized energy usage throughout the manufacturing process is presented as crucial to achieving both economic and environmental sustainability in the manufacturing sector.
Keywords: Energy Consumption; Green Manufacturing; Sustainable Production; Global Warming; Environmental Degradation

1 INTRODUCTION

Green manufacturing refers to the sustainable production of goods using processes that are environmentally friendly and energy-efficient, ensuring minimal waste of natural resources [1]. Irani and Gupta [2] describe green manufacturing as a paradigm that employs systems and techniques that are both eco-friendly and cost-effective. The increasing awareness of environmental risks, particularly those associated with global warming, has driven the adoption of green manufacturing practices. These practices emphasize reducing energy consumption, recycling materials, and minimizing unwanted outputs [3].

The main emphasis in green manufacturing is the adoption of manufacturing processes that lower the consumption of energy. To achieve the concept of green manufacturing, the manufacturers normally result to use of recycled materials, change in the design of factory, designing processes and use of equipment that do minimise the consumption of energy [4]. The green manufacturing is a multi-dimensional concept that is not limited to the use of environmental designs products only but also encompasses the use of raw materials that are environmentally friendly, application of distribution systems that are environmentally friendly and the reuse of the products after they have served their course. This paper main focus is on the reduction in energy consumption in the different system levels of manufacturing using scheduling system.

Manufacturing processes normally consume a lot of energy, the energy intensiveness of the manufacturing processes in either industry has been found to be high [5]. In the advent of the sustainable manufacturing processes, there is need for adoption of energy saving manufacturing processes. According to Jawahir[1] recycling of products reduces the energy consumption as the energy that could have been used to prepare new raw materials is significantly reduced. Manufacturers all over the world normally produce heat and operate machineries using different types of energy. The commonly used sources of energy include electricity, natural gas and other forms of fossil fuel. In the usage of these sources of energy, Green manufacturing endeavours to create product systems that consume less material and reduce unwanted outputs in order to reduce the high energy usage [7].

In the developed countries the industrial emissions resulting from fossil fuels use have been blamed to be responsible for the greatest contributing of greenhouse effect. For instance, in the USA the industrial energy use contribute to 30% of the greenhouse gas emission in the country and which has been a major contributor to the climatic change [8]. An example of the gas emitted by the energy intense industries includes the carbon dioxide which has the highest prevalence among the greenhouse gases. The increasing concentrations of C02 in the atmosphere causes a great threat to environment, there is thus the need for industries to adopt sustainable manufacturing processes that reduce emission of the carbon fuels.

In 2030, the energy demand is predicted to have risen by 45%, this energy will be greatly required to power machines, electricity is one of the energy sources that the demand is predicted to keep on increasing. The sources of the electricity are mainly carbon based sources.

2 MOTIVATION TO REDUCING ENERGY CONSUMPTION

The rising awareness on the effects of global warming has resulted to environmentalists pushing for the measures that ensure environmental sustainability. There is pressure from governments and United Nations to ensure that manufacturers adopt processes that are environmentally friendly. The environmental conservation has thus become the responsibility of each and every person, this underscores the need for green manufacturing [9]. The mandate stems from the need to use energy that is cost effective, in the 21st century competition has become very stiff and manufactures have to device production processes that are cost effective and can compete favourably in the global market. Therefore, the integration of the technological processes that are energy efficient with the economical mindset of cost cutting makes green manufacturing a reality [10]. The production of same commodity using lesser energy is a way of making extra cash.

Global warming has also been a world challenge; the world is experiencing unpredictable weather patterns and climate changes that have been attributed to the greenhouse effect. The main cause has been pollution and emission of gases mainly from the manufacturing plants and other human activities. Failure to embrace measures to reduce the global warming by being sensitive to the natural environment, the natural resources will end up being wasted and in near future the generation will suffer due to the lack of resources or face harsh conditions such as increased UV radiations due to depletion of ozone layer [11]. The manufacturing industries are thus tasked with being at fore front of adopting environmental sustainable processes [12].

3 ENERGY CONSUMPTION IN MANUFACTURING

The concept of green manufacturing is a relatively new concept that has been used as an option. However, the advent of realisation of the eminent danger of global warming and the financial benefits resulting from green manufacturing has made it a mandate and manufacturers are obligated to use manufacturing processes that are not energy intensive [13]. In the manufacturing process, energy is key to running of the plants and consumption of energy is evident in different levels of the manufacturing process. Evans [14] found that the manufacturing activities are major users of energy in the world accounting for over one-third of the world's usage of energy. It is factual that the world population is on the increase and there is significant rise in living standards which translates to increased demand of manufactured goods. The challenge facing the manufacturing sectors is the energy consumption. As the populations grow, more manufactured products are required and subsequently a lot of energy is used to manufacture the products. Therefore, manufacturing systems and processes that are energy efficient should be incorporated in the production process [15].

There are many researches that have been carried to provide knowledge on the ways energy consumption can be reduced at various levels of manufacturing system. This literature review focuses on the energy consumption reduction in the levels of manufacturing; the main focus will be on the system level and use of dynamic scheduling. Despite of the system level being key in the manufacturing system, there is little research that has been carried on this level of manufacturing. Bearing in mind that the system level cross-cuts the whole manufacturing process, efficiency in the level can lead to significant reduction in the consumption of energy.

3.1 The Process Level

Process level refers to the activities that are undertaken in manufacturing, they include refining, cutting, grinding and milling [16]. Energy has been found to be largest operating expense after the raw materials in the process level; there is thus the need to reduce energy consumption at the process level in order to ensure cost effectiveness of the processes. According to [17] modern technologies that reduce the use usage of energy at the process level are key to overall result of realising that manufacturing is energy efficient. Once a plant has been built, the management normally makes decision that relate to the consumption of energy and the related variable cost of production. In order to ensure that there is energy reduction in the process level of manufacturing, modern technologies can be adopted to ensure that systems are operating at levels that ensure maximisation of production and reduce the energy consumed [18]. For instance, the use of computer aided systems to control the processes of manufacturing.

In the comparison of power consumption between manual control of machines and computerised systems, it was found that the computer control systems have reduced the energy consumption with a 1-3% energy saving in the computerised system. The computer control systems that were applied were the multi variable predictive model and the real time technologies for optimisation. These technologies hold the production processes at multiple constraints which enabled carrying out trade-off in the operation process resulting to maximisation of production and subsequent saving of energy.

3.2 The Equipment Level

The equipment level in manufacturing involves the care and maintenance of the equipment that are used in the manufacturing. For efficient energy consumption machines and equipment should be in good condition to avoid energy wastage through leakages and slow output [19]. Once a plant has been built, it goes to the processes of operation depending on the decisions that are made and engineers instructions. Just like any other machine, the machines undergo wear and tear and there is thus the necessity of retrofitting the equipment to ensure that the machine remains efficient. It has however been found that the retrofitting is normally limited after the plant is already in operation. The resulting factor is that the systems and equipment end up being not economical in terms of the energy usage. It has been found that the selection and development of better technology leads to better energy utilisation in the process retrofitting.

This method of upgrading of new technologies is commonly referred to as *smart revamp* and has been acclaimed for being cost effective and significantly reduces energy consumption. A leading Asian company dealing with chemical manufacturing was engaged in a retrofit process in one of its aromatic plants. In the retrofit, energy consumption was one of the key factors warranting the move; hence a study was conducted on the energy improvement of the whole aromatic plant. The results of the study showed a 20% percent overall reduction of the energy required in the whole plant. This study did not focus on the separate unit but on the whole aromatic plant. The study points to positive benefits of the retrofit technologies in ensuring that energy consumption is reduced.

3.3 The System Level

The system level entails design that ensure that energy consumption is reduced through continuous integration of processes through scheduling which ensures energy is not lost in between the processes [20]. Energy efficient designs play a great role in the manufacturing processes and ensuring that cost effectiveness is realised. Green and flexible manufacturing that is geared at reducing energy usage is achieved through the system level which employs the use of hybrid dynamic systems [21]. The hybrid dynamic systems normally have two distinct characteristics in which there is continuous and discrete behaviour in the manufacturing. The discrete behaviour is classic and there is application of constancy in the energy consumption while the dynamic scheduling is continuous and is based on ensuring that energy consumption is minimised through time in which the lowest time possible is used for a production.

There are two main scheduling processes used in the system level which include the classic and the dynamic scheduling [22] stated that good quality solution to the scheduling problems is a crucial factor if effective utilisation of flexible manufacturing systems is to be achieved and reduce the consumption of energy.

In the classic, the manufacturing parts are normally delivered to machines in batches; these batches are normally in the right sizes. The batches normally create intersection points in which energy may be consumed without production. This to some extent increases energy consumption. On the otherhand the use of the dynamic scheduling ensures that the efficiency in energy is achieved as the intersection constraints are avoided. In the dynamic scheduling the parts in the manufacturing are normally delivered to the buffers that are being used in the machine at a continuous flow, which allows equal distribution of time [23]. The stretch of execution time of a manufacturing process leads to more consumption of energy in the process of manufacturing, therefore having discontinuous batches in the classic level has substantial energy loses that can be saved if a continuous flow was implemented. In the dynamic scheduling the manufacturer considers the energy losses that could be saved from the classic scheduling. In some manufacturing systems, the maximisation of the performance is key and this has been found to have an effect in the minimisation of the energy that is consumed through lean manufacturing [24]. In a research to explore energy based constrained scheduling of tasks that were real time. The findings of the studies have shown significant saving of energy in execution of tasks.

Scheduling is crucial when set of resources are required to be shared in order to manufacture items at the same time. The main goal behind scheduling is to ensure that machines operate in a manner that is efficient and that time factor is utilised efficiently in the manufacturing. The processing in the dynamic scheduling is the determining factor, here the machines rely on automated systems that are controlled by computers, therefore continuity is achieved as there is to interference and disturbance of the system, the results for the dynamic scheduling is that there is fixed off line that guarantees system efficiency.

4 FACILITY LEVEL AND SUPPLY CHAIN

The facility level involves the energy consumption that relates to the whole plant points of energy consumption. The reduction of energy consumption at facility level can be effected from the design stage of the factory [25]**.** The initial design that is used for a plant determines the energy that will be required in the operation. Facility energy efficiency is greatly influenced by the engineers when doing the initial designs of the facility. The manufacturing facilities normally have common features in which the utility systems consume the fossil fuel which in turn produces power and steam to run the facility's process of manufacturing [26]. Suitable design and ensuring that there is proper integration of the processes and systems of utility are key to ensuring energy efficiency. According to [25] it is possible for engineers to create facilities that combine optimised design process and energy consumption efficiency. This is true if the initial designs of the facility are made with foresight of the issues relating to reduction of energy consumption.

An example of energy reduction at facility level is the undertaking by Aspen Tech and BP that have designed a next generation olefin a plant separation system. The new design of olefin has been found to reduce the consumption of energy by 15% compared to other facilities of similar function. For the reduction in energy consumption at the energy level, engineers need to use integrated engineering process that is based on the smart technologies that are currently in place.

Researches carried have shown that in the manufacturing process, the acquiring of raw materials is very crucial to ensuring efficiency and reducing the levels of energy consumption [27]. The supply chain involves the manufactures acquiring the right materials to be used for production from the suppliers. To reduce energy consumption manufacturers can use recycled materials and employ the green chain supply strategy in which the suppliers are to abide by environmental requirements of the manufacturer. Even though this does not impact directly on the manufacturing process, the green supply impacts positively on environment and ensures sustainability by encouraging practices that are environmentally friendly. In addition, the supply chain is supposed to ensure that the raw materials being delivered to the plant do not require a lot of energy in the process of manufacturing [28].

5 CONCLUSION

Manufacturing processes are energy intensive and account for over one third of the total energy consumption. As the world population continues to grow, so is the need for energy. This energy used is normally fossil and the more the energy used the more the emission of greenhouse gases to the atmosphere. The challenge that has resulted from emissions of the gases has been the climatic changes normally marked by the global warming. With the changes in climate there are many challenges that are offing and one of them is that in future there may be no enough energy to sustain the growing demand.

The industries thus have to tackle the challenge by devising energy efficient processes in their manufacturing activities. To achieve this adoption of green manufacturing that focuses on reducing the energy consumption is a mandate for every manufacturer. The green manufacturing should be integrated in all levels in the system of manufacturing, starting from the starting from the process, system level equipment level, system level to the facility level and the supply chain. Saving energy is thus a key strategy that is needed by manufacturers to ensure that environmental sustainability is achieved and there is marked reduction on usage of the fossil fuels.

COMPETING INTERESTS

The authors have no relevant financial or non-financial interests to disclose.

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PREDICTIVE MAINTENANCE USING ML TO OPTIMIZE PLANT EFFICIENCY AND REDUCE EMISSIONS

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Abstract: In the modern industrial landscape, the integration of predictive maintenance (PdM) using machine learning (ML) has become essential for optimizing plant efficiency and minimizing emissions. This paper explores the transformative potential of predictive maintenance, which leverages data-driven insights to anticipate equipment failures and facilitate timely interventions. By transitioning from traditional maintenance strategies—reactive and preventive—to a proactive approach, organizations can significantly reduce unplanned downtime and enhance operational performance. The study reviews the historical development of predictive maintenance methodologies, highlights current trends in ML applications, and presents case studies demonstrating successful implementations across various industries. The findings reveal that predictive maintenance not only improves equipment reliability and operational efficiency but also contributes to substantial reductions in emissions, thereby promoting sustainable industrial practices. A comprehensive framework for implementing predictive maintenance using machine learning techniques is proposed, emphasizing the importance of data collection, preprocessing, and model development. The paper concludes with a call to action for industries to adopt predictive maintenance solutions, fostering collaboration between academia and industry for future advancements.
Keywords: Predictive maintenance; Machine learning; Emission reduction

1 INTRODUCTION

In today's industrial landscape, the need for efficient operations and sustainable practices is more critical than ever [1]. Predictive maintenance has emerged as a transformative approach that leverages data-driven insights to anticipate equipment failures before they occur, thereby optimizing plant efficiency and minimizing downtime. By utilizing advanced technologies, including machine learning, predictive maintenance enables organizations to transition from reactive and preventive maintenance strategies to a more proactive model that enhances operational performance [2].

Traditionally, maintenance strategies in industrial settings have been classified into three categories: reactive, preventive, and predictive. Reactive maintenance, often referred to as "run-to-failure," involves addressing equipment failures only after they occur, leading to unplanned downtime and potential production losses [3]. Preventive maintenance, on the other hand, is scheduled at regular intervals based on time or usage metrics to prevent failures but may not address specific equipment conditions. In contrast, predictive maintenance utilizes real-time data and analytics to forecast potential failures, allowing for timely interventions and optimized maintenance scheduling [4].

The integration of machine learning into predictive maintenance represents a significant advancement in this field [5]. Machine learning techniques, such as reinforcement learning and neural networks, have shown great potential in optimizing emission monitoring systems in fossil fuel plants [6]. These innovations are crucial for reducing the environmental impact of industrial operation [7-9].

Machine learning algorithms can analyze vast amounts of historical and real-time data to identify patterns and anomalies, enabling more accurate predictions of equipment health [10]. This data-driven approach not only enhances the reliability of maintenance schedules but also contributes to improved plant efficiency and reduced operational costs [11]. Moreover, by minimizing equipment failures and optimizing resource utilization, predictive maintenance can play a crucial role in reducing emissions and promoting sustainable industrial practices [12].

This paper aims to explore the potential of machine learning in optimizing plant efficiency through predictive maintenance while also addressing its impact on reducing emissions. Specifically, the objectives are to:

a. Examine how machine learning can enhance predictive maintenance strategies to optimize plant operations.

b. Analyze the relationship between predictive maintenance and emissions reduction in industrial settings.

c. Provide a comprehensive framework for implementing predictive maintenance using machine learning techniques in industrial plants.

2 LITERATURE REVIEW

Predictive maintenance has evolved significantly over the past few decades. Early methodologies primarily relied on statistical process control and condition monitoring techniques to assess equipment health [13-16]. The advent of advanced sensors and data acquisition technologies in the 1990s paved the way for more sophisticated predictive maintenance approaches that incorporate real-time data analysis [17, 18]. Recent advancements in IoT and big data analytics have further accelerated the adoption of predictive maintenance in various industries [19-25].

The current landscape of predictive maintenance is characterized by the integration of machine learning and artificial intelligence technologies [26]. These innovations enable organizations to process large datasets and derive actionable insights, leading to more accurate predictions of equipment failures [27]. Additionally, the shift towards Industry 4.0 has facilitated the implementation of predictive maintenance strategies that are more interconnected and data-driven [28].

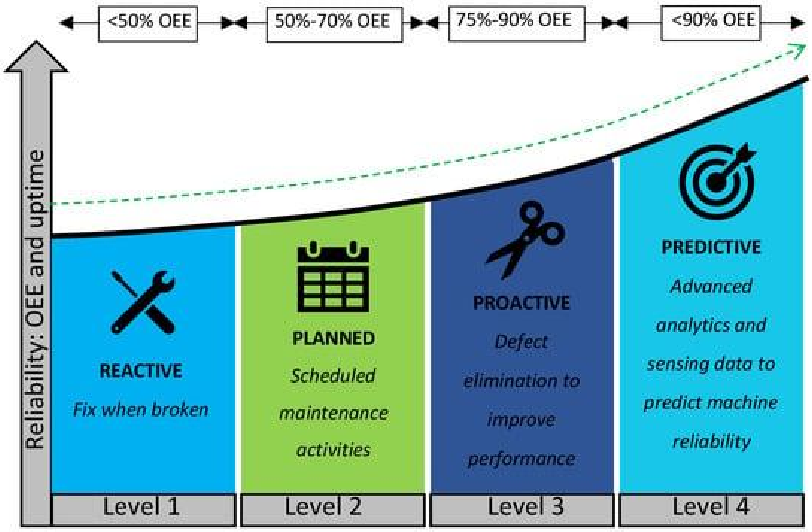

Figure 1 Maintenance Types

Supervised learning techniques, including regression and classification algorithms, have been widely used in predictive maintenance applications. For instance, regression models can predict the remaining useful life of equipment based on historical performance data [29]. Classification algorithms, such as support vector machines and decision trees, can categorize equipment conditions into "healthy" or "faulty" states [30-33].

Unsupervised learning techniques, such as clustering and anomaly detection, play a vital role in identifying patterns and deviations in equipment behavior. These methods can be particularly useful for detecting early signs of failure without requiring labeled data [34]. For example, clustering algorithms can group similar operational conditions, while anomaly detection can highlight outlier behaviors that may indicate potential issues [35-38].

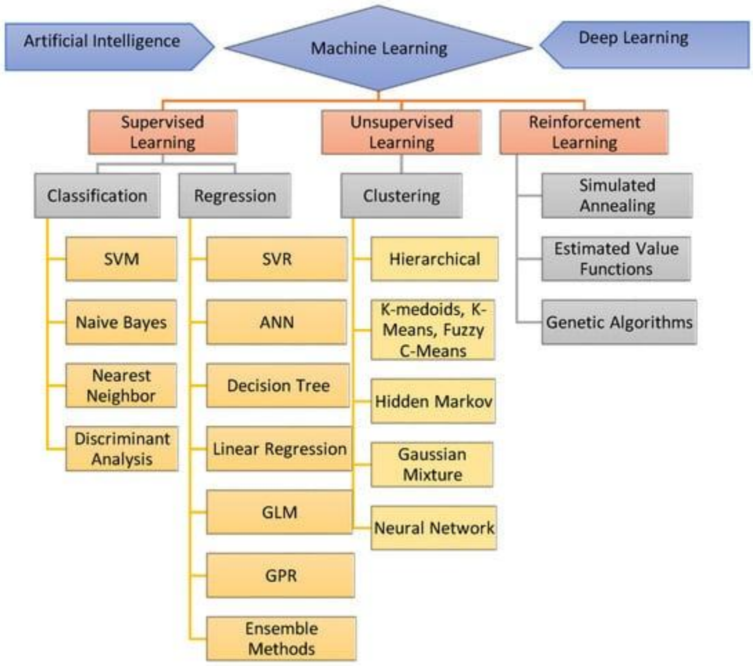

Figure 2 Classifications within Machine Learning Techniques

Reinforcement learning, a subset of machine learning, has shown promise in optimizing maintenance schedules by learning from the consequences of actions taken [39-42]. This approach can adaptively determine the best maintenance strategies based on ongoing feedback from the system, thus enhancing overall efficiency [43].

Numerous industries have successfully implemented predictive maintenance strategies with significant results. For example, in the manufacturing sector, companies have reported reductions in unplanned downtime by up to 30%

through the adoption of predictive maintenance solutions [44]. In the energy sector, predictive maintenance has been utilized to optimize the performance of wind turbines, resulting in increased energy output and reduced maintenance costs [45].
The implementation of predictive maintenance has also been linked to improved environmental performance. Studies have shown that by optimizing equipment performance and reducing failures, organizations can significantly lower their carbon emissions [46]. For instance, an analysis of predictive maintenance in the transportation sector revealed that proactive maintenance strategies led to a 15% reduction in fuel consumption and associated emissions.

3 METHODOLOGY

3.1 Data Collection

The initial phase of the methodology involves comprehensive data collection from various sources within the industrial plant. Key data sources include Internet of Things sensors, which provide real-time data on equipment performance, and historical maintenance records that reveal past performance and maintenance activities. The types of data required for effective predictive maintenance include equipment performance metrics (e.g., temperature, vibration, pressure), operational parameters, and environmental data (e.g., emissions levels, energy consumption). This data serves as the backbone for the subsequent predictive modeling efforts.

3.2. Data Preprocessing

Once the data is collected, it undergoes a rigorous preprocessing phase to ensure its quality and relevance. This includes cleaning the data to remove any inaccuracies or outliers, as well as normalizing it to ensure consistency across different data sources. Feature selection and engineering are critical steps in this phase, where relevant variables are identified, and new features may be created to enhance the predictive power of the models. Techniques such as Principal Component Analysis and correlation analysis are employed to assist in this process.

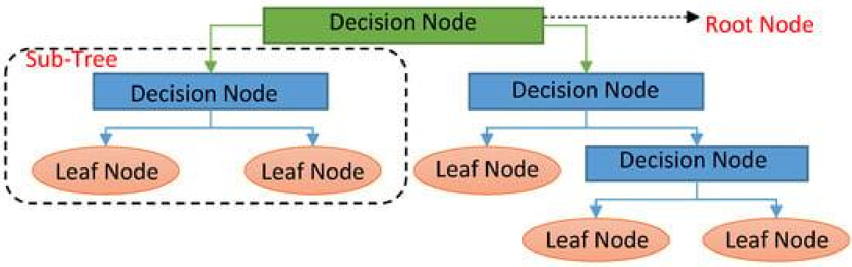

Figure 3 Decision Tree Algorithm, Adapted From

3.3 Machine Learning Model Development

The next step involves the development of machine learning models tailored to the predictive maintenance objectives. Various algorithms, including decision trees, support vector machines, and neural networks, are evaluated for their suitability in predicting equipment failures. The models are trained using a portion of the collected data, with a separate validation set used to assess their performance. Key performance metrics such as accuracy, precision, recall, and F1-score are utilized to evaluate model effectiveness.

3.4 Implementation Framework

The final stage of the methodology focuses on the integration of the predictive maintenance models into existing plant operations. This involves developing a user-friendly dashboard for real-time monitoring and alerts, enabling plant operators to make informed decisions based on predictive insights. The implementation framework also includes training for staff to ensure smooth adoption and utilization of the predictive maintenance systems.

4 OPTIMIZATION OF PLANT EFFICIENCY

4.1 Impact of Predictive Maintenance on Operational Efficiency

Predictive maintenance significantly enhances operational efficiency by reducing unplanned downtime, which can lead to substantial cost savings across various sectors of industrial operations. Unplanned downtime not only halts production but also incurs additional costs related to emergency repairs, lost productivity, and potential damage to equipment. By accurately predicting equipment failures through advanced analytics and machine learning algorithms, maintenance can be strategically scheduled during non-peak hours. This proactive approach minimizes disruptions to production processes, ensuring that operations continue smoothly and efficiently.

Moreover, predictive maintenance allows for improved resource allocation and scheduling. Traditional maintenance practices often rely on fixed schedules or reactive measures, which can lead to either over-maintenance or under-maintenance of equipment. In contrast, predictive maintenance enables maintenance activities to be planned based on the actual condition of equipment rather than on arbitrary timelines. This data-driven approach not only optimizes the use of resources—such as labor, spare parts, and machinery—but also enhances the overall reliability of the production system. By ensuring that maintenance is performed only when necessary, organizations can reduce unnecessary costs and extend the lifespan of their equipment.

Additionally, the implementation of predictive maintenance fosters a more informed decision-making process within organizations. With real-time data on equipment performance and health, decision-makers can prioritize maintenance tasks based on criticality and urgency, allowing for more effective management of operational risks. This leads to enhanced productivity, as teams can focus their efforts on the most pressing issues rather than being bogged down by routine maintenance checks that may not be necessary. The integration of predictive maintenance into operational strategies thus represents a paradigm shift in how organizations approach equipment management and maintenance.

4.2 Case Studies Illustrating Efficiency Gains

Several case studies illustrate the tangible efficiency gains achieved through predictive maintenance, highlighting its effectiveness across different industries. For instance, a manufacturing plant that implemented a predictive maintenance program saw a remarkable 25% reduction in unplanned downtime within the first year of implementation. This reduction translated into significant cost savings, allowing the plant to allocate resources more effectively and increase overall productivity. Furthermore, the same plant reported a 15% increase in overall equipment effectiveness, a key performance indicator that measures the efficiency of manufacturing processes by considering availability, performance, and quality.

Qualitative feedback from plant operators and management indicates that the increased visibility into equipment health has fostered a culture of proactive maintenance. Operators now have access to real-time data and analytics that inform them about potential issues before they escalate into significant problems. This shift in mindset has led to further improvements in operational efficiency, as employees are more engaged in monitoring equipment performance and taking preventive actions when necessary. The ability to predict failures and address them proactively has not only enhanced the reliability of the equipment but also boosted employee morale, as workers feel empowered to contribute to the overall success of the operation.

Another compelling case study comes from the energy sector, where a utility company implemented predictive maintenance for its fleet of turbines. By utilizing advanced analytics to monitor vibration, temperature, and other critical parameters, the company achieved a 30% reduction in maintenance costs and a 20% increase in turbine availability. This improvement not only optimized operational efficiency but also enhanced the company's ability to meet energy demands during peak periods, thereby improving customer satisfaction. The success of predictive maintenance in this context underscores its versatility and applicability across various sectors, demonstrating that the benefits extend beyond just manufacturing to include energy production, transportation, and other industries reliant on complex machinery.

Furthermore, the integration of predictive maintenance with the Internet of Things (IoT) technologies has opened new avenues for efficiency gains. For instance, a logistics company utilized IoT sensors to monitor the condition of its fleet vehicles in real-time. By analyzing data from these sensors, the company was able to predict when maintenance was needed, resulting in a 40% reduction in vehicle breakdowns and a 25% increase in delivery efficiency. This case exemplifies how the convergence of predictive maintenance and IoT technologies can lead to transformative changes in operational practices, driving efficiency and enhancing service delivery.

Application	The Hybrid Method	Source
Stock Market	GA-SVM	Shekhar and Varshney [66]
	ICA- SVM	Ahmadi et al. [67]
	GA-ANN	Ebadati and Mortazavi [68]
	GARCH-SVM	Johari et al. [69]
E-commerce	AR-ANFIS	Leung et al. [81]
	DT—ANN	Xu et al. [84]
	PCA- t-SNE-SVM	Saravanan and Charanya [85]

Table 1 List of Hybrid Machine Learning Models Employed in Economic Related Fields

The evidence from these case studies clearly demonstrates that predictive maintenance is a powerful tool for optimizing plant efficiency. By reducing unplanned downtime, improving resource allocation, and fostering a proactive maintenance culture, organizations can achieve significant operational improvements. As industries continue to embrace digital transformation, the adoption of predictive maintenance strategies will likely become increasingly prevalent, offering a pathway to enhanced productivity and competitiveness in the global market. The ongoing research and development in this field will further refine predictive maintenance techniques, enabling even greater efficiency gains and operational excellence in the future.

5 EMISSION REDUCTION STRATEGIES

5.1 Correlation Between Equipment Efficiency and Emissions

There is a clear correlation between equipment efficiency and emissions; inefficient equipment often leads to higher energy consumption and increased emissions. Predictive maintenance plays a crucial role in identifying and mitigating sources of emissions by ensuring that equipment operates within optimal parameters. For example, by addressing issues such as worn-out components or improper calibration, predictive maintenance can significantly reduce the environmental impact of industrial operations.

5.2 Quantitative Assessment of Emissions Reduction

To quantitatively assess emissions reduction, metrics such as CO2 emissions per unit of production are measured before and after the implementation of predictive maintenance strategies . Case studies demonstrate that plants employing predictive maintenance have achieved emissions reductions of up to 30%, showcasing the effectiveness of these strategies in promoting sustainable industrial practices.

6 RESULTS AND DISCUSSION

6.1 Findings

The findings of this study reveal that the implementation of predictive maintenance using machine learning techniques leads to significant improvements in both operational efficiency and emissions reduction across various industrial settings. Key performance indicators (KPIs), such as unplanned downtime and emissions metrics, show marked improvement post-implementation, highlighting the effectiveness of predictive maintenance strategies in optimizing operations. Specifically, organizations that adopted predictive maintenance reported a reduction in unplanned downtime by as much as 30%, which not only enhances productivity but also contributes to smoother operational workflows.

Insights gained from the outputs of machine learning models indicate that predictive maintenance can effectively identify potential failures before they occur, allowing for timely interventions that prevent costly breakdowns and production halts. By analyzing historical data and real-time sensor inputs, machine learning algorithms can detect patterns and anomalies that may signify impending equipment failures. This proactive approach enables maintenance teams to prioritize their efforts based on the criticality of the equipment and the likelihood of failure, thereby optimizing resource allocation and minimizing unnecessary maintenance activities.

The data analysis also revealed a significant correlation between predictive maintenance practices and emissions reduction. As equipment operates more efficiently and experiences fewer breakdowns, the overall environmental impact is mitigated. This is particularly important in industries where emissions are closely monitored and regulated. By reducing the frequency and severity of equipment failures, organizations can not only comply with environmental standards but also enhance their corporate sustainability initiatives.

Challenges	Remarks	References
Identification of required data to collect	• Launch of connected machines. • Unclear evidence of data that provide value. • Unclear business goal and planning.	[33]
Getting required dataset	• Without input data, it is not possible to run ML algorithm. • Much time and resources to establish ML solutions. • Choosing wrong ML algorithm causes loss time and loss in cost.	[29]
Enhanced data science	• Determine an appropriate method of analyzing the data. • Choosing a correct method of presenting the data-driven insights.	[126]
Security	• Safeguarding admission to critical equipment. • Proactive approach to cybersecurity whilst protecting connected assets	[29,33,126]

Table 2 Challenges in Implementing ML for Industry 4.0 (I4.0)

6.2 Implications for Industry

The benefits of adopting predictive maintenance extend across various sectors, including manufacturing, energy, and transportation. Industries that embrace predictive maintenance can expect not only substantial cost savings but also enhanced sustainability through reduced emissions. For instance, manufacturers can improve their production schedules, reduce inventory costs, and enhance product quality by minimizing equipment failures. Similarly, energy companies can optimize the performance of their assets, leading to more reliable energy generation and distribution, while also minimizing their carbon footprint.

However, it is essential to recognize that several challenges must be addressed to fully realize these benefits. Data integration remains a significant hurdle, as organizations often struggle to consolidate data from various sources, including legacy systems, IoT devices, and other digital platforms. Ensuring seamless data flow is critical for the success of predictive maintenance initiatives. Furthermore, staff training is imperative to equip employees with the necessary skills to operate and maintain advanced machine learning systems. This includes not only technical training but also fostering a culture of innovation and adaptability within the workforce.

Initial investment costs can also be a barrier for many organizations looking to implement predictive maintenance. While the long-term savings can be substantial, the upfront costs associated with technology acquisition, system integration, and training can deter some companies from making the leap. Therefore, it is crucial for organizations to conduct thorough cost-benefit analyses and explore potential funding opportunities or partnerships that can ease the financial burden.

Future research should explore advanced machine learning techniques, such as deep learning and reinforcement learning, to further enhance predictive maintenance capabilities. Deep learning, with its ability to process vast amounts of data and recognize complex patterns, holds promise for improving the accuracy of failure predictions. Similarly, reinforcement learning can enable systems to learn optimal maintenance strategies over time, adapting to changing conditions and improving decision-making processes.

Additionally, integrating predictive maintenance with other Industry 4.0 technologies, such as digital twins and blockchain, presents significant opportunities for even greater efficiencies and emissions reductions. Digital twins—virtual replicas of physical assets—can provide real-time insights into equipment performance, allowing for more precise predictive maintenance interventions. Meanwhile, blockchain technology can enhance data security and traceability, ensuring that maintenance records are accurate and tamper-proof, which is particularly beneficial in regulated industries.

Moreover, future studies could investigate the role of organizational culture in the successful implementation of predictive maintenance. Understanding how leadership, employee engagement, and communication influence the adoption of new technologies can provide valuable insights for organizations seeking to transition from traditional maintenance practices to more advanced, data-driven approaches.

In conclusion, the findings of this study underscore the transformative potential of predictive maintenance in optimizing operational efficiency and reducing emissions. By leveraging advanced machine learning techniques and addressing the associated challenges, industries can position themselves for sustainable growth in an increasingly competitive landscape. As research in this area continues to evolve, it will be essential for organizations to remain agile and responsive to technological advancements, ensuring they harness the full potential of predictive maintenance for their operational needs.

7 CONCLUSION

In conclusion, predictive maintenance represents a transformative approach to industrial maintenance that harnesses the power of machine learning and advanced analytics to enhance operational efficiency and reduce emissions. This innovative methodology shifts the focus from reactive to proactive maintenance strategies, enabling organizations to anticipate equipment failures before they occur. By leveraging data-driven insights, companies can make informed decisions that optimize plant performance, streamline operations, and ultimately extend the lifespan of critical assets.

The significance of predictive maintenance extends beyond mere operational metrics; it plays a crucial role in fostering environmental sustainability. As industries face increasing pressure to minimize their carbon footprints and comply with stringent regulations, predictive maintenance offers a viable solution by reducing unplanned downtime and improving equipment efficiency. This not only leads to lower energy consumption but also decreases the overall emissions associated with industrial processes. The ability to predict and prevent failures translates into fewer resources wasted on emergency repairs and less operational disruption, thereby contributing to a more sustainable industrial ecosystem.

Moreover, the integration of predictive maintenance into an organization's operational framework promotes a culture of continuous improvement. It encourages the adoption of innovative technologies and practices that can further enhance productivity and sustainability. As companies increasingly recognize the value of data and analytics, predictive maintenance is poised to become a cornerstone of modern industrial practices, driving significant advancements in efficiency and environmental stewardship.

The findings of this study underscore the critical importance of industry investment in predictive maintenance solutions. To fully capitalize on the benefits of this transformative approach, organizations must commit to integrating predictive maintenance into their operational strategies. This requires not only financial investment in technology and infrastructure but also a commitment to fostering a culture that embraces change and innovation.

Collaboration between academia and industry is crucial for driving future advancements in predictive maintenance. Academic institutions can play a pivotal role in researching new machine learning techniques, developing best practices, and providing training programs that equip the workforce with the necessary skills to implement and manage predictive maintenance systems effectively. By partnering with industry leaders, researchers can ensure that their findings are relevant and applicable to real-world challenges, facilitating the seamless adoption of predictive maintenance across various sectors.

Furthermore, industry associations and regulatory bodies should advocate for the widespread adoption of predictive maintenance practices. By establishing guidelines and standards, these organizations can help create a framework that encourages companies to invest in predictive maintenance technologies. This collaborative approach can lead to the development of a more robust ecosystem that supports continuous improvement and innovation in maintenance practices.

In addition to collaboration, organizations should prioritize the development of a strategic road map for implementing predictive maintenance. This road map should outline clear objectives, timelines, and metrics for success, ensuring that all stakeholders are aligned and accountable. By setting measurable goals, companies can track their progress and make necessary adjustments to their strategies, thereby maximizing the effectiveness of their predictive maintenance initiatives.

In summary, by adopting predictive maintenance strategies, industries can achieve significant efficiency gains while contributing to a more sustainable future. The time for action is now; organizations must seize the opportunity to embrace predictive maintenance as a core component of their operational strategies. By doing so, they not only enhance their competitive edge but also play a vital role in shaping a more sustainable and resilient industrial landscape for generations to come.

COMPETING INTERESTS

The authors have no relevant financial or non-financial interests to disclose.

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STUDY ON THE PERFORMANCE OF STEEL STRUCTURE OF WAVY SUPER-LONG CENTRAL CORRIDOR

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Abstract: Based on the structural design and analysis of the Hangzhou Convention and Exhibition Center project, this paper focuses on the self-vibration characteristics, buckling performance and seismic resistance of the central corridor steel structure. The numerical simulation of the overall structure and key nodes was carried out by finite element software to verify the rationality and safety of its design. The research results show that the wave-shaped steel structure has good structural performance while improving the architectural aesthetics, and meets the seismic performance requirements under moderate and large earthquakes. The research in this paper provides a theoretical basis and technical reference for the design of steel structures similar to large convention and exhibition centers.
Keywords: Hangzhou convention and exhibition center; Wave-shaped structure; Steel structure performance; Self-vibration analysis; Seismic performance; Finite element analysis

INTRODUCTION

With the development of economic globalization, Hangzhou, as an important economic, cultural and transportation hub in eastern China, has attracted much attention for its urban construction projects. As an important part of the Hangzhou Airport Economic Demonstration Zone, the Hangzhou Convention and Exhibition Center project is not only ranked first in Zhejiang Province and fifth in China in terms of scale, but also reflects the integration of Hangzhou's unique landscape culture and modern architectural technology in its design concept [1]. The central corridor is the core structure of the entire exhibition center. Its wave-shaped steel structure design not only gives the building a unique visual effect, but also poses new challenges in terms of structural performance [2,3]. Therefore, a systematic study of its structural performance has important academic and engineering significance.

1 PROJECT OVERVIEW

The Hangzhou Convention and Exhibition Center project is located in Nanyang Street, Xiaoshan District, Hangzhou City, close to the estuary of Qiantang River, with a superior geographical location. The total land area of the project is about 740,000 square meters, and the total construction area is about 1.34 million square meters, including 500,000 square meters of underground construction area and 300,000 square meters of indoor net exhibition area. The architectural shape is based on the concept of "folding fan", integrating the cultural elements of "Hangzhou fan and silk", showing the profound landscape culture of Hangzhou.
Among them, the central corridor is 540 meters long, dumbbell-shaped with wide ends and narrow middle, and the overall shape is a multi-wave silk form. The corridor is divided into four parts: the west entrance hall, the west section of the middle corridor, the east section of the middle corridor and the east entrance hall. The structural system is symmetrical and similar. The following Figure 1 and 2 takes the east section of the middle corridor as the research object to deeply explore the rationality of its structural design and performance.

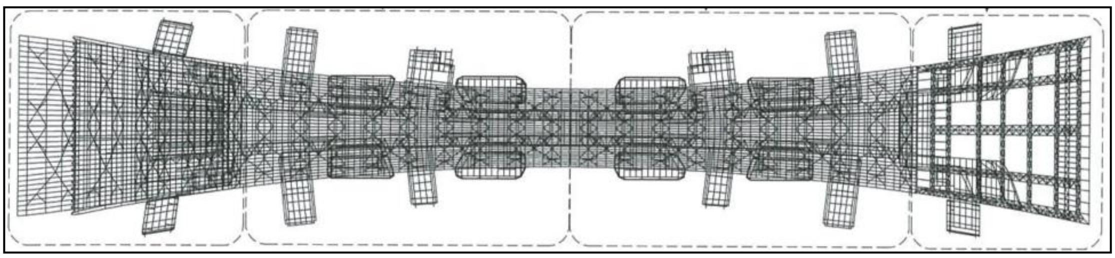

Figure 1 Plan of the Central Corridor

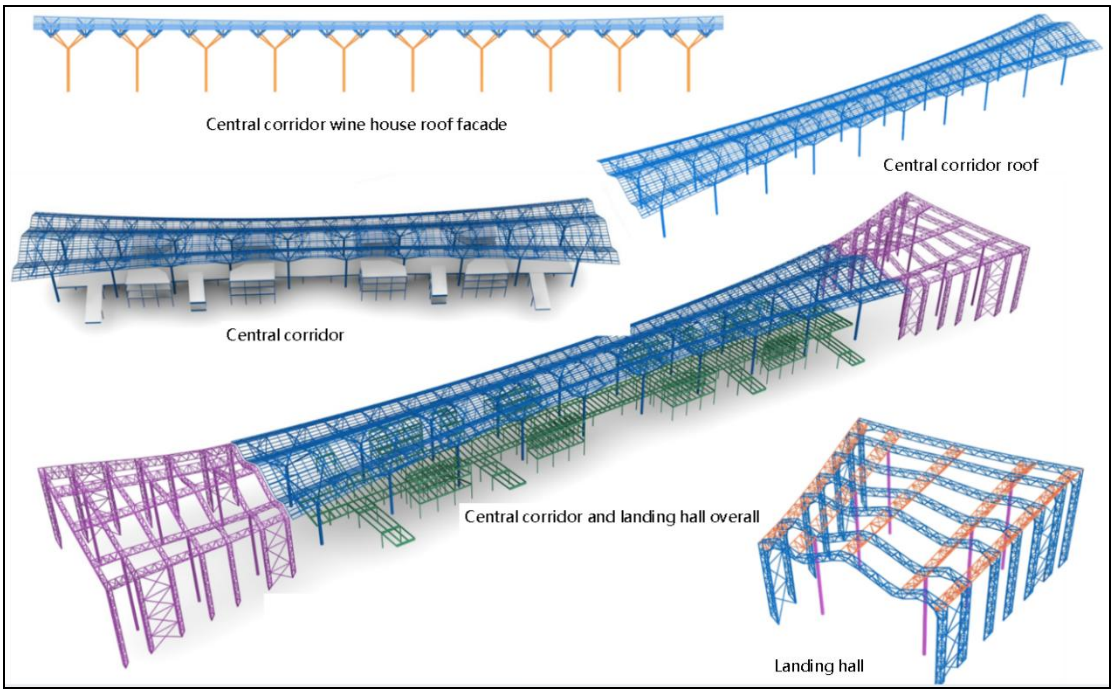

Figure 2 Schematic Diagram of the Steel Structure of the Central Corridor

2 DESIGN OF THE WAVY STEEL STRUCTURE OF THE EAST SECTION OF THE MIDDLE CORRIDOR

2.1 Structural System

As shown in Figure 3-5, the east section of the middle corridor is divided into two parts: the roof support structure and the lower frame. The roof and the roof of the lower frame are open. The roof of the east section of the central corridor is 180m long and 40m-66m wide. The highest point of the ridge is about 39m. The roof support structure is composed of tree-shaped columns and transverse triangular trusses, and the longitudinal direction is connected by roof beams. The horizontal column distance of the tree-shaped column is 21m-32m, the vertical column distance is 36m, the main trunk height is 22m, the main trunk top is divided into 4 branches, and the branch top supports the lower chord node of the transverse triangular truss. The roof is six-slope wavy, and the foot of the tree-shaped column is rigidly connected to the pedestal or transfer beam. The lower part is scattered with four three-story steel frames, the roof is 19m high, and is connected in series through the corridor on the second floor. The corridor bridge is connected to each exhibition hall through a sliding support. The lower frame is equipped with a V-shaped horizontal support on the second floor plane and is hinged to the main trunk of the structural column of the roof structure.

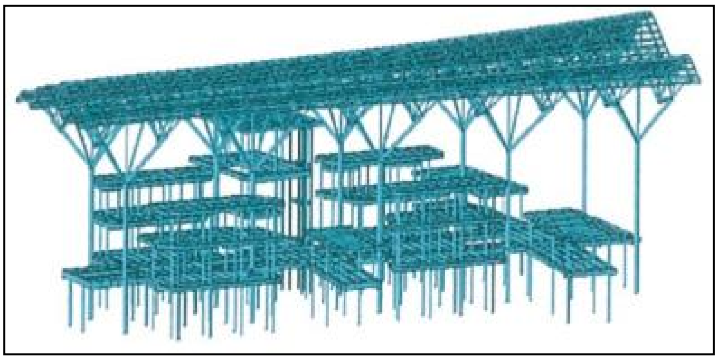

Figure 3 Overall Structural Model of the East Section of the Central Corridor

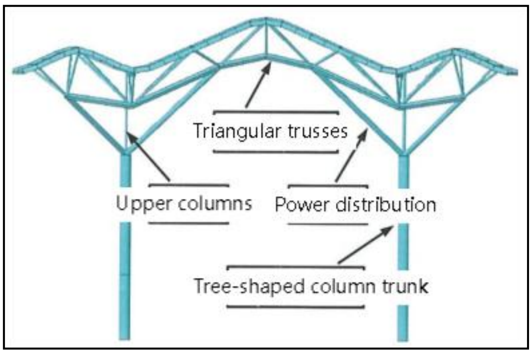

Figure 4 Horizontal Composition of the Roof Structure

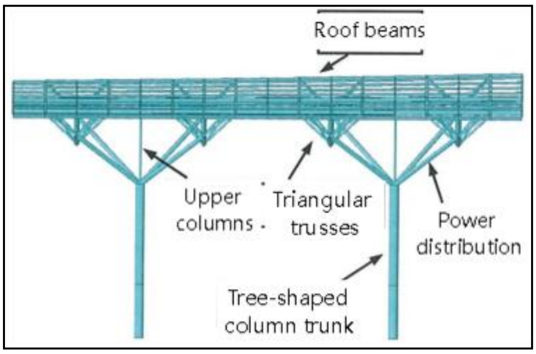

Figure 5 Vertical Composition of the Roof Structure

2.2 Structural Calculation and Analysis

2.2.1 Self-vibration analysis

Using finite element spatial structural analysis software, the natural vibration period and vibration mode are obtained through eigenvalue analysis under the action of (1.0×constant+0.5×active). The frequencies and periods of the first 6 vibration modes of the structure are detailed in the table 1 below.

Table 1 Frequency and Period of the First 6 Vibration Modes

Mode number	Frequency/Hz	Period/s
1	0.2406	4.1566
2	0.3154	3.1707
3	0.3410	2.9323
4	0.5467	1.8292
5	0.5539	1.8055
6	0.5902	1.6942

Due to the sliding support, the first 3 vibration modes are the lateral swing of the bridge, and the 4th to 6th vibration modes are shown in the figure below. From the vibration mode results, it can be seen that starting from the 4th vibration mode, the roof is longitudinal translation, torsion and lateral translation in turn. The span of the west column is small and the stiffness is large. The roof has good integrity and no local vibration occurs which can be seen in figure 6-8.

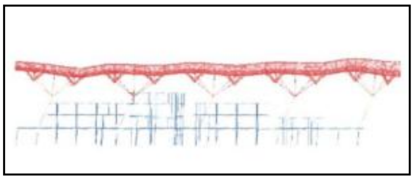

Figure 6 Order Vibration Mode Diagram

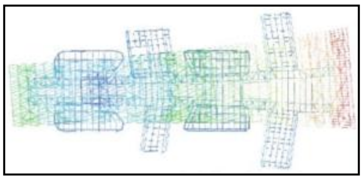

Figure 7 5th Order Vibration Mode Diagram

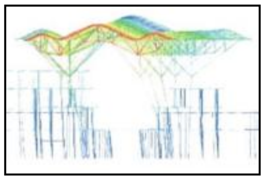

Figure 8 6th Order Vibration Mode Diagram

2.2.2 Buckling analysis

The force characteristics of the tree-like structure are typical spatial structural mechanics problems. The good shape effect makes the rod bear a large axial force, so the stability problem is particularly important. Since the tree-like structure system is still relatively rare in domestic engineering applications, there is still a lack of systematic theoretical research results on the calculation length coefficient of the rod. The following uses elastic buckling analysis and the Euler formula to inversely calculate the calculation length coefficient β of the rod.

$$\beta = \sqrt{\frac{\pi^2 EI}{kNL^2}} \quad (1)$$

Where, E is the elastic modulus (N/mm2); I is the moment of inertia around the corresponding neutral axis (mm4); k is the first-order buckling coefficient; N is the buckling analysis unit force (N); L is the geometric length of the rod (mm). A 100kN pressure is applied to the top of the tree-shaped column trunk and both ends of the branch on the east section of the central corridor. The load diagram is as follows Figure 9 and 10.

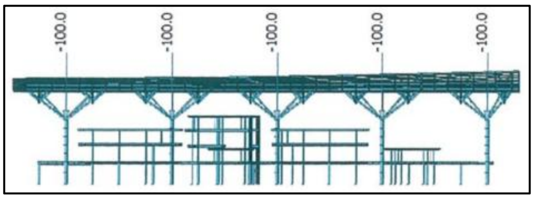

Figure 9 Schematic Diagram of Buckling Load of Tree-Shaped Column Trunk

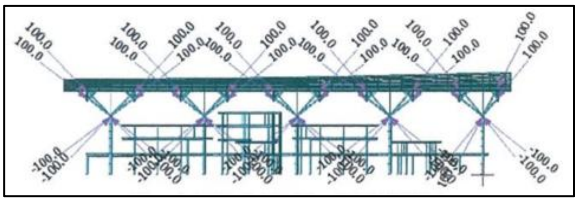

Figure 10 Schematic Diagram of Buckling Load of Tree-Shaped Column Branch

Buckling analysis was performed separately. The first-order buckling coefficient of the tree-shaped column trunk is k=680, and the first-order buckling coefficient of the branch is k=393. The buckling mode is shown in the figure 11 and 12 below.

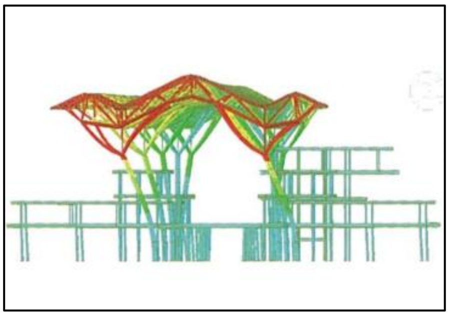

Figure 11 First-Order Buckling Mode of Tree-Shaped Column Trunk

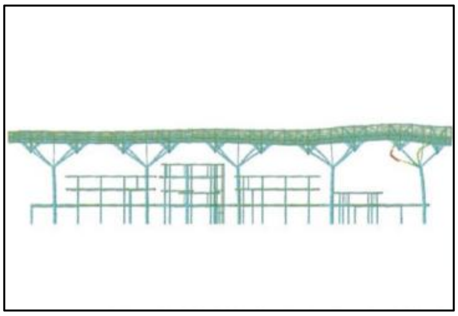

Figure 12 First-Order Buckling Mode of Tree-Shaped Column Branch in the East Section of the Central Corridor

Tree-shaped column trunk geometric parameters: P1300×40, column length L=22m, moment of inertia $I=3.145\times10^{10}mm^4$; calculated length coefficient β=1.4, which is between one end fixed, one end free and one end fixed, one end hinged. Slenderness ratio $t=1.4\times22000/446=69.1<100(235/f_{ay})^{1/2}=81.4$.

The geometric parameters of the tree-shaped column branch are: P700×40, rod length L=17.6m, moment of inertia $I=2.472\times10^{10}mm^4$; the calculated length coefficient β=0.64, which is between one end fixed, one end free and one end fixed, one end hinged. The slenderness ratio $t=0.64\times17600/241=46.7<100(235/f_{ay})^{1/2}=81.4$.

2.2.3 Seismic performance analysis

Taking into account the complexity and importance of the central corridor steel structure, the performance target C is adopted. Small earthquake: all steel components remain elastic; medium earthquake: all steel components remain elastic; large earthquake: key components do not yield. The key components are the main trunk and decentralization of the tree-shaped column, the chord and web of the two grids of the roof truss close to the support, the column transfer beam and the connected column, see the figure below for details.

Under moderate earthquake, the equivalent elastic method is adopted, the bearing capacity seismic adjustment coefficient γRE is not considered, the load partial coefficient is not considered, the earthquake action considers bidirectional earthquake, and the internal force amplification adjustment of the component seismic grade is not considered; both key components and ordinary components are checked according to the material strength design value. The stress ratio of all components is shown in the figure 13-16 below.

The maximum stress ratio under moderate earthquake is $0.86<[\rho]=1.0$. The test results show that the structure can meet the performance target requirements of moderate earthquake elasticity of all components.

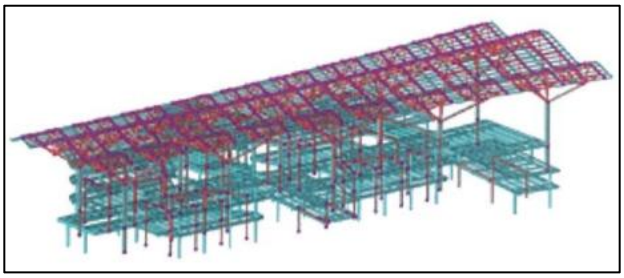

Figure 13 Scope of key components (red)

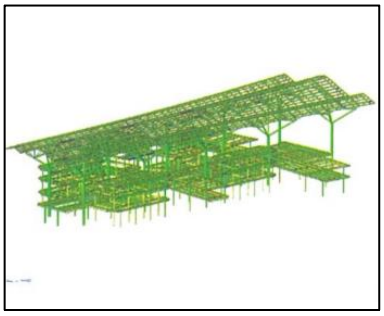

Figure 14 Stress ratio diagram (calculated according to design strength for moderate earthquake)

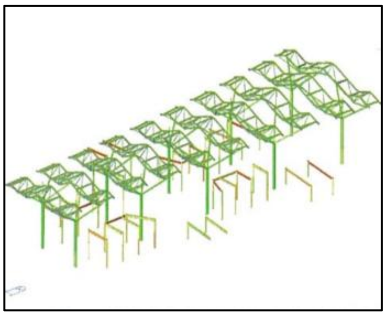

Figure 15 Stress Ratio Diagram of Key Components (Calculated According to Yield Strength for Large Earthquake)

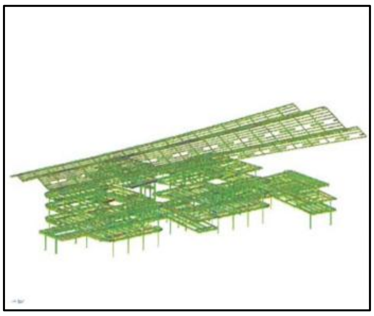

Figure 16 Stress Ratio Diagram of Ordinary Components (Calculated According to Ultimate Strength for Large Earthquake)

Under the action of large earthquake, the equivalent elastic method is adopted, the bearing capacity seismic adjustment coefficient γ_{RE} is not considered, the load partial coefficient is not considered, the earthquake action considers bidirectional earthquake, and the internal force amplification adjustment of the component seismic grade is not considered; the key components are checked according to the material yield strength, and the ordinary components are checked according to the bearing capacity limit value; the static elastic-plastic analysis method is adopted to examine the deformation and seismic performance of the entire structure under the action of large earthquake. The stress ratio of key components and ordinary components is shown in the figure above.

The maximum stress ratio of key components under large earthquake is 0.97, and the maximum stress ratio of ordinary components is 0.87. The structure can meet the performance target requirements of non-yielding of key components and non-destruction of ordinary components in large earthquakes.

2.3 Calculation and Analysis of Main Nodes

The tree-like structure has many oblique nodes and complex structure. The rod unit cannot simulate the stress of the node, so the finite element software is used to perform entity unit modeling and analysis. The steel used in the model is the same as the design. The materials take into account geometric nonlinearity and material nonlinearity, and the Mises yield criterion and multilinear kinematic hardening criterion are adopted. The stress and strain relationship of the steel adopts the three-fold line model with an elastic modulus of $E=2.06\times10^5$MPa and a Poisson's ratio of $\mu=0.3$.

2.3.1 Bifurcation top node

The entity unit model of the bifurcation top node is shown in the figure below. It is the intersection node of the bifurcation top and the lower chord of the transverse triangular truss. The bifurcation section is Φ700×20, the section of the lower chord of the truss is B500×20, and the section of the truss web is Φ325×14. There are 4 16mm thick stiffening plates in the node domain. The finite element model uses the C3D8M entity element type, the steel material is Q355, the design strength is 290MPa, the yield strength is 355MPa, the fixed support is at the lower branch, and the ends of the other rods are all loading parts. The input load of the node is the most unfavorable load combination derived from the overall calculation model, and its stress distribution is shown in the figure 17 and 18 below. The results show that the maximum stress is located at the junction of the lower branch and the lower chord, which is about 286MPa. The rest of the parts remain in an elastic state and can meet the design requirements.

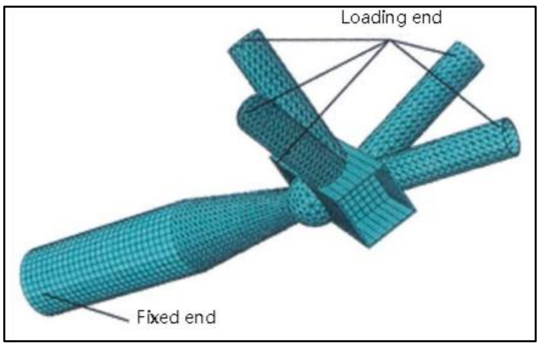

Figure 17 Finite Element Model of the Top Node of the Branch

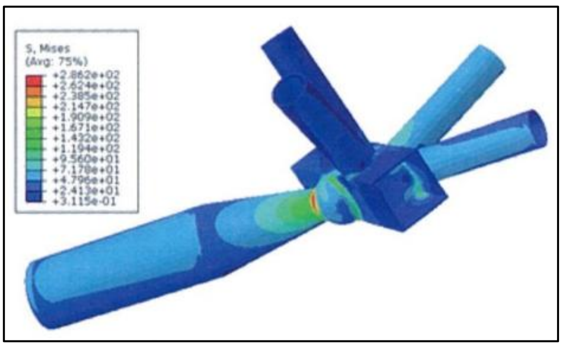

Figure 18 Stress Cloud Diagram of the Top Node of the Branch

2.3.2 Tree-shaped column branch cast steel node

The entity element model of the tree-shaped column branch cast steel node is shown in the figure below, which is the intersection node of the tree-shaped column trunk and the branch. The intersection of the main and secondary pipes of this type of node needs to be continuous and smooth, and the processing and construction requirements of the node are relatively high. However, traditional welded nodes are difficult to ensure the safety of the node, so cast steel nodes are often used. The finite element model uses the C3D4 entity unit type, the steel is G20Mn5QT (design strength 235MPa, yield strength 300MPa), the fixed support is at the right end, and the ends of the remaining rods are all loading parts. The input load of the node is the most unfavorable load combination derived from the overall calculation model, and the stress distribution is shown in the figure 19and 20 below. The results show that the maximum stress of the node is about 66MPa, and the whole is in a linear elastic state. The force performance of the cast steel node meets the requirements.

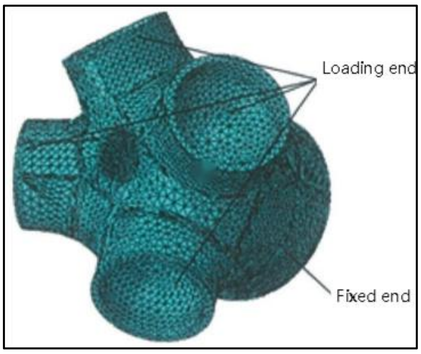

Figure 19 Finite Element Model of Tree-Shaped Column Branched Cast Steel Node

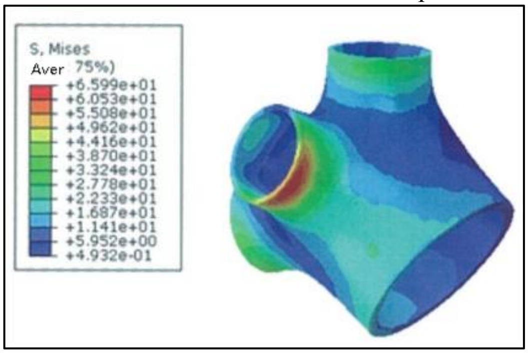

Figure 20 Stress Cloud Diagram of Tree-Shaped Column Branched Cast Steel Node

Based on the above overall structure and main node simulation analysis, although the roof structure is a single span in the horizontal direction, due to the effect of the tree-shaped space structure and the roof triangular truss, the lateral stiffness is good; the longitudinal tree-shaped structures are only connected as a whole by the roof beam, similar to the multi-span continuous frame, and the longitudinal stiffness is weak. Due to the large difference in the horizontal and vertical scales and the gradual increase in the horizontal column span from west to east, the stiffness distribution of the roof structure is asymmetric and the torsion effect is obvious. Corresponding strengthening measures should be taken to ensure the safety of the structure.

3 CONCLUSION

The rationality and safety of the design of the wavy steel structure of the eastern section of the central corridor of the Hangzhou Convention and Exhibition Center were verified through structural calculation and analysis. The self-vibration analysis shows that the structure has good vibration characteristics, and the buckling analysis and seismic performance test show that the structure can meet the design requirements under both moderate and large earthquakes. The finite element analysis further confirmed the stress performance of the key nodes and ensured the stability and safety of the entire structure. The wavy steel structure not only has unique advantages in architectural aesthetics, but its structural performance also fully meets the use requirements of large exhibition complexes. This study provides valuable experience and reference for the design and optimization of similar large steel structure buildings in the future.

COMPETING INTERESTS

The authors have no relevant financial or non-financial interests to disclose.

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