Research on Technical supervision of Steam turbine in nuclear power plant

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Abstract. Based on the technical characteristics of nuclear power turbine, the technical differences between nuclear power turbine and thermal power turbine are analyzed. Based on the premise of nuclear safety and combined with the characteristics of nuclear power plants, the feasible supervision mechanism of conventional island turbine and the daily management responsibilities of nuclear power supervision are studied. Extensive research and collection of nuclear power related data, including technical specifications, operation procedures, maintenance procedures, etc., through the analysis and collation of these data, the technical supervision content of nuclear power conventional island turbine is studied, highlighting the differences with thermal power turbine technical supervision.

Keywords: Nuclear power turbine; technical supervision; nuclear safety.

1. Introduction

In recent years, with the proposal of the dual-carbon goal, nuclear power, as a kind of clean energy and can meet the dual-carbon requirements, has attracted more and more attention, and domestic nuclear power has ushered in a period of rapid development. Nuclear power, in essence, belongs to the power industry, and should carry out technical supervision according to the traditional management mode of the power industry[1]. Technical supervision has made a great contribution to the safe operation of power grid and unit, and has become a common and always existing supervision and management method in the electric power industry. Another attribute of nuclear power is that it is nuclear-related and has a bearing on public safety, so special emphasis is placed on nuclear safety[2]. For nuclear safety, there is already a complete and independent supervision system, but the main focus of nuclear safety supervision is on the safety equipment on the nuclear island, and less attention is paid to the supervision of the system and equipment on the conventional island, such as the turbine body, auxiliary equipment, generators and so on. Generally speaking, the current domestic nuclear power plants have been able to basically meet the requirements of the technical supervision of the power industry from the technical point of view, but the lack of the construction of the technical supervision system of the power industry[3].

At present, some steam turbine technical supervision work has been carried out on the conventional island of nuclear power plants in China. However, due to the technical supervision standards that can be directly referred to in the implementation process, relatively complete technical supervision system standards of thermal power generation industry can only be referred to in large numbers[4-5]. Since the operation parameters of conventional nuclear power island are lower than that of thermal power generation, the system, equipment and structure of conventional nuclear power island are also different from that of thermal power generation, so the technical standards of thermal power generation often do not meet the technical supervision requirements of conventional nuclear power island. In terms of the supervision of the conventional island of nuclear power, if a set of conforming supervision system of electric power technology can be established according to the characteristics of nuclear power technology, it will be a supplement to the existing nuclear safety supervision, which is both necessary and feasible from the technical and implementation levels. Therefore, it is a very necessary task to study the technical supervision mechanism and supervision content of conventional island turbine in nuclear power plant.

Foreign institutions related to nuclear power operation generally focus on technical management, such as the International Atomic Energy Agency, the World Nuclear Operators Association, the Owners' Federation, the United States Nuclear Power Operation Institute and many other well-known foreign organizations have issued a series of standard guidelines in terms of technical management practices, and in terms of system and equipment supervision. Such as performance test, design and manufacturing, nuclear island core, equipment maintenance, medium - and long-term projects and other aspects of the formation of a relatively perfect technical

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management system[6]. The form of foreign nuclear power technology management is mainly implemented through technical support, its core point is to support the safe operation of the unit, it is directly supervised health condition; Performance testing is the direct monitoring of the availability of the plant's systems and equipment; Medium - and long-term project supervision is used to solve the major problems existing in the unit[7].

The main implementation unit of technical supervision of domestic nuclear power plants is the Institute of Electrical Science under each nuclear island group, which is responsible for technical service and technical supervision at the same time. It has a good knowledge of its nuclear power plants, so it is relatively easy to carry out the work. However, it should be realized that there are few researches on the technical supervision of nuclear power in China. At present, domestic nuclear power plants can basically meet the requirements of technical supervision of the electric power industry from the technical point of view, but there is a lack of construction of technical supervision system of the electric power industry. At present, some steam turbine technical supervision work has been carried out on the conventional island of nuclear power plants in China. However, due to the technical supervision standards that can be directly referred to in the implementation process, relatively complete technical supervision system standards of thermal power generation industry can only be referred to in large numbers[8].

2. Technical characteristics of steam turbine in nuclear power plant

2.1 Low main steam parameters

Common nuclear power reactors include pressurized water reactor, boiling water reactor, heavy water reactor and air-cooled reactor, etc. The main steam pressure of conventional island turbine is generally saturated steam or slightly superheated steam, and the pressure is generally between 5 and 7MPa[9]. The steam of the steam turbine in the boiling water reactor nuclear power plant is in contact with the nuclear reactor, while the steam working medium of other types of steam turbine is not in contact with the reactor, so there is basically no problem of non-radioactive contamination. The operation personnel of the nuclear power turbine do not need additional special protection. New types of nuclear reactors emerging in recent years, such as improved gas-cooled reactors, molten salt proliferation reactors, fast neutron reactors, etc., are similar to traditional thermal power units. Nuclear islands can provide superheated steam above 500℃ [10]. Therefore, subcritical or supercritical high-temperature reheat turbines can be selected for the selection of conventional island turbines, and the types and technical requirements of the turbines used are basically the same as those of conventional thermal power plants.

2.2 Large main steam flow

The obvious difference between nuclear power turbine and thermal power turbine is that the steam flow of nuclear power turbine is very large. Take the AP1000 unit of Haiyang Nuclear Power Plant as an example, the main steam flow is up to 6000t/h. This is mainly due to the low initial parameters and low steam pressure of nuclear power turbine, which makes the ideal enthalpy drop of nuclear power turbine much lower than that of thermal power plant. Therefore, under the same unit output conditions, the steam mass flow required by nuclear power turbine is about 2 times that of thermal power turbine. In addition, the steam pressure of nuclear power turbine is smaller than that of thermal power turbine, and the steam density is also smaller, resulting in the specific steam capacity of nuclear power turbine is larger than that of thermal power turbine. Therefore, the volume flow of main steam of nuclear power turbine is about 3-5 times of that of thermal power turbine.

The volume flow of nuclear steam makes the whole structure of the turbine very large. The centrifugal force of the steam turbine is directly proportional to the square of the rotating speed. For a steam turbine with a full speed of 3000r/min, the length of its final stage blade cannot be too long due to the restrictions of centrifugal force and material strength, and the volume flow of nuclear steam is large, so it is necessary to increase the number of low pressure cylinders. However, the maximum volume flow of steam at the exhaust outlet of the low pressure cylinder mainly depends on the length of the final stage blade. In order to avoid the excessive number of low-pressure cylinders, which may lead to too long turbine shaft, most turbines in large-capacity nuclear power plants adopt the half-speed turbine with a speed of 1500r/min, which can greatly reduce the centrifugal force and avoid the restrictions emphasized by materials. Moreover, the length of the final stage blade of the low-pressure cylinder can be increased, thus increasing the volume flow of the exhaust port. In addition, the low pressure cylinder adopts the double flow structure.

2.3 High steam humidity

The steam humidity of nuclear power turbine is generally relatively high, which means that the main steam is basically saturated or with small superheat, resulting in the flow part of the turbine is basically in the wet steam working state, which is very different from that of thermal power unit. For the low-pressure cylinder of the nuclear power turbine, under such wet steam working conditions, the humidity of the steam at the exhaust outlet of the low-pressure cylinder will reach about 25% if no dehumidification measures are taken, thus the safe and reliable operation of the final stage blade cannot be guaranteed. In addition, high humidity also brings many problems to the safe and economic operation of the steam turbine. The water content of the steam is large, and the water droplets may erode and corrodes the structure of the steam turbine, thus affecting their life and performance. There is also the problem of reduced efficiency in the steam turbine, which is mainly because the accelerated water droplets consume more energy than the accelerated steam flow, and the water droplets impact on the blade to produce a certain braking effect, which brings additional losses. The overspeed problem of steam turbine in nuclear

power plant is much more prominent than that of steam turbine in thermal power plant. Therefore, special measures need to be taken. This is mainly due to the high water content. Therefore, in the design of wet steam turbine in nuclear power plant, the separation of water and the prevention of water erosion should be emphasized.

2.4 Half-speed machine

With the continuous improvement of the single capacity of nuclear power turbine, the new projects are basically above 1000MW. At present, the largest single capacity of nuclear power plant in China is 1750MW. The volume flow of nuclear steam makes the whole structure of the turbine very large. The centrifugal force of the steam turbine during operation is proportional to the square of the rotating speed. Therefore, limited by blade materials and centrifugal force, the length of the final stage blade of the full-speed turbine cannot meet the requirements of the flow area. However, the centrifugal force can be significantly reduced by reducing the turbine speed, such as 1500r/min, so longer final stage blade can be selected.

In addition, under the same output, the steam flow of nuclear power turbine is more than 2 times that of ultra-supercritical thermal power unit, and the number of low pressure cylinders is also more than that of thermal power unit, generally 3-4 low pressure cylinders. Moreover, due to the limitation of the parameters of the steam generator of nuclear reactor, the design of nuclear power turbine should include base load.

2.5 Reheater for soda separation

If no additional measures are taken, the high humidity of the high-pressure cylinder exhaust steam of nuclear power turbine will result in high humidity of the steam in the low-pressure cylinder. In order to effectively control the steam humidity, it is necessary to add a soda separator. The soda separation reheater has also become an indispensable equipment for nuclear power turbine, which is also an obvious difference from the thermal power turbine. The soda separation reheater consists of two parts: soda separator and reheater. In thermal power units, in order to ensure that the inlet steam of the low pressure cylinder retains a certain superheat, and at the same time, the steam humidity of the final blade of the low pressure cylinder can be controlled at about 10%, the exhaust steam of the high pressure cylinder is generally introduced into the boiler reheater to heat again, and then into the low pressure cylinder to do work, so as to improve the steam superheat and reduce the exhaust steam humidity.

However, in nuclear power units, since there is only superheater without reheater on nuclear island, the steam generator in nuclear island is equivalent to the superheater of thermal power boiler. The steam provided by nuclear island is generally saturated steam with pressure of 5-7MPa and humidity below 0.25%, and the main steam itself has no superheat. When the saturated main steam enters the high-pressure cylinder of the steam turbine to expand and do work, when the steam pressure drops to about 1.0-1.5MPa, the humidity of the steam has increased to 10%-13%. If the steam with such high humidity enters the low-pressure cylinder to continue to expand and do work, then the exhaust humidity of the final stage blade of the low-pressure cylinder will reach 20%-25%. This will significantly reduce the efficiency of the steam turbine and cause serious water erosion in the flow part of the steam turbine. Serious water erosion may cause the unit to fail to work normally.

Therefore, the steam separation reheater must be added in the nuclear power unit to control the humidity of the exhaust steam at the last stage of the low pressure cylinder. The reheater is usually composed of two parts: Soda separator and reheater, after the high-pressure cylinder exhaust steam is introduced into the soda separation reheater, the soda separator first separates the wet steam, dehydrates the water in the wet steam, and then enters the reheater to reheat the wet steam through the high-pressure cylinder extraction or main steam, so that the inlet steam of the low pressure cylinder has a superheat of 70-80℃. So that the low pressure cylinder last stage exhaust steam humidity can be controlled within the safety line of 10%.

3. Technical Management

Different from thermal power overhaul cycle, the overhaul (preventive maintenance) cycle of nuclear power turbine is determined by the refueling overhaul cycle (C) of nuclear power plant, which is generally 18 months. For each refueling overhaul cycle, only part of the steam turbine equipment is serviced (preventive maintenance). The regular island overhaul cycle is currently 4 refueling overhaul cycles. For example, in Haiyang Nuclear Power Plant, the overhaul of HY101 completed the maintenance of high-pressure cylinders and No.1 low-pressure cylinders, and the maintenance of HY201 completed the maintenance of high-pressure cylinders.

The technical departments of traditional thermal power plants are generally three departments: Production and Technology Department, Maintenance Department and Operation Department, while the technical departments related to nuclear power plants have system equipment department, technical support department, operation Department, overhaul department, mechanical maintenance department, Engineering Department and design management Department, etc. Each department has section-level departments under it. The division of labor is overlapping and repeated, but the management levels and responsibilities are different. Because the nuclear power industry has a high level of safety requirements, there is a big difference between it and thermal power plants in terms of management system and professional setting. First of all, there is a big difference between the establishment of nuclear power plants and thermal power plants. The technical departments of traditional thermal power plants are generally three departments: Production and Technology Department, Maintenance Department and Operation Department, while the technical departments related to nuclear power plants have system equipment department, technical support department, operation Department, overhaul department, mechanical maintenance department, Engineering Department and design management Department, etc. Each department has section-level

departments under it. The division of labor is overlapping and repeated, but the management levels and responsibilities are different. Secondly, the management of steam turbine equipment and systems is three-dimensional. Different departments monitor, test and analyze the health status, performance and safety of equipment from different perspectives to make a comprehensive evaluation. Third, the management of steam turbine equipment and systems is fragmented. The division of labor of technicians is meticulous, and each of them is specially responsible for the management of some equipment and systems. The work within their management scope can be detailed and in-depth, but they lack a comprehensive understanding of relevant equipment and systems. Finally, the division of labor between different departments to deal with the same problem is clear and clear. Problem raising, cause analysis and treatment measures, implementation and supervision, acceptance and other links belong to different departments. After the completion of one link, it will be reviewed and entered into the next link. Online closed-loop management is implemented.

4. Supervision mechanism and management responsibilities

Conventional island turbine technical supervision of nuclear power plant covers the whole process supervision and management of turbine body, auxiliary equipment and related systems, such as selection, design, manufacturing, installation, commissioning, operation and maintenance, overhaul, performance test, life and aging management, etc. The technical supervision of conventional island steam turbines in nuclear power plants takes safety and quality as the center, takes technical standards as the basis, takes testing and inspection as the main means, and combines the application of new technologies, new processes, new materials and new equipment (hereinafter referred to as the "Four new") to carry out the work dynamically.

The technical contents of the technical supervision of the conventional island steam turbine of nuclear power plant should be specified and specific requirements should be put forward according to the technical characteristics, structure, parameters of the steam turbine of nuclear power plant and the influence of the steam turbine failure on the nuclear island (nuclear safety). Nuclear power plants and relevant units (nuclear power groups, Electric power Research Institutes, etc.) shall, in accordance with the requirements of DL/T 1051 and with reference to relevant standards, formulate implementation rules and carry out technical supervision of steam turbines on regular island of nuclear power plants.

An organizational system of technical supervision under the responsibility of the leaders in charge of nuclear power plants shall be established, the working system and process of technical supervision shall be perfected, and the corresponding detailed rules of supervision shall be formulated. A technical supervision network should be established at different levels to clarify the responsibilities and powers of technical supervision organs and personnel at different levels. Technical supervision should be carried out according to the characteristics of nuclear power plant management, and requirements should be put forward for the traceability, integrity and standardization of quality documents.

A supervision work plan shall be formulated, which shall include work requirements, work contents, responsible units, time nodes, etc., and a summary of supervision work shall be issued every six months or a year. Technical supervision meetings should be organized regularly to coordinate and solve specific problems in supervision work. The technical supervisory personnel shall check the new information in time, correctly evaluate the effectiveness and accuracy of the relevant technical standards of the equipment or facilities under supervision according to the newly promulgated national and industrial standards and the technical requirements of the equipment, and rectify the problems found in time. Technical supervision personnel should have the corresponding professional ability and skills, and each unit should organize regular special training work.

The technical supervision shall take every quarter (year) as a cycle to summarize the supervision work. The content of the summary report shall at least include the completion of the main supervision work, the highlights of the work, the difficulties of the work, the results of the work, the problems found, the cause analysis, the treatment process and the improvement measures, and the next supervision work plan. The technical supervision shall timely inspect the discovered problems or the problems of other units. If the problems are found, the technical supervision shall issue an early warning or alarm sheet, and follow up the implementation of the rectification. The problems found in the process of technical supervision shall be included or supplemented into the next annual supervision work plan, and the implementation of the rectification shall be supervised in the process of implementation.

5. Conclusion

This paper studies the technical characteristics of the conventional island turbine in nuclear power plant and analyzes the differences between it and the conventional thermal turbine. Based on the premise of nuclear safety and combined with the characteristics of nuclear power plants, the feasible supervision mechanism of conventional island steam turbine and the daily management responsibilities of nuclear power supervision are studied. Through extensive research and collection of nuclear power related data, including technical specifications, operation procedures, maintenance procedures, etc., through the analysis and collation of these data, this paper studies the technical supervision content of nuclear power conventional island turbine, and highlights the differences from thermal power turbine technical supervision. According to the life flow of nuclear power turbine, this project provides the technical supervision contents and requirements covering the whole process supervision and management, such as selection, design, construction, installation,

commissioning, operation and maintenance, overhaul, performance test, life and aging management, etc.
The technical supervision of conventional island turbine in nuclear power plant is the whole process of turbine construction and production, including design review, equipment selection, supervision and acceptance, installation and commissioning, trial production, operation, maintenance and technical transformation. This project is a basic theoretical research, the research results are directly applied to the whole field above, applicable to the proposed nuclear power plant, under construction, in operation, has a very wide range of application prospects. Through the research of this project, a good foundation has been laid for the technical supervision of conventional island turbine in nuclear power plant.

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