Scholar Publishing Group
Kinetic Mechanical Engineering
https://doi.org/10.38007/KME.2022.030206
ISSN 2790-2676 Vol. 3, Issue 2: 46-55

Optimization of Multi-pressure Condenser Combining Artificial Intelligence and Deep Learning Algorithm

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Keywords: Artificial Intelligence, Deep Learning, Multi-Pressure Condenser, Economic Benefit

Abstract: As we all know, no matter how big the capacity of pure condensing unit is, the last stage exhaust steam contains huge residual heat, but eventually this part of heat will be released into the environment through the cooling tower, which will have a certain impact on the unit and the ecological environment. This paper aims to study the optimization of multi-pressure condenser combining artificial intelligence and deep learning algorithm. In this paper, Matlab is chosen as the modeling tool of condenser. According to the modular modeling concept of Matlab, the condenser model is divided into seven subsystems according to the structure. Based on the heat calculation and heat balance theory of condenser, seven subsystems are modeled by Simulink modeling platform, and then connected to establish the simulation model of single-pressure condenser in large power plant, and on this basis, the double-pressure condenser model is built. After determining the accuracy of condenser model, this paper uses the established model with certain accuracy to analyze the performance and economic benefits of different condenser tubes (including copper tubes). And stainless steel and titanium. Each material has significant differences in thermal conductivity, corrosion resistance and cost, among which titanium tube has the lowest thermal conductivity, the best corrosion resistance and the highest cost. In this paper, the investment cost, service life and operation performance of the tubes are comprehensively reviewed, the scope of each material is introduced in detail, and suggestions are put forward according to different design requirements, which provides a basis for the selection of condenser tubes.

1. Introduction

Condenser is one of the most important equipments in thermal power plants and nuclear power plants, and it is also an important auxiliary equipment on the turbine side. The main task of the condenser is to condense the steam turbine exhaust into water, and to form and maintain a certain vacuum at the steam turbine exhaust port. Its reliability directly affects the safety and economic operation of the whole power plant. The failure of condenser will lead to overheating of boiler and turbine unit, endangering the safety of the whole power plant. In thermal power plants and nuclear power plants, due to condenser failure, boiler explosion and forced power failure occasionally occur, which brings certain risks to power generation safety. Back pressure, vacuum value, final difference and condensate removal of condenser itself are also closely related to the economy of the whole plant [1-2].

In the research of multi-pressure condenser optimization, which combines artificial intelligence and deep learning algorithm, many scholars have studied it, and achieved good results. For example, Albright B reformed Fulaerji Thermal Power Plant with high back pressure circulating water. After the reform, the exhaust temperature of the unit increased, the vacuum degree of the condenser decreased, and the design and operation parameters also changed. Corresponding measures should be taken to improve the safety of the unit. After detailed calculation and analysis, considerable economic benefits can be obtained after the high back pressure heating reform [3]. Yu analyzed and compared different thermodynamic calculation methods of steam turbines under off-design conditions, pointed out the disadvantages of different methods, focused on the problems existing in thermodynamic methods, and improved the calculation method on the basis of the existing thermodynamic methods. By using the improved thermodynamic method, a 200MW unit was calculated in detail, and the correction curve of heat rate was obtained [4].

This paper focuses on the condensing system of the steam turbine side, aiming at establishing the cycle-deck mathematical simulation model of the condenser, including single-pressure condenser and multi-pressure condenser, by using MATLAB simulation tool and according to the idea of hierarchical modeling of complex systems. On the basis of this model, aiming at the diversity of condensers in service at present, this paper mainly selects an appropriate mathematical model for condensers and makes reasonable changes according to the actual simulated condensers. Dynamic modeling is carried out to simulate the whole operation process of the condenser correctly and comprehensively, determine the input data and output data of the condenser, and design its interfaces with other components (such as the last stage of steam turbine/small steam turbine/circulating water pump, etc.) according to the actual operation conditions. Using this model, the energy-saving optimal operation of condenser is studied and the corresponding conclusions are drawn. The energy-saving potential of multi-pressure condenser and the influence of different process numbers on the optimal operation of condenser are studied.

2. Research on the Optimization of Multi-Pressure Condenser Combining Artificial Intelligence and Deep Learning Algorithm.

2.1. Mathematical Model of Condenser

The mathematical model of condenser is composed of a series of differential equations, and the stable approximate solution suitable for the simulation field is obtained after the transformation of explicit Euler method. The algorithm is implemented by MATLAB/SIMULINK platform. To prevent the problems of infinite loop (feedback algorithm disorder failure)/zero divided amount/delay, the storage module and timing assignment module are properly designed in the model loop algorithm. Therefore, the mathematical model is the basis of this condenser model, and its accuracy and real-time directly affect the accuracy and speed of the model, so the establishment of the mathematical model is very important [5-6]. According to the structural characteristics of power plant condenser, this paper divides its mathematical model into shell side and tube side. According to the different physical properties of the working medium in the condenser, the shell side is divided into three zones: steam zone, air zone and hot well water zone. On the whole, lumped parameter method and energy/mass conservation law are adopted, and considering the difference of pipe diameters in the top of the main condensation zone and some air cooling zones, the heat transfer coefficient is modified [7-8].

2.2. Energy Saving Research of Multi-Pressure Condenser

The vacuum pump subsystem is set up for the vacuum pump, and its main outputs are: suction (steam-air mixture) mass flow and dry air quality, etc. These data are used to calculate the partial pressure of air and steam in the condenser; The input items are: vacuum pump inlet pressure P (i.e. condenser pressure), inlet steam partial pressure Ps, inlet steam saturation temperature T and vacuum pump speed V. The main formulas are as follows [9-10]:

$$V_{air} = \eta\mu\pi d^2 vl\left[(1-h)^2 - k^2\right] \tag{1}$$

Where, VAIR-inspiratory volume flow rate, m3/h;
η-volumetric efficiency;
μ —— arrangement coefficient of impeller blades; D —— outer diameter of impeller, m;
ν —— speed of vacuum pump, m/s;
L —— impeller width, m;
H —— relative submergence depth, m;
K —— hub ratio.

The lower the average pressure of the condenser, the lower the corresponding average condensation temperature. The average back pressure of the multi-pressure condenser can be examined by examining the average condensation temperature. Study on design condition of single pressure condenser. The condensation temperature of single-pressure condenser and double-pressure condenser can be simulated by MATLAB model established in this paper. At the same time, in order to get the average condensation temperature of the three-pressure condenser, a three-pressure condenser model is established on the basis of the single-pressure condenser model: three single-pressure condensers are connected end to end, and become the low-pressure steam chamber, the medium-pressure steam chamber and the high-pressure steam chamber of the three-pressure condenser, respectively, and the exhaust steam quantity of the low-pressure cylinder, the exhaust steam quantity of the small turbine, the drainage quantity, the evacuated air quantity, the heat exchange area of the condenser, the steam-air space volume of the condenser, the normal air leakage admittance, the shaft seal air leakage admittance and the fault air leakage admittance are received The average condensation temperature of the three-pressure condenser can also be calculated by using the three-pressure condenser model. As the running speed of the three-pressure condenser model is slow, when the number n of condenser pressures is greater than or equal to 4, the average condensing temperature is obtained by combining the approximate algorithm with the single-pressure condenser model instead of using the single-pressure condenser model in series, and the calculation formula is as follows [11-12]:

$$T_{sm} = T_{w1} + \frac{(n+1)\gamma}{2nmC_{\omega}} + \frac{\gamma}{n^2 mC_{\omega}} \times \frac{1}{e^{K_1 A / G_W^{C_W}} - 1} \tag{2}$$

Where TSM is the average condensing temperature of multi-pressure condenser;

Tw1 —— condensation temperature of high-pressure steam chamber of multi-pressure condenser, which is simulated by single-pressure condenser;

K1 —— heat transfer coefficient of high-pressure steam chamber of multi-pressure condenser, which is simulated by single-pressure condenser;

N —— pressure number of multi-pressure condenser;

M—— circulating rate of cooling water of multi-pressure condenser;

γ-latent heat of vaporization of multi-pressure condenser;

CW-specific heat capacity of cooling water;

A-average heat transfer area of multi-pressure condenser;

CW-specific heat capacity of cooling water;

Gw-cooling water flow rate;

2.3. Application of Artificial Intelligence and Deep Learning Algorithm in the Optimization of Multi-Pressure Condenser

Condenser is essentially a shell-and-tube heat exchanger, but its structure is complex, involving phase change and multi-component problems, and its performance can directly affect the stability of the whole steam turbine system, so it is highly concerned by researchers. Considering that the experimental research method is influenced by experimental conditions and experimental time cost, this paper adopts artificial intelligence and deep learning simulation methods to do numerical research. The numerical simulation method not only greatly reduces the time, manpower and material resources required by the experimental method, but also can decompose many important parameters, such as speed, heat transfer coefficient, pressure and temperature, which will become an important basis for designing efficient and reasonable condensers [13-14].

2.4. Influence of Pressure Change of Double-Pressure Condenser on Unit Economy

When the unit is running under pure condensing condition and the vacuum does not reach the limit vacuum, the output of the unit will increase with the pressure drop of the double-pressure condenser, and the greater the back pressure drop, the less the steam consumption of the same power generation will be. When the external temperature and unit load are constant, the pressure of the double-pressure condenser depends on the circulating water flow. By increasing the flow rate of circulating water to reduce the pressure of the double-pressure condenser, the generating power of the unit increases, while the power consumed by the pump increases [15-16]. Therefore, this becomes the problem of calculating the maximum value. When the difference between the power increment of the unit and the power consumed by the pump is the largest, the net profit power of the system is the largest. Under this operating condition, the back pressure of the double-pressure condenser is the best back pressure, which is the best vacuum. The net profit power of the system defined above is the difference between the power generated by the unit and the power consumed by the pump under a certain operating condition. To sum up, when the unit operates in the best vacuum condition, the economy is the best. To determine the optimal vacuum, it is necessary to calculate the off-design operation characteristics of the double-pressure condenser. Figure 1 shows the flow chart of determining the optimal vacuum [17-18].

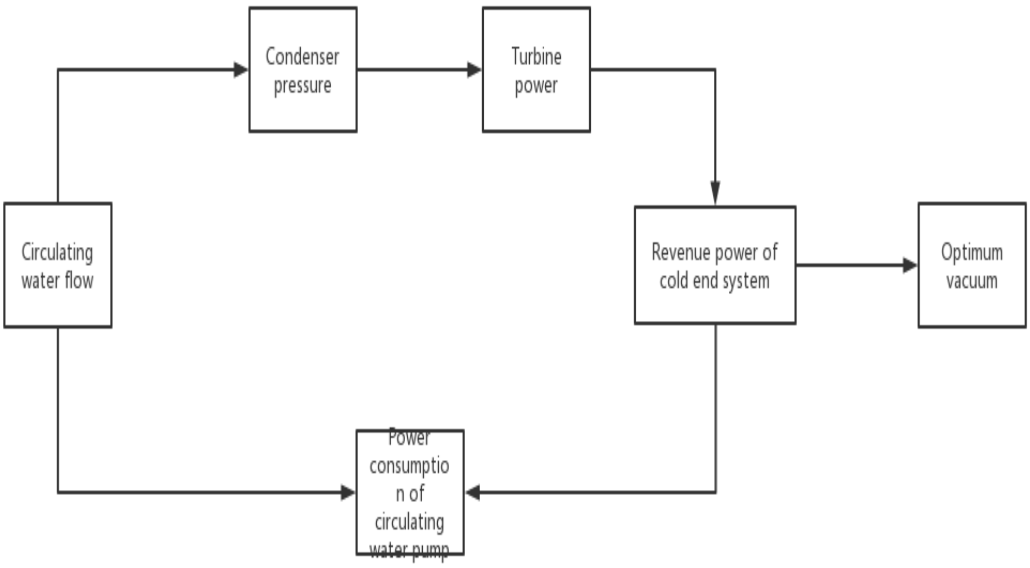

Figure 1. Flow chart for determining the optimal vacuum under pure condensing condition

3. Research and Design Experiment on the Optimization of Multi-Pressure Condenser with Artificial Intelligence and Deep Learning Algorithm.

3.1. Verification of Condenser Matlab Model

After the condenser model is established, static debugging and dynamic debugging are needed. Static debugging refers to whether the mathematical relations of the model itself are correct and can be accurately realized. Secondly, whether the model itself can run and output the results. That is, static debugging is the detection and adjustment of the function of the model itself. For this MATLAB model, after checking and ensuring the complete and accurate expression of each dynamic mathematical relationship, the structure has been modified accordingly, for example, the application of storage element and mandatory initial value module, all of which have optimized the structure of the model itself, solved the problems of disorder and infinite loop operation, and enabled the model to output corresponding results at a certain dynamic speed. After the static debugging of the model is completed, the condenser model is debugged dynamically, that is, whether the output results of the model are reasonable and correct is investigated. After ensuring the dynamic accuracy of the model, many extended studies can make in-depth analysis and draw reliable conclusions through the model. This paper mainly analyzes the dynamic debugging of the model.

3.2. Experimental Design

In this paper, the multi-pressure condenser is optimized and the experiment is designed. Firstly, the relationship between the average condensing temperature of condensers and pressure levels is analyzed. Two groups of condensers with different power are selected, and the change of condensing temperature at the end of the same pressure is analyzed. Secondly, it is the feasibility verification of the high back pressure heating transformation of multi-pressure condenser.

4. Research and Experimental Analysis on the Optimization of Multi-Pressure Condenser with Artificial Intelligence and Deep Learning Algorithm.

4.1. The Relationship between the Average Condensing Temperature of Condenser and Pressure Series

In this paper, the influence of pressure series change of multi-pressure condenser on the temperature of the unit is studied. Select two groups of different multi-pressure condensers, and record their average condensation temperatures at the same pressure. The experimental data are shown in Table 1.

Table 1. Change of average condensation temperature of two sets of multi pressure condensers under different pressure stages

	0	2	four	six	eight	10	12
Test1	32.6	31.6	31.4	31.38	31.36	31.34	31.32
Test1	34.2	33.8	33.4	33.36	33.32	33.28	33.0

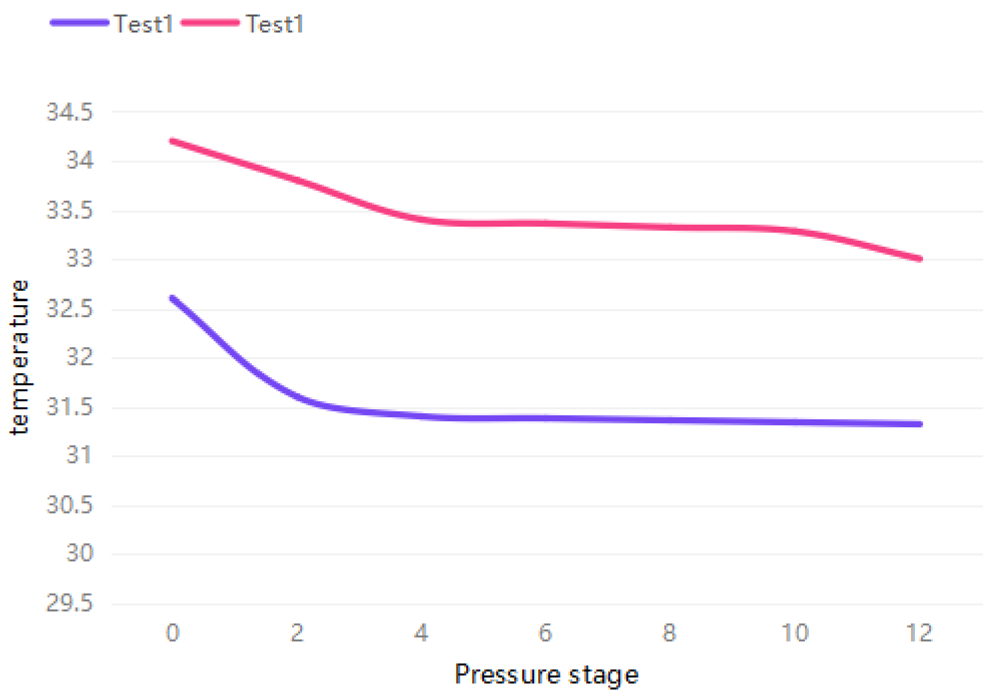

Figure 2. Relation curve between average condensing temperature and pressure stages of condenser

As shown in Figure 2, when the pressure level N increases, Tsm decreases, that is, the vacuum degree of condenser increases and the thermal efficiency increases; Among them, the change from n=1 to n=2 is the most significant. However, when the pressure number n is greater than 4, the Tsm decreases with it. When n is larger, Tsm tends to be stable. If you look at the multi-pressure condenser with a pressure series of less than 4, from single-pressure condenser to double-pressure condenser, Tsm decreases greatly. However, from double pressure to triple pressure, Tsm decreases little, but the resulting economic benefits may still exceed the increase of operation, maintenance and cost caused by the complex structure of triple pressure condenser. From the three-pressure condenser to the four-pressure condenser, such a modest reduction in Tsm has been difficult to make up for the cost problem caused by the complexity of the structure. Therefore, it is of little significance that the pressure level of multi-pressure condenser reaches more than 4. Generally speaking, higher-level multi-pressure condensers are not used in engineering. Three-pressure condenser is also considered, but double-pressure condenser is often used in engineering because of its simple arrangement of exhaust chamber, circulating water pipe, water chambers at both ends of circulating water and circulating water pipe.

4.2. Feasibility Verification of High Back Pressure Heating Transformation of Multi-pressure Condenser

In order to ensure the safe operation of the unit in circulating water heating, it is necessary that the unit can meet the heat load requirements of heating users in all working conditions under different external environments. If the unit can operate safely under full load during the peak heating period, then the unit can operate safely under all working conditions. Therefore, it is necessary to check whether the maximum pressure of the double-pressure condenser exceeds the maximum design back pressure of the unit under full load, whether the exhaust temperature of the low-pressure cylinder exceeds the limit value, and whether the axial thrust meets the safety requirements. Therefore, this paper studies the changes of the high pressure side, low pressure side and average back pressure of the double-pressure condenser under full load heating operation. The experimental data are shown in Table 2.

Table 2. Back pressure and ambient temperature of double pressure condenser under full load

	-25	-20	-15	-10	-5	0
High pressure side pressure	60	47	40	31	25	19
Average pressure	54	43	35	28	23	17
Low pressure side pressure	47	37	31	25	19	15

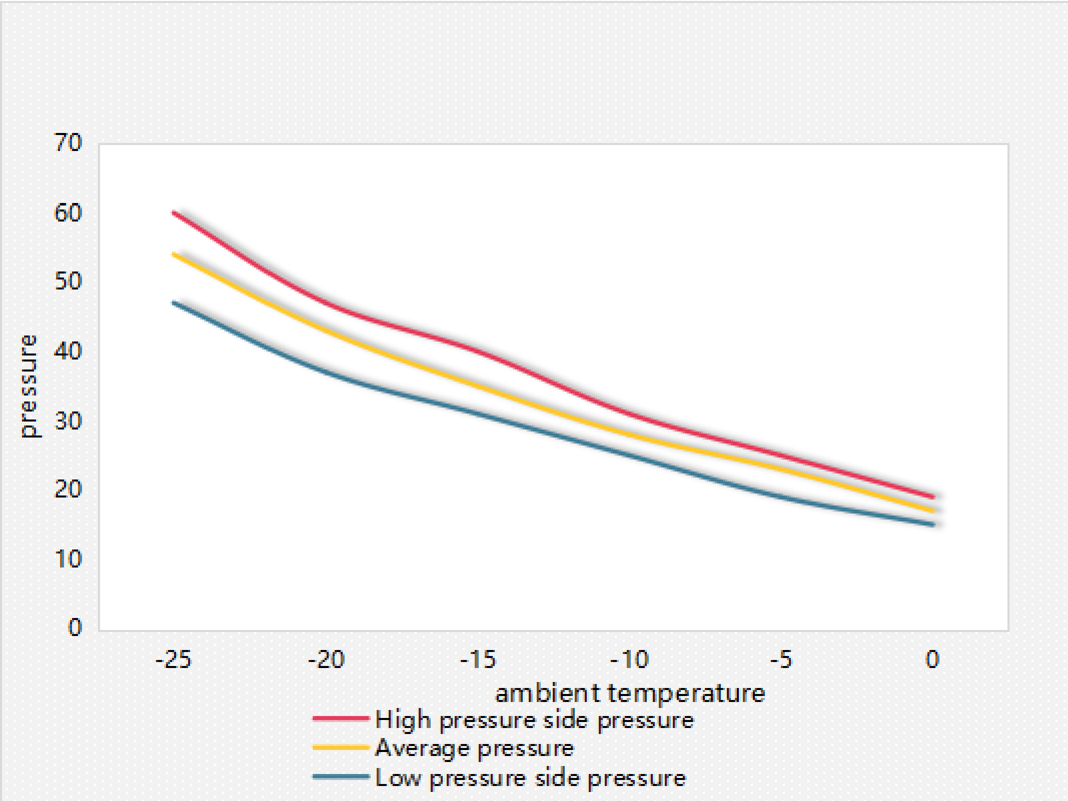

Figure 3. Relation curve between back pressure and ambient temperature of double pressure condenser under full load

As can be seen from Figure 3, the maximum pressure value of the high-pressure side of the double-pressure condenser is 59.76kPa, which is lower than the maximum allowable operation value of the unit of 65kPa, and the exhaust temperature of the corresponding low-pressure cylinder is 81.06℃, which is lower than the exhaust temperature limit value of 85℃. From the point of view of steam exhaust temperature and pressure, it can meet the requirements of safe operation of the unit. However, the high back pressure heating operation will not only increase the exhaust pressure and temperature, but also have certain influence on the axial thrust of the last stages of the unit, the expansion of the cylinder, the condenser, etc. Therefore, it is necessary to check whether the above influences can meet the requirements of safe operation in safe operation.

5. Conclusion

In this paper, the general surface condenser of thermal power plant is modeled and studied by MATLAB software, including single-pressure condenser and multi-pressure condenser. The model is based on the thermodynamic calculation and dynamic mathematical model of the condenser, and has certain commonness, which is suitable for condensers of large, medium and small size, all kinds of pipes and all kinds of pipe arrangement. The input and output of the model simulate the physical parameters of condensers in actual operation, and all kinds of condensers only need to input the relevant structural parameters when they are used. After the model is established, the condenser operation data of a 600MW supercritical thermal power unit is selected for testing by using the data collected from the power plant. By comparing the output parameters with the actual condenser operation data, the error is within 0.2%, which is within the allowable range of engineering application. The innovation of this paper lies in establishing a detailed and comprehensive dynamic model of condenser by using MATLAB, the most basic modeling tool, which makes it readable, compatible and inheritable. In addition to considering the conventional mathematical dynamic model of condenser, new elements are added in the modeling process, such as the correction coefficient of condenser tube row pattern and the corrosion coefficient of cooling water tube blockage in the calculation process of total heat transfer coefficient, which makes the application range of the model wider, more practical and improves the accuracy. In this paper, the performance comparison and economic benefit analysis of all kinds of tube condensers are made by using this model, and my own opinions on energy saving are also put forward by using this model. In fact, the MATLAB tool itself is a very constructive basic modeling language, and its application in the aerospace field has been extended to various manufacturing industries. It is also an innovation to apply MATLAB tools to thermal engineering, to simulate the preparation of electric energy or dynamic energy devices.

Funding

This article is not supported by any foundation.

Data Availability

Data sharing is not applicable to this article as no new data were created or analysed in this study.

Conflict of Interest

The author states that this article has no conflict of interest.

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