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MATHEMATICAL MODEL OF A STEAM TURBINE CONDENSER

The paper analyses the existing calculation methods for steam turbine condenser. The refined methods for calculating the condenser have also been considered. The dependency of the vapor pressure in the condenser on the temperature of the cooling water and the steam flow rate into the condenser have been considered. It can be seen from the obtained dependencies that the calculation of the condenser according to the ARTI and HEI (USA) methods coincides with the passport data. It is recommended to use the ARTI and HEI (USA) techniques for equipment diagnostics, and to use the KTP and USTU-UI techniques when studying ways to increase the efficiency of the condenser. The mathematical model of the KG2-6200 condenser has been tested at the Almaty CHPP-2.

Keywords: condenser; diagnostic model, mathematical model, calculation methods, efficiency.

Introduction. The thermal design calculations of a condenser can be carried out using several methods. So, it is necessary to choose the most suitable calculation method. According to the chosen calculation method, it is possible to develop a mathematical model of the condenser and carry out computational experiments.

The scientific novelty of the work is as follows:

1. The analysis of existing methods and refined methods for calculating steam turbine condensers has been carried out.
2. A mathematical model of a steam turbine condenser has been developed and the dependences of the steam pressure in the condenser on the temperature of the cooling water and the steam flow into the condenser are shown.
3. Recommendations for the use of calculation methods have been developed.

Materials and methods. There are various methods for calculating the steam turbine condenser. In this work, we will consider the following methods: All-Russian Technological Institute (ARTI), Kaluga Turbine Plant (KTP), Ukhta State Technical University (USTU-UI), USA Heat Exchange Institute (HEI (USA)).

Each method has its advantages and disadvantages. The methods of ARTI, HEI (USA) can give an estimate of the average heat transfer coefficient based on the integral operating and design characteristics of the equipment [1, p. 26]. The methods of KTP, USTU-UI make it possible to calculate the condenser taking into account the separate effect of air and contamination suction on the steam pressure in the condenser [1, p. 27], but when changing one of the process parameters, it is necessary to clarify the values of the thermophysical properties of water and condensate film depending on temperature.

In addition, many scientific researchers have developed refined calculation methods.

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A. G. Shempelev and P. V. Iglin developed a method for calculating the degree of supercooling of condensate at its bottom at various air inflows in the vacuum system of a turbine unit. It was found that a 4-fold increase in the air flow into the vacuum system leads to an increase in condensate supercooling from 3.5 to 11 °C. Thus, an increase in condensate supercooling leads to additional heat losses of up to 1100 kW in the turbine unit per cycle in the power generation mode and up to 500 kW per cycle in the heat generation mode [2, p. 1].

P. V. Iglin developed a refined method for calculating the condenser, with the help of which it is possible to obtain its characteristics during condensation of pure steam and during condensation of steam from a steam-air mixture in any operating mode of a turbine unit with variable air suction [3], [4].

B. E. Murmanskii, K. E. Aronson, Yu. M. Brodov developed a calculation method that allows predicting the residual life and assessing the condition of the steam turbine condensers. On the basis of this method, two models have been developed. The first model can be used when information is available on the operating time of the condenser before the failure of the tubes, as well as a priori information, based on the analysis of the metal of the condenser tubes, that the condenser is in normal operating condition. In cases where there is no accurate information on the operating time of the condenser tubes at the CHPP, the second model, based on censored samples, is proposed to assess the condition of the condenser. [5, p. 785].

The authors of [6] have developed a methodology for assessing heat fluxes entering the condenser when the turbine is operating in the heat generation mode. It has been shown that for the efficient operation of the built-in bundle as part of the condensation system, all heat fluxes entering in addition to the wheel space should be directed to the regenerative heating zone under the built-in condenser bundles through special water distribution devices, and the inlet zone itself must be separated from the condenser chamber by casings [6, p. 30].

K. E. Aronson, S. I. Khayet developed a method for accounting for the separate effect of contamination and air inleakage on the value of steam pressure in the condenser. The method is based on the combined characteristic of the condenser and the ejector, consisting of two sections [7, p. 200]. The same method is described in [8], [9], [10].

Results. When developing a mathematical model, it is necessary to choose a calculation method. For this, thermal design calculation for a condenser was made using the methods of ARTI, KTP, USTU-UI, HEI (USA). The initial data for the compilation of the mathematical model were taken from the passport data for the KG2-6200 condenser of the Almaty CHPP-2. The mathematical model has been tested at the Almaty CHPP-2. The testing results are presented in [11].

Various dependencies were built using a mathematical model of the condenser.

Figure 1 shows the dependency of the vapor pressure in the condenser on the temperature of the cooling water at the inlet. The graph shows the data obtained in the calculations according to the methods of ARTI, KTP, USTU, HEI and the passport characteristic of the condenser. The dependency graph is built at a steam flow $D_s = 325$ t/h, fouling factor $\alpha = 1$, cooling water flow $G_w = 16000$ m³/h.

Figure 1 – Dependency of the vapor pressure in the condenser on the temperature of the cooling water

From Figure 1 it follows that the calculation of the condenser according to the ARTI and HEI methods is as close as possible to the passport characteristics.

Figure 2 shows the dependency of the steam pressure on the steam flow into the condenser. It also shows the data obtained in the calculations according to the methods of ARTI, KTP, USTU, HEI and the passport characteristic. The dependency graph is built at the consumption of cooling water $G_w = 16000 \text{ m}^3/\text{h}$, the cooling water temperature at the inlet $t_{lw} = 25 \text{ }^\circ\text{C}$, fouling factor $\alpha = 1$.

It can be seen from the figure that at a steam flow D_c from 150 to 325 t/h, the calculation by the ARTI and HEI methods is as close as possible to the passport characteristics.

The results from the calculation by the methods of KTP and USTU differ slightly from the passport data, since the calculations require constant refinement of the thermophysical properties of water and steam.

It is recommended to use the ARTI and HEI calculation methods for equipment diagnostics, and the KTP and USTU methods for the study of intensification methods.

Figure 2 – Dependency of the steam pressure in the condenser on the steam flow into the condenser

Using a mathematical model developed using the KTP method, heat transfer was intensified using annular grooves [11].

Discussion. At the moment, in the Republic of Kazakhstan, there are no diagnostic models of the condenser and, accordingly, they are not used. Therefore, the primary task was to develop a mathematical model of the condenser. When developing a mathematical model, the experience of other authors, the features of the operation of equipment, the ability to collect information and conduct experiments were taken into account.

The feature of this work in comparison with other works is that the mathematical model of the condenser is included in the software product “KTI”, where there are applications with the values of the thermophysical properties of water and steam depending on the temperature [12] – [14].

In addition, using this mathematical model of the condenser, it is possible to carry out various studies on the intensification of heat transfer, diagnostics of the condition of the equipment.

Conclusion. Methods for calculating the condenser by ARTI, HEI (USA), KTP, USTU-UI, as well as refined methods obtained by researchers have been considered. To develop a mathematical model, it is necessary to choose a calculation method. For this, thermal design calculation for a condenser was made using these methods. The mathematical model has been tested at the Almaty CHPP-2.

The dependency of the vapor pressure in the condenser on the temperature of the cooling water and the steam flow rate into the condenser have been presented. From the dependencies shown it follows that the calculation of the condenser according to the ARTI and HEI methods is as close as possible to the passport characteristics.

The results from the calculation by the methods of KTP and USTU differ slightly from the passport data, since the calculations require constant refinement of the thermophysical properties of water and steam.

It is recommended to use the ARTI and HEI calculation methods for equipment diagnostics, and the KTP and USTU methods for the study of intensification methods.

The mathematical model of the condenser can be used when conducting an energy audit of a plant, in production, in the process of training heat power specialists when performing virtual laboratory work.

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БУ ТУРБИНАСЫ КОНДЕНСАТОРЫНЫҢ МАТЕМАТИКАЛЫҚ ҮЛГІСІ

Жұмыста бу турбинасы конденсаторын есептеудің қолданыстағы әдістемелеріне талдау жүргізілген. Сонымен қатар конденсатор есептеудің нақтыланған әдістемелері қарастырыл-

ған. Салқындататын су температурасынан және конденсатордағы бу шығынынан конденсатордағы бу қысымының байланысы қарастырылған. Алынған байланыстардан БРТИ және ЖАИ (АҚШ) әдістемелері бойынша конденсатордың есептеуі паспорт деректерімен үйлесетіні көрінеді. Жабдықты диагностикалау үшін БРТИ және ЖАИ (АҚШ) әдістемелерін, конденсатордың тиімділігін арттыру тәсілдерін зерттеу кезінде КТЗ және УМТУ-УПИ әдістемелерін пайдалану ұсынылады. КГ2-6200 конденсаторының математикалық үлгісі АлЭС 2-ЖЭО сынап байқалған.

Түйін сөздер: конденсатор, диагностикалық үлгі, математикалық үлгі, есептеу әдістемелері, тиімділік.

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МАТЕМАТИЧЕСКАЯ МОДЕЛЬ КОНДЕНСАТОРА ПАРОВОЙ ТУРБИНЫ

В работе представлен анализ существующих методик расчета конденсатора паровой турбины. Также рассмотрены уточненные методики расчета конденсатора. Рассмотрены зависимости давления пара в конденсаторе от температуры охлаждающей воды и расхода пара в конденсатор. Из полученных зависимостей видно, что расчет конденсатора по методикам ВТИ и ИТО (США) совпадают с паспортными данными. Для диагностики оборудования рекомендовано использовать методики ВТИ и ИТО (США), а при исследовании способов повышения эффективности конденсатора использовать методики КТЗ и УГТУ-УПИ. Математическая модель конденсатора КГ2-6200 апробирована на АлЭС ТЭЦ-2.

Ключевые слова: конденсатор, диагностическая модель, математическая модель, методики расчета, эффективность.