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DESIGN CHARACTERISTICS OF THE HORIZONTAL STEAM GENERATOR PGV-1000

The materials of the article consider the design characteristics of horizontal steam generators PGV-1000 for WWER NPPs. The NPP steam generator, in particular the PGV-1000 steam generator, is a specific heat exchange unit. This unit, together with a nuclear reactor and a steam turbine, is one of the main equipment of multi-circuit (double-circuit) steam turbine NPPs. The steam generator produces working steam using heat dissipated from the reactor core by the cooling medium and sent to the heat exchange surface of the steam generator. NPP steam generators, connecting the contours of the coolant and the working substance, equally belong to each of them. The heat-absorbing medium in the steam generator is the working substance (water, steam). PGV-1000 type NPP steam generators with pressurized water reactors produce dry saturated steam. The requirement to maintain high purity of the coolant is due to the heat transfer surfaces of such steam generators made of austenitic stainless steel with electropolished surfaces. WWER reactors do not allow the coolant to boil in the core, so the temperature of the coolant at the outlet of the reactor (at the inlet to the steam generator) is always lower than the saturation temperature corresponding to the water pressure in the coolant circuit. Underheating of the coolant to the saturation temperature (approximately 25 ÷ 30 °C) guarantees the exclusion of vaporization even in the most loaded reactor channels. The design characteristics of modern horizontal steam generators such as PGV-1000 of various modifications provide high technical and economic performance of NPP units with WWER-1000 and high maintainability, which allows to extend the service life of domestic NPPs.

Keywords: horizontal steam generator PGV-1000, mathematical model, design characteristics.

I. Introduction

The NPP steam generator, in particular the PGV-1000 steam generator, is a specific heat exchange unit. Together with a nuclear reactor and a steam turbine, this unit belongs to the main equipment of multi-circuit (double-circuit) steam turbine NPPs [1, 2, 3].

The steam generator produces working steam using heat dissipated from the reactor core by the cooling medium and directed to the heat exchange surface of the steam generator. NPP steam generators, connecting the coolant circuits and the active substance, belong equally to them [4].

Thermal, hydraulic, and structural characteristics of the horizontal steam generator NPP with PGV-1000 in nominal mode are shown in table 1.

The heat-absorbing medium in the steam generator is the working substance (water, steam). PGV-1000 type NPP steam generators with pressurized water reactors produce dry saturated steam.

The requirement to maintain the high purity of the coolant is due to the heat transfer surfaces of such GHGs from austenitic stainless steel with electropolished characters.

II. The goal of the work

Design structural characteristics of the horizontal steam generator PGV-1000 for nuclear power plants with WWER.

The nuclear steam generator is an essential component of a pressurized water nuclear power plant, which plays an important role in the safety and efficiency of a nuclear power plant. Therefore, a reliable thermal-hydraulic model for modeling a nuclear steam generator is critical.

This model can be used to evaluate experimental data and licensing processes.

Table 1. Thermal, hydraulic and structural characteristics of the horizontal steam generator of the NPP with PGV-1000 at the nominal mode of operation of the power uni

The name of the parameter	Numeric value of the parameter
1	2
Thermal power, MW	750
Steam productivity, kg / s	408
The steam pressure generated is MPa	6,27
Steam temperature, ^{0}C	278,5
The temperature of the feed water, ^{0}C	225
Coolant consumption, kg / s	4100
Coolant pressure, MPa	15,7
The temperature of the coolant at the inlet to the steam generator, ^{0}C	320
The temperature of the coolant at the outlet of the steam generator, ^{0}C	289
Mean logarithmic temperature pressure, ^{0}C	23,1
Heat transfer coefficient, W / (m^2 · K)	6370
Average heat flux density, W / m^2	6370
Area of the heat transfer surface (on the external diameter of pipes), m^2: estimated actual	 5096 6115
The average velocity of the coolant in the pipes, m / s	4,2
The average velocity of steam coming out of the evaporation mirror, m / s	0,382
The average speed of steam at the entrance to the louver separator, m / s	0,38
The humidity of steam at the outlet of GHG,%, no more	0,25
Diameter and wall thickness of heat transfer surface pipes, mm	16 × 1,5

Number of pipes	11000
Average length, m	11,1
Total length, m	124460
The inner diameter of the coolant collector in the area of pipe rolling, mm	834
The internal diameter of the collector of feed water, mm	270
Length of the collector of feed water, mm	9300
Number of dispensing pipes	16
The internal diameter of distributing pipes, mm	16
The number of rows in the louver separators	8
The angle of inclination of the row to the horizon, deg	64
Height of the separator above the water level, mm	650
The distance from the axis of the upper row of pipes to the immersed perforated sheet, mm	260
Diameter of openings in the immersed perforated board, mm	15
Step of arrangement of openings (on a square), mm	52
The internal diameter of pipelines of supply and removal of the heat carrier, mm	870
The internal diameter of the supply water supply pipeline, mm	382
The internal diameter of the pipeline of removal of fresh steam, mm	210

III.Main part

Structurally, the steam generator PGV-1000 for NPPs with WWER is a single-hull double-circuit heat exchanger of horizontal location with a submerged tube bundle.

The steam generator consists of a housing, inlet, and outlet collectors of a U-shaped tube bundle of the heat exchange surface, a distributing collector of feed water, a built-in separation device, a steam exhaust system, a purge, and a drainage system.

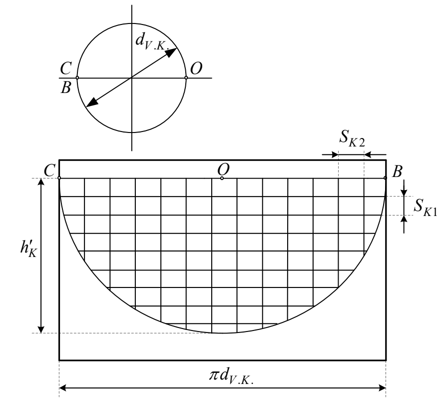
The cylindrical part is divided into three shells, the middle of which has an increased thickness because it is weakened by cylindrical vertical collectors passing through it. Collectors are used for the supply and discharge of primary coolant.

The heat exchange surface consists of two symmetrical parts (left and right), each including half of the distributing and collecting collectors connected by U-shaped pipes. The number of pipes in each part equals half of the total number of pipes.

The area for fixing the pipes in each semi-collector is equal to ¼ the fraction of the circle with the diameter, which is the diameter of the collector. (fig. 1)

The heat transfer surface pipes are arranged in packages (fig. 2), the number of rows is 2 ÷ 3 in height. In the top row is the maximum number of packets 3 ÷ 5.

The distance between rows of packages and between packages in a row usually equals 2 ÷ 3 steps of pipe gratings. It is used to accommodate the supporting structures of the heat exchange surface and the device for introducing feed water into the steam generator (space between inner packages is used to accommodate feed water drains). Thus the pipe board is semicircular. As a result, the U-shaped pipe includes two horizontal sections and two curved sections for radial entry into the collector. For simplification, the collector is conditionally replaced by a flat tubular board located at a distance of half the radius from the center of the collector.

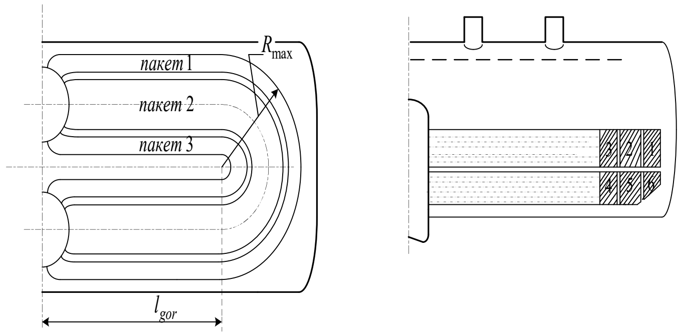


d v.k.– the inner diameter of the collector,

h’k – the distance between the first and last rows of the collector,

S_{k1} S_{k2} – pipe lattice steps

Fig. 1. Location of PT pipes on GHG collectors



l_{ger} – the length of the horizontal part of the pipes

R_{max} – radius of pipes with the greatest bend

Fig. 2. Placement of pipe packages in the PA

The collectors include 11,000 horizontal beam pipes. The inner diameter of the pipes is 16 mm. The wall thickness is 1.5 mm. The average length is 11.3 m. The pipes are rolled by the explosion to the entire thickness of the collector with subsequent boiling. Collectors are attached to the housing through thermal compensators.

The beam tubes rest on the spacer grilles. An immersed perforated sheet is located above the beam to equalize the load of the evaporation mirror. Nutrient water is supplied through a pipeline inserted into the housing through a thermal compensator.

The pipeline feed water on four perforated assignments goes to an entrance zone of a surface of heat exchange. In the inlet zone, there is a greater temperature pressure, so it produces more steam. The direction to this zone of cold feedwater leads to a decrease in vapor content due to the condensation of steam. This scheme of supply of feedwater somewhat equalizes the vapor content in the cross-section of the water volume, which leads to approximately equal velocities of steam at the entrance to the vapor space.

Steam separation takes place in inclined louver separators (on steam generators manufactured after 1992, it is absent). The ceiling, which receives steam and is a perforated shield, helps to equalize the velocities of steam currents in the volume of separation. Separated liquid through the pipes enters the level along the walls of the housing.

The steam is discharged through seven pairs of steam outlets arranged in a checkerboard pattern. To ensure the required purity of the steam, periodic and continuous purging and drainage are provided, carried out through the fittings placed along the lower forming body.

WWER reactors do not allow the coolant to boil in the core, so the temperature of the coolant at the outlet of the reactor (at the inlet to the steam generator) is always lower than the saturation temperature corresponding to the water pressure in the coolant circuit. Underheating of the coolant to the saturation temperature (approximately 25 ÷ 30 ° C) guarantees the exclusion of vaporization even in the most loaded reactor channels.

The temperature level of cooling of VVER type reactors is low. Operating reactors have a coolant outlet temperature of not more than 325 ° C. To obtain higher parameters of the generated steam, the steam generator is carried out at low-temperature pressures. The minimum temperature pressure takes place at the outlet of the coolant from the evaporator of the steam generator. Its value is 10 ÷ 20 ° C. At such temperature pressures, the calculated value of the heat transfer surface is quite large. Therefore, four steam generators (four circulation loops) are installed on the VVER-1000 reactor, which allows not to stop the reactor, but only to reduce its power in case of equipment failure.

Since the pressure of the coolant is significantly higher than the pressure of the working fluid, the water of the primary circuit flows through the pipe system in the heat exchange surface of the steam generator and the working substance - in the intertube space. Circulation of the working substance (boiler water) in the intertube space is natural with transverse washing of the pipes. Nutrient water is fed into the lowering section of the natural circulation circuit. It mixes with a saturation temperature and enters from below on the surface that transfers heat, heats, and boils. The mixture of steam and liquid enters the separator, where the separation of dry saturated steam is.

The object of modeling the thermal scheme of the steam generator without a superheater and the economizer is allocated in a separate site which is given in fig. 3,4. Nourishing water with temperature is fed into the body of the steam generator, where it mixes with boiler water, goes down the evaporator, and boils on the outer surface of the pipes. The feedwater is heated (saturation temperature of the working fluid) in the evaporator due to the condensation of some steam.

The mathematical model of the steam generator includes the following dependencies [5–15]:

a) the equation of heat balance of the steam generator:

$$Q_{PG} = \left(D + D_{SN} + D_{PR}\right) \cdot \left(i'_S - i_{PV}\right) + \left(D + D_{SN}\right) r;$$

$$G\left(i'_1 - i''_1\right)\eta_{PG} = \left(D + D_{SN} + D_{PR}\right) \cdot \left(i'_S - i_{PV}\right) + \left(D + D_{SN}\right) r,$$

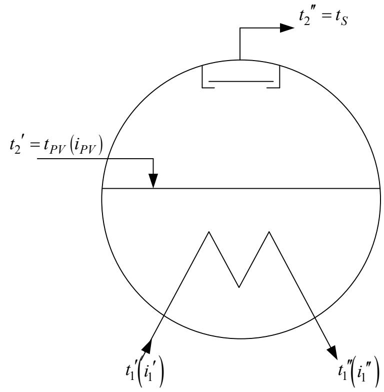


Fig. 3. Schematic thermal diagram of the horizontal steam generator PGV-1000

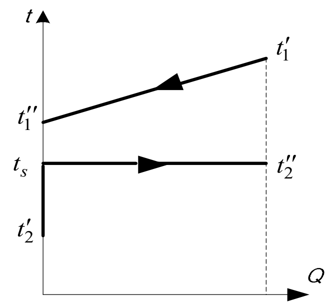


Fig. 4. t-Q diagram of the horizontal steam generator PGV-1000

where Q_{PG} – the amount of heat transferred from the coolant to the working fluid in the GHG;

G – mass flow rate,

i'_1 , i''_1 – enthalpy of the coolant at the inlet to the GHG and out of it;

η_{PG} – KKD PG;

D – GHG steam productivity;

$D_{PR} = \left(0,005 \div 0,01\right) D$ – water consumption for GHG purge;

$D_{SN} = (0,015 \div 0,03) D$ – steam consumption for own needs; i_{PV} – enthalpy of feed water;

i'_s – enthalpy of water at saturation temperature;

r – hidden heat of vaporization.

b) equation of material balance of the working substance:

$$Dpv = Dpv + Dsn + D = Dpr + Disp, \quad (2)$$

where Dpv, Disp – costs: nutrient water, working substance through the evaporation zone;

c) equation of material balance for the coolant:

$$Gr = G \cdot 4, \quad (3)$$

where Gr – coolant flow through the reactor;

d) heat transfer equation:

$$Q = k \cdot F \cdot \Delta t_{sr} \quad (4)$$

where k – heat transfer coefficient;

F– heat transfer area;

Δt_{sr} – the average temperature pressure between the coolant and the working substance.

Conclusion

Scientific research is aimed at solving the problems of increasing the efficiency, reliability, environmental friendliness and safety of the production of electric, thermal and other types of energy by complex thermal energy systems (CTS), such as power units of thermal and nuclear power plants, gas pumping units of gas pumping stations, power generating equipment of heat networks and others.

This represents an important and urgent problem of national significance for Ukraine, which is directly related to the introduction of energy-saving technologies in various sectors of the economy and industry, the effective use of energy resources, and the prevention of large-scale man-made disasters. In this regard, there is a need to develop new effective theories and methods for analyzing the quality of functioning and structural-parametric synthesis of CTS, their diagnostics and reliability forecasting, both in the process of design and construction, and during operation.

The scientific novelty of the performed research consists in the development and development of theories and new methods of simulation modeling, determination of reliability and optimization of parameters of technological processes in power equipment, which are intended for the creation and organization on the basis of modern information technologies of computer systems for intellectual support of the activities of the operational personnel of the CTS.

The design characteristics of the horizontal steam generator PGV-1000 were calculated, which provide high technical and economic performance indicators for the operation of NPPs with WWER-1000.

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КОНСТРУКТИВНІ ХАРАКТЕРИСТИКИ ГОРИЗОНТАЛЬНОГО ПАРОГЕНЕРАТОРА ПГВ-1000

У матеріалах статті розглянуто конструктивні характеристики горизонтальних парогенераторів ПГВ-1000 для АЕС ВВЕР. Парогенератор АЕС, зокрема парогенератор ПГВ-1000, є специфічною теплообмінною установкою. Цей агрегат разом з ядерним реактором і паровою турбіною є одним з основних устаткування багатоконтурних (двоконтурних) паротурбінних АЕС. Парогенератор виробляє робочу пару, використовуючи тепло, що розсіюється від активної зони реактора охолоджуючим середовищем і направляється на теплообмінну поверхню парогенератора. Парогенератори АЕС, з'єднуючи контури теплоносія і робочої речовини, однаково належать кожному з них. Теплопоглинаючим середовищем у парогенераторі є робоча речовина (вода, пара). Парогенератори АЕС типу ПГВ-1000 з водоводяними реакторами виробляють суху насичену пару. Вимога дотримання високої чистоти теплоносія обумовлена теплообмінними поверхнями таких парогенераторів з аустенітної нержавіючої сталі з електрополірованими поверхнями. Реактори ВВЕР не допускають кипіння теплоносія в активній зоні, тому температура теплоносія на виході з реактора (на вході в парогенератор) завжди нижче температури насичення, що відповідає тиску води в контурі теплоносія. Недогрів теплоносія до температури насичення (приблизно 25 ÷ 30 °C) гарантує виключення пароутворення навіть у найбільш завантажених каналах реактора. Конструктивні характеристики сучасних горизонтальних парогенераторів типу ПГВ-1000 різних модифікацій забезпечують високі техніко-економічні показники блоків АЕС з ВВЕР-1000 та високу ремонтопридатність, що дозволяє продовжити термін служби вітчизняних АЕС.

Ключові слова: горизонтальний парогенератор ПГВ-1000, математична модель, конструктивні характеристики

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КОНСТРУКТИВНЫЕ ХАРАКТЕРИСТИКИ ГОРИЗОНТАЛЬНОГО ПАРОГЕНЕРАТОРА ПГВ-1000

В материалах статьи рассмотрены конструктивные характеристики горизонтальных парогенераторов ПГВ-1000 для АЭС ВВЭР. Парогенератор АЭС, в частности парогенератор ПГВ-1000, является специфической теплообменной установкой. Этот агрегат вместе с ядерным реактором и паровой турбиной является одним из основных оборудования многоконтурных (двухконтурных) паротурбинных АЭС. Парогенератор производит рабочий пар, используя рассеивающееся от активной зоны реактора охлаждающей средой тепло и направляется на теплообменную поверхность парогенератора. Парогенераторы АЭС, соединяя контуры теплоносителя и рабочего вещества, все равно принадлежат каждому из них. Теплопоглощающей средой в парогенераторе является рабочее вещество (вода, пар). Парогенераторы АЭС типа ПГВ-1000 с водо-водяными реакторами производят сухой насыщенный пар. Требование соблюдения высокой чистоты теплоносителя обусловлено теплообменными поверхностями таких парогенераторов из нержавеющей аустенитной стали с электрополированными поверхностями. Реакторы ВВЭР не допускают кипения теплоносителя в активной зоне, поэтому температура теплоносителя на выходе из реактора (на входе в парогенератор) всегда ниже температуры насыщения, что соответствует давлению воды в контуре теплоносителя. Недогрев теплоносителя до температуры насыщения (примерно 25÷30°C) гарантирует исключение парообразования даже в наиболее загруженных каналах реактора. Конструктивные характеристики современных горизонтальных парогенераторов типа ПГВ-1000 различных модификаций обеспечивают высокие технико-экономические показатели блоков АЭС с ВВЭР-1000 и высокую ремонтопригодность, что позволяет продлить срок службы отечественных АЭС.

Ключевые слова: горизонтальный парогенератор ПГВ-1000, математическая модель, конструктивные характеристики.