TOMSK
POLYTECHNIC
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ТОМСКИЙ
ПОЛИТЕХНИЧЕСКИЙ
УНИВЕРСИТЕТ

INDIVIDUAL HOMEWORK ASSIGNMENT GUIDELINES

“Design, Maintenance and Engineering of Nuclear Power Plants”

Master program

“Nuclear Power Engineering”

Tomsk 2019

Individual homework assignment 1
“Determination of NPP efficiency indicators in the condensation and cogeneration mode”

Goal and objectives

1. Specific steam flow in turbine d_0 and heat rate $q_{ту}$;
2. Turbine efficiency $\eta_{ту}$, $\eta_{ту}^{а}$ and NPP efficiency $\eta_{с}$, $\eta_{с}^{н}$;
3. The annual consumption of nuclear fuel $B_{г}$.

$$Q_{ту}=\frac{G_0\cdot\left(h_0-h_{пв}\right)+G_{дв}\cdot\left(h_{пв}-h_{дв}\right)}{10^3}$$

Brief information

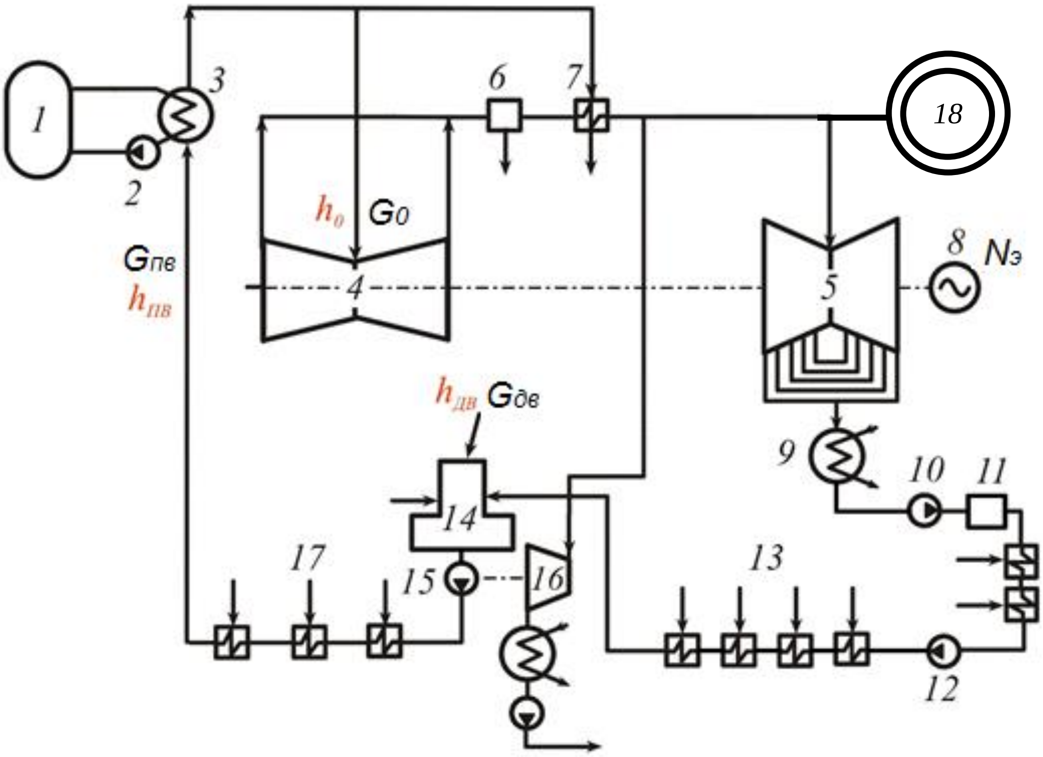

Fig. 1. A simplified diagram of the thermal condensation power unit.

Two-circuit nuclear power plant is working in cogeneration mode, producing both electrical and thermal power.

Known flow and properties of nuclear power plant working fluid, which scheme is shown in Fig. 1: 1 – reactor; 2 – main circulation pump; 3 – steam generator; 4, 5 – low pressure and high pressure turbines; 6 – separator; 7 – reheater; 8 – generator; 9 – condenser; 10, 12 – condensate pumps of the 1st and 2nd lifting; 11 – block desalting unit; 13 – low-pressure heaters; 14 – deaerator; 15 – feed water pump; 16 – turbine driving feed water pump; 17 – high-pressure heaters; 18 – heat supply unit (thermal energy consumer).

Nomenclature

$N_э$, MW	- electric power turbine system;
$N_e^{тп}$, MW	- effective power turbine drive;
G_0, kg/s	- steam flow in turbine;
$G_{пв}$, kg/s	- feedwater flow rate;
$G_{дв}$, kg/s	- make-up water flow rate;

h_0, kJ/kg - enthalpy of steam at the turbine inlet;
$h_{\text{пв}}$, kJ/kg - enthalpy of feed water;
$h_{\text{дв}}$, kJ/kg - enthalpy of make-up water;
$\eta_{\text{тр1}}$, % - efficiency of heat transport of the 1st circuit (Pipes efficiency);
$\eta_{\text{пг}}$, % - efficiency of the steam generator;
$\eta_{\text{р}}$, % - efficiency of the reactor system;
$\text{э}_{\text{сн}}$, % - specific consumption of service power
K, MW·day/ton - average specific energy output of enriched nuclear fuel;
$T_{\text{уст}}$, hr/yr - number of hours of use of installed capacity.

Calculation Algorithm

1. Overall turbine's heat flow, MW

$$Q_{\text{ту}} = \frac{G_0 \cdot (h_0 - h_{\text{пв}}) + G_{\text{дв}} \cdot (h_{\text{пв}} - h_{\text{дв}})}{10^3}.$$

2. Absolute effective efficiency

$$\eta_{\text{e}} = \frac{N_{\text{e}} + N_{\text{e}}^{\text{тп}}}{Q_{\text{ту}}},$$

here, $N_{\text{e}} = \frac{N_{\text{э}}}{\eta_{\text{г}}}$.

3. Turbine system efficiency

$$\eta_{\text{ту}} = \frac{\eta_{\text{e}}}{\eta_{\text{г}}}.$$

4. Specific steam flow in turbine d_0, kg/(kW·hr)

$$d_0 = \frac{3,6 \cdot G_0}{N_{\text{э}}}.$$

5. Steam turbine plant (STP) heat rate, for generating electricity, kJ/(kW·hr)

$$q_{\text{ту}} = \frac{3600}{\eta_{\text{ту}}}.$$

6. Steam Generator heat load, MW

$$Q_{\text{пг}} = \frac{G_{\text{пв}} \cdot (h_0 - h_{\text{пв}})}{10^3}.$$

7. Efficiency of heat transport of the 1st circuit

$$\eta_{\text{тр2}} = \frac{Q_{\text{ту}}}{Q_{\text{пг}}}.$$

8. NPP Efficiency (gross)

$$\eta_{\text{c}} = \eta_{\text{р}} \cdot \eta_{\text{тр1}} \cdot \eta_{\text{пг}} \cdot \eta_{\text{тр2}} \cdot \eta_{\text{ту}}.$$

9. Overall reactor heat flow, MW

$$Q_{\text{р}} = \frac{N_{\text{э}}}{\eta_{\text{c}}}.$$

10. NPP Efficiency (net)

$$\eta_{\text{c}}^{\text{н}} = \eta_{\text{c}} \cdot \left(1 - \frac{\text{э}_{\text{сн}}}{100}\right).$$

11. Amount of burnup fuel, ton/yr

$$B_{\text{г}} = \frac{Q_{\text{р}} \cdot T_{\text{уст}}}{24 \cdot K}.$$

12. Specific consumption of fuel:
    a. In tons of coal equivalent, ton/kW h :

$$b_{ce} = \frac{34{,}1}{q_{\text{ту}}} \cdot 10^{-6}.$$

    b. In tons of nuclear fuel, ton/kW h:

$$b_{nf} = \frac{B_{\text{г}}}{N_e \cdot T_{\text{уст}}} = \frac{1}{2{,}4 \cdot 10^4 \cdot \eta_c \cdot K}.$$

13. Heat flow on production of electricity:

$$Q_{\text{ту}}^{e} = Q_{\text{ту}} - Q_c / \eta_{\text{тп}} \cdot \eta_{\text{пот}}.$$

14. Electrical efficiency of nuclear power plant (with heat supply):

$$\eta_e^{hs} = \frac{N_e + N_e^{\text{тп}}}{Q_{\text{ту}}^{e}}.$$

15. Thermal efficiency of nuclear power plant:

$$\eta_t = \eta_{\text{тп}} \cdot \eta_{\text{пот}}.$$

16. Gross electrical NPP Efficiency (with heat supply)

$$\eta_c^{hs} = \eta_{\text{р}} \cdot \eta_{\text{тр1}} \cdot \eta_{\text{пг}} \cdot \eta_{\text{тр2}} \cdot \eta_{\text{ту}}.$$

17. Gross thermal NPP Efficiency (with heat supply)

$$\eta_c^{hs} = \eta_{\text{р}} \cdot \eta_{\text{тр1}} \cdot \eta_{\text{пг}} \cdot \eta_{\text{тр2}} \cdot \eta_t.$$

18. Amount of burned fuel on production of electricity, ton/yr

$$B_{\text{г}}^{hs} = \frac{N_e \cdot T_{\text{уст}}}{24 \cdot K \cdot \eta_c^{hs}}.$$

19. Specific consumption of fuel on production of electricity (with heat supply):
    a. In tons of coal equivalent, ton/kW h :

$$b_{ce}^{hs} = \frac{3600 \cdot Q_{\text{ту}}^{e}}{N_e}$$

    b. In tons of nuclear fuel, ton/kW h:

$$b_{nf} = \frac{B_s^{hs}}{N_e \cdot T_{\text{уст}}} = \frac{1}{2{,}4 \cdot 10^4 \cdot \eta_c^{hs} \cdot K}.$$

References

1. Sesonske, A. Nuclear power plant design analysis / A. Sesonske. — Oak Ridge: TN USA: USAEC, 1973. — 487 p. – ISBN 0870790099.
2. Frangopoulos, C.A. Cogeneration: Technologies, Optimisation and Implementation / C.A. Frangopoulos. – Stevenage UK: IET,2017. – 344 p. – ISBN: 978-1-78561-055-4.

Individual homework assignment 2
"Determination of the optimal pressure in the condenser of an NPP."

Goal and objectives

1. Determine heat exchange surface area F and the main dimensions of the condenser n_{tubes}, L (number and length of tubes).
2. With reference to designed condenser determine how the pressure in the condenser changes if the actual flow rate of cooling water is reduced and becomes equal to G'_w.
3. Build $t-Q$ - diagram of condenser.

Brief information

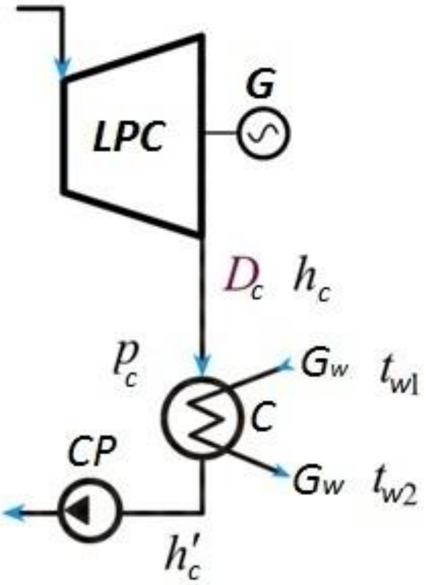

Fig.2. Scheme of simple condensing unit:
LPC – low pressure turbine cylinder; G – generator; C – condenser; CP – condensate pump

Condenser of steam turbine plant (Fig. 2) provides pressure after turbine p_c with the following initial parameters: cooling water input temperature t_{w1}, cooling water flow G_w, steam flow to the condenser D_c.

Material and dimensions $d_o \, x \, \delta_{wall}$ of tubes, number of strokes z for cooling water are known.

Notes:

- take into account the dependence of the rate w'_w of cooling water in the tubes on the flow rate G'_w;
- cooling water density is assumed to be equal ρ_w=1000 kg/m³;
- average heat capacity of the cooling water equals c_w =4,186 kJ/kg;
- coefficient of contamination of tubes equals a_0 =0,65…0,85.

Nomenclature

p_c, MPa	- pressure behind the turbine;
t_{w1}, °C	- cooling water temperature at condenser input;
t_{w2}, °C	- cooling water temperature at condenser input;

t_{sc}, °C - saturation temperature at a pressure in the condenser;
G_w, kg/s - cooling water flow rate;
D_c, kg/s - exhausts team flow rate;
d_o, m - the outer diameter of the tubes;
d_i, m - the inner diameter of the tubes;
δ_{wall}, m - tube wall thickness;
w_w, m/s - speed of cooling water in the condenser tubes;
a_0 - coefficient of tubes contamination;
a_m - correction factor for tubes material;
G'_w, kg/s - actual flow rate of cooling water;
w'_w, m/s - actual speed of the cooling water in tubes;

Calculation Algorithm

The first part of the task is design calculation of the condenser. Define the heat exchange surface area and the main dimensions of the condenser on the set parameters p_c, t_{w1}, G_w etc., calculating consequently:

1. The multiplicity of cooling

$$m = \frac{G_w}{D_c},$$

where G_w - cooling water flow rate, kg/s; D_c - steam flow rate to the condenser, kg/s;

2. The number of heat exchange tubes.

$$n_{tubes} = \frac{4 \cdot G_w \cdot z}{\pi \cdot d_i^2 \cdot \rho_w \cdot w_w},$$

where z - number of strokes for cooling water;
$d_i = d_o - 2 \cdot \delta_{wall}$ - the inner diameter of the tube, m; w_w - water speed in the tubes, m/s.

3. Heating of the cooling water in the condenser, ºC

$$\Delta t_w = \frac{r}{c_w \cdot m},$$

where r - the latent heat of vaporization at pressure p_c, kJ/kg. Determined by the water and water steam table by temperature t_{sc} or pressure kg°C).

4. Cooling water temperature at the output of condenser, ºC

$$t_{w2} = t_{w1} + \Delta t_w.$$

5. Thermal power transferred to the cooling water in the condenser, kW

$$Q_c = G_w \cdot c_w \cdot \Delta t_w.$$

6. Average temperature difference, ºC

$$\Delta t_{av} = \frac{\Delta t_w}{\ln\left(\frac{t_{sc} - t_{w1}}{t_{sc} - t_{w2}}\right)}$$

where t_{sc} - saturation temperature at a pressure in the condenser p_c.

7. Specific steam load d_c of the condenser is set. Initially accepted within the range 40…60 kg/(m²·x), and then checked.
8. The heat transfer coefficient is calculated according to one of the two equations.

At $t_{w1} \le 35°C$

$$k = 4070 \cdot a \cdot \left(\frac{1{,}1 \cdot w_w}{d_i^{0{,}25}} \right)^x \cdot \left[1 - \frac{0{,}52 - 0{,}002 \cdot d_{к} \cdot \sqrt{a}}{1000} \cdot \left(35 - t_{w1}\right)^2 \right] \cdot$$

$$\cdot \left[1 - \frac{z-2}{10} \cdot \left(1 - \frac{t_{w1}}{35} \right) \right] \cdot \Phi_d \,;$$

At t_{w1}=35…45°C

$$k = 4140 \cdot \left(\frac{1{,}1 \cdot w_w}{d_i^{0{,}25}} \right)^{0{,}6 \cdot a} \cdot \left[1 + 0{,}002 \cdot \left(t_{w1} - 35 \right) \right] \cdot \left[1 - \frac{z-2}{10} \cdot \left(1 - \frac{t_{w1}}{45} \right) \right] \cdot \Phi_d \,,$$

where k - in W/(m²·K);

$x = 0{,}12 \cdot a \cdot \left(1 + 0{,}15 \cdot t_{w1}\right)$;

$a = a_0 \cdot a_m$ – coefficient considering contamination and tube material;

a_0 =0,65…0,85 – coefficient considering tube contamination;

a_m - a correction factor that takes into account the material of tube: 0,95 –copper-nickel alloys; 1 – brass; 0,92 – copper-nickel; 0,85 – stainless steel; 0,9 – titanium.

w_w - speed of cooling water in the tubes, m/s;

d_i - the inner diameter of the tubes, mm;

t_{w1} - cooling water temperature at input, °C;

z - number of water strokes in the condenser;

Φ_d - coefficient considering the effect of steam load of condenser. Coefficient Φ_d equals1.

9. The area of heat transfer surface, m²

$$F = \frac{Q_c}{k \cdot \Delta t_{av}} \,.$$

10. The length of the heat exchange tubes, m

$$L = \frac{F}{n_{tubes} \cdot \pi \cdot d_o} \,,$$

where d_o - the outer diameter of the tubes, m.

11. Estimated value of the specific heat of the condenser, kg/(m²·hr)

$$d_c^{calc} = \frac{3600 \cdot D_c}{F} \,.$$

12. Compare value d_c^{calc} with given in point 7. At considerable (more than 3%) mismatch consider $d_c = d_c^{calc}$ and recalculate starting with point 8.

The second part of the problem is verification of calculations. In the new mode, the parameters will be indicated by a dash.

Define how the pressure changes in the condenser if actual cooling water if flow rate is reduced and becomes equal to G'_w. Calculate consequently:

Actual speed of the water in tubes $w'_w = w_w \cdot \dfrac{G'_w}{G_w}$,

where G_w, w_w - nominal (design, passport) flow rate and speed of cooling water.

Actual multiplicity of cooling $m' = \dfrac{G'_w}{D_c}$.

13. Actual heating of the cooling water in the condenser, ºC

$$\Delta t'_w = \frac{r}{c_w \cdot m'} ,$$

where r - the actual value of the latent heat of vaporization. Initially taken as 2400 kJ/kg, and then checked;

c_w - heat capacity of cooling water, kJ/(kg°C).

14. Heat transfer coefficient at actual cooling water speed w'_w. Determined by the equation in point 8 at values d_c и Φ_d as in design calculation.
15. Under heating in the condenser to saturation at the actual flow rate of the cooling water

$$\delta t_н = \frac{\Delta t'_w}{\exp\left(\dfrac{k' \cdot 3,6}{c_w \cdot m' \cdot d_c}\right) - 1} .$$

16. Saturation temperature in the condenser at the actual input temperature

$$t'_{sc} = t_{w1} + \Delta t'_w + \delta t_н .$$

17. Pressure in condenser p'_c at the actual input temperature. Determined by the water and water steam table as pressure of saturation at the temperature t'_{sc}.
18. Calculated value of the latent heat of vaporization r_{calc}, kJ/kg. Determined by the water and water steam table by temperature..and pressure p'_c.
19. Compare calculated value r_{calc} with given in point 15. At considerable (more than 3%) mismatch consider $r = r_{calc}$ and recalculate starting with point 13.

References

1. Sesonske, A. Nuclear power plant design analysis / A. Sesonske. — Oak Ridge: TN USA: USAEC, 1973. — 487 p. – ISBN 0870790099.
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Individual homework assignment 3
“Determination of the optimal selection pressure for powering the NPP deaerator”

Goal and objectives

1. Calculate turbine efficiency for the basic mode η_{tu} .
2. Determine expenditures and particular settings for the mode with the new value of the degree of pressure reduction $k_{th} = p_1/p_D$ in reducer.
3. Calculate turbine efficiency for the new mode η_{tu}^{new} .
4. Analyze the influence of the degree of pressure reduction k_{th} on the efficiency of steam turbine plant.

Brief information

The condensing unit is composed of a deaerator D and two surface-type regenerative preheaters HPH-1, HPH-2 (Fig. 3). Deaerator D is connected in parallel with the preheater HPH-1 ("fork" scheme).

Main parameters of the working fluid for the basic mode are known.

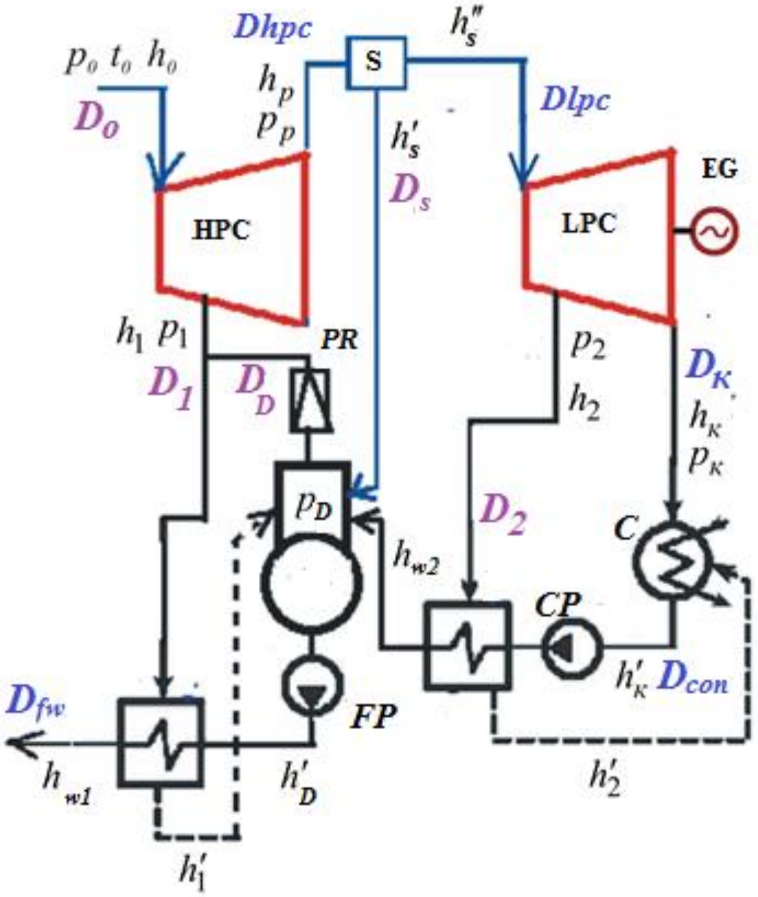

Fig.3. Thermal scheme of a turbine plant with "fork" connection circuit of deaerator: HPC, LPC– turbine high and low pressure cylinders; S – separator; EG – electric generator; C- condenser, CP, FP – condensate and feed pumps; HPH-1, HPH-2 – regenerative surface type heaters; D – deaerator; PR – pressure reducing device

Nomenclature

D_0, kg/s - steam flow in the turbine;

D_1, kg/s	- steam flow in the heater HPH-1;
D_D, kg/s	- steam flow in the deaerator;
D_2, kg/s	- steam flow in the heater HPH-2;
D_s, kg/s	- water (condensate) flow from separator;
D_{fw}, kg/s	- feed water flow;
D_{con}, kg/s	- main condensate flow;
$D_{к}$, kg/s	- exhaust steam flow;
h_0, kJ/kg	- enthalpy of steam at the turbine input;
h_p, kJ/kg	- enthalpy of steam behind turbine HPC;
h'_s, kJ/kg	- enthalpy of the water discharged from the separator;
h''_s, kJ/kg	- enthalpy of dry steam after separator;
h_k, kJ/kg	- enthalpy of exhaust steam after the turbine;
$h'_{к}$, kJ/kg	- enthalpy of water after the condenser;
h_1, kJ/kg	- enthalpy of heating steam HPH-1;
h'_1, kJ/kg	- drainage enthalpy of heating steam HPH-1;
h_{w1}, kJ/kg	- enthalpy of the water after HPH-1;
h'_D, kJ/kg	- enthalpy of feed water after the deaerator;
h_2, kJ/kg	- enthalpy of heating steam HPH-2;
h'_2, kJ/kg	- drainage enthalpy of heating steam HPH-2;
h_{w2}, kJ/kg	- enthalpy of the water after HPH-2;
k_{th}	- throttling coefficient. equal to p_1/p_D

Calculation Algorithm

1. Show the process of steam expansion in hs - diagram and put the values of designed parameters.
2. Calculate the efficiency of the turbine for the basic mode
$$\eta_{tu} = \frac{D_0 \cdot (h_0 - h_1) + D_{HPC} \cdot (h_1 - h_p) + D_{LPC} \cdot (h''_s - h_2) + D_{к} \cdot (h_2 - h_{к})}{D_{fw} \cdot (h_0 - h_{w1})}.$$
3. Calculate new pressure in the deaerator $p_D^{new} = k_{th}^{new} \cdot p_1$.
4. Find new enthalpy of water $.h'_{D.new}.$ at deaerator output as enthalpy of saturated water under pressure p_D^{new}.
5. Determine the equation of heat and material balances of deaerator and define new flow of heating steam D_D^{new}
$$D_1 \cdot h'_1 + D_D^{new} \cdot h_1 + D_s \cdot h'_s + D_{con}^{new} \cdot h_{w2} = D_{fw} \cdot h'_{D.new};$$
$$D_1 + D_D^{new} + D_s + D_{con}^{new} = D_{fw}.$$
6. Define a new value of steam flow at the output of HPC $D_{HPC}^{new} = D_0 - D_1 - D_D$
7. Compare new D_{HPC}^{new} and basic D_{HPC} values of steam flow at the output of HPC. If the relative error exceeds 3%, it is necessary to recalculate some elements of the scheme.
8. Put down the equation of heat and material balances for the separator.
$$D_{HPC}^{new} \cdot h_p = D_{LHC}^{new} \cdot h''_s + D_s^{new} \cdot h'_s$$

$$D_{HPC}^{new} = D_{LHC}^{new} + D_{s}^{new}$$

9. Solve these equations and determine the flow D_{s}^{new}.
10. Repeat steps 4 - 6 with new value of steam flow D_{s}^{new} from separator.
11. When the difference of values D_{HPC}^{new} in this and previous step becomes less than 3%, it is necessary to recalculate heater HPH-2.
12. Make HPH-2 equation of heat balance, solve it and find new flow D_{2}^{new} of heating steam

$$D_{2}^{new} \cdot \left(h_2 - h_2'\right) = D_{con}^{new} \cdot \left(h_{w2} - h_{к}'\right).$$

13. Using equation from step 1 calculate the efficiency of the turbine for the new mode.

References

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3. Drbal, L.F. Power plant engineering / L.F. Drbal, P.G. Boston, K.L. Westra, R.B. Erickson. – New York, NY USA: Chapman and Hall, 1996. – 858 p. – ISBN 0 412 06401 4.

Individual homework assignment 4
“Determination of the optimal selection pressure for powering the NPP deaerator”

Goal and objectives

1. Determine the flow rate of fresh steam D_0 and electric efficiency for the condensation (before reconstruction) turbine installation $\eta_{ту}$.
2. Connect the network heater, determine the steam flow to it and recalculate the thermal scheme of the TPP.
3. Determine the electrical power $N_э^{т}$ and efficiency of the turbine installation $\eta_{ту}^{э}$ for generating electricity after reconstruction with a constant flow of fresh steam $D_0 = D_0^{т}$.
4. Make up a power balance for the reconstructed NPP.

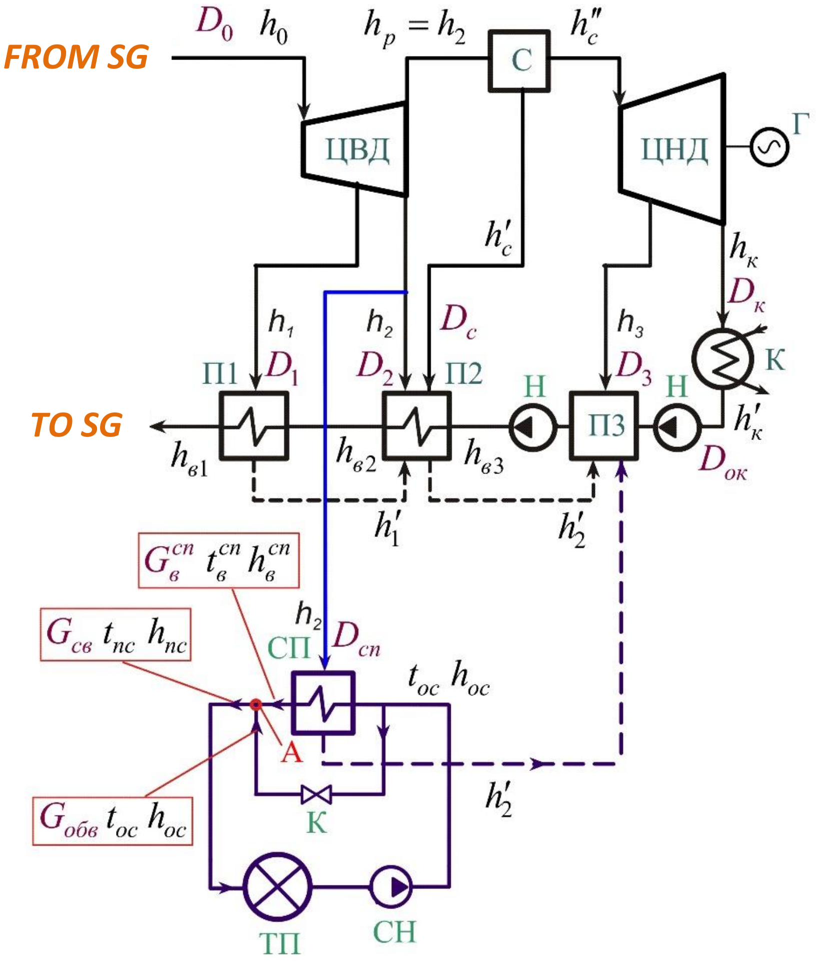

Fig. 4. The design scheme of a steam-turbine plant: ЦВД, ЦНД – cylinders of the turbine; С – separator; Г – power generator; П1, П2, П3 – regenerative heaters; Н – pump; СП – network heater; ТП – heat consumers; СН – network pump.

Brief information

Condensation power plant unit has three regenerative heaters (figure 1) in its scheme. The variant of reconstruction of the power unit is considered with the purpose of organizing unregulated steam selection in the turbine for heat supply for heating and hot water supply purposes.

The heat load of the supplied heat $Q_т$ and the temperatures of the water on the inlet and outlet of heat system in the basic mode are set as $t_{пс} / t_{ос}$.

Notes:

- Calculation of the thermal scheme of the reconstructed (with the network heater) steam turbine installation is performed with the same flow of fresh steam as in the condensing TPP;
- drain of the heating steam from the network heater should be directed to П3;
- regulation of the network water temperature, which is supplied to the consumers, should be made by bypassing (bypass) the network heater;
- pressure losses in the pipelines and during compression in the pumps should be neglected.

Nomenclature

$N_э$, MW - electric power of the condensing turbine unit;
$N_э^т$, MW - electric power of the reconstructed TPP (with a network heater);
p_0, MPa - pressure of fresh steam;
t_0, °C - temperature of fresh steam;
$p_к$, MPa - pressure of the exhaust steam (in the condenser);
$p_р$, MPa - separation pressure (after MPC);
p_1, MPa - steam pressure in the first bleed;
p_2, MPa - steam pressure in the second bleed;
p_3, MPa - steam pressure in the third sbleed;
η_{oi}, % - relative internal efficiency of the turbine;
$\theta_н$, °C - underheating of the water to saturation in regenerative heaters;
$\eta_м$, % - mechanical efficiency turbine unit;
$\eta_{эг}$, % - efficiency of an electric generator;
$Q_т$, MW - thermal load of the network heater;
$p_{св}$, MPa - average pressure of the network water;
$t_{пс}$, °C - the temperature of the network water in the "direct" line;
$t_{ос}$, °C - the temperature of the network water in the "reverse" line;
$\theta_н^{сп}$, °C - underheating of the water to saturation in the network heater;
h_0, kJ/kg - the enthalpy of fresh steam;
$h_к$, kJ/kg - the enthalpy of the exhausted steam;
$h'_к$, kJ/kg - the enthalpy of the main condensate after the condenser;
$h''_с$, kJ/kg - the enthalpy of dry steam after the separator;
$h'_с$, kJ/kg - the enthalpy of water after the separator;
h_1, kJ/kg - enthalpy of heating steam in the first bleed;
h_2, kJ/kg - enthalpy of heating steam in the second bleed;
h_3, kJ/kg - enthalpy of heating steam in the third bleed;
h'_1, kJ/kg - enthalpy of drainage (condensate) of the heating steam of the first bleed;
h'_2, kJ/kg - enthalpy of drainage (condensate) of heating steam of the second bleed;
h'_3, kJ/kg - enthalpy of drainage (condensate) of heating steam of the third bleed;
$h_{в1}$, kJ/kg - enthalpy of heated water after П1;

$h_{\text{в2}}$, kJ/kg - enthalpy of heated water after P2;
$h_{\text{в3}}$, kJ/kg - enthalpy of heated water after P3;
D_1, kg/s - consumption of heating steam for P1;
D_2, kg/s - consumption of heating steam for P2;
D_3, kg/s - consumption of heating steam for P3;
$D_{\text{с}}$, kg/s - water flow from the separator.

Calculation Algorithm

1. The main results of calculating the thermal scheme for the condensation regime are given in table of initial data. In addition, we calculate some energy indicators:
   a. The flow rate of fresh steam D_0 to the turbine is found from the energy equation

$$\left[D_0\cdot(h_0-h_1)+(D_0-D_1)\cdot(h_1-h_2)+(D_0-D_1-D_2-D_{\text{с}})\cdot(h''_{\text{с}}-h_3)+\right.$$
$$\left.+D_{\text{к}}\cdot(h_3-h_{\text{к}})\right]\cdot\eta_{\text{м}}\cdot\eta_{\text{эг}}=N_{\text{э}},$$

here $N_{\text{э}}$ - в кВт; h_0, $h_1, h_2, \ldots$- in kJ/kg; $D_{\text{к}}$ - outlet steam flow rate.

   b. Total heat power of turbine unit, kW

$$Q_{\text{ту}}=D_0\cdot(h_0-h_{\text{пв}}),$$

here $h_{\text{пв}}=h_{\text{в1}}$ - enthalpy of feed water at the steam generator inlet, kJ / kg.

   c. Efficiency of the turbo-electric unit

$$\eta_{\text{ту}}=\frac{N_{\text{э}}}{Q_{\text{ту}}},$$

here $N_{\text{э}}$ - in kW.

2. To calculate the flow rate of network water we will use the following equation

3. $$G_{\text{св}}=\frac{Q_{\text{т}}\cdot 10^3}{h_{\text{пс}}-h_{\text{ос}}},$$

here $Q_{\text{т}}$ - in MW; $h_{\text{пс}}$, $h_{\text{ос}}$ - enthalpy of the network water in the "direct" and "reverse" lines, kJ/kg. They could be determined by the pressure $p_{\text{св}}$ and temperatures $t_{\text{пс}}$ and $t_{\text{ос}}$.

4. Connect the network heater to the second selection. In this case, this condition should be fulfilled

$$t_{\text{нас2}}-\theta_{\text{н}}^{\text{сп}}>t_{\text{пс}},$$

here $t_{\text{нас2}}$ - saturation temperature at pressure p_2.

5. Let us find in this case the temperature of the network water directly behind the mains heater:

$$t_{\text{в}}^{\text{сп}}=t_{\text{нас2}}-\theta_{\text{н}}^{\text{сп}}.$$

6. If the obtained temperature $t_{\text{в}}^{\text{сп}}$ exceeds the set temperature of the network water $t_{\text{пс}}$ in the "straight" line, then it is necessary to route part of the network water to the bypass of the network heater along the bypass line. As a result, the temperature of the network water sent to consumers can be reduced to the set value $t_{\text{пс}}$.

7. Calculate what the flow of network water $G_{\text{в}}^{\text{сп}}$ should go through the district heater, and what is on the bypass line $G_{\text{обв}}$. To do this, we will compose and solve the heat balance equation for point A (Figure 1)

$$G_{\text{в}}^{\text{сп}}\cdot h_{\text{в}}^{\text{сп}}+\left(G_{\text{св}}-G_{\text{в}}^{\text{сп}}\right)\cdot h_{\text{ос}}=G_{\text{св}}\cdot h_{\text{пс}},$$

here $h_{\text{в}}^{\text{сп}}$ - enthalpy of net water directly for the SP, kJ / kg. It could be defined using pressure $p_{\text{св}}$ and temperature $t_{\text{в}}^{\text{сп}}$.

8. Define the flow of heating steam to the DH from the corresponding heat balance equation

$$D_{\text{сп}}\cdot\left(h_2-h_2'\right)=G_{\text{в}}^{\text{сп}}\cdot\left(h_{\text{в}}^{\text{сп}}-h_{\text{ос}}\right).$$

9. Recalculate the thermal scheme of the turbine installation taking into account the connection of the district heater. At the same time, the consumption of heater P1 does not change from the connection of the network heater.

a. To do this, we will compile and jointly solve the system from the equations of thermal and material balances for the separator, heaters П2 and П3. As a result, we find the flow rates $D_2^{\text{т}}$ and $D_3^{\text{т}}$ of heating the steam for П2, П3 and the flow of water from the separator.

$$\left(D_0-D_1-D_2^{\text{т}}-D_{\text{сп}}\right)\cdot h_2=D_{\text{с}}^{\text{т}}\cdot h'+_{\text{с}}\left(D_0-D_1-D_2^{\text{т}}-D_{\text{сп}}-D_{\text{с}}^{\text{т}}\right)\cdot h_{\text{с}}''$$

$$D_2^{\text{т}}\cdot\left(h_2-h_2'\right)+D_1\cdot\left(h_1'-h_2'\right)+D_{\text{с}}^{\text{т}}\cdot\left(h_{\text{с}}'-h_2'\right)=D_0\cdot\left(h_{\text{в}1}-h_{\text{в}2}\right)$$

$$D_3^{\text{т}}\cdot h_3+\left(D_1+D_2^{\text{т}}+D_{\text{с}}^{\text{т}}+D_{\text{сп}}\right)\cdot h_2'+D_{\text{ок}}^{\text{т}}\cdot h_{\text{к}}'=D_0\cdot h_{\text{в}3}$$

$$D_3^{\text{т}}+\left(D_1+D_2^{\text{т}}+D_{\text{с}}^{\text{т}}+D_{\text{сп}}\right)+D_{\text{ок}}^{\text{т}}=D_0$$

b. Electric power $N_{\text{э}}^{\text{т}}$ in the heating mode is found from the turbine power equation

$$\Big[D_0\cdot\left(h_0-h_1\right)+\left(D_0-D_1\right)\cdot\left(h_1-h_2\right)+\left(D_0-D_1-D_2^{\text{т}}-D_{\text{с}}^{\text{т}}-D_{\text{сп}}\right)\cdot\left(h_{\text{с}}''-h_3\right)+$$
$$+D_{\text{к}}^{\text{т}}\cdot\left(h_3-h_{\text{к}}\right)\Big]\cdot\eta_{\text{м}}\cdot\eta_{\text{эг}}=N_{\text{э}}^{\text{т}},$$

10. Calculate the heat consumption for the turbine unit for the generation of electrical energy, kW

$$Q_{\text{ту}}^{\text{э}}=D_0\cdot\left(h_0-h_{\text{пв}}\right)-Q_{\text{т}},$$

here $Q_{\text{т}}$ - in kW.

11. We will calculate the efficiency of a turbine installation for generating electricity

$$\eta_{\text{ту}}^{\text{э}}=\frac{N_{\text{э}}}{Q_{\text{ту}}^{\text{э}}},$$

here $N_{\text{э}}$ - in kW.

12. Let's formulate the power balance equation for the turbo installation in the heating mode

$$D_0\cdot\left(h_0-h_{\text{пв}}\right)=D_{\text{к}}\cdot\left(h_{\text{к}}-h_{\text{к}}'\right)+\frac{N_{\text{э}}}{\eta_{\text{м}}\cdot\eta_{\text{эг}}}+Q_{\text{т}}$$

here $N_{\text{э}}$ and $Q_{\text{т}}$ - in kW; $D_{\text{к}}=D_0-D_1-D_2^{\text{т}}-D_3^{\text{т}}-D_{\text{сп}}-D_{\text{с}}^{\text{т}}$ - steam flow rate on the outlet of turbine, kg/s.

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