Problem

Design (?) a cycle arrangement for STP NPP with Z RFWH stages at pre-assigned values of $\boldsymbol{p_0}$, $\boldsymbol{t_0}$, $\boldsymbol{p_к}$ ***(etc)*** *and electrical output of* $\boldsymbol{N_э}$.

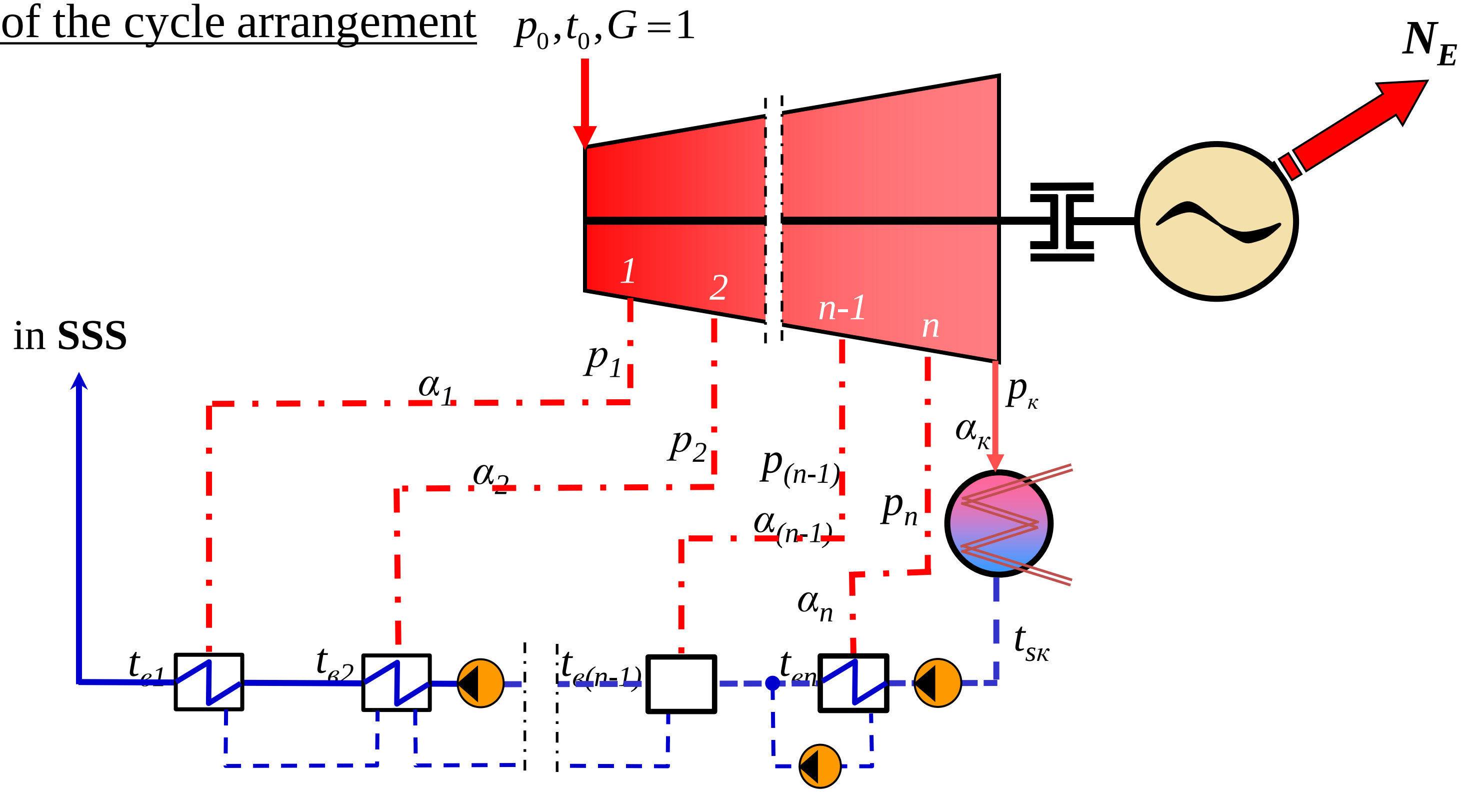
Note: a) ***"etc."***: the parameters may be set for steam reheating, moisture separation, heat dispatching for external customers, i.e. everything that impacts the structure of the turbine and steam expansion in the turbine;

b) in our case, the type of heaters is set.

Design a cycle arrangement:

- make a flowchart for steam turbine plant with sequential location of heaters, their connection to the turbine and installation of the required number of pumps
- determine the parameters for steam and water at the nodal points of the flowchart (parameters for water at the heaters outlet and those for the steam at the turbine outlet)
- determine water and steam flows in relative units (related to the steam flow for the turbine) or in CGS units expressed through the steam flow for the turbine. It is determined by solving the equation system of heat and material balance for heaters and other thermal and mechanical equipment
- determine the steam flow for the turbine in dimensional quantities (kg/s, t /h) by the energy equation of the turbine
- determine the indices of heat efficiency: absolute EF, specific heat and steam flows

1. Design of the cycle arrangement



2. Determination of the parameters at the nodal points of the flowchart and design of the parameter table

2. Determination of parameters по подогревателям (water and drain at the outlet)

Water heating in the turbine: from $t_{sк} = f(p_к)$ to $t_{s0} = f(p_0)$

Feed water temperature:

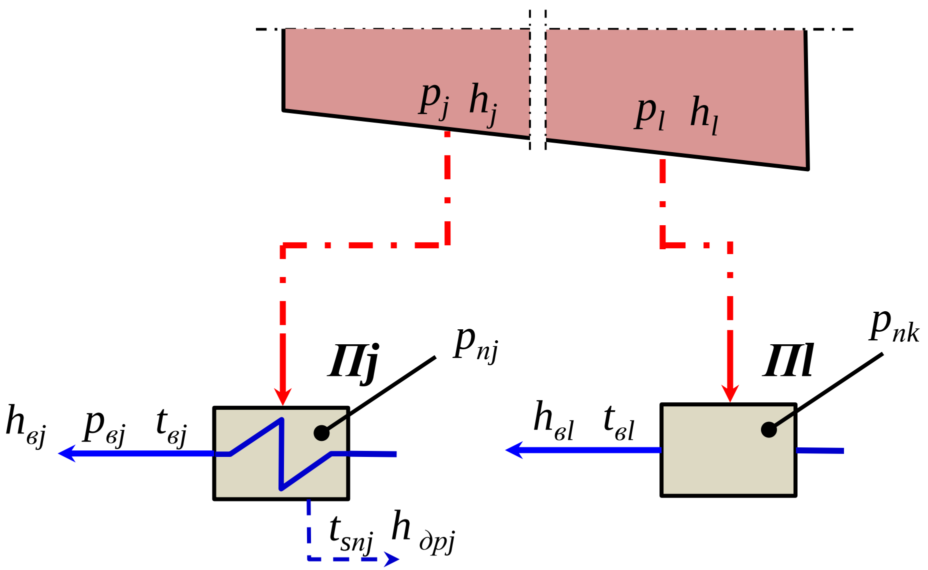
$$\left(t_{пв}^{opt}\right)_Z = t_{sк} + \frac{z}{z+1}\left(t_{s0} - t_{sк}\right) = t_{в1}$$

Water heating in the regenerative heating stage:

$$\Delta t_{вj} = \frac{\left(t_{в1} - t_{sк}\right)}{z}$$

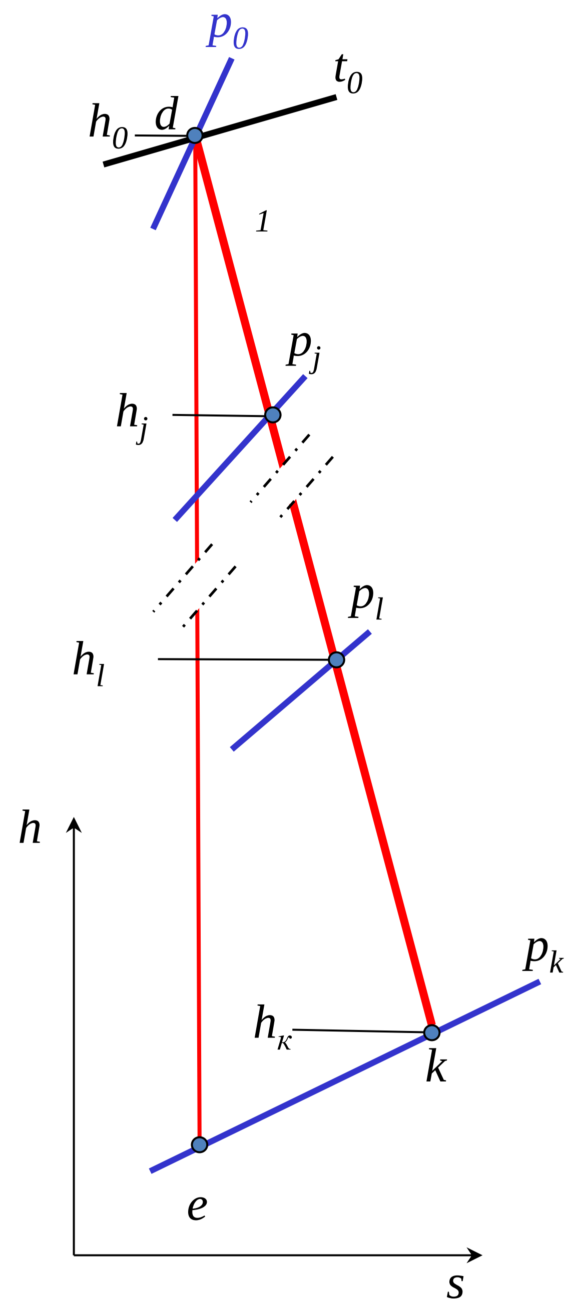
Water temperature at the outlet of the *j*-th regenerative heating stage:

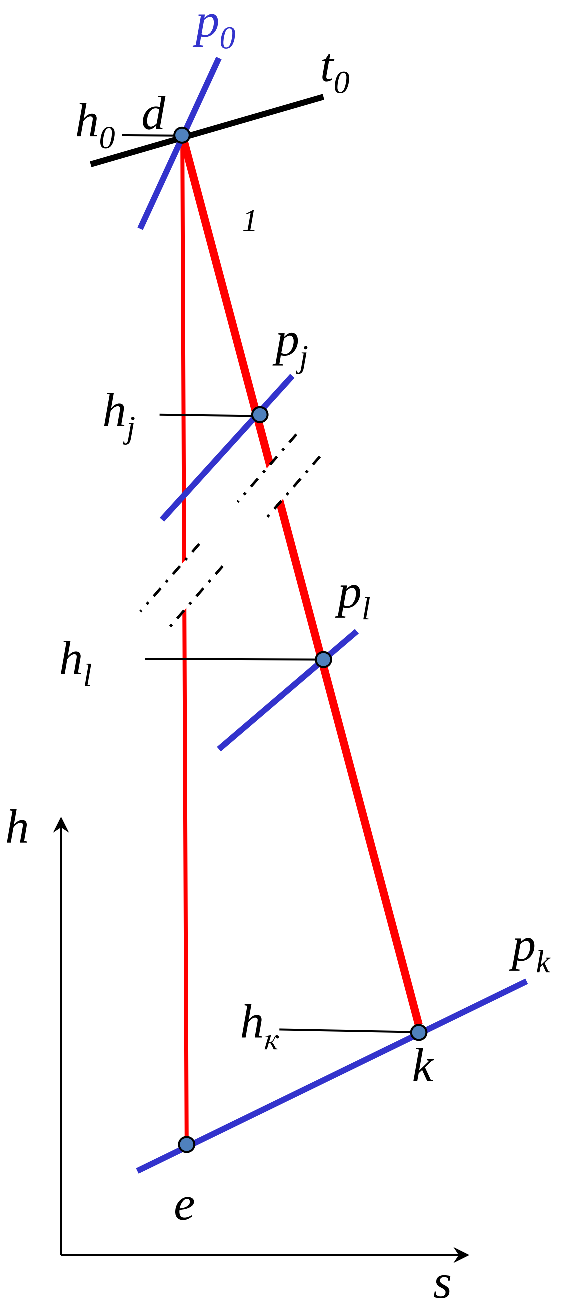
$$t_{вj} = t_{в(j+1)} + \Delta t_{вj}$$



0. $t_{вj}$
1. $t_{snj}=t_{вj}+\Theta$
2. $p_{nj}=f\,(t_{snj})$
3. $h_{дpj}=f\,(t_{snj})$
4. $p_{вj}$ *is determined by the pressure built by the pump circulating water through the j-th heater*
5. $h_{вj}=f\,(t_{вj},\,p_{вj})$
6. $p_j=\,p_{nj}\,(0{,}97\div 0{,}98)$
7. H_j *is determined by steam expansion in the turbine*

0. $t_{вl}$
1. $t_{snl}=t_{вl}$
2. $p_{nl}=f\,(t_{snl})$
3. $h_{вl}=f\,(t_{snl})$
4. $p_{вl}\,=\,p_{nl}$
5. $p_l=\,p_{nl}\,(0{,}97\div 0{,}98)$
6. h_l *is determined by steam expansion in the turbine*





p_0
t_0
h_0
d
1
p_j
h_j
p_l
h_l
h
p_k
$h_к$
k
e
s

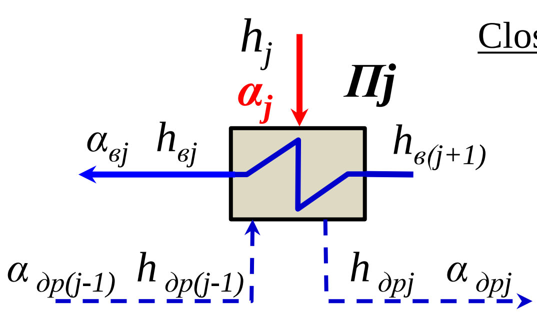
Table 1 – Parameters of steam and water according to the cycle arrangement

No.	Extraction steam			Heater drain			Water at the heater outlet			Reduced power generation factor
	p_j	t_j	h_j	p_{nj}	t_{snj}	$h_{\partial pj}$	$t_{вj}$	$p_{вj}$	$h_{вj}$	y_j
	MPa	*°C*	*kJ/kg*	*MPa*	*°C*	*kJ/kg*	*°C*	*MPa*	*kJ/kg*	-
0	p_0	t_0	h_0	-	-	-	-	-	-	1
1										
…										
ПП	p_{nn}	t_{nn}	h_{nn}	-	-	-	-	-	-	-
…										
Z										
K	$p_к$	$t_к$	$h_к$	-	-	-	-	-	-	0

Generation and solution of heat and material balance equations

(determination of steam and water flows according to the cycle arrangement)

The heaters are considered in sequence against the water flow. Why?

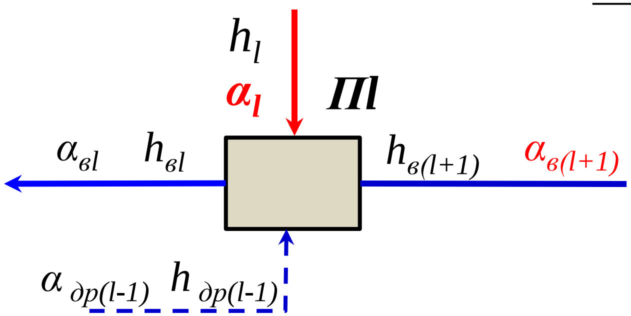


Closed heater

$$\alpha_j\left(h_j - h_{\partial pj}\right) + \alpha_{\partial p(j-1)}\left(h_{\partial p(j-1)} - h_{\partial pj}\right) = \alpha_в\left(h_{вj} - h_{в(j+1)}\right)$$

$$\alpha_{\partial pj} = \alpha_j + \alpha_{\partial p(j-1)}$$

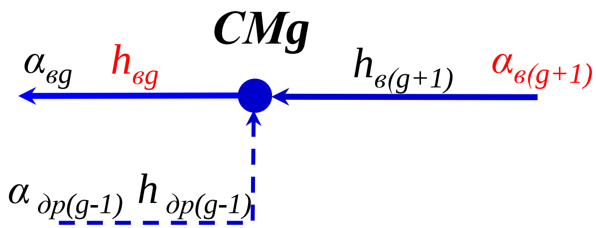
Mixing heater



$$\alpha_{\text{в}(l+1)} h_{\text{в}(l+1)} + \alpha_l h_l + \alpha_{\text{д}p(l-1)} h_{\text{д}p(l-1)} = \alpha_{\text{в}l} h_{\text{в}l} \frac{1}{\eta_n}$$

$$\alpha_{\text{в}l} = \alpha_{\text{в}(l+1)} + \alpha_l + \alpha_{\text{д}p(l-1)}$$

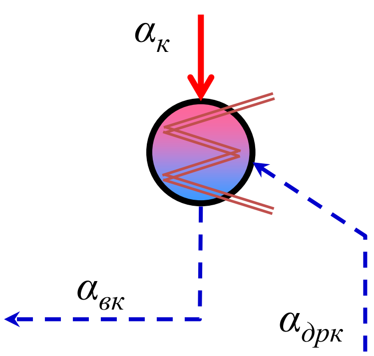
Mixing point



$$\alpha_{\text{в}(g+1)} h_{\text{в}(g+1)} + \alpha_{\text{д}p(g-1)} h_{\text{д}p(g-1)} = \alpha_{\text{в}g} h_{\text{в}g}$$

$$\alpha_{\text{в}g} = \alpha_{\text{в}(g+1)} + \alpha_{\text{д}p(g-1)}$$

Condenser material balance



A) according to the material balance of the regenerative heaters:

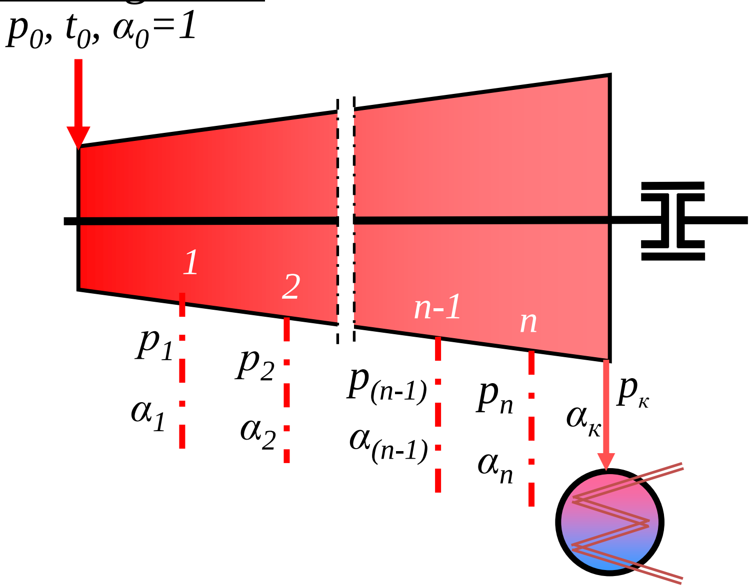
$$\alpha_{\text{к}} = \alpha_{\text{вк}} - \alpha_{\text{дрк}}$$

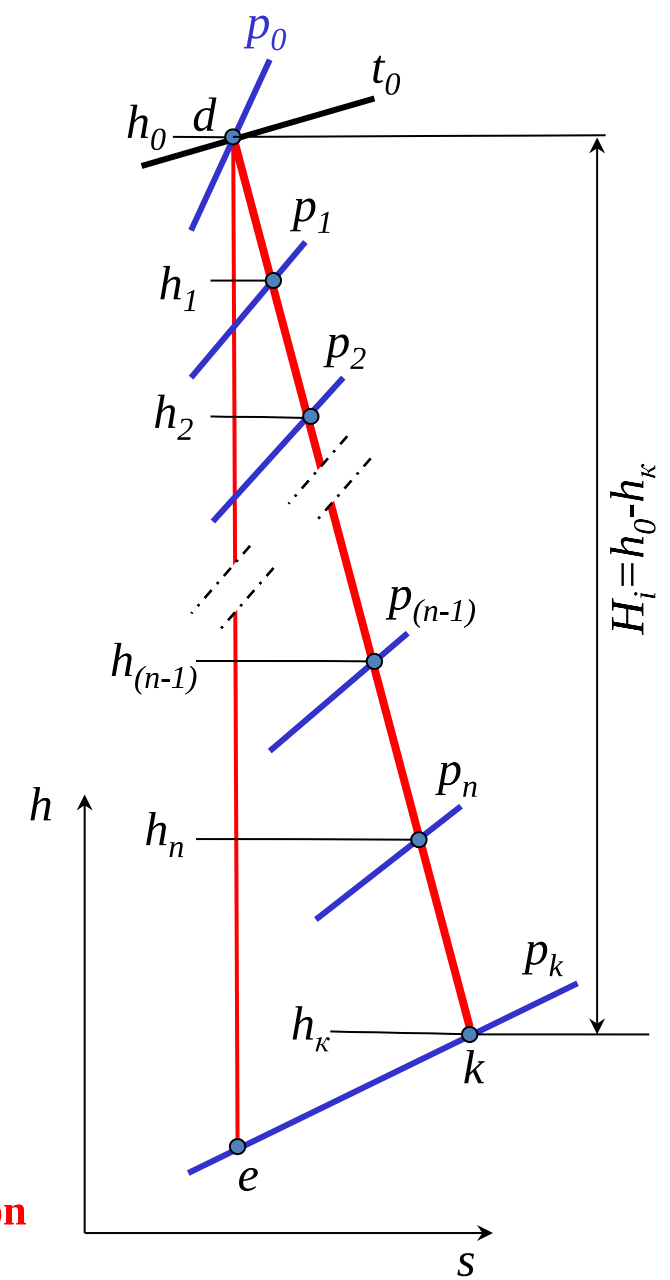
B) according to the material balance of the turbine:

$$\alpha_{\text{к}} = 1 - \sum_{j=1}^{z} \alpha_j$$

= !

Determination of the steam flow for the turbine and steam and water flows according to the cycle arrangement





Internal turbine power generated by α_0:

$$L_i = \alpha_1(h_0-h_1)+\alpha_2(h_0-h_2)+\ldots+\alpha_n(h_0-h_n)+\alpha_\kappa(h_0-h_\kappa)$$

$$=1\cdot(h_0-h_\kappa)-\alpha_1(h_1-h_\kappa)-\alpha_2(h_2-h_\kappa)-\ldots-\alpha_n(h_n-h_\kappa)$$

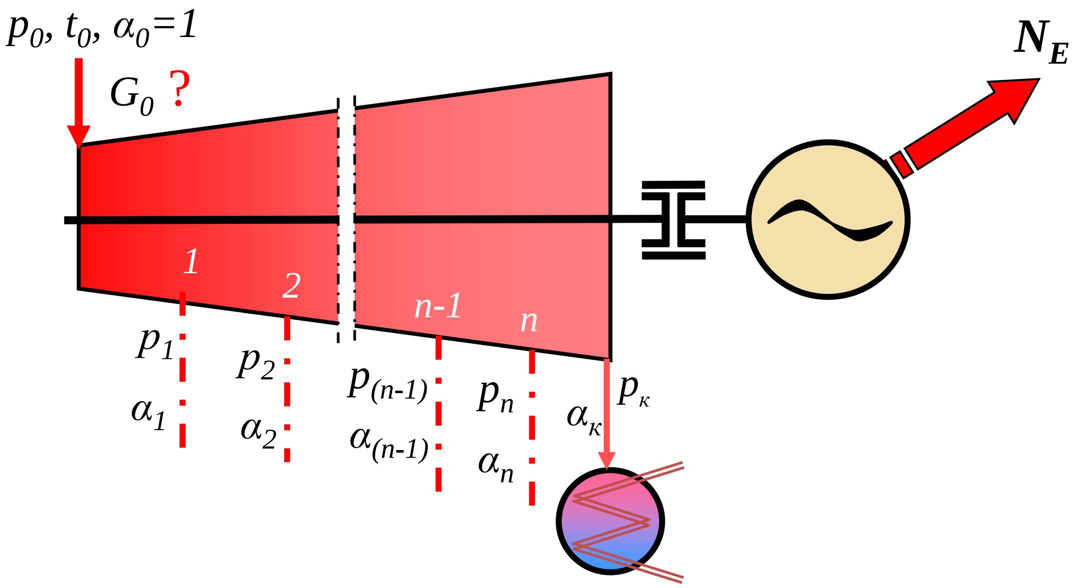
$$=(h_0-h_\kappa)\left[1-\alpha_1\frac{(h_1-h_\kappa)}{(h_0-h_\kappa)}-\alpha_2\frac{(h_2-h_\kappa)}{(h_0-h_\kappa)}-\ldots-\alpha_n\frac{(h_n-h_\kappa)}{(h_0-h_\kappa)}\right]$$

$$=H_i\left(1-\sum_{j=1}^{n}\alpha_j y_j\right)=H_{экв}$$

$$\frac{(h_j-h_\kappa)}{(h_0-h_\kappa)}$$

j from 1 to n **the factor of reduced power generation by the *j*-th extraction steam**

$$(h_0-h_\kappa)=H_i$$



$$G_0 = \frac{N_Э}{H_{экв}\eta_м\eta_{эг}} = \frac{N_Э}{H_i\left(1 - \sum_{j=1}^{n}\alpha_j y_j\right)\eta_м\eta_{эг}}, \quad kg/s$$

$$G_0 = \frac{N_Э}{H_i\eta_м\eta_{эг}} + \sum_{j=1}^{n} G_j y_j,$$

$$G_j = \alpha_j G_0$$

Reduced power generation factor

$$\frac{(h_j - h_к)}{(h_0 - h_к)} = y_j$$ ← for the turbine without reheating

$$0 \le y_j \le 1$$

For the turbine with reheating

$$H_i = (h_0 - h_к) + \left(h_{пп} - h^*_{пп}\right)$$

- for extraction before reheating:

$$y_j = \frac{\left(h_j - h_к\right) + \left(h_{пп} - h^*_{пп}\right)}{\left(h_0 - h_к\right) + \left(h_{пп} - h^*_{пп}\right)} = \frac{\left(h_j - h_к\right) + \left(h_{пп} - h^*_{пп}\right)}{H_i}$$

- for extraction after reheating:

$$y_f = \frac{\left(h_f - h_к\right)}{\left(h_0 - h_к\right) + \left(h_{пп} - h^*_{пп}\right)} = \frac{\left(h_f - h_к\right)}{H_i}$$