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The impact of changes in electric power plant unit values on selected indicators of steam condenser

Abstract. *The article discusses the impact of changes in electric power plant unit values on selected indicators of the steam condenser. Discussed and shown on the charts is the relationship of the indicators of the steam condenser and the capacity of the power unit. The research focussed on the impact of sediments in the condenser tubes on the increase of resistance of the heat transfer for selected values of the power unit. Moreover, the effects of tube cleaning of the steam turbine condensers are presented using an example of the condenser SF-11420-5.*

Streszczenie. *W artykule przedstawiono wyniki badania wpływu zmiany mocy elektrycznej bloku energetycznego na wskaźniki skraplacza pary. Omówiono i pokazano na wykresach zależność wskaźników skraplacza pary od mocy elektrycznej bloku energetycznego. Zwrócono uwagę na oddziaływanie osadów w rurkach na wzrost oporów przenoszenia ciepła dla wybranych wartości mocy bloku oraz przedstawiono efekty czyszczenia rurek skraplaczy turbin parowych na przykładzie skraplacza SF-11420-5.* ***(Wpływ zmiany mocy elektrycznej bloku energetycznego na wartości wybranych wskaźników skraplacza pary)***

Key words: condenser, power unit, power of the power unit, heat
Słowa kluczowe: skraplacz, blok energetyczny, moc bloku, ciepło

Introduction

The changing demand for electrical energy and its dependence on numerous factors are translated into the necessity of forecasting and scheduling of generation of energy. The obligations of individual power units in relation to the Operator of the Transmission System as regards generation of electric energy in every hour of the trading day are equal to the reference energy which includes:

- electrical energy resulting from the current working points (BPP),
- electrical energy resulting from the operation of primary and secondary control systems.

Therefore, during the day, the operating power unit should generate the daily power output scheduled depending on the demand of the National Energy System (KSE).

For each load of the power unit we can determine the operating parameters on the heat side with the minimum energy losses and minimum value of the energy consumption. Due to the fact that the technical condition and operating parameters of the condenser are significant for the heat rate of the turbine set, it is important to ensure the operating control of its equipment and installations, including the cooling water pump, depending on the capacity of the power unit.

Relationship of the steam condenser ratios and the capacity of the power unit

The power characteristics of the turbine set defining the dependence of the heat used by the turbine set and the condenser upon the generated power can be defined based on the results of the measurements of values necessary to carry out a heat balance at various loads [1]:

$$Q_{ts} = m_{pt}\left(i_{pt} - i_{pm1t}\right) + \sum_{j=1}^{n_{uw}} m_{pj}\left(i_{pt} - i_{pj}\right) + \sum_{j=n_{uw}}^{n_u} m_{pj}\left(i_{pm2t} - i_{pj}\right) + m_{D2}\left(i_{pm2t} - i_{sk}\right) \tag{1}$$

$$= \frac{P}{\eta_{ot}\eta_{tw}\eta_m\eta_g\eta_{dl}},$$

where: Q_{ts} – heat flux taken over by the turbine and the condenser, W; m_{pt}, i_{pt} – mass flow (kg/s) and enthalpy (J/kg) of steam at the turbine inlet; i_{pm1t}, i_{pm2t} – enthalpy of outgoing steam and returning steam from the interstage superheater; m_{pj}, i_{pj} – mass flow and steam enthalpy at the consewcutive extraction; m_{D2} – mass flow of incoming steam to the condenser; i_{sk} – condensate enthalpy; n_u – number of steam bleedings; n_{uw} – number of bleedings in the HP part of the turbine; η_{ot} – ideal efficiency of the cycle; η_{tw} – internal efficiency of the turbine; η_m – mechanical efficiency of the turbine set; η_g – generator efficiency; η_{dl} – energy loss ratio in the glands; P – active power at the generator terminals, W.

The heat balance without taking into account the radiation heat losses and additional influx of the medium are described by the equation [1, 2, 3]:

$$m_{D2}\left(i_2 - i_{sk}\right) = m_{wch}c_w\left(t_{w2} - t_{w1}\right) \tag{2}$$

or

$$m_{D2}\left(i_2 - i_{sk}\right) = F_{ws}k_s\Delta T_l\,, \tag{3}$$

where: m_{wch} – mass flow of cooling water; c_w – specific heat of water; t_{w1} i t_{w2} – temperature of cooling water at the inlet and outlet to.from the condenser; i_2 – steam enthalpy at the condenser inlet; i_{sk} – condensate enthalpy; F_{ws} – surface of heat transfer; k_s – heat transfer coefficient through the condenser tubes depending on design and use (water speed and tube cleanliness); ΔT_l – average logarithmic temperature difference between the steam and cooling water.

The mass flow of cooling water amounts to:

$$m_{wch}=\frac{m_{D2}\left(i_2-i_{sk}\right)}{c_w\left(t_{w2}-t_{w1}\right)}\,. \tag{4}$$

The basic quality parameters characteristic of the condenser operation include: absolute pressure in the condenser, heating area of cooling water, temperatures increase (differences) [1, 4, 5, 6].

Condenser pressure, commonly referred to as the vacuum, is equal to the steam saturation pressure of cooling water at the condenser inlet. Based on research of various types and various powers it can be assumed that the change by 1% to the vacuum results at the same steam consumption in the change to the power value by 1÷2% of the rated value [1]. The following pressure values in condensers are assumed [6]:

- (3,5÷4,5) kPa for cooling in the open cooling system,
- (6,5÷7,5) kPa in the closed system.

Heating area of cooling water is the difference between the temperature of cooling water t_{w2} at the condenser outlet and water temperature at the condenser inlet t_{w1}. This parameter in connection with the water mass influx allows to describe energy loses transferred from the steam to the cooling water in the condenser and it equals:

$$\Delta t_w=t_{w2}-t_{w1}\,. \tag{5}$$

The average value of Δt_w depending on the design of the condenser used can have the following values:

- (4÷6)K for single -pass condensers,
- (7÷9)K for parallel-pass condensers,
- (10÷12)K for three- and four-pass condensers.

Temperature accumulation (difference) results from heat exchange through the tube wall, between the condensate with saturation parameters and cooling water and can be described by the following formula

$$\delta_t=t_2-t_{w2}\,. \tag{6}$$

For the rated load of the condenser the value δ_t should be (3÷6)K. Temperature differences δ_t characterise the degree of excellence of condenser operation and can be considered the basis for the evaluation of its condition [1]. Fig. 1 presents the schematic diagram of the analysed system of the cooling water and system-water block system showing individual pieces of equipment and points of measurements.

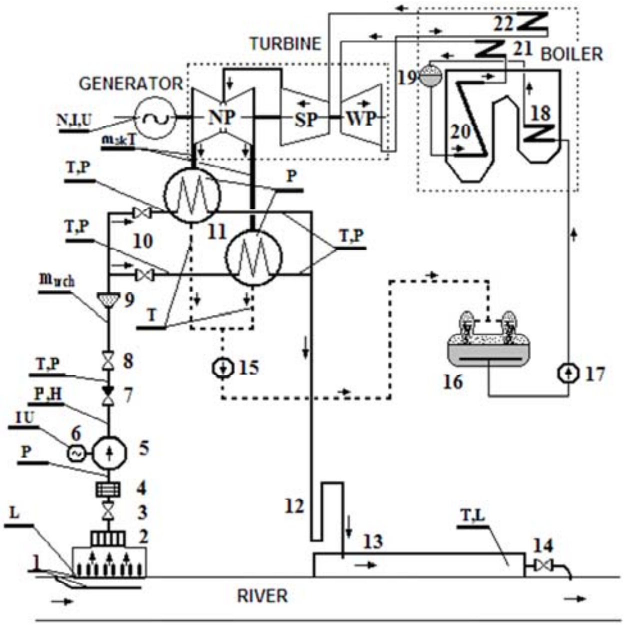

Fig 1. Measuring system of the analysed cooling water circulation and the steam-water system of the power unit according to [7]: 1 – floating diaphragm, 2 – coarse, 3 – gate at the pump suction, 4 – rotating sieve, 5 – cooling water pump, 6 – pump motor, 7 – non-return flap valve, 8 – throttle at pump discharge, 9 – cooling water rotating filter, 10 – throttles condensers, 11 – condensers, 12 – drain trap at cooling water discharge (siphon well), 13 – warm water discharge canal, 14 – gate at water discharge from discharge canal to the river, 15 – condensate pump, 16 – feed water tank, 17 – feed water pump, 18 – water heater, 19 – boiler drum, 20 – evaporator, 21 – fresh steam superheater, 22 – Re-superheater , HP (WP) – high pressure part of turbine, MP (SP) – medium pressure part of the turbine, LP (NP) – low pressure part of the turbine. Measurements: H – lifting height, I – current intensity, L – level, N – electrical power, P – pressure, T – temperature, U – voltage

Checking the basic work parameters and determining their quality characteristics were carried out under operating conditions. The change to the power of the power unit results in the change to the flow mass of the cooling water of turbine condensers, which affects their quality operating parameters and in particular, the absolute pressure (vacuum) and consequently the power of the power unit [4, 6].

The value of the mass flow of cooling water at the change of position of the rotor blades of cooling water were shown in Fig. 2. The operation of the system was assessed at 217 MW of the power of the power unit by changing the water mass flow from 22500 Mg/h to 30000 Mg/h by setting the angle of the pump rotor blades within the range of adjustment 0÷100%. During the measurements the temperature of cooling water at the condensers inlet was 16ºC. Fig. 3 presents the values of pressures in the condenser as a result of change of cooling water stream.

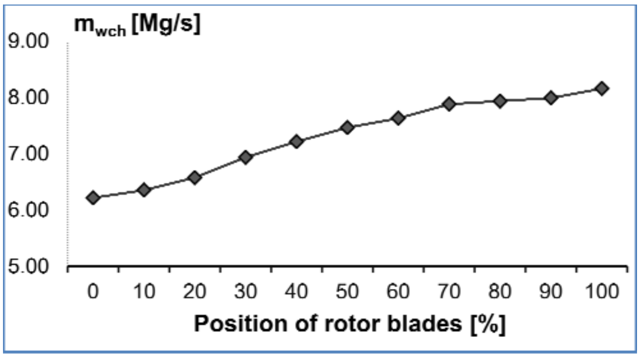

Fig. 2. Mass flow of cooling water at the condenser inlet

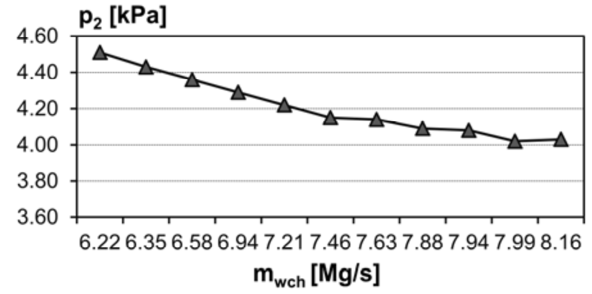

Fig. 3. Pressure in the condensere at 217 MW power unit

In case of the examined system the increase of the influx of cooling water to the condenser resulted in the increase of the pressure in the condenser and affected the power value of the power unit. It supports the justification of application of the water stream adjustment by the cooling water pump within the whole range of electrical adjustment of the power of the power unit.

Fig. 4 presents pre-heating of cooling water resulting from the change to the cooling water stream to the condensers. Pre-heating amounted to 11,3 K at the mass flow of cooling water 6216 kg/s, as well as 8,6 K and 8,8 K at 8158 kg/s and it exceeded the designed value of 8,7 K during the test at the full adjustment of cooling water stream for the 217 MW power unit.

Based on the test results of the above ratio and taking into account the remaining measurements it can be assumed that a possible reason of incorrect operation of the condenser was additional throttling of cooling water after the condenser.

The above has been proved by an additional condenser tightness test at 140 and 215 MW. The decrease of vacuum obtained as a result of it was 0,07 and 0,05 kPa/min, which allows to rate the condenser as very good.

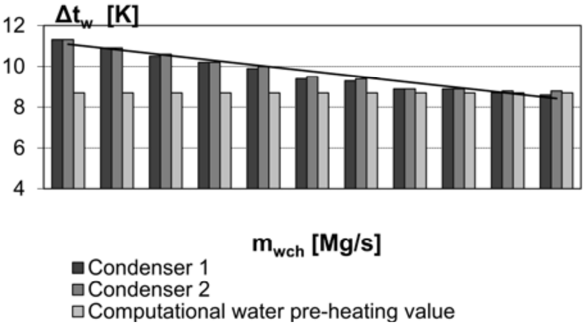

Fig. 4. Pre-heating of cooling water at 123,61 kg/s steam mass flow to condensers

Table 1 presents the values of pressure changes in the condenser, the power consumed by the adjustable pump engine ΔP_s and of capacity of the power unit as a result of the changeable flow of cooling water.

Table 1. Balance of the power of the power unit, pump engine and pressure in the condenser

Balance of power and pressure		
Power of 217MW power unit, t_{w1} = 16,0°C		
Change to pressure in the condenser [kPa]	Change to power of the power engine [kW]	Change to the power of the power unit [kW]
4,51	731	0
4,43	784	136
4,36	850	119
4,29	921	119
4,22	972	119
4,15	1007	119
4,14	1035	17
4,09	1112	85
4,08	1155	17
4,02	1200	102
4,03	1241	-17
Δp_2 0,48	**ΔP_s 510**	**ΔP_g 816**

At the maximum control of rotor blades of the cooling water pump, the pump motor consumed the power by 510 kW more than at the minimum control. The maximum cooling water stream resulted in the increase of the negative pressure in the condenser by approximately 0,48 kPa. In order to calculate the value of the power obtained after the change to absolute pressure in the condenser it was assumed that 1 kPa results in the change of the power of the power unit by about 1,7 MW [6]. After carrying out calculations we obtained the value of 816 kW increase in the power of the power unit and finally, after taking into account the value of capacity consumed by the pump engine the excess capacity of 306 kW of the power unit was achieved. The balance presented indicates that increasing of the vacuum as a result of increased flow of cooling water through the condenser is economically justified. It can be noticed that the most significant effect was obtained within the adjustment of water steam up to 60% of the position of the pump rotor blades.

Fig. 5 presents reference characteristics of the relationship of the condenser pressure in the function of the power unit capacity and cooling water temperature. The assumed water temperature was 16ºC, which allowed to determine the pressure values for 140 and 200 MW. The comparison of empirical pressure values in the condenser amounting to 4,15 kPa for 217 MW with the reading of 4,1 kPa from the graph allows to conclude that the mass flow of cooling water of 7465 kg/s can ensure achieving the reference pressure.

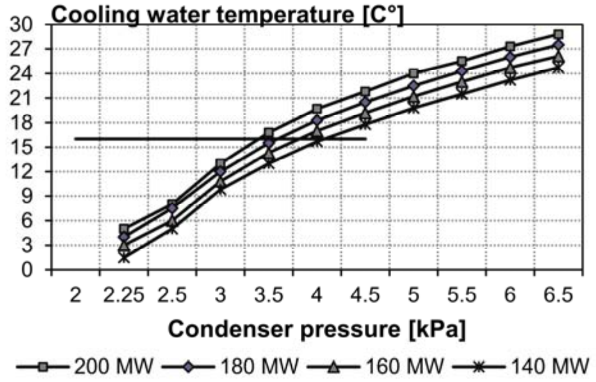

Fig. 5. Condenser pressure in the cooling water and power function according to [11]

Due to the above it can be said that after taking into account the external conditions (hydrological and temperature conditions) at the power load of the power unit within the range from 130 to 225 MW, the cooling water pumps should work at the maximum capacity. This assumption may turn out incorrect under some conditions when the increase in power consumption for the drive of cooling water pumps in order to provide additional water quantity is greater than the corresponding increase of the turbine efficiency as a result of decrease in the steam rate.

The impact of sediments in the tubes on the condenser ratios for selected power unit values

Water pollution results in sediments formed on the tube walls of condensers, these sediments being composed in particular of such chemical compounds as: calcium carbonate, magnesium carbonate as well as corrosion products of copper and steel alloys [8, 9]. Other chemical compounds include: copper chlorides and sulfides as well as zinc and manganese compounds. Sediments are formed when insoluble organic particles suspended in water deposit on the surface of water flow. The factors that add to deposition include particles structures and sizes as well as temperature and slow water flow rate. Sediments may include sand grains, slime, iron oxides and reaction products with some chemical substances [2, 10]. Sediment on the surface of heat exchange decrease the heat transfer coefficient. Table 2 presents the results of quality parameters of the condenser before and after cleaning for three power unit values.

The basic indicator of the condenser operation, which is affected to a considerable degree by tubes contamination on the side of cooling water, is temperature differences [8]. Fig. 6 presents the average values of temperature differences for individual power values of the power unit.

Table 2. Measurements and calculations of results of condenser cleaning according to [7]

Contents			Symbol	Dimension	Measurements before cleaning			Measurements after cleaning		
					Power of the power unit [MW]					
					140	160	212	140	160	212
Condenser 1	Condensate	Temperature	t_{sk}	°C	19,6	20,2	22,7	18,9	20,7	24,6
	Water	Temp. before	t_{w1}	°C	7,23	7,28	7,28	8,44	8,96	9,33
		Temp. after	t_{w2}	°C	14,0	14,8	15,9	14,8	16,1	18,7
		Heating zone	Δt_w	K	6,76	7,50	8,64	6,33	7,15	9,36
	Temperature differences			K	5,58	5,39	6,74	4,11	4,62	5,92
	Cleanliness coefficient			%	77,1	85,7	82,9	93,4	88,6	91,5
	Heat transfer coefficient			W/m^{2}K	1,96	2,18	2,20	2,44	2,43	2,46
Condenser 2	Condensate	Temperature	t_{sk}	°C	19,5	20,0	22,5	19,2	20,7	24,7
	Water	Temp. before	t_{w1}	°C	7,20	7,22	7,25	8,42	8,99	9,34
		Temp. after	t_{w2}	°C	14,4	15,1	16,4	15,1	16,5	19,2
		Heating zone	Δt_w	K	7,21	7,89	9,10	6,65	7,52	9,90
	Temperature differences		δt_2	K	5,14	4,93	6,18	4,10	4,17	5,44
	Cleanliness coefficient		c_{z2}	%	85,2	92,7	90,5	102	99,1	102
	Heat transfer coefficient		k_{pw}	W/m^{2}K	2,16	2,34	2,39	2,70	2,62	2,74
Heat rate (gross value)			q_{Bb}	kJ/kWh	9272	9224	9023	9085	9081	8909
Fuel rate			b_b	g/kWh	0,416	0,414	0,405	0,407	0,407	0,400

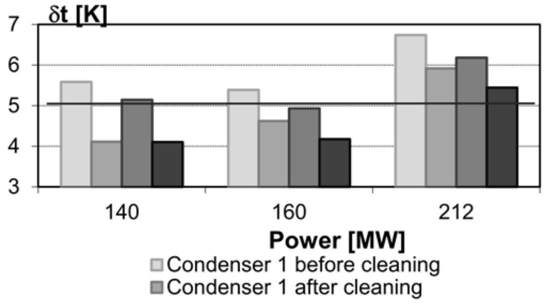

Fig. 6. Average value of temperature differences before and after cleaning condensers

The increase of temperature differences in the condenser results in the deterioration of the vacuum and the change of value of generated power. The reference temperature differences amount to 5 K at the rated heat load of the condensers.

After removing sediments, this parameter was 5,9 K and 5,4K, which is respectively 18% and 8% higher than normal temperature differences, but it is 16% lower than the value calculated before cleaning (temperature differences were 6,7 K and 6,2 K).

Moreover, there was an improvement of the heat transfer coefficient in the condensers by 25% at 140 MW and by approximately 12% at 160 MW and 212 MW as compared to the values obtained in calculations carried out before cleaning tubes. The result achieved adds to decreasing thermal resistance values in the condenser, which results in lowering steam pressure at the inlet and in increase of generated power. Fig. 7 shows the values of heat transfer coefficients in condensers 1 and 2 before and after removing sediments.

The cleaning of tubes internal surfaces affected the heat rate and resulted in the decrease of this value by approximately 148 kJ/kWh. Fig. 8 shows the values of heat rate before and after cleaning condensers for selected power values.

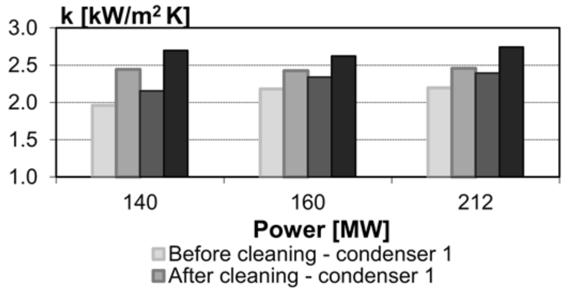

Fig. 7. Heat transfer coefficient before and after cleaning in condensers 1,2

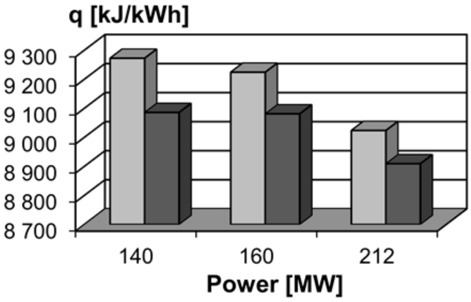

Fig. 8. Heat rate at the power unit

The average heat rate as described above refers to the medium power of the 160 MW power unit.

Fig. 9 presents the difference of the heat rate and the change of fuel quantity for 140, 160 and 212 MW. In order to calculate the mass of unused fuel the average calorific value of coal 22300 kJ/kg was used. The average value of decrease of fuel consumption after removing sediments is 6,64 g/kWh. It should be noted that the above values are approximate because they do not take into account the additional impact of other parameters (inert gases, change of temperature of inlet cooling water, momentary changes of cooling water mass flow etc.).

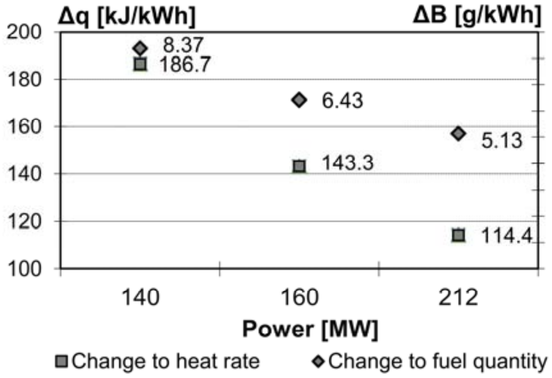

Fig. 9. Change to the heat rate and fuel quantity for the assumed power values

Moreover, what is of significance is the exactness of the measuring instruments used for the readings (their class, technical condition, correctness of reading). Therefore, the issue of thermal resistance being the consequence of contamination of the surface of the heat exchange is of particular importance and in case of turbine condensers it should be the basic element of the control of its operation.

Remarks and conclusions

Based on the analysis carried out it can be said that due to type of operation and tasks of the energy system there is a need to load the power units with active power. For any load of the power unit it is possible to determine operating parameters on the thermal side, when there are minimum losses of energy and minimum value of heat rate. Other significant factors affecting the efficiency and availability of the power unit include: the technical condition and condenser's operating parameters. What is of particular significance is the operation control depending on the power of the power unit, its equipment and auxiliary systems, including the cooling water pump.

It should be assumed that the adjustment to propeller pumps results in increasing the operation effectiveness of power units and it allows to adjust the stream of cooling water to the change of capacity of the power unit (turbine load) and to the amount of steam coming to the condenser. The examination of quality parameters of the turbine condenser operation shows that the minimisation of losses in the condenser is achieved by maintaining in it a low vacuum at the possible level, this vacuum being conditioned in a considerable degree by the stream of cooling water.

A significant indicator of the condenser operation is temperature differences, the value of this indicator being conditioned in a considerable degree by the contamination of tubes on the cooling water side. Maintaining the tubes surface clean ensures the optimum heat consumption per unit of generated electrical energy and it affects the value of generated electrical power of the power unit.

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