The influence of steam extractions operation dynamics on the turbine efficiencies and losses

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Abstract: *In this paper are presented results of a low-pressure steam turbine energy and exergy analysis during turbine extractions opening/closing. All possible combinations of extractions opening/closing are observed. The highest mechanical power which can be produced by this turbine (when all steam extractions are closed) is 28017.48 kW in real and 31988.20 kW in an ideal situation. For all observed steam extractions opening/closing combinations is obtained that energy efficiency and energy losses range is relatively small (from 87.56% to 87.94% for energy efficiency and from 3360.46 kW to 3970.72 kW for energy losses). Trends in energy and exergy losses (destructions) are identical for all observed extractions opening/closing combinations. Analyzed turbine efficiencies (both energy and exergy) will decrease for a maximum 1% during the steam extractions closing. Turbine steam extractions closing decrease turbine efficiencies and increases turbine losses (destructions), what is valid from both energy and exergy aspects.*

KEYWORDS: STEAM TURBINE, STEAM EXTRACTIONS, OPERATION DYNAMICS, EFFICIENCY, LOSSES

1. Introduction

A variety of steam turbines can be found in the power plants worldwide. Main steam turbines are usually complex steam turbines which consist of several cylinders connected to the same shaft [1, 2]. Auxiliary steam turbines are usually used for the additional mechanical power producing or for a direct drive of various mechanical power consumers [3, 4].

It should be highlighted that nowadays, steam turbine is not the mechanical power producer only, it is also a machine for steam delivery (heat energy delivery) to various heaters inside the power plant [5, 6]. Steam delivery to the heaters is performed through steam turbine extractions. Complex multi-cylinder steam turbines usually have few steam extractions from each cylinder [7, 8], while auxiliary steam turbines usually did not have any steam extraction [9]. Therefore, steam extractions are essential part of recent steam turbines and they can notably influence steam turbine performance.

Steam turbine performance during various extractions operation dynamics can be investigated by using several possible techniques – two of such techniques are energy and exergy analyses [10, 11], which are applied in this paper.

In this paper is performed analysis of low-pressure steam turbine developed power, energy and exergy efficiencies as well as losses for each possible steam extractions opening/closing combination. Steam extractions closing will surely increase turbine developed power, but it is interesting to observe what will happen with turbine efficiencies and losses in such operating regimes.

2. Description of the analyzed steam turbine

Scheme of the analyzed low-pressure steam turbine along with operating points required for the analyses, is presented in Fig. 1.

Low-pressure turbine analyzed in this paper is the last cylinder of a complex, two cylinder steam turbine. Both cylinders (high-pressure and low-pressure cylinder) are connected to the same shaft which drives an electric generator. Between mentioned cylinders is mounted re-heater. Details related to the whole described turbine and power plant in which it operates can be found in [12].

Steam re-heater delivers superheated steam to the analyzed low-pressure turbine. The turbine has four steam extractions (operating points 2, 3, 4 and 5) which are used for steam delivery to the components of low-pressure feed water heating system (deaerator and low-pressure feed water heaters) [13]. The remaining steam mass flow rate, which expand through all the stages of the observed turbine, is finally delivered to steam condenser for condensation [14].

The observed steam turbine is analyzed as an independent component (the influences of steam extractions opening/closing on other power plant components or on the entire steam power plant are not considered). Due to simplicity, it is considered that each steam turbine extraction can be fully opened or fully closed (partially opened extractions are not observed).

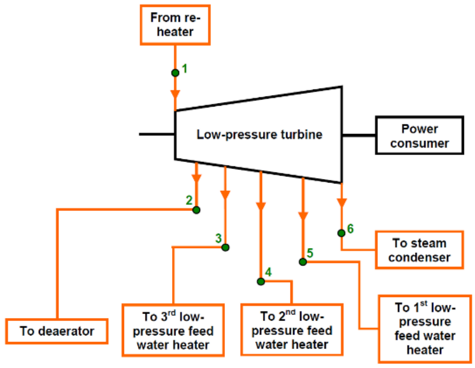

Fig. 1. *Scheme and marked operating points of the analyzed low-pressure steam turbine*

Ideal (isentropic) and real (polytropic) steam expansion processes through the analyzed turbine are shown in Fig. 2 (operating points are in accordance to Fig. 1). Real (polytropic) steam expansion process is marked with numbers from 1 to 6, while ideal (isentropic) expansion is marked with numbers from 1 to 6i. Ideal (isentropic) process assumes that steam specific entropy remains constant during expansion [15]. Steam extractions are marked with red arrows (operating points 2, 3, 4 and 5).

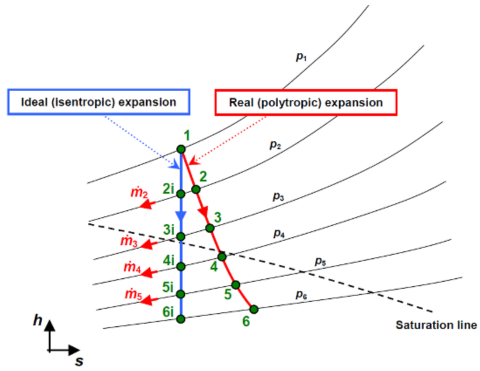

Fig. 2. *Steam real (polytropic) and ideal (isentropic) expansion processes through the analyzed turbine in h-s diagram*

3. Equations for the low-pressure steam turbine energy and exergy analysis

3.1. General energy and exergy equations and balances

The main energy and exergy balance equations are [16]:

$$\dot{Q}_{\mathrm{in}} + P_{\mathrm{in}} + \sum \dot{E}n_{\mathrm{in}} = \dot{Q}_{\mathrm{out}} + P_{\mathrm{out}} + \sum \dot{E}n_{\mathrm{out}} + \dot{E}n_{\mathrm{L}}, \quad (1)$$

$$\dot{X}_{\mathrm{in}} + P_{\mathrm{in}} + \sum \dot{E}x_{\mathrm{in}} = \dot{X}_{\mathrm{out}} + P_{\mathrm{out}} + \sum \dot{E}x_{\mathrm{out}} + \dot{E}x_{L}, \quad (2)$$

where $\dot{Q}$ and $\dot{X}$ are heat energy and exergy transfer, P is mechanical power, index in is related to the inlet (input), index out is related to outlet (output) and index L is related to the loss (energy or exergy). $\dot{E}n$ and $\dot{E}x$ are total energy and exergy flow of any fluid stream which can be calculated as [17]:

$$\dot{E}n = \dot{m} \cdot h, \quad (3)$$

$$\dot{E}x = \dot{m} \cdot \varepsilon, \quad (4)$$

where $\dot{m}$ is mass flow rate, h is specific enthalpy and ε is specific exergy. Always valid mass flow rate balance is:

$$\sum \dot{m}_{\text{in}} = \sum \dot{m}_{\text{out}}, \quad (5)$$

while overall energy and exergy efficiency equation can be presented as [18]:

$$\eta_{\text{en (ex)}} = \frac{\text{cumulative energy (exergy) output}}{\text{cumulative energy (exergy) input}}. \quad (6)$$

3.2. Equations for the energy and exergy analysis of the observed low-pressure steam turbine

Equations for the energy and exergy analyses of the investigated low-pressure steam turbine are presented in this subsection for a situation when all of the steam extractions are open. Equations for the turbine energy and exergy analyses when one or more steam extractions are closed will be defined by using the same equations (mass flow rate through closed extraction is equal to zero).

Equations for the low-pressure steam turbine energy analysis (all steam extractions open), according to Fig. 1 and Fig. 2, are:

- Turbine real (polytropic) mechanical power:

$$P_{\text{re}} = \dot{m}_1 \cdot (h_1 - h_2) + (\dot{m}_1 - \dot{m}_2) \cdot (h_2 - h_3) + (\dot{m}_1 - \dot{m}_2 - \dot{m}_3) \cdot (h_3 - h_4) + (\dot{m}_1 - \dot{m}_2 - \dot{m}_3 - \dot{m}_4) \cdot (h_4 - h_5) + (\dot{m}_1 - \dot{m}_2 - \dot{m}_3 - \dot{m}_4 - \dot{m}_5) \cdot (h_5 - h_6). \quad (7)$$

- Turbine ideal (isentropic) mechanical power:

$$P_{\text{id}} = \dot{m}_1 \cdot (h_1 - h_{2\text{i}}) + (\dot{m}_1 - \dot{m}_2) \cdot (h_{2\text{i}} - h_{3\text{i}}) + (\dot{m}_1 - \dot{m}_2 - \dot{m}_3) \cdot (h_{3\text{i}} - h_{4\text{i}}) + (\dot{m}_1 - \dot{m}_2 - \dot{m}_3 - \dot{m}_4) \cdot (h_{4\text{i}} - h_{5\text{i}}) + (\dot{m}_1 - \dot{m}_2 - \dot{m}_3 - \dot{m}_4 - \dot{m}_5) \cdot (h_{5\text{i}} - h_{6\text{i}}). \quad (8)$$

- Turbine energy loss (energy destruction):

$$\dot{E}n_{\text{L}} = P_{\text{id}} - P_{\text{re}}. \quad (9)$$

- Turbine energy efficiency:

$$\eta_{\text{en}} = \frac{P_{\text{re}}}{P_{\text{id}}}. \quad (10)$$

Exergy analysis depends on the ambient conditions. The ambient conditions (dead state conditions) in this analysis are: pressure of 1 bar and a temperature of 25 °C. For the steam turbine exergy analysis, the relevant turbine mechanical power is real (polytropic) power, calculated by Eq. 7 for the situation when all steam extractions are open. Equations for the exergy analysis of investigated low-pressure steam turbine with all steam extractions open, Fig. 1, are:

- Turbine exergy inlet (input):

$$\dot{E}x_{\text{in}} = \dot{m}_1 \cdot \varepsilon_1. \quad (11)$$

- Turbine exergy outlet (output):

$$\dot{E}x_{\text{out}} = \dot{m}_2 \cdot \varepsilon_2 + \dot{m}_3 \cdot \varepsilon_3 + \dot{m}_4 \cdot \varepsilon_4 + \dot{m}_5 \cdot \varepsilon_5 + \dot{m}_6 \cdot \varepsilon_6 + P_{\text{re}}. \quad (12)$$

- Turbine exergy loss (exergy destruction):

$$\dot{E}x_{\text{L}} = \dot{E}x_{\text{in}} - \dot{E}x_{\text{out}}. \quad (13)$$

- Turbine exergy efficiency:

$$\eta_{\text{ex}} = \frac{P_{\text{re}}}{\dot{E}x_{\text{in}} - \dot{E}x_{\text{out}} + P_{\text{re}}}. \quad (14)$$

All equations for the analyzed turbine during one or more steam extractions closing remains the same as presented above, from Eq. 7 to Eq. 14. The closing of one or more steam turbine extractions means that steam mass flow rate through closed steam extraction is equal to zero. All other steam operating parameters remain the same as in the situation when all steam turbine extractions are open. The calculation principle is always the same, regardless of observed steam turbine extractions opening/closing combination.

4. Steam operating parameters required for low-pressure steam turbine energy and exergy analysis

Each fluid flow stream operating parameters (in each operating point from Fig. 1) measured in the power plant are found in [12]. Using measured operating parameters, all the others, required for the energy and exergy analyses are calculated with NIST-Refprop 9.0 software [19]. Steam operating parameters in each operating point from Fig. 1 and Fig. 2 are presented in Table 1 for real (polytropic) expansion process and in Table 2 for ideal (isentropic) process. It should be highlighted that ideal expansion process is a process between the same pressures and it uses the same mass flow rates as the real (polytropic) process, but in ideal process steam specific entropy remains always constant, as at the turbine inlet.

Table 1. *Steam operating parameters in each operating point of the analyzed turbine – real (polytropic) steam expansion*

O.P.	Temperature (°C)	Pressure (bar)	Mass flow rate (kg/s)	Specific enthalpy (kJ/kg)	Specific entropy (kJ/kg·K)	Specific exergy (kJ/kg)
1	371.000	17.090	33.200	3187.0	7.1065	1072.8
2	279.153	7.980	3.170	3012.8	7.1574	883.4
3	165.472	2.730	1.790	2796.0	7.2027	653.1
4	98.456	0.960	1.570	2625.4	7.2442	470.1
5	68.301	0.290	1.240	2455.8	7.2892	287.1
6	41.490	0.080	25.430	2343.1	7.4868	115.4

O.P. = Operating point (refers to Fig. 1.)

Table 2. *Steam operating parameters in each operating point of the analyzed turbine – ideal (isentropic) steam expansion*

O.P.	Pressure (bar)	Mass flow rate (kg/s)	Isentropic specific enthalpy (kJ/kg)	Isentropic specific entropy (kJ/kg·K)
1	17.090	33.200	3187.0	7.1065
2i	7.980	3.170	2985.1	7.1065
3i	2.730	1.790	2754.8	7.1065
4i	0.960	1.570	2574.3	7.1065
5i	0.290	1.240	2393.5	7.1065
6i	0.080	25.430	2223.5	7.1065

O.P. = Operating point (refers to Fig. 2.)

Steam operating parameters in each analyzed turbine operating point found in [12] were presented in a situation when all steam extractions are open. Steam extractions closing do not affect steam operating parameters, they remain the same as presented in Table 1 and Table 2 (only the steam mass flow rate is set to zero for any closed extraction).

The analyzed low-pressure steam turbine has four steam extractions (operating points 2, 3, 4 and 5, Fig. 1). All possible combinations of the steam extractions opening/closing are presented in Table 3. Turbine operating parameters were investigated for each possible combination.

From Table 3 can be seen that the first combination is when all steam turbine extractions are open while the last combination is when all steam turbine extractions are closed. There are four possible combinations when one turbine extraction is closed and all the others are open (combinations from 2 to 5, Table 3) and six possible combinations when two turbine extractions are open and two are closed (combinations from 6 to 11, Table 3). Finally, there are four possible combinations when three steam extractions are closed with only one open (combinations from 12 to 15, Table 3).

Table 3. *Steam extractions opening/closing combinations*

Steam extractions combination number	Steam extractions* (2-3-4-5)
1	o-o-o-o
2	c-o-o-o
3	o-c-o-o
4	o-o-c-o
5	o-o-o-c
6	c-c-o-o
7	o-c-c-o
8	o-o-c-c
9	c-o-c-o
10	c-o-o-c
11	o-c-o-c
12	c-c-c-o
13	o-c-c-c
14	c-o-c-c
15	c-c-o-c
16	c-c-c-c

* o = extraction open; c = extraction closed

5. The results of the low-pressure steam turbine energy and exergy analysis during steam extractions opening/closing

The change in real (polytropic) and ideal (isentropic) turbine mechanical power during steam extractions opening/closing is presented in Fig. 3. It is evident that trends in both ideal and real power are identical and that ideal power is higher than the real one, regardless of the observed combination (because the ideal power did not consider losses which occur during steam expansion).

As can be expected, combination 1 when all steam extractions are open resulted with the lowest mechanical power, while combination 16 which represents all closed steam extractions resulted with the highest produced mechanical power (both ideal and real). The highest mechanical power which can be produced by this turbine (all steam extractions closed) is 28017.48 kW in real and 31988.20 kW in an ideal situation. If only one steam extraction is closed (combinations from 2 to 5), the highest produced mechanical power is observed when the first steam extraction is closed (combination 2). In the situation of two closed extractions (combinations from 6 to 11), the highest power is obtained when first two extractions are closed (combination 6). Finally, the highest power in the situation when three steam extractions are closed is obtained in combination 12 when first three extractions are closed.

From Fig. 3 can be concluded that closing the steam extractions which are the closest to the turbine inlet has a notable effect on the increase in turbine power because more steam will expand through the turbine and more mechanical power will be produced.

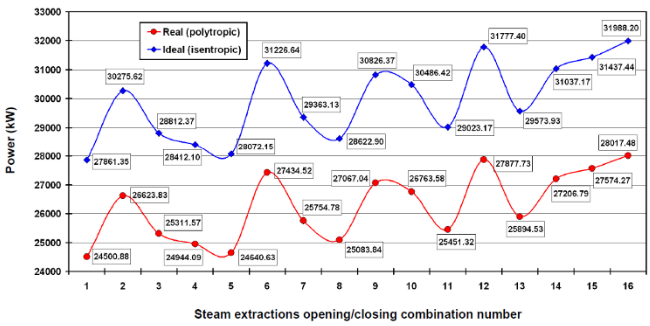

Fig. 3. *Change in real (polytropic) and ideal (isentropic) power during turbine extractions opening/closing*

The influence of steam extractions opening/closing on the observed low-pressure turbine energy efficiencies and energy losses is presented in Fig. 4. The highest energy efficiency and the lowest turbine energy loss can be seen when all steam extractions are open (combination 1), while one of the lowest turbine energy efficiency and the highest energy loss is observed in a situation when all steam extractions are closed (Combination 16). For all observed steam extractions opening/closing combinations, it can be concluded that energy efficiency and energy loss range is relatively small (from 87.56% to 87.94% for energy efficiency and from 3360.46 kW to 3970.72 kW for energy loss).

Final conclusion which can be derived from Fig. 3 and Fig. 4 is that steam extractions closing increases produced mechanical power and energy losses, while simultaneously decreases turbine energy efficiency.

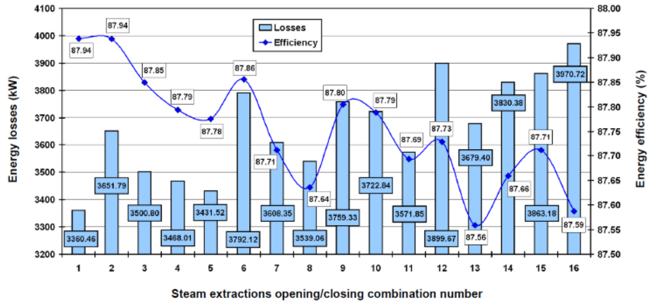

Fig. 4. *Change in energy losses and energy efficiencies during turbine extractions opening/closing*

Exergy input of the observed turbine is always the same (equal to 35616.96 kW), regardless of the observed extractions opening/closing combination. However, turbine exergy output is changing for the observed extractions opening/closing combinations, as presented in Fig. 5. The highest turbine exergy output equal to 32498.99 kW can be observed in combination 1 (all extractions opened), while the lowest turbine exergy output equal to 31848.76 kW is obtained in combination 16 (all extractions closed). From Fig. 5 can also be observed that steam extractions closing from the turbine inlet to the turbine outlet reduce exergy output.

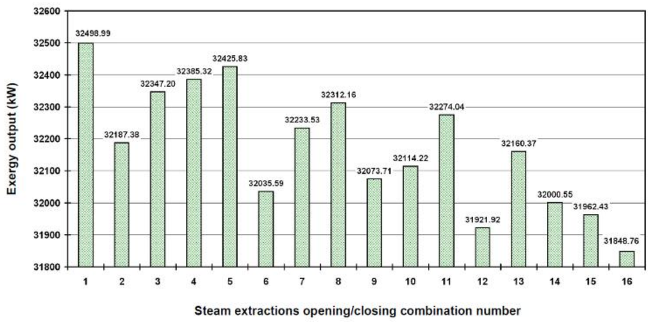

Fig. 5. *Change in exergy output during turbine extractions opening/closing*

Change in exergy loss (exergy destruction) and exergy efficiency of the observed low-pressure steam turbine during extractions opening/closing is presented in Fig. 6.

Comparison of turbine energy losses (energy destructions), Fig. 4, and turbine exergy losses (exergy destructions), Fig. 6, shows that the trends in losses are identical for all observed extractions opening/closing combinations. Exergy efficiencies show slightly different trends in comparison to energy efficiencies. However, the dominant conclusion is valid regardless of the observed analysis – steam extractions closing decreases turbine efficiencies and increases turbine losses (destructions).

For the observed extractions opening/closing combinations, turbine exergy efficiency range is between 88.71% and 88.14%. It can be concluded that observed turbine efficiencies (both energy and exergy) will decrease for a maximum 1% during the steam extractions closing.

Further analysis related to the observed low-pressure steam turbine and steam extractions opening/closing combinations will be based on various Artificial Intelligence (AI) methods and processes [20-22]. The aim will be to find optimal steam extractions opening/closing combination (along with partially opened extractions) to perform the complete optimization of the observed steam turbine.

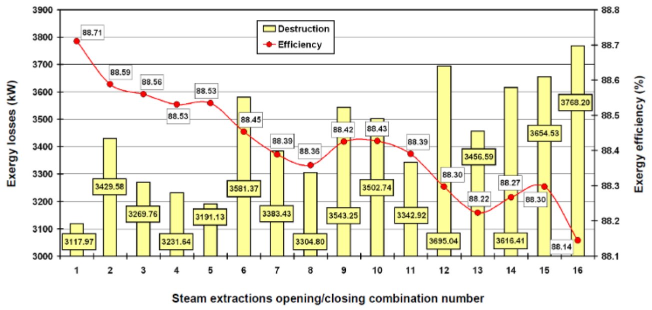

Fig. 6. *Change in exergy losses and exergy efficiencies during turbine extractions opening/closing*

6. Conclusions

This paper presents energy and exergy analysis results of a low-pressure steam turbine during its extractions opening/closing. It is observed all possible combinations of extractions opening/closing, with whole mass flow rates (partial mass flow rates were not observed). The most important obtained conclusions are:

- The highest mechanical power which can be produced by this turbine (when all steam extractions are closed) is 28017.48 kW in real and 31988.20 kW in an ideal situation.
- Closing the steam extractions which are the closest to the turbine inlet has a notable effect on the increase in turbine power because more steam will expand through the turbine and more mechanical power will be produced.
- For all observed steam extractions opening/closing combinations is obtained that energy efficiency and energy losses range is relatively small (from 87.56% to 87.94% for energy efficiency and from 3360.46 kW to 3970.72 kW for energy losses).
- Trends in energy and exergy losses (destructions) are identical for all observed extractions opening/closing combinations.
- Observed turbine efficiencies (both energy and exergy) will decrease for a maximum 1% during the steam extractions closing.
- Steam extractions closing decreases turbine efficiencies and increases turbine losses (destructions), what is valid from both energy and exergy aspects.

7. Acknowledgment

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8. References

[1] Guo, J. Q., Li, M. J., Xu, J. L., Yan, J. J., & Ma, T. (2020). Energy, exergy and economic (3E) evaluation and conceptual design of the 1000 MW coal-fired power plants integrated with S-CO2 Brayton cycles. Energy Conversion and Management, 211, 112713. (doi:10.1016/j.enconman.2020.112713)

[2] Bolatturk, A., Coskun, A., & Geredelioglu, C. (2015). Thermodynamic and exergoeconomic analysis of Çayırhan thermal power plant. Energy conversion and management, 101, 371-378. (doi:10.1016/j.enconman.2015.05.072)

[3] Mrzljak, V., Senčić, T., & Žarković, B. (2018). Turbogenerator steam turbine variation in developed power: Analysis of exergy efficiency and exergy destruction change. Modelling and Simulation in Engineering, 2018. (doi:10.1155/2018/2945325)

[4] Mrzljak, V., Poljak, I., & Mrakovčić, T. (2017). Energy and exergy analysis of the turbo-generators and steam turbine for the main feed water pump drive on LNG carrier. Energy conversion and management, 140, 307-323. (doi:10.1016/j.enconman.2017.03.007)

[5] Nikam, K. C., Kumar, R., & Jilte, R. (2020). Exergy and exergo-environmental analysis of a 660 MW supercritical coal-fired power plant. Journal of Thermal Analysis and Calorimetry, 1-14. (doi:10.1007/s10973-020-10268-y)

[6] Naserbegi, A., Aghaie, M., Minuchehr, A., & Alahyarizadeh, G. (2018). A novel exergy optimization of Bushehr nuclear power plant by gravitational search algorithm (GSA). Energy, 148, 373-385. (doi:10.1016/j.energy.2018.01.119)

[7] Nikam, K. C., Kumar, R., & Jilte, R. (2020). Economic and exergoeconomic investigation of 660 MW coal-fired power plant. Journal of Thermal Analysis and Calorimetry, 1-15. (doi:10.1007/s10973-020-10213-z)

[8] Kopac, M., & Hilalci, A. (2007). Effect of ambient temperature on the efficiency of the regenerative and reheat Çatalağzı power plant in Turkey. Applied Thermal Engineering, 27(8-9), 1377-1385. (doi:10.1016/j.applthermaleng.2006.10.029)

[9] Mrzljak, V., Prpić-Oršić, J., & Poljak, I. (2018). Energy power losses and efficiency of low power steam turbine for the main feed water pump drive in the marine steam propulsion system. Pomorski zbornik, 54(1), 37-51. (doi:10.18048/2018.54.03)

[10] Mrzljak, V., & Poljak, I. (2019). Energy analysis of main propulsion steam turbine from conventional LNG carrier at three different loads. NAŠE MORE: znanstveni časopis za more i pomorstvo, 66(1), 10-18. (doi:10.17818/NM/2019/1.2)

[11] Anđelić, N., Mrzljak, V., Lorencin, I., & Baressi Šegota, S. (2020). Comparison of Exergy and Various Energy Analysis Methods for a Main Marine Steam Turbine at Different Loads. Pomorski zbornik, 59(1), 9-34. (doi:10.18048/2020.59.01)

[12] Vakilabadi, M. A., Bidi, M., & Najafi, A. F. (2018). Energy, Exergy analysis and optimization of solar thermal power plant with adding heat and water recovery system. Energy conversion and management, 171, 1639-1650. (doi:10.1016/j.enconman.2018.06.094)

[13] Mrzljak, V., Poljak, I., & Medica-Viola, V. (2016). Efficiency and losses analysis of low-pressure feed water heater in steam propulsion system during ship maneuvering period. Pomorstvo, 30(2), 133-140. (doi:10.31217/p.30.2.6)

[14] Medica-Viola, V., Pavković, B., & Mrzljak, V. (2018). Numerical model for on-condition monitoring of condenser in coal-fired power plants. International Journal of Heat and Mass Transfer, 117, 912-923. (doi:10.1016/j.ijheatmasstransfer.2017.10.047)

[15] Medica-Viola, V., Baressi Šegota, S., Mrzljak, V., & Štifanić, D. (2020). Comparison of conventional and heat balance based energy analyses of steam turbine. Pomorstvo, 34(1), 74-85. (doi:10.31217/p.34.1.9)

[16] Aljundi, I. H. (2009). Energy and exergy analysis of a steam power plant in Jordan. Applied thermal engineering, 29(2-3), 324-328. (doi:10.1016/j.applthermaleng.2008.02.029)

[17] Mrzljak, V., Poljak, I., & Medica-Viola, V. (2017). Dual fuel consumption and efficiency of marine steam generators for the propulsion of LNG carrier. Applied Thermal Engineering, 119, 331-346. (doi:10.1016/j.applthermaleng.2017.03.078)

[18] Kanoğlu, M., Çengel, Y. A., & Dinçer, İ. (2012). Efficiency evaluation of energy systems. Springer Science & Business Media.

[19] Lemmon, E. W., Huber, M. L., & McLinden, M. O. (2010). NIST Standard Reference Database 23, Reference Fluid Thermodynamic and Transport Properties (REFPROP), version 9.0, National Institute of Standards and Technology. R1234yf. fld file dated December, 22, 2010.

[20] Lorencin, I., Anđelić, N., Mrzljak, V., & Car, Z. (2019). Genetic algorithm approach to design of multi-layer perceptron for combined cycle power plant electrical power output estimation. Energies, 12(22), 4352. (doi:10.3390/en12224352)

[21] Mrzljak, V., Anđelić, N., Lorencin, I., & Sandi Baressi Šegota, S. (2021). The influence of various optimization algorithms on nuclear power plant steam turbine exergy efficiency and destruction. Pomorstvo, 35(1), 69-86. (doi:10.31217/p.35.1.8)

[22] Anđelić, N., Baressi Šegota, S., Lorencin, I., Poljak, I., Mrzljak, V., & Car, Z. (2021). Use of Genetic Programming for the Estimation of CODLAG Propulsion System Parameters. Journal of Marine Science and Engineering, 9(6), 612. (doi:10.3390/jmse9060612)