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OPERATING CHARACTERISTICS OF THE CARGO TURBOPUMP

Key words

Operation, steam turbine, turbopump.

Summary

The article presents the characteristic values of a turbopump set, for example, efficiency, and specific and hourly steam consumption for various loads of the set. Characteristic values were designated by means of the operational measurement results of a turbopump installed on a vessel carrying oil-related products.

Introduction

Power plants are economically based both on the efficiency of appliances installed and their proper operation. Operational research is aimed at estimating the efficiency of heat engine plant devices and permits the confirmation in what degree designer assumptions are fulfilled, reveals errors of construction, mounting and operation. In the research object being considered, i.e. a cargo turbopump, power was controlled in the simplest way, by throttling. Steam was throttled in the turbine's control valve, decreasing the mass flow rate and the value of steam pressure. The simplicity of this solution, however, is burdened with a serious disadvantage, because it is the least economical way of power control caused by losses of throttling the whole stream of steam produced in the boiler. The application of throttling power control at constant pressure prevailing in the condenser will cause the available thermal drop of steam in the turbine to be smaller, thereby increasing the specific steam consumption. The research of a steam turbine is usually conducted in an indirect way, which means that the value sought for is determined by calculations using measurements of other values, which is why it is necessary to point out the values indispensable for calculations and the location of their measurement. The research method must also contain equations and mathematical relationships permitting the determination of the values sought for.

Operational research of the cargo turbopump set was carried out during shipyard trials of a newly-built vessel in order to confirm the design assumptions. Measurement results enabled the authors to carry out a wider analysis of the cargo turbopump work and to determine a number of characteristic values.

1. Description and research results

The turbopump set under research consisted of a steam turbine driving a centrifugal pump through a reduction gear. The set was mounted on a vessel carrying oil-related products built at Samsung Heavy Industry shipyard in 2005.

The vessel's basic particulars [3]:

- Deadweight…………………115 525 t
- Length………………………249.8 m
- Width………………….........43.8 m
- Draft …………......................21.3 m
- Speed ……………….................15 w
- Main engine type ……..HSD B&W 7S60MC
- Rated power ……………...15 100 kW
- Rotational speed ………….101.4 rpm
- Propeller diameter ………...8 000 mm

The turbopump set consists of the following elements [2], [4]:

Steam turbine

Produced by Shinko Ltd

- Type ……………………………RX2-2
- Kind…………….velocity compounded impulse turbine (Curtis wheel)
- Power ……………………..…1290 kW
- Impeller's rotational speed … 6992 rpm
- Steam pressure ……………....1.42 MPa
- Steam temperature ………….....198.9^{o}C
- Steam consumption ………..14 190 kg/h
- After-turbine steam pressure ….33.3 kPa

Cargo pump

- Type ……………………….KVL 450-3
- Capacity …………………......3000 m^3/h
- Rotational speed ……………1330 rpm
- Total head …………………..….130 m.w.c.
- Suction head …………………..5 m.w.c.

Reduction gear

- Rotational speed ………..6992/1330 rpm

A diagram of turbopump set with locations of measuring instruments is presented in Fig. 1 [1], [5].

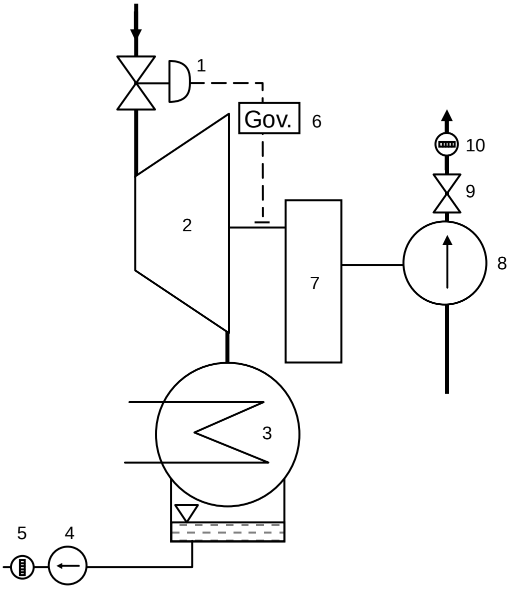

Fig. 1. Schematic diagram of turbine-pump unit, 1 – control valve, 2 – steam turbine, 3 – condenser, 4 – pump, 5 – flowmeter of condensate, 6 – speed governor, 7 – reduction gear, 8 – cargo pump, 9 – delivery valve, 10 – flowmeter

During turbopump trials the following values were measured:

D_p [kg/h] – steam mass flow,
p_p [MPa] – steam pressure before control valve,
p_c [MPa] – steam pressure after control valve,
p_w [MPa] – steam pressure in the condenser,
Q_w [m^3/h] – volumetric flow rate of water,
H [m.c.w.] – total head of pump (based on delivery and suction pressure measurements and the geometrical dimensions of the pump).

During trials, turbine 2 worked in accordance with the control characteristic, and a qualitative control system was employed for power control. The opening degree of control valve 1 varied the pressure and steam amount supplied to turbine 2. A change of turbine load was implemented by valve 9 on the delivery side of cargo pump 8, by altering the stream value of liquid pumped. In the case of measuring the stream of steam mass, the measurement of the condensate stream on the turbine condenser outlet was assumed, permitted by standards [1], [2], as equivalent to the amount of steam supplied to the turbopump (during trials the steam was directed exclusively to the turbopump). For the measurement of steam mass stream and the factor pumped by the cargo pump, flow meters were mounted in the plant, 5 and 10 respectively. Measurements of pressure and temperature values of selected media in the plant were made by means of standard measuring equipment of such plants.

For cargo pump trials, fresh water at 28.9^{o}C temperature was used as liquid. In accordance with tables [6] its density ρ_w was equal to 996.02 kg/m^3.

The selected values were measured in steady work states, assuming that the conditions were stabilised after about 30 minutes from changing the turbine load. The parameters were not measured immediately after the turbine, due to the short section of steam outlet piping from the turbine and lack of stub pipes permitting the mounting of measuring instruments. Measurement results obtained in the course of trials are presented in Table 1.

Table 1. Results of the turbopump's operational research (for n = 1332 rpm of the pump)

No. of point	Consumption of steam	Steam pressure before control valve	Steam pressure after control valve	Pressure in turbine condenser	Volumetric flow rate of water	Total head of pump
	D_p [kg/h]	p_p [MPa]	P_c [MPa]	P_w [kPa]	Q_w [m^3/h]	H [m.w.c.]
1	9 486	1.43	0.86	31.8	764	163.96
2	11 548	1.41	1.05	33.2	1 665	156.79
3	12 826	1.41	1.19	33.7	2 378	144.70
4	13 981	1.43	1.30	33.3	3 043	130.88
5	14 113	1.43	1.32	33.4	3 205	126.09

Measurement results contained in Table 1 served for determining the characteristic values of the turbopump set.

2. Characteristic values of the turbopump tested

To determine the pump's characteristic values, such as the theoretic power of the turbine, specific steam consumption, the effective power of the pump, the overall efficiency of the set, the mathematical relationships presented below were used. Indexes i=1, 2, …,5 in the formulae correspond to the number of particular measurement points included in Table 1.

Effective power of the pump:

$$P_{pi} = \rho_w g Q_{wi} H_i \ \text{[kW]} \tag{1}$$

Theoretical power of the turbine:

$$P_{ti} = \dot{D}_{pi}\, \Delta h_{ti} = \dot{D}_{pi}\left(i_{ci} - i_{wi}\right) \text{[kW]} \tag{2}$$

To calculate power $P_{ti,}$ it is necessary to determine the drop of enthalpy Δh_{ti} as the difference i_{ci} of steam after the control valve and i_{wi} of steam in the condenser after its isentropic process of decompression in the turbine.

While the steam flows through the control valve (qualitative power control), the process of isenthalpic throttling takes place, enthalpy has a constant value, whereas steam pressure decreases. The process of isenthalpic throttling and theoretical drops of enthalpy Δh_t for particular measuring points is presented in Fig. 2.

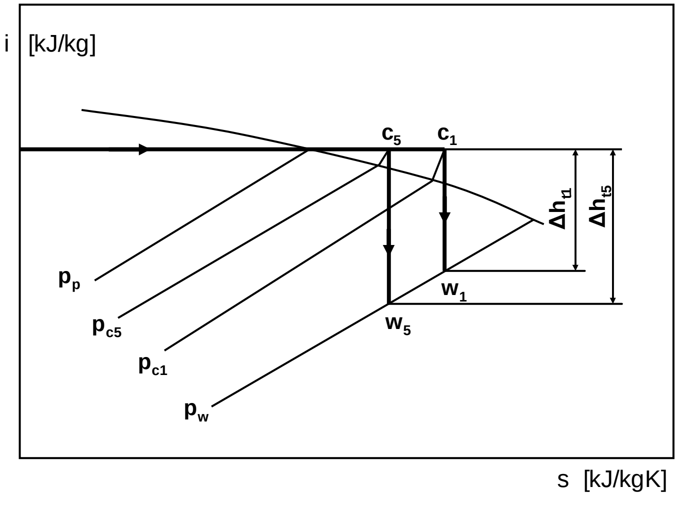

Fig. 2. Isenthalpic throttling of steam on the turbopump control valve

Fig. 2 presents only values and drops of enthalpies marked with indexes 1 and 5, which are cases when the turbine develops the lowest and the highest power.

Table 2 contains enthalpy values corresponding to measurement points from 1 to 5 read from tables [6].

Overall efficiency of the turbopump:

$$\eta_{ui} = \frac{P_{pi}}{P_{ti}} [-] \tag{3}$$

Specific steam consumption:

$$g_{pi} = \frac{\dot{D}_{pi}}{P_{pi}} \left[\frac{\text{kg}}{\text{kWh}}\right] \tag{4}$$

The results of calculations carried out with the use of formulae (1)–(4) and data contained in Tables 1 and 2 have been presented in Table 3.

Table 3. Calculation results of the turbopump work parameters (for n = 1332 rpm of pump)

No. of point	Pump effective power	Turbine theoretic power	Turbopump overall efficiency	Specific steam consumption
	P_p [kW]	P_t [kW]	η_u [-]	g_p [kg/kWh]
1	340.0	2 084.3	16.31	27.90
2	708.5	2 640.0	26.83	16.30
3	933.9	2 974.9	31.40	13.73
4	1080.9	3 281.7	32.89	12.93
5	1096.8	3 332.2	32.91	12.86

Based on results obtained placed in Tables 1 and 3, dependencies were prepared in graphic form in Fig. 3. Pump effective power P_p was accepted as the independent variable, and steam rate D_p, specific steam consumption g_p and the efficiency of the turbopump as a set were taken as dependent variables.

Analysing the course of curves presented in Fig. 3, large changes can be observed in the dependencies presented in the function of the pumped factor volume stream. With Q_w changes in the range 80–100%, the turbopump set reaches maximum efficiency values within 31–33%, with simultaneous specific steam consumption contained in the range 12.86–13.80 kg/kWh. The maximum specific steam consumption of 27.90 kg/kWh occurred with minimum pumped water rate constituting about 25% of the pump's nominal capacity.

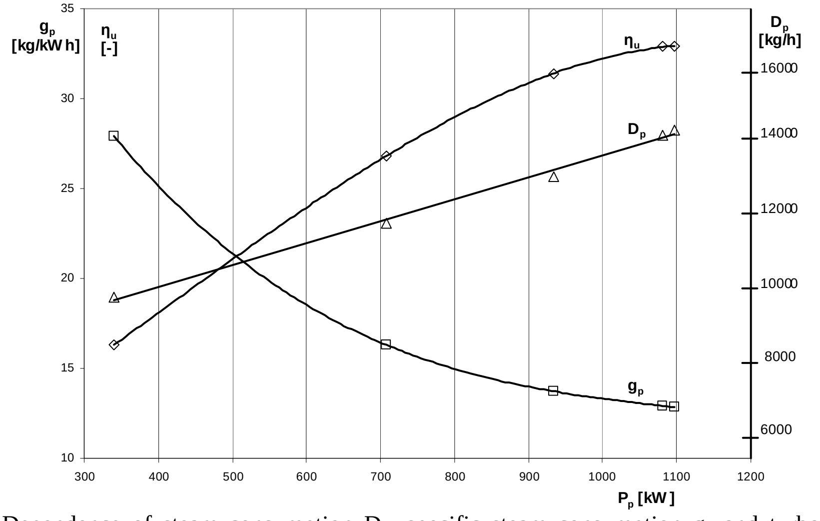

Fig. 3. Dependence of steam consumption D_p, specific steam consumption g_p and turbopump efficiency η_u in the function of pump effective power P_p

Conclusions

During trials, the assumed rated volume stream of pumped water of 3000 m^3/h was obtained, which permits confirming the correct selection of the turbopump set.

The obtained course of changes in the characteristic values of the turbopump set, in a wide range of pump capacity changes from 23 to 108%, allows the preparation of a number of recommendations for the operation of the turbopump set. These recommendations should particularly take into consideration the unit consumption of steam, strongly decreasing with the increase of pumped liquid stream. This translates into fuel consumption of the fired boiler and the efficiency of the boiler and turbopump plant.

References

1. DIN 57116/VDEO116, DIN 4787 T2, DIN 4788 T3.
2. PN-71/M-35520.
3. Shinko Cargo and Ballast Pump Turbine, Shinko Ind. Ltd, Hiroshima, 1998.
4. Ship’s no 9000112 Particulars, Samsung Heavy Industries, Korea.
5. Test Records for Cargo Oil Pump and Turbine, ship’s reports.
6. Wukałowicz M.: Tablice parowo-wodne. Wydawnictwo Naukowo-Techniczne, Warszawa 1975.

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Charakterystyki eksploatacyjne turbopompy ładunkowej

Słowa kluczowe

Eksploatacja, turbina parowa, turbopompa.

Streszczenie

W artykule przedstawiono wielkości charakterystyczne zespołu turbopompy, takie jak sprawność, jednostkowe i godzinowe zużycie pary dla różnych obciążeń zespołu. Wielkości charakterystyczne wyznaczono wykorzystując wyniki pomiarów eksploatacyjnych turbopompy zainstalowanej na statku do przewozu produktów ropopochodnych.