OPERATIONAL CHARACTERISTIC OF SELECTED MARINE TURBOUNITS POWERED BY STEAM FROM AUXILIARY OIL-FIRED BOILERS

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Abstract. This paper presents characteristic values and operational parameters of two selected marine auxiliary steam turbine units such as efficiency, and steam consumption per unit or per hour. For the purpose of the analysis, the cargo turbine pumps and turbogenerator have been selected. The characteristic values and operational parameters have been determined using the operational tests results for the turbounits installed on oil tankers at various power loads.

Keywords: marine auxiliary steam turbounits, exploitation characteristic

INTRODUCTION

The intention to reduce fuel consumption by power systems is motivated not only by economic concerns, but also by more restrictive regulations regarding acceptable emission of hazardous exhaust gases.

According to the literature sources (Kosowski 2005, Test results 2011, Krzyślak 2002), the purchase costs of fuel, oils, and lubricants equal to 50%-80% of the vessel operational costs. The situation will deteriorate when it becomes obligatory to use expensive low-sulphur fuels during the vessel operation in special zones.

In order to reduce the thread to the environment in terms of CO_2 emission, on 1st January 2013, the International Maritime Organization (IMO) entered into force the requirement regarding the Ship Energy Efficiency Management Plan (SEEMP), which is applicable to every vessel in operation and to new ships. The SEEMP ensures that the ship is exploited and operated optimally in respect of power consumption and the thread to the environment due to the CO_2 emission. In order to determine the permitted emission level of other toxic and harmful exhaust gas components, such as NO_x, CO, SO_x, and HC, the IMO adopted the requirements of the Energy Efficiency regulations contained in Annex IV of MARPOL 73/78. These requirements are based on ISO 8178.

One of the methods to reduce and limit the fuel consumption by marine power systems includes the utilization of waste-heat recovery systems for the waste-heat generated by the main engine in order to increase the volume of the steam generated in the waste-heat boilers. The steam is used for the heating purposes and it is also directed to the steam turbounits, where the steam turbine drives power generators and pumps. The steam is also generated in the auxiliary boilers which may be fired by petroleum-derived waste generated during the purification of the oily water and fuel and during the lubricating oil maintenance. Due to such a solution, the turbounit may be in operation while the main engine is not.

Moreover, the volume of fuel consumed by a marine power system is subject to the efficiency of the machines and devices installed, their appropriate selection and correct operation, power load, and power governing method.

The efficiency and fuel consumption for a particular machine or marine device may be assessed on the grounds of the operational tests results conducted at the ship. In the case of the analysed objects, their efficiency depends to the large extent on the power load and the

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power governing method. According to the literature data (Guo et al. 2016, Krzyślak 2002, Mrzljak et al. 2017,Yousri et al. 2014) and the results of the tests conducted up-to-day by the author (Behrendt 2015, Krause and Behrendt 2007), the efficiency of steam turbines decreases by as much as 50% when the machines are operated in the range from 25% to 30% of their nominal power.

The two power governing methods applied to low-power steam turbines are the quality governing method and the quantity-quality governing method.

The quality governing method is the simplest technique to regulate power. This method entails throttling the governor valve for the entire stream of steam fed to the turbine. The simplicity and effectiveness of this approach must be weighed against significant disadvantages. Steam throttling in the governor valve results not only in a decreased mass flow rate but also in a reduction of steam pressure.

The pressure reduction of the entire volume of the steam provided to the turbine has economic implications associated with increased fuel consumption. It happens due to the difference between the heat required to generate steam in the boiler with nominal parameters and the smaller amount of heat that is necessary to generate steam with lower parameters behind the governor valve.

Moreover, the pressure decrease resulting from the application of the power quality governing method, reduces the available theoretical and actual decrease in enthalpy in the turbine, when the pressure in the condenser is maintained at the same level. Accordingly, to maintain the required turbine power, the demand for steam must increase.

The said disadvantages occur to a lesser extent when the quantity-quality governing method is applied, where section chambers at the steam supply to the turbine are used. Each section chamber is equipped with a governor valve. Along with increasing demand for turbine power, the opening degree of the governor valve increases, resulting in the higher the mass flow rate as well as the pressure of the steam fed to the section. This procedure is the quality governing method. The quantity governing method is applied only when the section governor valve is entirely open, and the steam is not throttled. Further increase of turbine power requires the valves to be opened and the steam to be directed and supplied to the following sections. The quantity governing method in the pure form occurs when the governor valves are completely open for particular sections. Under these conditions, power control may be carried out by a change of the rate of flow of steam mass through the turbine. In practice, this requires step by step power control.

The number of section chambers and the mass flow rate for the steam flowing through them are designed so that the quantity governing method applies to the specific turbine power. For example, for 4 section chambers, the method may apply to 25%, 50%, 75% and 100% of the nominal power of the turbine. At the intermediate values, the quality – quantity governing method will apply. It should be noted that for a hypothetical turbine power load of 80%, the steam will be directed and supplied to four section chambers (Costanza and Rivadeneira 2015). However, when the steam is flowing through the first three chambers, it will not be throttled (the quality governing method), and only certain amount of the steam required for to reach 75% and 80% of power will be throttled by the governor valve of the fourth section (the quality governing method).

The quality – quantity governing method was applied in the tested turbogenerator, while the quantity governing method was used in the turbopump.

The research was conducted on ships during harbour acceptance tests (HAT) according to rules (normy).The goal of the tests was to prove that the turbounits reached such design parameters as developed power and steam consumption. Moreover, the gathered measurement data allowed to determine such additional operational parameters as, among the others, turbounits performance and unit steam consumption at various power load modes.

RESEARCH DESCRIPTION AND RESULTS

The turbounits tested consisted of a steam turbine, a reduction gear, a condenser, and a power generator installed on a common foundation. The research was carried out when the turbounits were supplied with steam generated by auxiliary oil-fired boilers.

The general technical and operational parameters of the turbounits subject to the research are presented in Table 1.

Table 1.
General technical and of the tested turbounits.

Turbounit		Turbogenerator	Turbopump
Steam turbine	Manufacturer	Shinko Ltd	Shinko Ltd
	Model	RG 64-M	RX 2-2
	Type	6-stage impulse mixed pressure	velocity compounded (Curtis wheel)
	Power control method	Quantity – quality governing method	Quantity governing method
	Nominal power [kW]	1000	1290
	Speed – turbine rotor [rpm]	10000	6992
	Speed – gear outlet [rpm]	1800	1330
	Steam pressure [MPa]	1.42	1.42
	Steam type	Saturated	Saturated
	Steam temperature [°C]	198.9	198.9
	Pressure in the condenser [kPa]	-90.0	-75.0
	Steam demand at nominal power [kg/h]	11000	14190
Power consumer	Type	Power generator	Centrifugal pomp
	Manufacturer	NISHISHIBA Co.	Shinko Ltd
	Nominal power [kW]	1000	-
	Voltage [V]	450	450
	Current frequency [Hz]	60	60
	Speed – rotor [rpm]	1800	1330
	Nominal capacity [m^3/h]	-	3000
	Pump head [m.w.c.]	-	130

Source: Authors' elaboration, Ship's Particular (2005), Shinko RG, Shinko Cargo

A diagram of the turbounit showing the location of the measurement equipment and power control system is shown in Figure 1.

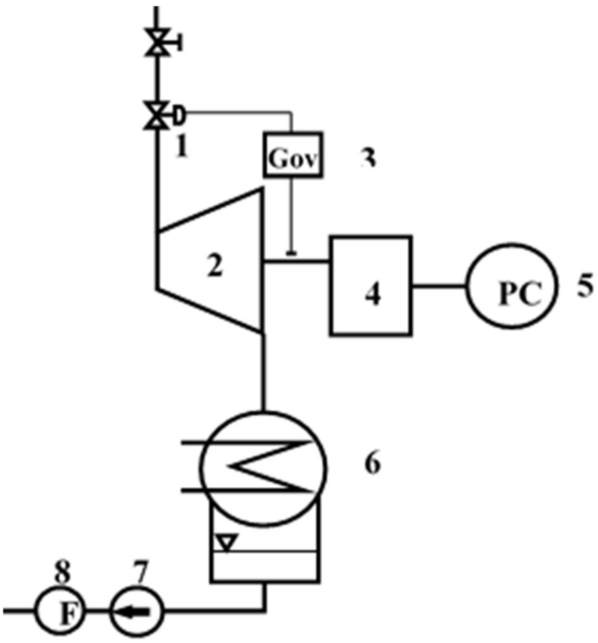

Fig. 1. Schematic diagram of turbine unit
1 – governor valve, 2 – steam turbine, 3 – speed governor, 4 – reduction gear, 5 – power consumer, 6 – condenser, 7 – condensate pump, 8 – flowmeter of condensate

Source: Authors' elaboration.

When the research, the turbounits were working according to the regulatory parameters. Due to that, it was possible to maintain the turbine 2 rotational speed constant. The opening degree of governor valve 1, that changed the steam amount and parameters, was controlled and adjusted by the rotational speed governor 3.
In terms of the turbogenerator, the turbine power load was changed by switching on and switching off the power consumers, while in the case of the turbopump – by changes to the opening degree of the valve on the discharge pipeline of the cargo pump.
The power load of the turbogenerator, the pressure of medium and their temperature were read from the measurement devices being the equipment elements in the marine systems.
The stream mass flow rate of the steam fed to the turbounits was determined on the basis of the measured condensate mass flow rate exiting condenser 6. For that purpose, flowmeter 8 was used. While, in order to determine the mass flow rate for the medium pumped through the turbopump, the flow rate measured by the flowmeter at the discharge pipeline was used.
The measurements were carried out 30 minutes after the power load had been changed and the turbounits work was stabilised (Test Records 2005, Test Results 2001).
The results for the turbopump and the turbogenerator are presented in Table 2 and Table 3 accordingly.

Table 2.
Results of the turbopump's operational test (for n = 1332 rpm).

Item	Steam consumption	Steam pressure before governor valve	Steam pressure after governor valve	Pressure In turbine condenser	Volumetric flow rate of water	Total head of pump
	D_{pt} [kg/h]	p_{pt} [MPa]	p_{ct} [MPa]	p_{wt} [kPa]	Q_{wt} [m3/h]	H [m.w.c.]
1	9 486	1.43	0.86	- 68.2	764	163.96
2	11 548	1.41	1.05	- 66.8	1665	156.79
3	12 826	1.41	1.19	- 66.3	2378	144.70
4	13 981	1.43	1.30	- 66.7	3043	130.88
5	14 113	1.43	1.32	- 66.6	3205	126.09

Source: Authors' elaboration, Ship's Particular (2005), Shinko RG, Shinko Cargo

Table 3.
Results of the turbogenerator's operational test (for n = 1800 rpm).

Item	Steam consumption	Relative generator power	Generator power	Steam pressure in turbine inlet	Pressure in turbine condenser
	D_{pg} [kg/h]	P_w [%]	P_g [kW]	p_{pg} [MPa]	p_{wg} [kPa]
1	6230	25	250	1.42	- 92.7
2	7820	50	500	1.41	- 92.6
3	9610	75	750	1.40	- 90.0
4	11300	100	1000	1.42	- 90.6
5	11920	110	1100	1.42	- 91.8

Source: Authors' elaboration, Ship's Particular (2005), Shinko RG, Shinko Cargo

Table 3 does not include the steam pressure values after the power control block. The parameter was impossible to be measured due to the turbogenerator quality – quantity governing method.
The measurement and calculation results included in Table 2 and Table 3 were used to specify the operational parameters of the turbounits.

SELECTED OPERATIONAL PARAMETERS OF TURBOUNITS

The mathematical relations used in the thermodynamics [Kosowski 2005] have been applied to determine operational parameters of the turbounits such as the theoretical power of steam turbines, unit steam consumption in relation to demanded power, and turbounits' general efficiency.
The theoretical power of the steam turbines was calculated by reading from the i-s graph the theoretical decrease in the enthalpy for the values of the steam pressure measured at the

turbine inlet and the pressure in the condenser, and by multiplying the theoretical enthalpy decrease by the steam mass flow.

The steam mass flow was established by multiplying water volume at the condenser outlet (read on the flowmeters) and the water density specified for the measured condensate temperature.

The power demanded by the pump in the turbopump unit was determined by multiplying the measured water volume at the pump suction, specified liquid density in relation to its temperature and the pump head determined on the grounds of the pressure measurement at the pump suction. The general turbounits efficiency was determined by dividing the demanded power by the power consumer by the turbine theoretical power. The unit steam consumption by the turbounit was established by dividing the demanded steam by the power demanded by the power consumer.

The calculations were conducted for 5 measurement points (presented in Table 1 and Table 2) for each turbounit.

The results for the turbopump operational parameters are presented in Table 4 and for the turbogenerator in Table 5.

Table 4.
Calculation results of the turbopump's operational parameters.

No. of point	Pump effective power	Turbine theoretic power	Turbopump overall efficiency	Specific steam consumption
	P_{pt} [kW]	P_{tt} [kW]	η_{tt} [-]	d_{pt} [kg/kWh]
1	340.0	2084.3	16.31	27.90
2	708.5	2640.0	26.83	16.30
3	933.9	2974.9	31.40	13.73
4	1080.9	3281.7	32.89	12.93
5	1096.8	3332.2	32.91	12.86

Source: Authors' elaboration.

Table 5.
Calculation results of the turbogenerator's operational parameters.

No. of point	Generator effective power	Turbine theoretic power	Turbogenerator overall efficiency	Specific steam consumption
	P_{pg} [kW]	P_{tg} [kW]	η_{tg} [-]	d_{pg} [kg/kWh]
1	250	1290	19.42	24.92
2	500	1618	30.92	15.64
3	750	1988	37.71	12.81
4	1000	2339	42.72	11.30
5	1100	2467	44.60	10.83

Source: Authors' elaboration.

The data presented in Tables 3-5 enabled to draw up Figure 2. The figure shows a unit steam consumption by turbounits and Figure 3 where turbounits efficiency is included.

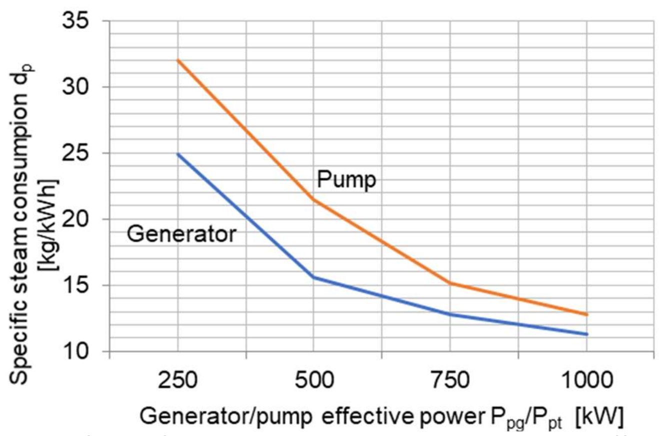

Fig. 2. Relation of specific steam consumption to consumer's effective power.
Source: Authors' elaboration.

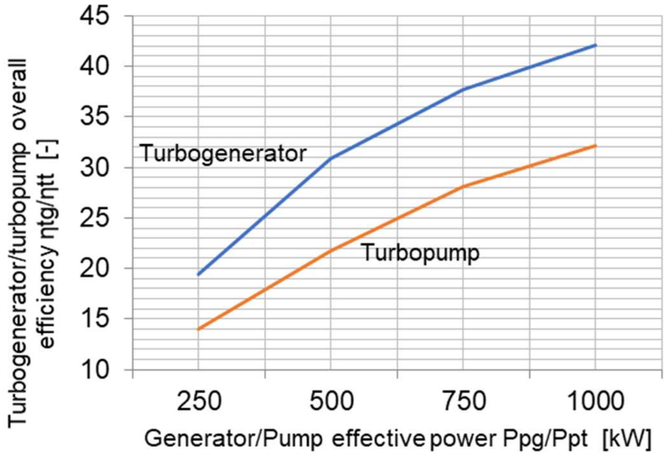

Fig. 3. Relation of turbine units overall efficiency to consumer's effective power.

Source: Authors' elaboration.

CONCLUSION

The operational parameters estimated for the tested turbounits imply the following conclusion:

- Measured steam consumption, when the turbogenerator was loaded with operational power, equalled to 11,300 kg/h, and was 3% higher than provided in the technical documentation; while the turbopump at the nominal power used 13,981 kg/h of the steam, which means that the steam consumption is 2,5% lower than the consumption parameter included in the technical documentation;
- The nominal power of consumer was obtained for both turbounits. In the case of the turbogenerator, the generator nominal power was exceeded by 10%, while for the pump in the turbopump unit the nominal power head was reached;
- The computed efficiency results for turbounits vary significantly. For a turbogenerator, the efficiency may equal from 19.42% at the 25% nominal load to 42.72% at the 100% nominal load. While for a turbopump it may be within the range from 16.31% at 34% nominal power to 32.89% at 108% pump nominal power.
- The results are mainly affected by:
  - The power quality – quantity governing method applied at the turbogenerator nominal power load equalled to 25%, 50%, 75% and 100%, resulting in throttling only the part of steam supplied to the section chamber (steam is supplied to the remaining section chambers without throttling). For a turbopump, a quality power governing method was applied. It consists of throttling all steam directed to the turbine;
  - The pressure in the turbogenerator condenser was maintained at the lower level in the range from – 90.0 to – 92.7 kPa (in the turbopump condenser the range was from – 66.3 to – 68.2 kPa). Due to that fact, the theoretical enthalpy decrease for the steam in the turbine was increased;
  - Power generators characterise with higher efficiency within the range from 95% to 97%, while the centrifugal pumps' efficiency with a large amount of a medium is between 90% to 92%.
- The minimum values of the unit steam consumption are within the range of turbounit power changes equalled from 70% to 100% of their nominal power.

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REFERENCES

Behrendt C. (2015), Operational characteristics of selected marine turbogenerator powered by steam from oil-fired boiler, Scientific Journals of the Maritime University of Szczecin no 44(116), pp. 9-13.

Costanza V, Rivadeneira P.S. (2015), Optimal supervisory control of steam generators operating in parallel. Energy, no. 93, pp 1819-1831.

Guo S., Liu P., Li Z., (2016), Data reconciliation for the overall thermal system of a steam turbine power plant. Applied Energy, no.165, pp 1037-1051.

Kosowski K. (2005) Ship Turbine Power Plants. Thermodynamical Cycles. Gdańsk, Wydawnictwo Foundation for the Promotion of Marine Industry.

Krause P., Behrendt C. (2007), Operating characteristics of the cargo turbopump, Maintenance Problems no 3/2007(66), pp.121-127.

Krzyślak P. (2002), Podnoszenie sprawności cieplnych układów turboparowych, Wydawnictwo Politechniki Gdańskiej.

Mrzljak V., Poljak I., Mrakovcic 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, no 140 (217), pp 307-323.

Normy (2001), Normy: DIN 57116/VDEO116, DIN 4787 T2, DIN 4788 T3, PN PN-71/M-35520.

Shinko RG, Shinko RG 64M-3 turbine, Shinko Official Website. Available at: https://www.shinkohir.co.jp/en/catalog.html [Accessed 09. March. 2018].

Shinko Cargo, Shinko Cargo and Ballast Pump Turbine, Shinko Official Website. [online] Available at: https://www.shinkohir.co.jp/en/catalog.html [Accessed 26 March. 2018].

Ship's Particular (2005), Ship's no 9000112 Particulars, Samsung Heavy Industries, Korea, [internal ship documentation].

Test Records (2005), Test Records for Cargo Oil Pump and Turbine, [internal ship documentation].

Test results (2011), Test results of official shop trial, Mitsui Engineering & Shipbuilding Co. Ltd, [internal ship documentation].

Yousri M.A., Welaya M., Mosleh Nader R. (2014), Thermodynamic analysis of a combined solid oxide fuel cell with a steam turbine power plant for marine applications, Brodogradnja/Shipbuilding no 65 (1), pp 97-116.

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