IMPACT OF THE SHIP GENERATING SETS' POWER FACTOR ON THE DETERMINATION OF THE LOAD FACTOR IN AUXILIARY ENGINE

Dariusz TARNAPOWICZ[1], Zbigniew MATUSZAK[2]

[1] *Maritime University of Szczecin, Poland, e-mail: d.tarnapowicz@am.szczecin.pl*
[2]*Maritime University of Szczecin, Poland, e-mail: z.matuszak@am.szczecin.*

Abstract
In order to evaluate the work of marine power plants, it is necessary, among other things, to determine the load factor in auxiliary engines. The load factor's value is usually used in analyzes of economical exploitation of the power plant, and also in the ecological aspect – limitation of exhaust emissions by auxiliary engines. In many scientific reports and publications, the load factor is determined directly from measurements of loads in generators (active power). The efficiency of the generator is not taken into account. In this article, the authors present the impact of the nature of the generator's load on its efficiency, and hence on the determination of the load factor in auxiliary engines.

Key words: *load factor of auxiliary engines; power factor; efficiency of synchronous generator*.

INTRODUCTION

Statistically, the most commonly used in shipbuilding industry methods of generating electricity on ships are autonomous generating sets consisting of combustion auxiliary engines (AE) and self-excited synchronous generators (G).

For the assessment of the operation of marine power plants, for example in terms of environmental protection or optimization of fuel consumption, it is crucial to determine the load factor for auxiliary engines (LF_{AE}). In the majority of studies, the load factor of auxiliary engines is a direct correlation with active power of the generator's load read on meters or recorders e.g.:(U.S. EPA, 2009). In this case, the excess power of auxiliary engines with respect to generators and the generator's efficiency are not taken into account. The importance of the AE load factor in terms of economy, but also ecology, is perfectly presented by the characteristics of the specific fuel consumption (SFC) depending on the load factor (LF_{AE}) (Tarnapowicz, Borkowski, 2016).

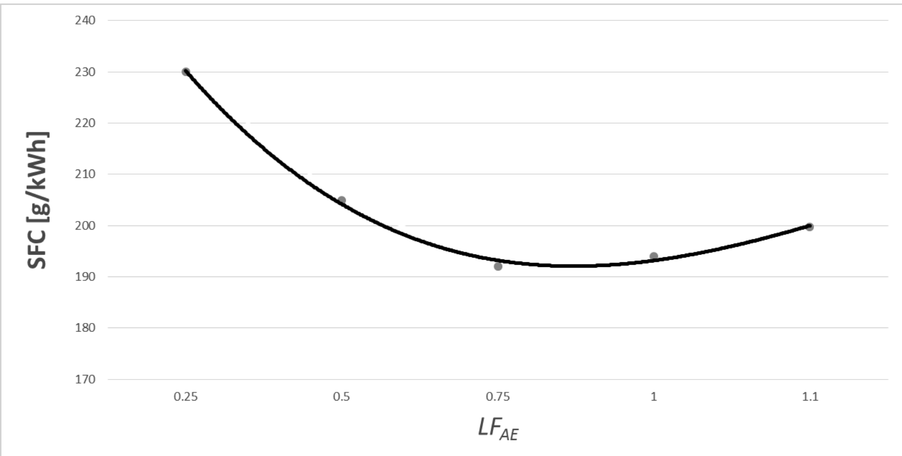

Fig. 1. Dependence of SFC in the function of LF_{AE} load factor (Tarnapowicz, Borkowski, 2016)

Based on the presented characteristics (Figure 1), it is possible to optimize the auxiliary engine's operation – achieving a minimum SFC. This optimization is carried out especially during the parallel operation of generating sets in the so-called asymmetrical work. The parallel work is performed on the ship in order to provide power reserve. Then we can deal with symmetrical work (symmetrical load of generating sets with minimum SFC). The second reason for parallel work of generating sets is to ensure power supply reliability. In this case, low load factor of auxiliary engines *(*LF_{AE}) would cause a high

SFC. In order to optimize the work of generating sets, an asymmetric operation is possible (asymmetric load of generating sets).

MATERIALS AND METHODS

Load factor of generating sets.
The load factor of auxiliary engines LF_{AE} that takes into account the excess power of the engine and the efficiency of generators demonstrates the following relation (Nicewicz, Sosiński, Tarnapowicz, 2014):

$$LF_{AE} = \frac{LF_{GS}}{\eta_G \cdot \alpha_{NM}} \quad (1)$$

where:
LF_{GS} – marine generating set (generator) load factor,
η_G – generator's efficiency,
α_{NM} – excess power factor of the auxiliary engine to the generator.

Factors of the excess power of the main engine in relation to the generator α_{NM} vary depending to the type of ship and the year of construction. On the basis of researches conducted by the authors, it can be concluded that the smallest values of factors were recorded on ships built after 2000. This leads to the conclusion that the significance of the factor α_{NM} for determination of LF_{AE} is smaller for newly built vessels. A summary of α_{NM} values on selected ships is shown in Table 1(Nicewicz, Tarnapowicz, 2012).

Tab. 1 excess power factor of the auxiliary engine to the generator on the test ships

Type of ship	Year of construction	α_{NM}
container ship	2005	1,05
container ship	1999	1,40
container ship	2001	1,05
container ship	2003	1,06
container ship	1982	1,21
semi-container ship	1986	1,62
bulk carrier	1993	1,60
bulk carrier	2003	1,10
bulk carrier	2000	1,09

The second feature taken into account in the formula (1) is the generator's efficiency. The efficiency of generator depends on several factors. The specification of synchronous generators includes dependences between the efficiency and the generator's load (ABB, 2012). At low loads of generators, the efficiency decreases. The second characteristic that affects the efficiency is the power of generators. Based on the analysis of the above-mentioned specification for various powers of generators, it can be stated that the efficiency of generators increases along with the increase of power (Tarnapowicz, Borkowski, 2016). The impact of the load on the generator's efficiency is very rarely analyzed. As already mentioned, the load of marine generators has a resistive-inductive nature. The power factor (cosϕ) can range from 0 to 1.Figure 2 presents the dependence of the generator's efficiency taking into account the nature of the load (generator with a power of 2545 kVA). Characteristics are prepared on the basis of specification for the selected generator. This feature shows a high dependence between the generator and the power factor (power factor - cosϕ). For small power factors, the generator's efficiency decreases by a few percent.

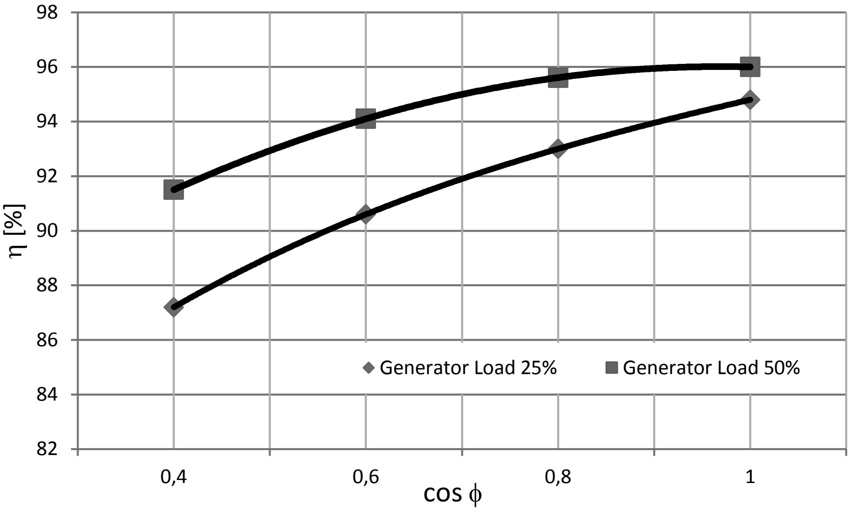

Fig. 2. The efficiency of the generator, depending on the power factor

An electrical ship network is a “soft” network. Powers of individual receivers are comparable to the power of the generating set. The main receivers are electric squirrel-cage motors. Their power changes along with the motor’s load (cosϕ). These motors are often underpowered (with a low power factor). Then the efficiency of the generator is lower.
The greatest differences in the nature of generating sets’ load can be observed in the parallel operation. According to the rules of qualifying societies, the distribution of active and passive powers between working in parallel generating sets must be uniform (with the same nominal powers of sets). In practice, this situation does not always occur. Controllers of the auxiliary engines’ rotations are responsible for the distribution of active powers. On the other hand, the distribution of passive powers (the nature of the generators’ load) is controlled by voltage regulators for generators – their static characteristics (U=f (Q) where U – generator’s load voltage, Q – Load of the generator with passive power). The vector diagram of synchronous generators (working in parallel in case of equal loads with active powers and different loads with passive power) is presented in Figure 3. It was made on the basis of equations (2):

$$\begin{aligned} \underline{E_1} &= \underline{U_1} + \underline{I_1} \cdot R + j \cdot \underline{I_1} \cdot X_r = \underline{U_1} + \underline{\Delta U_{I \cdot R}} + \underline{\Delta U_{I \cdot x}} \\ \underline{E_2} &= \underline{U_2} + \underline{I_2} \cdot R + j \cdot \underline{I_2} \cdot X_r = \underline{U_2} + \underline{\Delta U_{I \cdot R}} + \underline{\Delta U_{I \cdot x}} \end{aligned} \quad (2)$$

where:

E_1, E_2 - SEM induced in the winding of an armature during the generators’ loading
U_1, U_2 – voltage during the load of generators
I_1, I_2 – generator load currents,
R – resistance of the armature’s winding
X_r – reactance for the diffusion of the armature’s winding

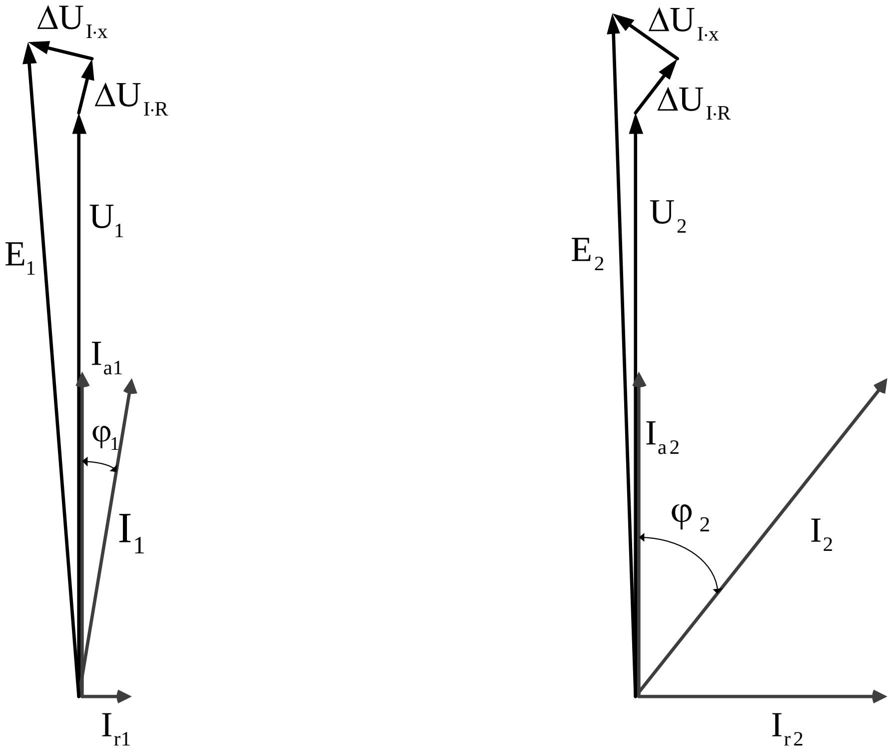

Fig. 3. Phasors for generators in parallel operation at different load of generators with passive power (different cos ϕ of generators).

RESULTS AND DISCUSSION

Figure 4 shows an example of changes in a power factor of a generator in the generating set for a modern container ship during one day. The vessel with a total length of 286.45 m was built in 2009. The researches were conducted during a sea voyage at the operation of an independent generating set. The measurement system enabled the record of data at intervals of one second. The measurements started on 3 February 2013 at 8 a.m. (traditional start of the machine watch on the ship) and ended at 8 a.m. on the following day (the end of machine watch). The time axis was formatted in such a way that subsequent values in seconds correspond to full hours.

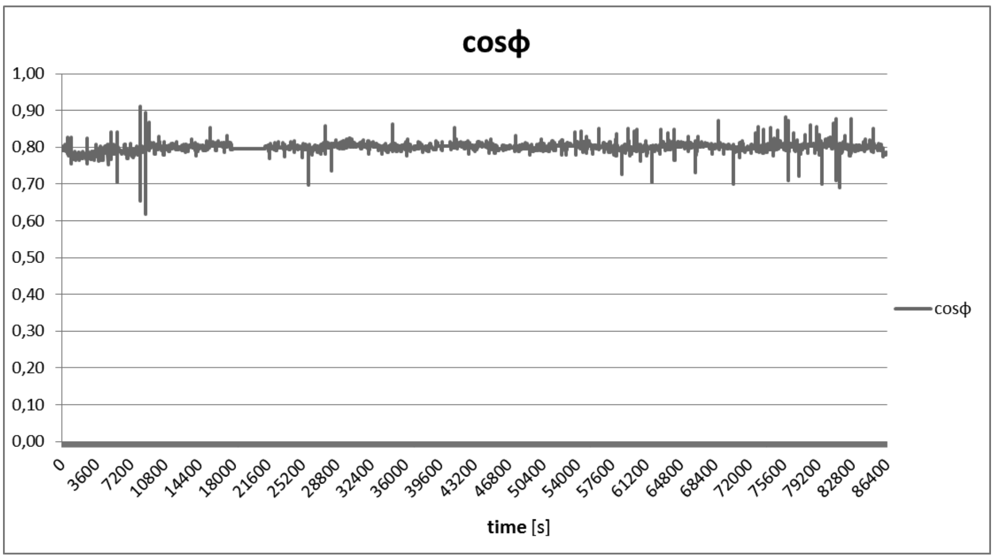

Fig. 4. Change in the nature of the load (cos ϕ) during the operation of a generating set within one day (sea voyage).

During the operation of a single generating set on the selected vessel, the power factor (cos ϕ) changed in the range from 0.62 to 0.92. In other cases, changes (cos ϕ) may be even greater.
Figure 5 shows the course of changes in power factor of parallel working diesel - generators on a modern bulk carrier. The vessel with a total length of 228 m was built in the year of 2013. The study was conducted during ship maneuvers at a port. The measurement system recorded data in 15 minute intervals.

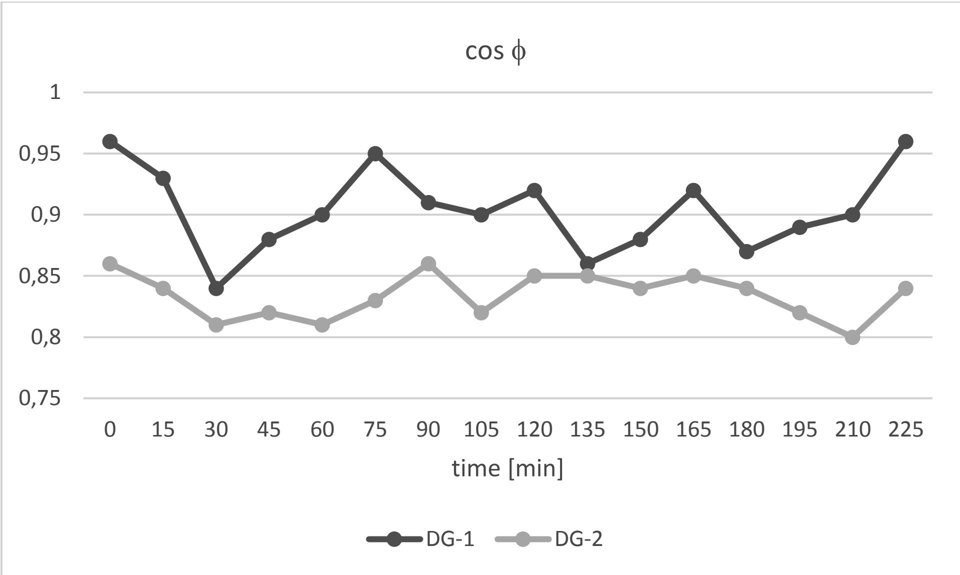

Fig. 5. Change in the nature of the load (through cos ϕ) during the parallel operation of two generator sets (maneuvers)

During parallel operation of two identical generator sets, the ratio of power factor oscillated between 0.8 and 0.96.
The results of both autonomous and parallel work of the generator sets have confirmed some changes in the nature of generator's load (through cos ϕ). This leads to a change in the efficiency of the generators, and thus affects the determination of the generator load factor.
The calculation of the load factor without taking into account cos ϕ is burdened with a large error caused by the wrong calculation of efficiency.

CONCLUSIONS

The load factor of marine auxiliary engines must be determine taking into account the factor of excess power of the engine in relations to the generator and the generator's efficiency (above all). One of the important factors affecting the efficiency is the nature of the generator's load (cos ϕ). The operation of a single generating set (cos ϕ) is determined by the load – usually the asynchronous engine is not always burdened with power rating. During the parallel operation of generating sets, there may be an uneven distribution of passive powers, and hence – a different cos ϕ of generators.

ACKNOWLEDGMENT

This research outcome has been achieved under the research project: Nowoczesne technologie w systemach "Shore to Ship" No 2/S/IEiAO/16 financed from a subsidy of the Ministry of Science and Higher Education for statutory activities

REFERENCES

1. U.S. EPA (2009) Environmental Protection Agency: Current Methodologies in Preparing Mobile Source Port-Related Emission Inventories. Final Report. *IFC INTERNATIONAL.* April 2009.
2. Tarnapowicz, D., Borkowski, T. (2016). Analysis of main ship propulsion operation

with shaft generator. *57th International Conference of Machine Design Departments (ICMD),* 2016 p 287-292
3. Nicewicz, G., Sosinski, M., Tarnapowicz, D. (2014) Identification of power factor in marine electrical grid. *Geoconference on energy and clean technologies, vol II.Book Series: International Multidisciplinary Scientific GeoConference-SGEM,* 2014 (pp. 391-398).
4. Nicewicz, G., Tarnapowicz D. (2012) Assessment of marine auxiliary engines load factor in ports. *Management Systems in Production Engineering* . No 3(7), 2012 p 12-17
5. ABB. (2012): Low Voltage Synchronous Generators for Industrial Applications, Technical Specfcations AMG2 2012, http://www.abb.com/product/2012.

Corresponding author:
Dariusz Tarnapowicz, Ph.D.Eng, Faculty of Marine Engineering, Institute of Marine Electrical Engineering and Vessel Automation, Maritime University in Szczecin, 70-500 Szczecin, Poland, and phone: 091-4809460, e-mail: d.tarnapowicz@am.szczecin.pl
Zbigniew Matuszak Prof. Eng, Faculty of Marine Engineering, Institute of Marine Propulsion Plants Operation, Maritime University in Szczecin, 70-500 Szczecin, Poland, phone: 091-4809414, e-mail: z.matuszak@am.szczecin.pl