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ASSESSMENT OF EXCESS POWER FACTOR IN MARINE GENERATING SETS

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Abstract

In the paper there has been presented a method of assessing auxiliary engines load based on identification tests of marine electric power systems loads of cargo vessels. The analysis has been illustrated by means of four auxiliary engines of an up-to date container ship 2200 TEU. A critical analysis of adjusting the auxiliary engines excess power factor to the active rated power of the generators of the currently operating generating sets.

Keywords: *marine power plants, marine electric power systems, generating sets, auxiliary engines*

1. Introduction

Generating subsystems of marine electric power systems consist mainly of synchronic generators driven by diesel engines which constitute independent generating sets. For most types of marine vessels they are the basic source of electric energy. Diesel engines when compared with other types of contemporary generator drive of marine electric power systems (e.g., combustible turbine engines or steam turbines) turn out to play the dominating role. The research carried out during the marine vessels operation determined the conditions for economical work of diesel engines driving the generators. The analyses presented in [8] show clearly that economical operation of generating sets to a great extend depends upon their load. According to [8] the work of the set appears to be the most economical at its load of 70% – 90%. At 50% – 70% of the load the increase of specific fuel consumption is negligible but at lower load values it is growing fast to reach the increase by 100% at the load of less than 20%. Thus, it appears to be significant that the power and the number of generating sets are adjusted in such a way that in various conditions of all vessel's characteristic operational states they can work at optimal load, that is at the load of 70% – 90%.

The issue of optimal operation of generating sets is connected with the adjustment of diesel engines power to the power of the generators. Diesel engines of power enlarged by 10% – 15% than the power of the generators have been suggested [3]. According to the research [8] the power of the diesel engines has been precisely adjusted to the rated power of the generators in marine power plants and the combustible engines excess power factor to the rated power of the generators equaled 1,05 – 1,25 (average 1,12). According to [8] at the generator's efficiency 0,92 – 0,94 the excess power of the engine appears to be negligible.

However, it should be remembered that in real operational conditions the load of the marine generating sets can be considerably lower than the rated power of the generator (installed power of generating set). It is proved by the results of the identification tests of the loads of marine electric power systems conducted by the author's of the paper on up-to-date cargo vessels partially discussed in [1, 4, 5, 6, 7, 9]. The knowledge of real need for electric energy during the vessel operation allows to assess the adjustment of excess power factor of the diesel engine to the power of the generator of the marine generating set and evaluate the real load of the diesel engine commonly known as the auxiliary engine. The issue shall be discussed more broadly in the further part of the paper.

2. Excess power factor in up-to-date power generating sets

The data concerning excess power factor of the auxiliary engines to the rated power of the generators of the electric power generating sets enclosed in the paper [8] come from the 70's of the last century and deal with vessels which have been out of service. Table 1 presents data concerning vessels currently in service which have undergone load identification tests of marine electric power systems. The vessels were constructed in the shipyards of Bulgaria, China, France, Japan, Yugoslavia, South Korea, Norway, Poland and Taiwan. The 14 types of vessels comprise six types of various size container ships (7500 TEU – 1100 TEU), two types of semi-containers, three types of bulk carriers, one type of general cargo vessel, a tanker DP2 and a chemical cargo carrier. The total length of the ships ranges within 72 – 300 meters. Power of the vessels main propulsion ranges within 1470 kW – 69440 kW.

Tab. 1. Values of the auxiliary engines excess power factor to the active power of the generators of the generating sets on the vessels tested for loads of marine electric power systems

Type of vessel	Date of construction	Auxiliary engine excess power factor to the active power of the generators
container vessel 7500 TEU	2004	1,05 1,05
container vessel 7500 TEU	2005	1,05 1,05
container vessel 5500 TEU	1999	1,40
container vessel 3050 TEU	2001	1,05
container vessel 2200 TEU	2003	1,06
container vessel 1100 TEU	1982	1,21
semi-container	1986	1,62
semi-container	1979	1,25
bulk carrier	1993	1,60
bulk carrier	2003	1,10
bulk carrier	2000	1,09
general cargo vessel	1979	1,46
tanker DP2	1993	1,07
chemical cargo carrier	1979	1,26 1,11

Generating sets installed in marine power plants of the vessels in question vary quite considerably in auxiliary engines excess power to the active rated power of the generators. Excess power factors range within 1,05 – 1,62. The smallest values of the factors have been recorded on vessels constructed after 2000. In case when generating sets of various power have been installed in the generating subsystem, in table 1 more than one factor values have been presented.

Data concerning peak loads of electric power systems and specified generating sets collected due to identification tests carried out on the cargo vessels in question deal with all registered operational states typical for the above mentioned vessels. This allows to determine not only the range to which the installed power of the whole electric power system or the generating sets has been made use of, but also to assess the real load of auxiliary engines driving the generating sets. The values of the peak load of generating sets used to be recorded for one hour time intervals and treated as a random variable due to which an empirical time series for the variable in question has been created.

As an example for the analysis data achieved for the generating sets of a container vessel 2200 TEU constructed in 2003 have been applied. The generating subsystem consisted of four identical generating sets of relatively small value of the auxiliary engine excess power factor to the power of the generator driven by the engine, that is 1,06. The character of the achieved peak loads distributions (for the one hour time intervals) of the generating sets has been shown in fig. 1 by means of the Box-and-Whisker plot achieved for each of the sets. The plots have been numbered from 1 to 4 which is adequate to the marking of the generating sets.

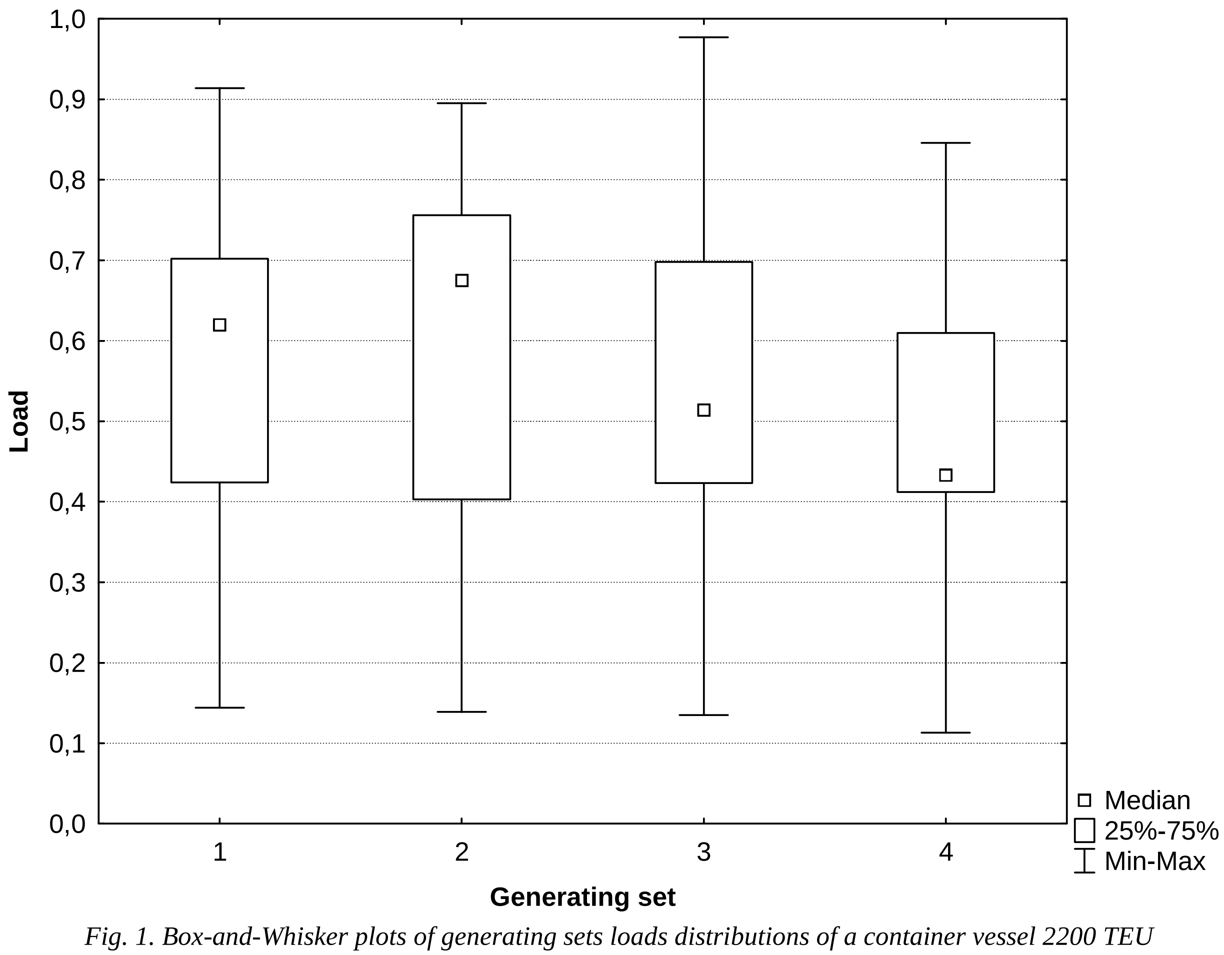

Fig. 1. Box-and-Whisker plots of generating sets loads distributions of a container vessel 2200 TEU

Due to the illustration of the achieved loads distributions of the generating sets by means of Box-and-Whisker plot introduced by Tukey in 1979 it is easy to compare their measures of location, dispersion and asymmetry, that is their minimal and maximal values, median and the upper and lower quartiles. The varied value of the peak load of the generating sets is estimated by means of comparing the length of four consecutive segments defining 25% of the registered peak load value. The variety of 50% of the most typical load values is proved by the box height of the plot adequate to the inter-quartile range. But asymmetry of the whole distribution is evaluated by comparing so called whiskers. If the upper whisker is longer than the bottom one the distribution is characterized by the right-hand side asymmetry and analogically, if the bottom whisker is longer than the upper one the distribution has left-hand side asymmetry. Asymmetry among 50% of the most typical peak load values is assessed due to the analysis of median location. If the median is closer to the upper (third) quartile, represented by the upper side of the Box-and-Whisker plot the distribution of the peak loads in the middle part is left-hand asymmetric and analogically, if the median is closer to the bottom (first) quartile represented by the bottom side of the Box-and-Whisker plot the distribution of the peak loads in the middle part is right-hand asymmetric.

The peak load distributions of the generating sets presented in fig. 1 make the basis for the analysis of auxiliary engines loads which shall be discussed in the further part of the paper.

3. The assessment of the excess power factor in the up-to-date generating sets

The peak load of the generating sets discussed in the previous chapter should be understood as the generator load – the registered peak values of the active power produced by the generator were referred to their rated active power. But there must be provided by the auxiliary engine greater power on the generator's shaft for its efficiency. And that is why in order to define the auxiliary engines load the generators' efficiency must be taken into account. If the generators' efficiency is taken on level 0,95 [2] the achieved distributions of the peak loads for the successive hours of the engine's work can be described by means of the Box-and-Whisker plots, which have been shown in fig. 2. Having the generators' efficiency on level 0,95 and the auxiliary engines excess power factor to the generators active rated power 1,06 the peak loads distributions of the generating sets and the auxiliary engines in fig. 1 and 2 differ quite insignificantly.

In fig. 2 there can be noticed considerably big differences between medians of the peak loads distributions of the auxiliary engines 1, 2 and 3, 4. This may be the result of the accepted by the ship owners technical service strategy for operating generating sets in reference to which sets 3 and 4 worked during the testing process longer than 1 and 2. Especially in the case of the generating set 2 working the shortest the influence of its switching on for the work while maneuvering which is connected with the use of 2 thrusters, whose power is approximate to the rated power of the generating sets, turned out to be very important for the value of the median.

The location of the load distributions' upper quartiles of the auxiliary engines 1, 3 and 4 in fig. 2 manifests that during 75% of the engines working time their peak load was lower than 70%, which according to [8] is regarded the lowest boundary of the auxiliary engines optimal load. The situation does not seem to be much better with the auxiliary engine 2 for which during 75% of working time the load did not exceed 75%. Thus, the auxiliary engines peak load at the presumed optimal level 70% – 90% occurred only during 25% of their working time.

Also in case of the longest working auxiliary engines 3 and 4 the location of the peak load distribution medians shows that for approximately half of the time they were working at the peak load below 50%. Apart from that for each of the auxiliary engines in question the peak load for 25% of their working time was below 40% which significantly worsens technical and economical conditions of their operation, especially because they were working on residual fuel. The smallest recorded values of the auxiliary engines peak load reached the level of approximately 15%.

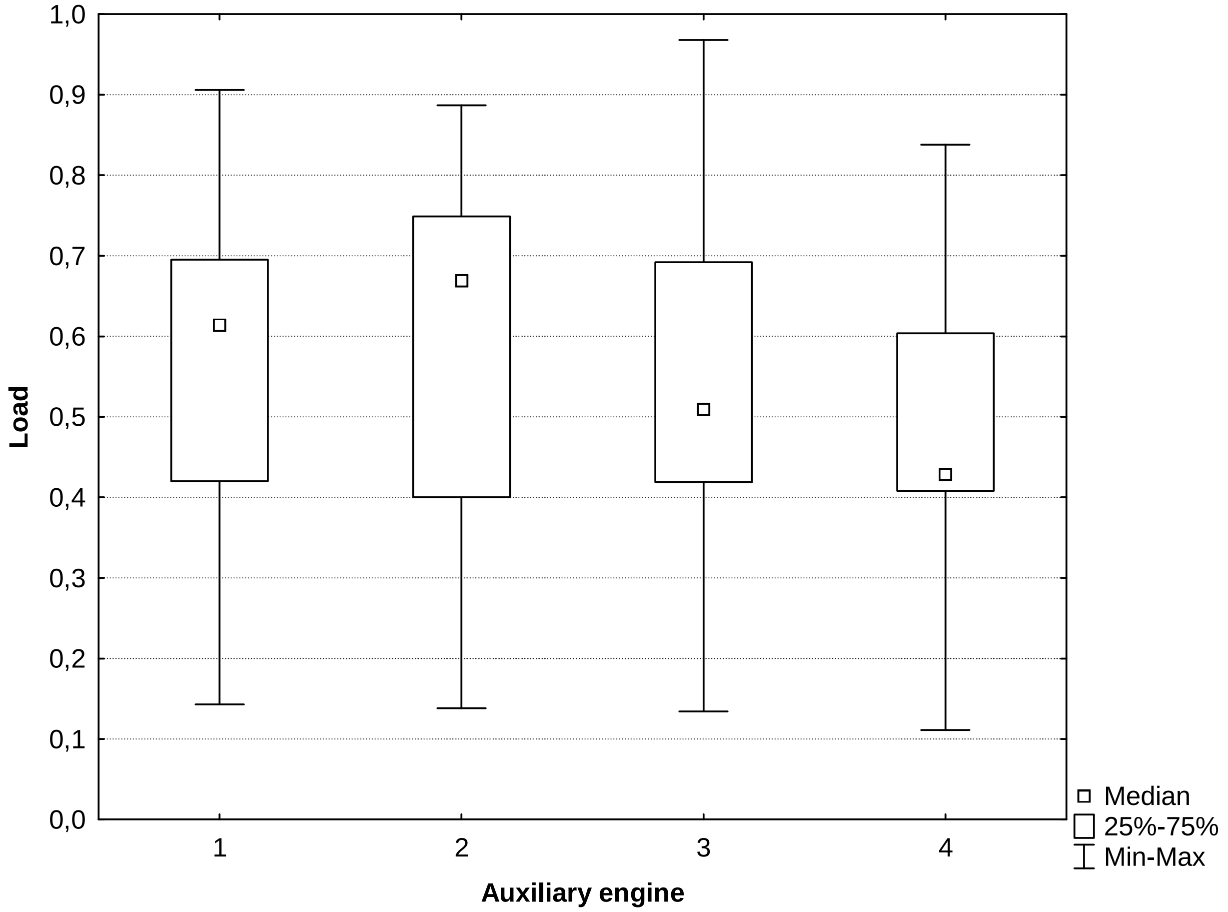

Fig. 2. Box-and-Whisker plots of load distributions of a container ship 2200 TEU auxiliary engines

It should be kept in mind that the auxiliary engines loads distributions shown in fig. 2 refer to the peak loads for the successive time intervals whose equivalent is one hour. Thus, in practice the auxiliary engines loads were even lower and the working time at the optimal loads 70 – 90% could be considerably shorter than 25% of the total working time of each of the engines.

The highest load values (more than 90%) were recorded in case of the auxiliary engine 3 (fig. 2). This was related to the malfunctioning of the diesel engine governor during manoeuvring with the use of thrusters and due to that unequal active power distribution between working in parallel generating sets – generating set 3 had its highest load then.

Due to the Box-and-Whisker plot the distributions of the auxiliary engine excess power factor to the peak power required on the generator's shaft (after the generator's efficiency has been taken into account) for the successive working hours of each of the sets can be presented. The distributions have been presented in fig. 3. In extreme cases the factor can reach even the value of 9 just as it occurred in case of the generating set 4.

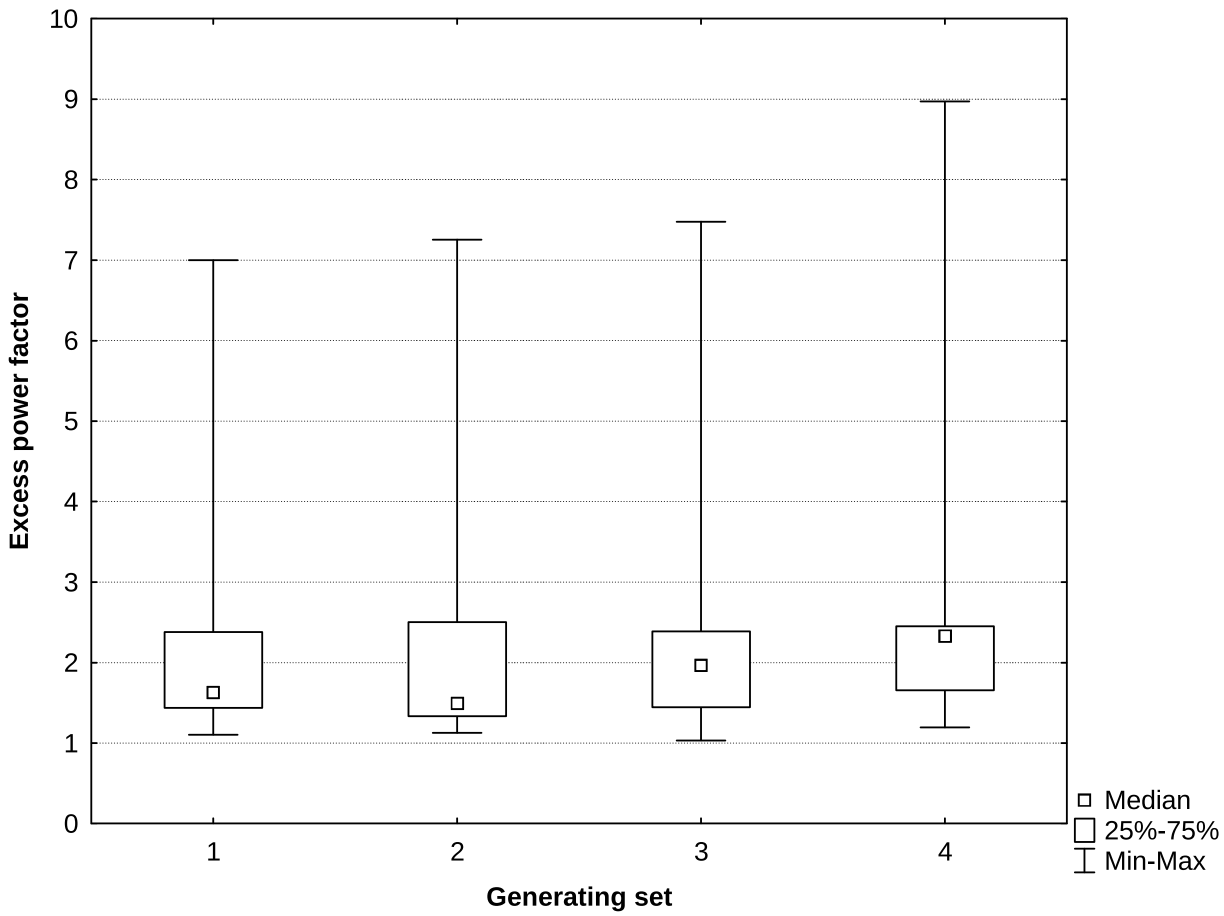

Fig. 3. Box-and-Whisker plots of the excess power factor distributions of a container ship 2200 TEU generating sets

4. Final remarks

The presented analyses deal with a vessel whose generating sets are characterised with one of the lowest auxiliary engines excess power factor to the active rated power of the generators from among the vessels referred to in table 1. At the same time the values of the generating sets peak loads registered during identification load tests of the electric power systems of cargo vessels outlined in table 1 belonged to the highest ones. In spite of that working time of the generating sets when the level of the peak load of the auxiliary engines ranged between 70 – 90 % equalled approximately 25% of their total working time during the research period covering a typically operational voyage of a ship between the ports of Europe and West Africa. Thus, it seems that no justification can be found for assuming higher values of the auxiliary engine excess power factor to the generator's active rated power of the installed generating sets when designing the cargo vessels. Identification tests of cargo vessels electric power systems loads carried out by the authors of the paper show clearly that in most cases generating sets work at considerably lower loads than the rated one and moreover too big excess power of the auxiliary engine stops its work being economical. When adjusting the number and power of generating sets statistical data concerning operation of marine electric power systems and probabilistic models of their loads in order to avoid possible design errors should be taken into consideration. Ship owning companies and their technical service have to struggle in case the generating sets of the marine power plants appear to be over dimensioned. The issue can be so essential that for example for the container vessel 1100 TEU enlisted in table 1 where the generating sets did not have the highest auxiliary engines excess power factor to the generator's rated power (1,21), residual fuel for the auxiliary engine needed to be changed for distilled fuel because of their too low load. Apart from the increase in fuel expenses, over the years of the vessel operation, some of the fuel and steam installation connected with preparing the residual fuel oil for the auxiliary engines stopped being used although the costs of its construction had required to be paid for.

Thus, collecting statistical data during vessels operation, especially by means of the up-to-date control systems which most marine power plants of the currently constructed vessels are equipped with, shall significantly contribute to discerning real working conditions of the machinery and devices as well as the development of marine industry.

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