Journal of POLISH CIMAC
Faculty of Ocean Engineering & Ship Technology
GDAŃSK UNIVERSITY OF TECHNOLOGY

ASSESSMENT OF REAL ACTIVE POWER LOAD OF MARINE GENERATING SETS IN OPERATIONAL CONDITIONS OF CONTAINER VESSELS

Zbigniew Matuszak, Grzegorz Nicewicz

Maritime Academy of Szczecin
ul. Wały Chrobrego 1-2, 70-500 Szczecin, Poland
tel.: +48 91 4809414, +48 91 4809442
e-mail: zbimat@am.szczecin.pl, nicze1@wp.pl

Abstract

As far as marine generating sets driven by diesel engines are concerned, it is assumed that the optimal active power load ranges between 70 – 90% [9]. At the same time there is no unequivocal way of assuming the value of the auxiliary engine excess power factor in relation to the generator's rated active power regarded as the rated power of the set [3, 9, 10]. According to the outcome of the authors' research carried out on contemporary transport vessels, the factor ranges within 1,05 – 1,62. In operational conditions, even at low values of excess power factor, the contribution of generating set working time at load 70 – 90% appears relatively short, which has been discussed in [10]. Eventually, the process of deterioration of auxiliary engines technical condition due to their long lasting operation at low loads gets accelerated and the operation turns out economically unprofitable due to the increase in specific fuel consumption. The paper deals with broader spectrum of individual generating sets' active power load on contemporary transport vessels based on long – standing identification tests of marine electric power system loads.

Keywords: *marine generating set, auxiliary engine, active power load*

1. Introduction

Electric power system load identification tests have been carried out on various types of contemporary transport vessels, e.g. container and semi - container ships, bulk carriers and general cargo vessels. Mainly, the value of active power peak loads at fixed time intervals, allowing for setting the boundary conditions of the systems' operation, has been focused on. The tests' methodology has been discussed in [11, 12]. The obtained results enable the assessment of the generated power of the marine electric power system and individual generating sets in operational conditions. According to the literature [2, 9], considering the optimal operational conditions of auxiliary engines, the assumed active power load of generating sets driven by diesel engines should range between 70 – 90% of their rated power. The tests proves that in practice such load value of generating sets occur relatively short when taking into account their total operational time. Therefore, in order to adjust the number of power generating sets in the marine power station and their excess power factor, it appears relevant to estimate the peak load distributions of contemporary operated power generation sets. Due to the paper space limit, mainly the character of generating sets' (GS) active power load of contemporary container vessels has been focused upon. They frequently turn out to be equipped with thrusters and capable of carrying vast numbers of reefer containers, where the demanded power may be compared to the power of a single generating set [13]. The tests outcome concerning other types of transport ships have been broadly discussed in the following works [2, 5, 6, 7].

The subject of the tests have been six container ships of various capacity: 7500 TEU, 7500 TEU, 5500 TEU, 3050 TEU, 2200 TEU and 1100 TEU equipped with certain fixed number of sockets to connect reefer containers. To ease the analysis the container ships have been marked with Roman numbers from I to VI. The marine power stations of I, II, IV and V consist of four generating sets, III contains three generating sets and a shaft generator and VI is equipped with two generating sets and a shaft generator. The vessels I, II, III, IV and V are supplied with thrusters, whereas VI is equipped with emergency electric drive.

2. Active power load of marine generating sets

For the analysis of the active power load of the marine generating sets the data on peak loads of the sets at the consecutive hours of the operation have been used. In case of IV, a 3050 TEU container vessel, the data on 24 hour peak loads have been made use of. In fig. 1 box-and-whisker plots of the obtained empirical distributions of the generating set loads have been shown; presenting the measures of location, dispersion and asymmetry of the distributions [14, 15]. The symbol of the generating set in fig. 1 consists of the ship's mark on which it was installed and its number it has been assigned on the vessel.

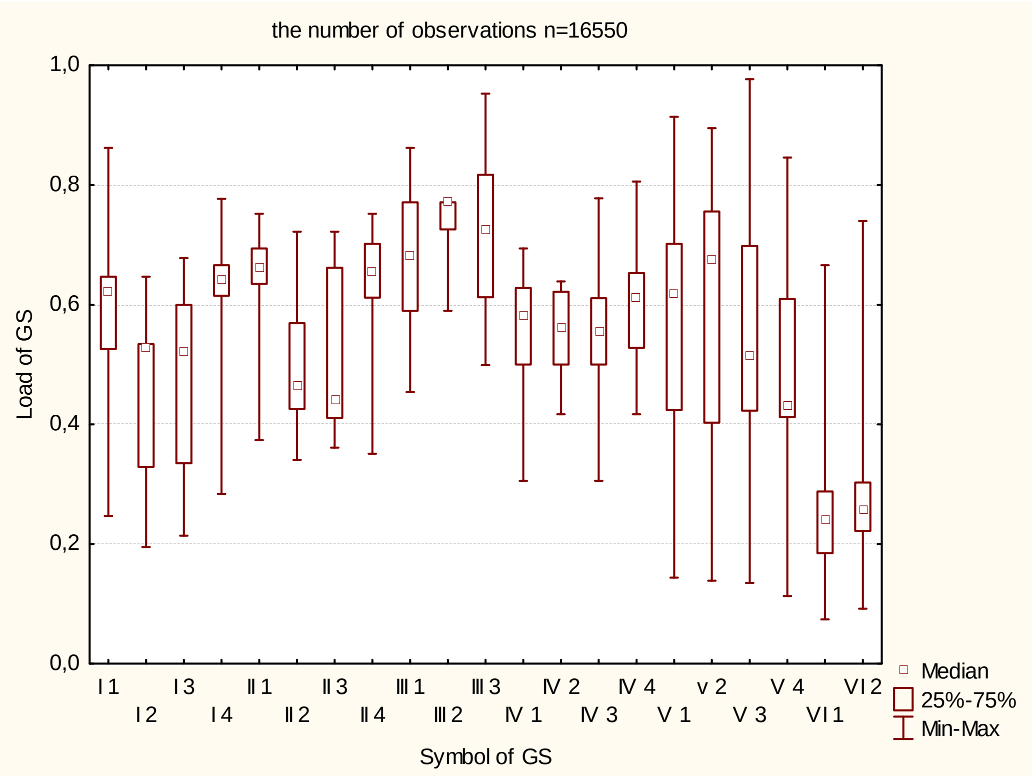

Fig. 1. Box-and-whisker plots of the generating sets' peak loads distributions from the tested container vessels

The location of the empirical distribution medians (in fig. 1) clearly shows that for over 50% of the time of operation most of the generating sets of the container vessels, the subject of the tests, (except of GS III 2 and III 3), their peak load turns out lower than 70%, which means that it is lower than the lower limit of the optimal load range. Only for 8 out of 21 analyzed generating sets the values of the recorded peak loads exceeded 80%.

Differences between peak loads distributions of particular generating sets installed on a vessel (if they are identical) come first of all from operational strategy accepted by the engine crew or ship owner technical services. Therefore, the data on peak loads in case of identical sets on individual vessels have been aggregated for the sake of a more general approach to the analysis outcome. In this way there have been constructed box-and-whisker plots of marine generating sets' peak loads distributions, shown in fig. 2. In case of vessels equipped with not identical power generating sets, they have been marked respectively with capital letters in the alphabetical order.

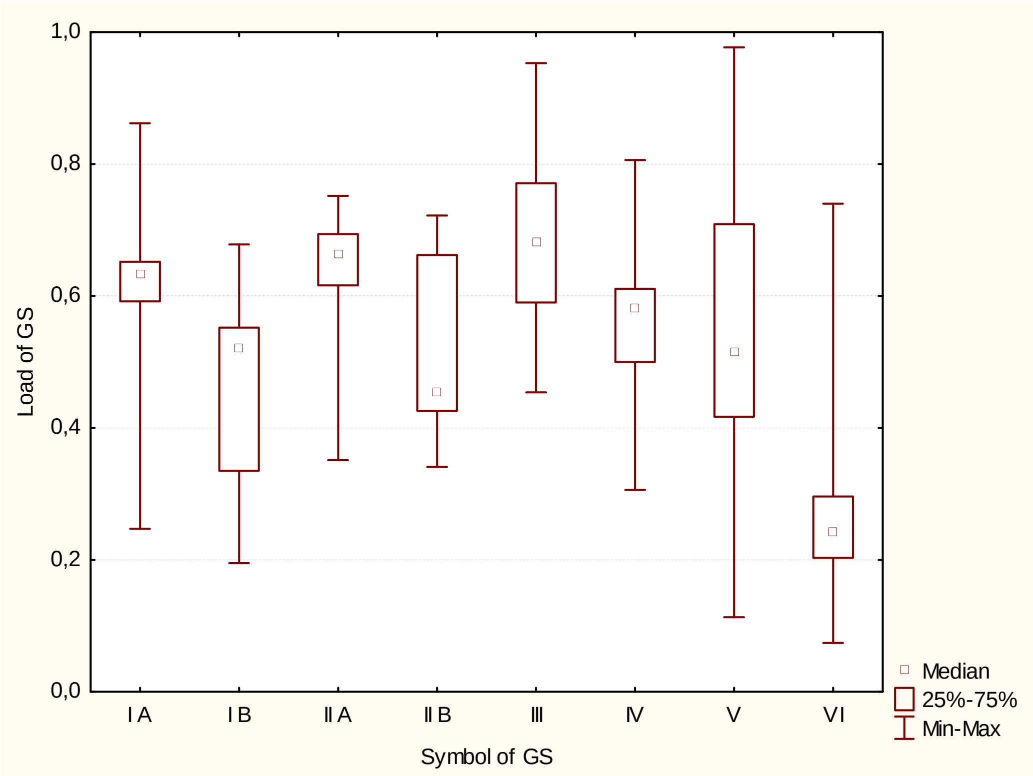

Fig. 2. Box-and-whisker plots of peak loads distributions of generating sets of the tested container ships for the aggregated data

The location of the medians of the obtained peak loads distributions for the generating sets I A, II A and III for the aggregated data (fig. 2) proves that for half of the operational time their hourly peak loads exceeded 60% of the set's rated active power. The median highest value has been recorded for generating sets installed on 5500 TEU container ship (III). As a rule, the peak loads of values higher than 70% do not occur more frequently than for 25% of the generating sets' operational time. An exception to that appear the data obtained for the generating sets of the container ship III, where the peak loads of values beyond 70% occurred for almost half of the time of operation.

3. The characteristic of the obtained empirical distributions of the generating sets' peak loads

The obtained peak loads empirical distributions of the container vessel generating sets are characterized for their asymmetry and they differ from the normal distribution, which is confirmed by the results of the statistical tests made by means of *STATISTICA 8.0* (there have been carried out the Shapiro-Wilk test if the sample number $n < 2000$, the Lilliefors and chi-square tests if the sample number $n > 2000$ as well as the normal probability plots have been computed). Some of the obtained distributions are known for their multi-modality. The example of the obtained results for the generating sets of 7500 TEU and 2200 TEU (I and V) container ships have been shown in fig. 3 and 4.

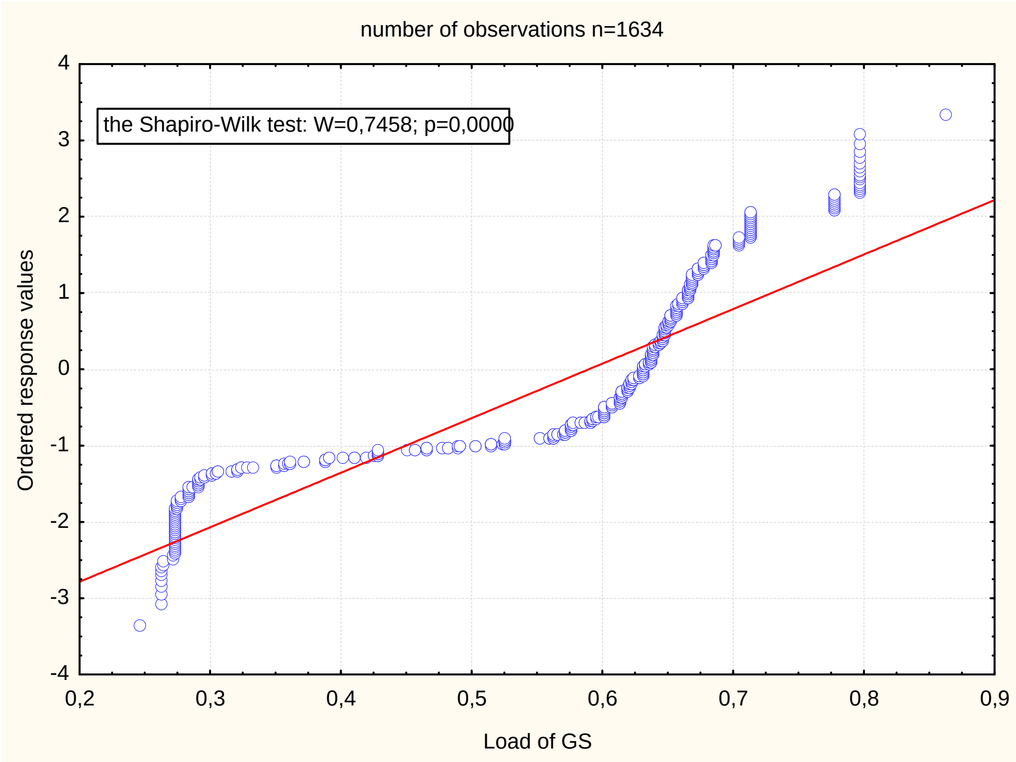

Fig. 3. Normal probability plot and the results of the Shapiro-Wilk test for the generating sets' peak loads of 7500 TEU container ship (I A)

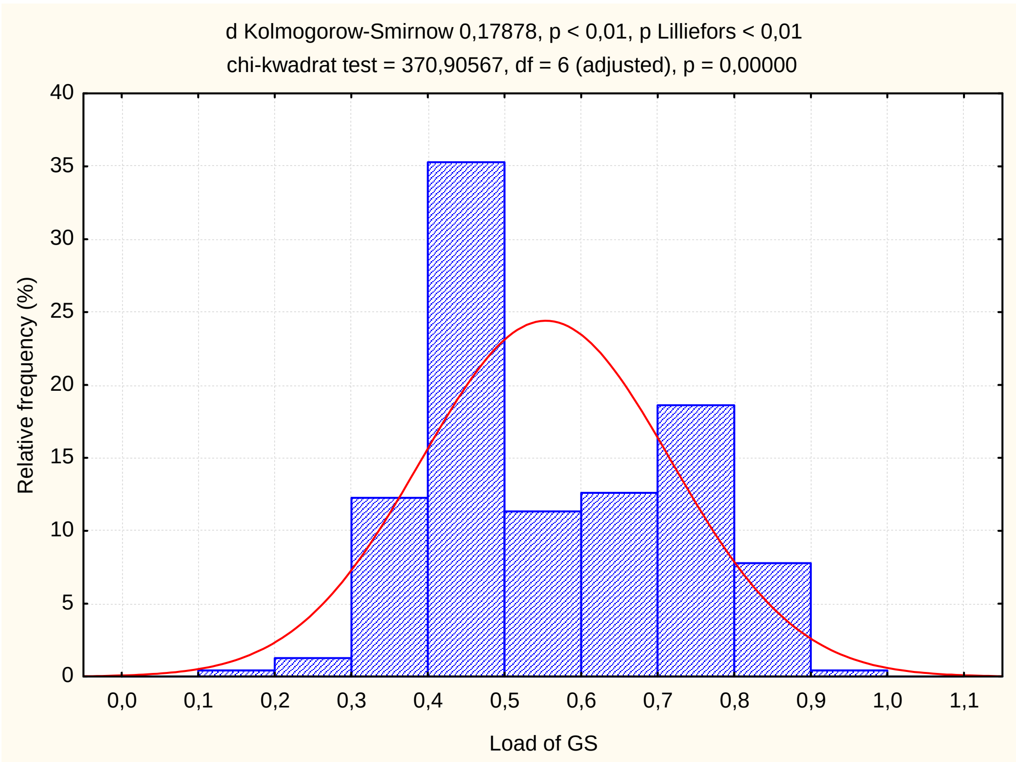

Fig. 4. Histogram of generating sets' peak loads of 2200 TEU container vessel (V) and the plotted probability density function of normal distribution (solid line) with the tests of goodness of fit results inserted

The character of the obtained empirical data on peak loads of the container vessels' generating sets does not allow for the estimation of the probability density functions of empirical distributions due to such tools like the program *STATISTICA 8.0* by means of well known functions of relatively simple theoretical distributions like normal, gamma, log-normal or exponential. The differences between the assumed models and the empirical distributions were statistically significant. The problem of estimating the probability density functions of empirical distributions of container ships' generating sets peak loads may be solved by the application of the so called distribution compositions (mixtures of distributions); however, it appears a dull, time consuming method and would go beyond the frames of the paper.

4. Final remarks

The presented analysis of the six container ships' generating sets peak loads (fig. 2) shows that only three (I A, II A, III) out of eight generating sets installed, for half of the time show hourly peak loads higher than 60%. The position of the lower quartiles (fig. 2) in case of the six types of generating sets (I A, II A, II B, III, IV, V) occurs above 40% of the sets' rated active power, thus, for 75% of the operational time the peak loads appear higher than this value. The least economic turns out the load of the generating sets of the 1100 TEU container vessel (VI).

The obtained empirical load distributions of the generating sets appear characteristic for their asymmetry and multi-modality. They considerably differ from the theoretical normal distribution. The applied test of goodness of fit for models in the form of other simple theoretical distributions like gamma, log-normal or exponential have not turned out the right ones to describe empirical distributions.

The collected statistical data on the peak loads values of the generating sets originate from container ships of various technical parameters; this refers also to the marine electric power systems and generating sets. Therefore, the hypothesis, that they belong to the same population, or in other words, that they can be treated as the realization of the same random sample, needs to be verified. Only such verification, on the basis of all the collected statistical material, enables to describe the general peak loads' value distribution of the considered container vessels' generating sets. For that purpose the Kruskal-Wallis test was applied because of the fact that the peak loads values distributions of the particular types of generating sets do not comply with the normal distribution [14, 15]. The test's detailed structure has been dealt with in [8]. The hypothesis verification has been carried out by means of the statistical package *STATISTICA 8.0*. The results have been presented in the table of the program *STATISTICA 8.0*; shown in fig. 5.

Symbol of GS	The Kruskal-Wallis test: H (7, N=16550) = 11439,69; p =0,000	
	N - total number of observation	Rank sum
I A	1634	18599489
I B	686	5942242
II A	2838	36324180
II B	908	9148490
III	1487	20356588
IV	234	2466567
V	1182	12902221
VI	7581	31219749

Fig. 5. The Kruskal-Wallis test results presented in the table of STATISTICA 8.0; N – total number of observations, 7 – number of degrees of freedom of the asymptotic distribution χ^2 of the statistic H, H – the value of the Kruskal-Wallis test statistic, p – p-value

The computed *p*-value proves that there are no bases for accepting the hypothesis of the data on peak loads values of particular types of the container ships' generating sets , in question, coming from the same general population at the assumed significance level α=0,05.

References

[1] Chybowski, L., Kijewska, M., Nicewicz, G., *Analiza obciążeń autonomicznych urządzeń prądotwórczych systemów energetycznych obiektów pływających.* II Międzynarodowa Konferencja Naukowa Systemy Wspomagania w Zarządzaniu Środowiskiem, Ekonomika i Organizacja Przedsiębiorstwa Rok LVI Nr 7 (666) Lipiec 2005, Słowacja, Zuberec 2005.

[2] Cichy, M., Kowalski, Z., Maksimow, J.I., Roszczyk, S., *Statyczne i dynamiczne własności okrętowych zespołów prądotwórczych*. Wydawnictwo Morskie, Gdańsk 1976.

[3] Figwer, J., *Zagadnienie wielkości mocy silnika napędowego w okrętowych zespołach prądotwórczych*. Budownictwo Okrętowe Nr 6, 1962.

[4] Kijewska, M., Matuszak, Z., Nicewicz, G., *Identyfikacja obciążeń systemu elektroenergetycznego siłowni okrętowych w rzeczywistych warunkach eksploatacyjnych*. SYSTEMS Journal of Transdisciplinary Systems Science Vol. 11 2006, pp. 334-340.

[5] Kijewska, M., Nicewicz, G., *Analiza rozkładu obciążeń zespołów prądotwórczych elektrowni okrętowej statku transportowego dla wybranego stanu eksploatacyjnego*. Надежность и Эффективность Технических Систем. Международный Сборник Научных Трудов, KGTU, Kaliningrad 2004, pp. 64-72.

[6] Kijewska M., Nicewicz G., *Estymacja gęstości rozkładu obciążeń zespołów prądotwórczych elektrowni okrętowej w wybranym stanie eksploatacji*. Zeszyty Naukowe Politechniki Gdańskiej nr 598 (seria: Budownictwo Okrętowe Nr LXV), Gdańsk 2004, pp. 79-87.

[7] Kijewska M., Nicewicz G., *Rozkłady empiryczne a rozkłady teoretyczne obciążeń autonomicznych zespołów prądotwórczych elektrowni okrętowych*. Надежность и Эффективность Технических Систем. Международный Сборник Научных Трудов, KGTU, Kaliningrad 2005, pp. 124-131.

[8] Kruskal W.H., Wallis W.A., *Use of Ranks in One-Criterion Variance Analysis*. Journal of the American Statistical Association, Vol. 47, No. 260. (Dec., 1952), pp. 583-621.

[9] Kuropatwiński, S., Lipski, T., Roszczyk, S., Wierzejski, M., *Elektroenergetyczne układy okrętowe*. Wydawnictwo Morskie, Gdańsk 1972.

[10] Matuszak, Z., Nicewicz, G., *Assessment of excess power factor in marine generating sets*. Journal of POLISH CIMAC – ENERGETIC ASPECTS, Vol. 3, No. 1, Gdańsk 2008, pp. 95-101.

[11] Matuszak, Z., Nicewicz, G., *Assessment of hitherto existing identification tests of marine electric power systems loads*. Polish Journal of Environmental Studies, Vol. 18, No. 2A, Olsztyn 2009, pp. 110-116.

[12] Matuszak, Z., Nicewicz, G., *Wykorzystanie szeregów czasowych do analizy obciążeń izolowanych systemów elektroenergetycznych*. Systemy Wspomagania w Zarządzaniu Środowiskiem – Monografia pod redakcją J. Kaźmierczaka, Zabrze 2008, pp. 185-191.

[13] Nicewicz G., *Obciążenie okrętowego systemu elektroenergetycznego a bezpieczeństwo statku*. Zeszyty Naukowe AMW im. Bohaterów Westerplatte Nr 168 K/1, X Konferencja Morska „Aspekty bezpieczeństwa nawodnego i podwodnego oraz lotów nad morzem", Gdynia 2007, pp. 205-215.

[14] Stanisz, A., *Przystępny kurs statystyki*. *Tom 1. Statystyki podstawowe*. StatSoft, Kraków 2006.

[15] StatSoft - *STATISTICA 8.0.*, *Podręcznik elektroniczny STATISTICA.*