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OPERATIONAL LOADS OF DIESEL ENGINES ON TRAILING SUCTION HOPPER DREDGERS IN THEIR MAIN SERVICE STATES

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Abstract

This paper presents results of operational investigations of eight trailing suction hopper dredgers. The investigations covered measurements of parameters which characterize service conditions of two main elements of dredger power systems, i.e. main and auxiliary engines.

Keywords*: trailing suction hopper dredgers, ship power plants, ship power systems.*

1. Introduction

Trailing suction hopper dredgers belong to the group of the largest technological ships and their power systems - to the most complex ones. Total output power of diesel engines installed on the largest dredgers of the kind exceeds 30000 kW.

Power system of suction hopper dredger consisted of diesel engines (both main and auxiliary ones) is intended for the satisfying of power demand from the side of main consumers (screw propellers, dredge pumps, jet pumps and bow thrusters) as well as of the group of auxiliary consumers. On the suction hopper dredgers a great variety of types of power systems can be found. Nevertheless the most often applied solution is the system having many variants, in which main engines satisfy the whole power demand from the side of main and auxiliary consumers in two basic service states of dredger: ”dredging work” and ”free-floating”. Then, auxiliary engines cover power demand from the side of auxiliary consumers in the service states in which main engines stand by (e.g. lying at anchor) [3,4].

In designing the power systems it is necessary to know operational loads of the diesel engines being elements of the system, first of all in the ship service state deemed crucial. In the case of the dredgers in question such state is associated with „dredging”. Service conditions which occur during the dredging are determined by the parameters assumed during design process of dredger power systems.

This paper presents characteristics of real loads of diesel engines on suction hopper dredgers during carrying out „dredging work” and also in the state of „free-floating” (in the sense of moving). The characteristics have been obtained as a result of wide operational investigations carried out on the dredgers which operated in the South Baltic, in the years 2000÷2003 and 2005÷2006 [3]. The results have been supplemented by the data dealing with three other dredgers, taken from the literature sources [5,6,7]. The main technical data of the eight dredgers, which characterize first of all their power systems, are given in Tab. 1. Two smallest dredgers: the *Kostera* and *Kronos* are fitted with the power system of the type III, which is characteristic of separate diesel engines intended for the driving of screw propellers, separate engines for the driving of dredge pumps, as well as integrated electric generating sets to ensure driving the loosening pumps, thruster and all auxiliary power consumers. The remaining power systems of the dredgers in question belong to the type I. The type is characteristic of that one group of main engines ensure driving main power consumers of all kinds, very often in the basic service states, and auxiliary power consumers. Differences in variants of the power system type consist in different power transmission systems of given main consumers. And, the type I.a constitutes the system in which all main consumers are driven by means of diesel - electric power systems. (the dredgers *Łęgowski and Bukowski*), the type I.b is such power system in which one kind of main power consumers characterized by the largest nominal power, i.e. screw propellers, is driven by main engines working in diesel – mechanical systems (i.e. through mechanical transmission gears), and the remaining kinds of main power consumers are driven by means of diesel – electric systems , the type I.c is characteristic of that two kinds of main consumers (usually main screw propellers and dredge pumps) are driven by main engines working in diesel-mechanical systems , and the remaining kinds of main consumers - by means of diesel-electric systems (the dredger *Lange Wapper*) and the last variant of the type I , i.e. the type I.d in which as many as three kinds of main power consumers are driven by main engines working in diesel-mechanical systems (the dredger *Nautilus*).

Tab.1. Technical characteristics of power systems of the investigated trailing suction hopper dredgers

Dredger	Year built	V_{HP}	Classes of dredgers	Type of power systems	$\sum N_{ME}^{nom}$	$\sum N_{AE}^{nom}$
		m^3			kW	kW
Kostera	1968/1993	310	small	III	798	306
Kronos	1964/1985	380	small	III	885	513
Łęgowski	1975	1600	small	I.a	2640	534
Bukowski	1974	1600	small	I.a	2560	392
Nautilus	1996	4400	medium	I.d	3700	350
Gogland	1982	8200	medium	I.b	8606	1850
Geopotes 15	1985	9960	large	I.b	11160	1285
Lange Wapper	1998	13700	large	I.c	11520	2340

V_{HP} - hopper (soil hold) capacity,

$\sum N_{ME}^{nom}$ - rated output power of main engines,

$\sum N_{AE}^{nom}$ - rated output power of auxiliary engines.

2. Operational loads of main engines

In order to determine operational characteristics of main and auxiliary engines on dredgers to know changes of the loads during a long period is necessary. A large number of instantaneous values of the loads make their correct statistical estimation possible. To the investigations which have been carried out for long periods, the stationary measuring instruments permanently installed on dredgers have appeared most suitable. The detail description of the measuring methods applied to the service investigations in question is given a.o. in [2] and [3]. On the basis of an analysis of initial investigations concerning changes of loads of main and auxiliary engines on suction hopper dredgers [3] the every 5th minute frequency of load measurements of main engines was assumed sufficient for further investigations.

The so determined values of main engine loads were used to determine the following parameters of load distribution characteristics:

N_{ME}^{av} - average load of main engine, kW;

$\overline{N}_{ME}^{av} = \frac{N_{ME}^{av}}{N_{ME}^{nom}}$ - average relative load of main engine, -;

σ_{ME} - standard deviation of main engine load distribution, kW;

$v_{ME} = \frac{\sigma_{ME}}{N_{ME}^{av}}$ - coefficient of variance of main engine load distribution, -.

The four dredgers (the *Nautilus*, *Gogland*, *Geopotes 15* and *Lange Wapper*) are characteristic of that their main engines satisfy power demand from the side of auxiliary power consumers in the main service states. Hence the service effective power of the main engines is equivalent to the entire power necessary to realize technological processes by the dredger. In the case of the four remaining dredgers the service effective power of auxiliary engines should be additionally taken into account.

The characteristics of load distributions of main engines on the investigated dredgers are given in Tab. 2. The load distributions of main engines on selected dredgers are presented in Fig. 1.

Tab.2. Characteristics of load distributions of main engines on trailing suction hopper dredgers engaged in carrying out the dredging work and free-floating

Dredger	Dredging work				Free-floating				References
	N_{ME}^{av}	$\overline{N}_{ME}^{av}$	σ_{ME}	v_{ME}	N_{ME}^{av}	$\overline{N}_{ME}^{av}$	σ_{ME}	v_{ME}	
	kW	-	kW	-	kW	-	kW	-	
Kostera	175,1	0,22	58,8	0,336	216,1	0,271	54,6	0,252	[∗]
Kronos	193,3	0,218	25,9	0,134	264,7	0,299	58,2	0,22	[∗]
Łęgowski	1165,1	0,441	371,2	0,319	1249,5	0,473	282,7	0,226	[∗]
Bukowski	1186,8 777,4*)	0,464 0,304	319,5 215,7	0,269 0,277	1297,3	0,507	223,7	0,172	[∗]
Nautilus	1553,2	0,42	319,3	0,26	1498,4	0,405	359,9	0,24	[5]
Gogland	4735,5	0,55	943,5	0,199	5464,6	0,635	875,1	0,16	[6]
Geopotes 15	6152,4	0,551	1215,1	0,197	6752,8	0,605	1529,1	0,226	[∗]
Lange Wapper	6932,7	0,602			7976,7	0,692			[7]
average		0,433		0,245		0,486		0,214	

*) – data which concern the dredging work in soft soils (silts)

[∗] – self investigations

In Tab. 3 are presented calculation results concerning load characteristics of main engines during carrying out particular operations within the scope of dredging work. In all cases the calculations, irrespective of a type and power system and number of main engines, were performed jointly for all the main engines installed on a given dredger.

The performed calculations of the parameters of load distributions of main engines during carrying out the dredging work have revealed that for particular dredgers the relative average loads are contained in the range of 0,218 ÷ 0,602 at the mean value of 0,433 and variation coefficient of the range of 0,134 ÷ 0,336 at the mean value of 0,245. Simultaneously attention should be paid to the fact that for the dredgers having their power systems of the type III (the *Kostera* and *Kronos*), the relative average loads are definitely smaller and contained in the range of 0,218÷0,22. This is connected with the larger total output power of the installed main engines intended for the driving of screw propellers and dredge pumps in the power systems of the 3rd type, as compared with that for the power system of the type I. The mean values of relative loads of main engines of the dredgers having the power systems of the type I are definitely larger and contained in the range of 0,42÷0,602 at the mean value of 0,505.

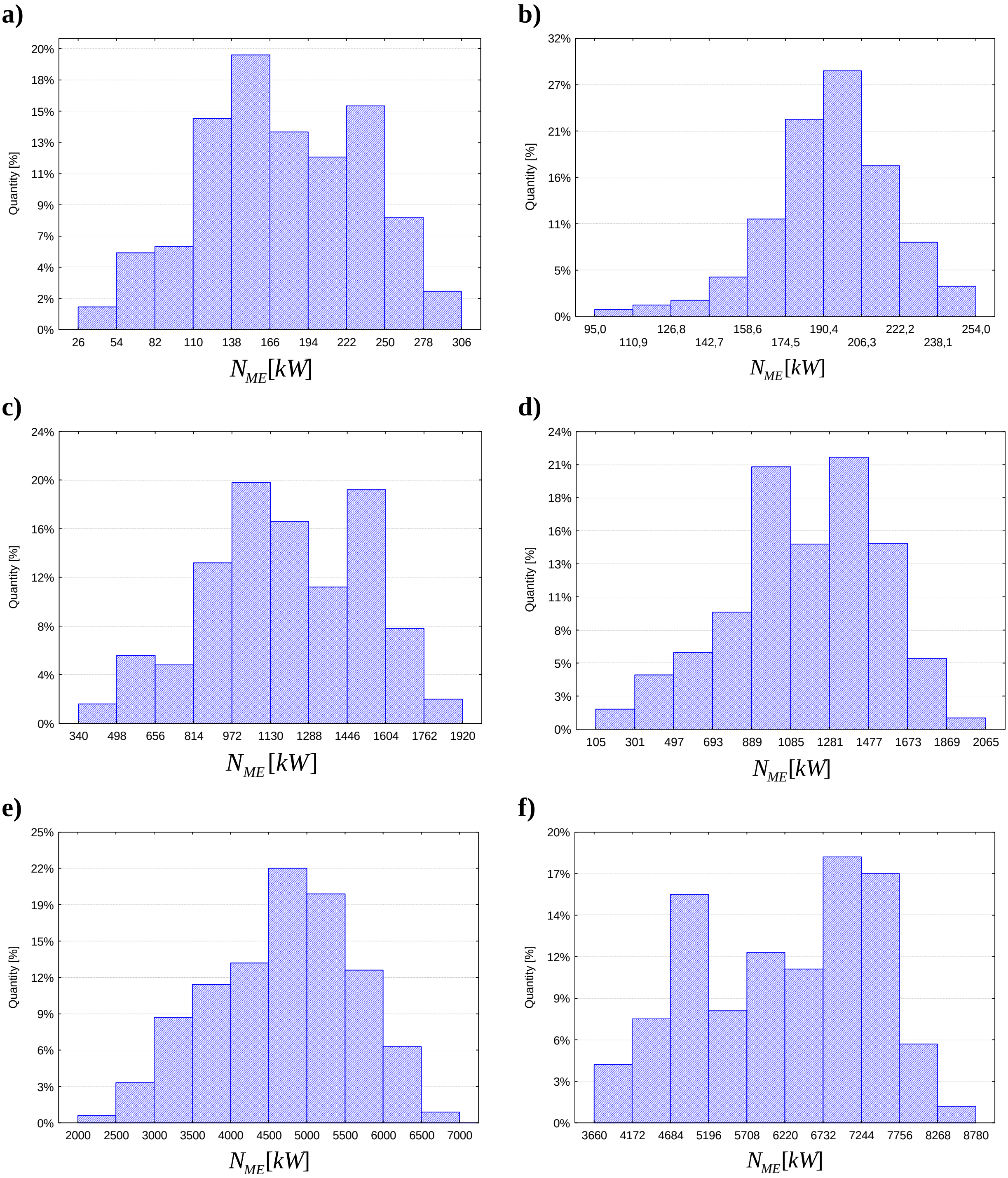

Fig.1. Load histograms of main engines on trailing suction hopper dredgers engaged in carrying out the dredging work; a) the Kostera, b) the Kronos, c) the Bukowski, d) the Łęgowski, e) the Gogland, f) the Geopotes 15

All the investigated dredgers operated in the water areas whose bed was formed of medium sandy soils, with the exception of the dredger *Inż. M. Bukowski* which additionally was engaged in maintenance work consisting in removing the silt out of bed of fairways. The silts belonged to the group of very soft soils. During operation in very soft soils other operational parameters of dredge pumps appear and jet pumps are standing by [9]. For the reasons the load distribution parameters of main engines on the dredger *Inż. M. Bukowski*, presented in Tab. 2 and 3, are given separately for the operations carried out in medium and very soft soils. As results from the data contained in Tab. 2 and 3, the loads of main engines on the dredger *Inż. M.*

Bukowski engaged in dredging work in very soft soils are smaller on average by about 30% as compared with dredging work carried out in medium soils.

For the service state of „free-floating” values of the relative average load of main engines are somewhat smaller than those for the service state of „dredging work” - their mean value is equal to 0,486. Simultaneously, relevant variation coefficients are smaller - their mean value is equal to 0,214. Like in the case of dredging work, the mean values of the relative loads of main engines of the dredgers equipped with power systems of the type III are definitely smaller and amount to 0,271÷0,299. The mean values of the relative loads of main engines of the dredgers equipped with power systems of the type I are definitely greater and are contained in the range of to 0,405-0,692 at the mean value of 0,553.

Tab.3. Characteristics of load distributions of main engines on trailing suction hopper dredgers engaged in carrying out the operations belonging to the dredging work

Dredger	Sailing from and to discharging area				Loading the spoil				Hydraulic unloading the spoil			
	N_{ME}^{av}	$\overline{N}_{ME}^{av}$	σ_{ME}	ν_{ME}	N_{ME}^{av}	$\overline{N}_{ME}^{av}$	σ_{ME}	ν_{ME}	N_{ME}^{av}	$\overline{N}_{ME}^{av}$	σ_{ME}	ν_{ME}
	kW	-	kW	-	kW	-	kW	-	kW	-	kW	-
Kostera	125,7	0,158	45,0	0,358	147,7	0,185	20,2	0,137	227,4	0,285	31,2	0,137
Kronos	190,7	0,215	37,4	0,197	196,3	0,227	13,9	0,071	193,3	0,218	21,3	0,11
Łęgowski	923,3	0,35	374,4	0,405	1479,3	0,56	182,8	0,124	1019,9	0,386	128,8	0,126
Bukowski	755,5	0,295	258,7	0,342	1551,4 827,1*)	0,606 0,323	126,6 146,8	0,082 0,177	1116,4 965,7*)	0,436 0,377	121,1 113,8	0,108 0,118
Nautilus	1452,3	0,392	225,3	0,155	1858,3	0,502	157,7	0,085	-	-	-	-
Gogland	4893,3	0,569	627,2	0,128	5692,8	0,661	340,4	0,06	3559,9	0,414	514,4	0,144
Geopotes 15	6412,9	0,575	1242,8	0,194	7057,3	0,632	397,1	0,057	4854,7	0,435	345,3	0,071
Lange Wapper	7611,6	0,661			7372,3	0,64			6210,7	0,539		
average		0,402		0,254		0,502		0,088		0,388		0,116

*) – data which concern the dredging work in soft soils (silts)

On the basis of the data given in Tab. 3 one can conclude that for six dredgers the largest average loads of main engines during carrying out the dredging work occur during loading the spoil. For the *Lange Wapper,* the largest of the dredgers, the greatest mean values of loads of main engines concern the sailing periods both in loaded and unloaded condition. The fact confirms the regularity indicated in [1,3 and 8] that for small and medium size hopper dredgers the loading of the spoil (in some cases – hydraulic unloading the spoil) is the most energy consuming operation being a part of dredging work, and for large and very large dredgers this is usually the floating both in loaded and unloaded condition.

Power system conditions and character of its work during sailing (moving) both in loaded and unloaded condition during the dredging work are close to those which occur during the state of „free-floating”. As results from the data given in Tab. 2 and 3, the mean values of loads of main engines on small dredgers in sailing operation during the dredging work, $(N_{ME}^{av})_{dw}^{sl}$ constitute $0{,}58 \div 0{,}74$ of the mean load of main engines during the free-floating, $(N_{ME}^{av})_{f-f}$. For medium and large dredgers the values amount to $(N_{ME}^{av})_{dw}^{sl} = (0{,}89 \div 0{,}97)(N_{ME}^{av})_{f-f}$. It results from distances between loading and unloading sites. For small dredgers the distances reach several nautical miles, which results in a large participation of maneuver periods when sailing (moving) during the dredging work and smaller values of mean loads of main engines. The larger the dredger the larger the distances between loading and unloading areas, and for large dredgers they reach a few dozen nautical miles [3,8].

3. Operational loads of auxiliary engines

As mentioned above, in the case of four investigated dredgers in the analyzed service states, apart from their main engines, also auxiliary engines were running as elements of the integrated electric generating sets (on the dredgers *Kostera* and *Kronos*) or the independent electric generating sets (on the dredgers *Inż. S. Łęgowski* and *Inż. M. Bukowski*). In Tab .4 the calculation results concerning load characteristics of auxiliary engines during the analyzed service states of dredger, are presented. In all the cases, regardless of a power system type and solution, and number of auxiliary engines, the calculations were performed jointly for all auxiliary engines installed on a given dredger.

Tab.4. Characteristics of load distributions of auxiliary engines on trailing suction hopper dredgers during carrying out the dredging work and free-floating

Dredger	Dredging work				Free-floating				References
	N_{AE}^{av}	$\overline{N}_{AE}^{av}$	σ_{AE}	ν_{AE}	N_{AE}^{av}	$\overline{N}_{AE}^{av}$	σ_{AE}	ν_{AE}	
	kW	-	kW	-	kW	-	kW	-	
Kostera	37,12	0,121	12,23	0,329	21,3	0,07	2,37	0,111	[*]
Kronos	56,22	0,11	26,14	0,465	24,1	0,047	3,11	0,129	[*]
Łęgowski	149,1	0,279	23,3	0,156	118,6	0,222	15,11	0,127	[*]
Bukowski	142,6	0,364	28,1	0,197	113,1	0,289	13,21	0,117	[*]

[*] – self investigations

The performed calculations of load distribution parameters of auxiliary engines during the dredging showed that for particular dredgers the relative average loads were contained in the range of 0,11 ÷0,364 at the mean value of 0,218, and the distribution variation coefficient in the range of 0,156 ÷0,465 at the mean value of 0,287. For the service state of „free-floating", the values of the relative average load of main engines are definitely smaller as compared with those in the service state of „dredging work"; their mean value equals 0,157. Also, variation coefficients are smaller; their mean value equals 0,121.

The first conclusion which comes to mind is that the relative average loads of auxiliary engines are definitely smaller as compared with those of main engines (the mean value for auxiliary engines during dredging amounts to 0,218 against that of 0,433 for main engines). This mainly results from that in the case of the designing of ship electric power plants number of auxiliary engines is usually assumed by one unit greater than that obtained from electric power balance calculations. It leads to a much greater rated power of installed auxiliary engines, and simultaneously results in smaller values of the relative average loads $\overline{N}_{AE}^{av}$.

The second conclusion is that the values of $\overline{N}_{AE}^{av}$ for auxiliary engines on the dredgers equipped with power systems of the 3rd type (the *Kostera and Kronos*) are definitely smaller than those for auxiliary engines installed on the dredgers with power systems of the 1st type (the *Łęgowski and Bukowski*). It can be explained by that on these dredgers they provide driving for two large power consumers (jet pump and bow thruster) , and by special character of work of the consumers (mainly during the loading). This results in the necessity of increasing the output power of installed auxiliary engines. The character of work of the consumers is also responsible for large values of the variation coefficients ν_{AE} for the dredgers with power systems of the type III (it concerns only the state of „dredging work").

4. Influence of size of a dredger on operational loads of its diesel engines

It is common knowledge that size of a dredger determines value of the power demanded to fulfill tasks of the dredger [8]. The average operational loads of all diesel engines N_{DE}^{av} for a given dredger represent power demand for realizing the dredger's tasks in a given service state. The main size parameter of trailing suction hopper dredger, specified as a rule in owner's design assumptions is the hopper (soil hold) capacity V_{HP}. The relation $N_{DE}^{av} = f(V_{HP})$ for the service state of „dredging work" was examined on the basis of such assumption. To this end, the data contained in Tab. 1, 2 and 4 were used. As a result the following relation was achieved (Fig. 2):

$$N_{DE}^{av} = 0{,}5264 \cdot V_{HP} + 171{,}91 \qquad (1)$$

as well as the following : the coefficient of correlation $R = 0{,}981$, the standard deviation $\sigma = 291{,}5\ kW$, the value of the test $F = 154{,}3$ for the sample number $m = 8$, and $F_{kr} = 5{,}99$ for $\alpha = 0{,}05$. The range of application of Eq. (1) is : $310 \le V_{ŁG} \le 13700\, m^3$.

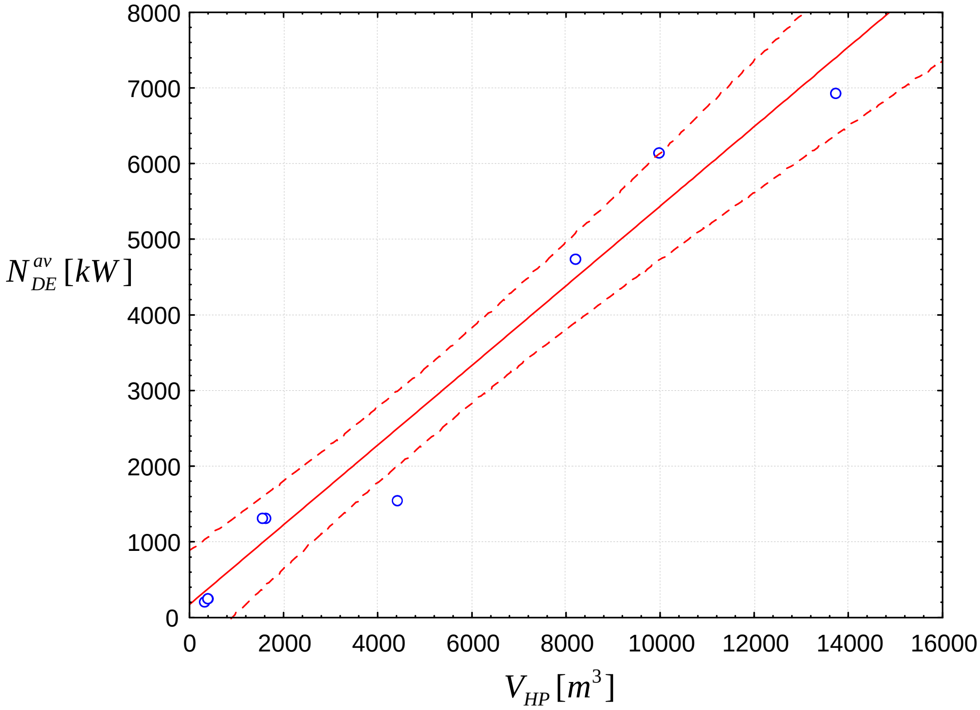

Fig .2. The relation $N_{DE}^{av} = f(V_{HP})$ for trailing suction hopper dredgers working in medium sandy soils

5. Summary

The performed investigations make it possible to formulate the following remarks and conclusions:

1) The values $\overline{N}_{ME}^{av}$ and v_{ME} obtained from measurements can be used to determine recommended operational loads for main engines to be selected in designing dredger power systems of the 1st type, first of all. For the service state of „dredging work" in medium soils the value of $\overline{N}_{ME}^{av} = 0{,}48 \div 0{,}64$ was determined on the assumption that the maximum loads of main engines were contained in the range of $(0{,}85 \div 0{,}9) N_{ME}^{nom}$;

2) The relation (1) can be used in preliminary design stages in order to determine average power demanded for realization of tasks of a dredger of a given soil hold capacity;
3) The achieved results may be useful for solving design problems of power plants of suction hopper dredgers as well as in establishing fuel consumption standards for diesel engines on dredgers of the kind.

Bibliography

[1] Bocheński D., *Design solution and working conditions of power systems for trailing suction hopper dredgers.* Polish Maritime Research, no 2/1999

[2] Bocheński D., Kubiak A., Jurczyk L.: *Pomiary parametrów charakteryzujących pracę układów technologicznych pogłębiarek.* Materiały XXII Sympozjum Siłowni Okrętowych *SymSO200,* Szczecin 2001.

[3] Bocheński D. (kierownik projektu) i in.: *Badania identyfikacyjne energochłonności i parametrów urabiania oraz transportu urobku na wybranych pogłębiarek i refulerów*. Raport końcowy projektu badawczego KBN nr 9T12C01718. Prace badawcze WOiO PG nr 8/2002/PB, Gdańsk 2002.

[4] Bocheński D., *Analiza rozwiązań konstrukcyjnych i zależności określających parametry układów energetycznych pogłębiarek ssących nasiębiernych.* Zeszyty Naukowe Akademii Morskiej w Szczecinie, nr 73. XXIV Sympozjum Siłowni Okrętowych *SymSO2003,* Szczecin 2003.

[5] Dokumentacja prób zdawczo-odbiorczych pogłębiarki „Nautilus", GSR, Gdańsk 1996

[6] Kompleksyjne technologiczieskie issledowanija sudov popolnienija unstrukcyja po effjektiwnoj eksploatacji ziemsnarjada „Gogland". GDK, Rostow nad Donem 1984.

[7] de Vries L., *Total performance simulations of ship energy concepts*. Wondermar II Workshop, Bremen 2004

[8] Vlasblom J. W., *Designing dredging equipment*. Lecture notes, TUDelft 2003-05

[9] Volbeda J., H., *Overflow effects when trailing very soft silts and clays.* WODCON X EADA, World Dredging Congress, Singapore 1983