

Investigations of operational driving loads of bucket chains and manoeuvre hoisting winches on multi-bucket dredgers

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ABSTRACT



The paper concerns problems of preliminary designing of bucket dredgers' power plants. This paper presents results of investigations of six bucket dredgers in service. The operational investigations consisted in measuring the parameters which characterize working conditions of two main receivers of mechanical energy: bucket chains and swing winches. In the paper characteristics of disposition of loading of bucket chains and swing winches are presented. They covered average value, standard deviation and coefficient of variance of loading disposition mutability. Examples of load distributions of chains' and group of swing winches on chosen dredgers during some period of time were given. Conclusions in view to average values of main receivers of mechanical energy and coefficients of variance of loadings spread were formulated. Results of investigations of dependence of average loadings of main receivers on their nominal power were presented. The results of work will be used in creation of random models describing real conditions of operation of power plant elements of dredgers.

Keywords: Bucket ladder dredgers, main receivers of mechanical energy, ship power plants, bucket chain, swing winches

INTRODUCTION

The main mechanical energy consumers on dredgers, regardless of their type, are intended for realizing the following technological processes [2]:

- ⇒ loosening, dredging and transporting the soil
- ⇒ positioning, manoeuvring and possible propelling the dredger.

Bucket chains and set of manoeuvre hoisting winches are the main consumers in question on multi-bucket dredgers in their basic design solution [7]. Knowledge of operational loads of main consumers is crucial problem in preliminary designing the dredger power plant. This paper presents results of service investigations dealing with driving loads of bucket chains and set of manoeuvre hoisting winches on multi-bucket dredgers. The investigations constituted a part of a greater research project on energy consumption of technological processes on dredgers of three basic types, performed in the years 2000÷2003 and 2005÷2006 [5, 8]. As to the multi-bucket dredgers, five such dredgers were subjected to the investigations and their results were supplemented with results of the tests carried out on the dredger *Ivan Bachvalov* by a measuring team of RCP-KB design office in Rostow upon Don [10].

The main technical data of the dredgers, concerning the parameters of bucket chains and manoeuvre hoisting winches, are presented in Tab. 1.

On all the investigated dredgers the bucket chains and manoeuvre hoisting winches were driven by diesel-electric power systems. The measurements were performed with the use

of specially designed measuring systems consisted of electronic digital multimeters co-operating with computer [4, 5]. The multimeters were used to measure and record versus time electric current (indirect measurement by shunt-voltage measuring) and voltage (direct measurement). This way value of the power consumed by electric motors driving a given consumer, was determined. By making use of the results and knowing efficiency characteristics of power transmission systems, instantaneous power values at drive coupling of a given main consumer, were determined. Operational loads of bucket chain are subjected to great and frequent changes, that results from character of consumer's working mode. The changeability of loads is associated mainly with cutting-in successive buckets to the soil (every 3 ÷ 4 sec on average). How large is the changeability can be illustrated by the mean value of the coefficient $N_{LC}^{max}/N_{LC}^{min}$ equal to 4.5 calculated for several loadings of a hopper barge during preliminary service measurements [5]. For the reason of the highly changeable character of bucket chain loads it was assumed that the measurements of the loads of the bucket chains and set of manoeuvre hoisting winches, will be performed every second [5].

In order to determine the driving load characteristics of bucket chains and manoeuvre hoisting winches it is necessary to know changes of the loads occurring for a long time. Large number of instantaneous values of loads makes it possible to properly perform their statistical estimation. The mean duration time of dredging work carried out by multi-bucket dredgers at sea amounts to about 2500 h/year [5]. Because of limited possibility of carrying out the measurements for such a long period on each of the investigated dredgers it was planned to

perform the service investigations for at least 5% of the working period of each of the investigated dredger, i.e. for about 125 h. As a rule the service investigations were carried out in 24 h cycle. Overall, the measurements were carried out for 732 h [8]. Number of samples for every investigated dredger was greater than 300000 and significantly exceeded the minimum number of samples [9].

Tab. 1. Main technical data of the multi-bucket dredgers subjected to the investigations in service

Dredger's name	Bucket-chain drive parameters		Drive parameters of set of manoeuvre hoisting winches			Q _{PW}
	N _{LC} ^{nom}	N _{LC}	T _{WM}	v _{WM}	number	
	kW	n. bckts/min	kN	m/min	-	
<i>Małż II</i>	88	24	57	10	4	250
<i>Rozgwiazda</i>	300	19	90	12	4	640
<i>Inż. T. Wenda</i>	310	19	90	12	4	640
<i>Usedom</i>	420	25	155 81.5	17.5 17.5	2 2	840
<i>Kategats</i>	400	25	155 81.5	17.5 17.5	2 2	800
<i>Ivan Bachvalov</i>	400	25	155 81.5	17.5 17.5	2 2	800

where:

- N_{LC}^{nom} – bucket chain nominal power
- N_{LC} – bucket chain speed
- T_{WM} – hoisting winch pull
- v_{WM} – hauling speed of manoeuvre hoisting winch
- Q_{PW} – design dredging rate of a dredger.

The performed investigations made it possible to determine the driving load distribution characteristics for bucket chains and set of manoeuvre hoisting winches during soil dredging operations, namely these of:

- N_{LC}^{sr}/N_{WM}^{sr} – mean load of bucket chain and manoeuvre hoisting winches, respectively
- σ_{LC}, σ_{WM} – standard deviations of load distributions of bucket chain and manoeuvre hoisting winches, respectively
- v_{LC} = $\frac{\sigma_{LC}}{N_{LC}^{sr}}$ – coefficient of variation of bucket chain load distribution
- v_{WM} = $\frac{\sigma_{WM}}{N_{WM}^{sr}}$ – coefficient of variation of load distribution of manoeuvre hoisting winches
- λ_{LC}^{cz}, λ_{WM}^{cz} – coefficients which determine participation of working period of bucket chain and manoeuvre hoisting winches during dredging, respectively.

OPERATIONAL LOADS OF BUCKET CHAINS

The investigations of load distribution characteristics of bucket chains were performed with taking into account kind of dredged soil. During the performed operational investigations the following kinds of soil were dredged:

- medium soils of the in- the- site density of 1.7 ÷ 1.95 t/m³, which can be additionally divided into:
 - non-cohesive soils, fine- and medium- grain, medium-compacted sandy soils
 - cohesive soils, medium sandy and plastic silts
- light soils of the in- the- site density of 1.4 ÷ 1.6 t/m³
- warps with loose sands or quick clays.

The operational measurement results for bucket chains supplemented with those performed on the dredger *Ivan Bachvalov* [10] are shown in Tab. 2, and in Fig. 1 – the example histograms of the operational loads for selected dredgers. The loads were grouped into 10 left-sidedly-opened intervals of quantization which covered the range (N_{LC}^{min} – N_{LC}^{max}); the values of N_{LC}^{min} and N_{LC}^{max} were taken into account as integers most close to real measurement results.

Tab. 2. Characteristics of bucket chain load distributions for multi-bucket dredgers

Kind of soil	Name of dredger	N _{LC} ^{nom}	N _{LC} ^{sr}	$\overline{N_{LC}^{sr}}$	σ _{LC}	v _{LC}	λ _{LC} ^{cz}	Source of information
		kW	kW	-	kW	-	-	
Medium	<i>Małż II</i>	88	28.16 ¹⁾ 28.92 ²⁾	0.32 0.329	9.67 10.76	0.343 0.372	0.97 0.94	the author's investigations
	<i>Inż. T. Wenda</i>	310	105.19 ¹⁾ 99.32 ²⁾	0.339 0.32	34.74 42.95	0.331 0.432	0.98 0.95	ditto
	<i>Rozgwiazda</i>	300	99.78 ¹⁾ 92.37 ²⁾	0.333 0.308	30.96 33.79	0.31 0.366	0.98 0.97	ditto
	<i>Usedom</i>	420	183.44 ¹⁾	0.437	41.62	0.227	0.99	ditto
	<i>Kategats</i>	400	195.68 ¹⁾	0.489	42.35	0.216	0.98	ditto
	<i>Ivan Bachalov</i>	400	186.64 ¹⁾	0.467	46.84	0.251		[10]
	Mean values			0.398 ¹⁾		0.281 ¹⁾	0.97	
Light	<i>Małż II</i>	88	21.22	0.241	4.03	0.189	0.96	the author's investigations
	<i>Inż. T. Wenda</i>	310	92.73	0.299	14.28	0.154	0.98	ditto
	<i>Rozgwiazda</i>	300	90.98	0.303	16.91	0.186	0.97	ditto
	<i>Usedom</i>	420	158.93	0.378	29.93	0.188	0.99	ditto
	<i>Kategats</i>	400	172.86	0.432	21.48	0.124	0.99	ditto
	<i>Ivan Bachalov</i>	400	165.91	0.415	28.67	0.173		[10]
	Mean values			0.345		0.169	0.98	

¹⁾ – medium sands, ²⁾ – medium silts

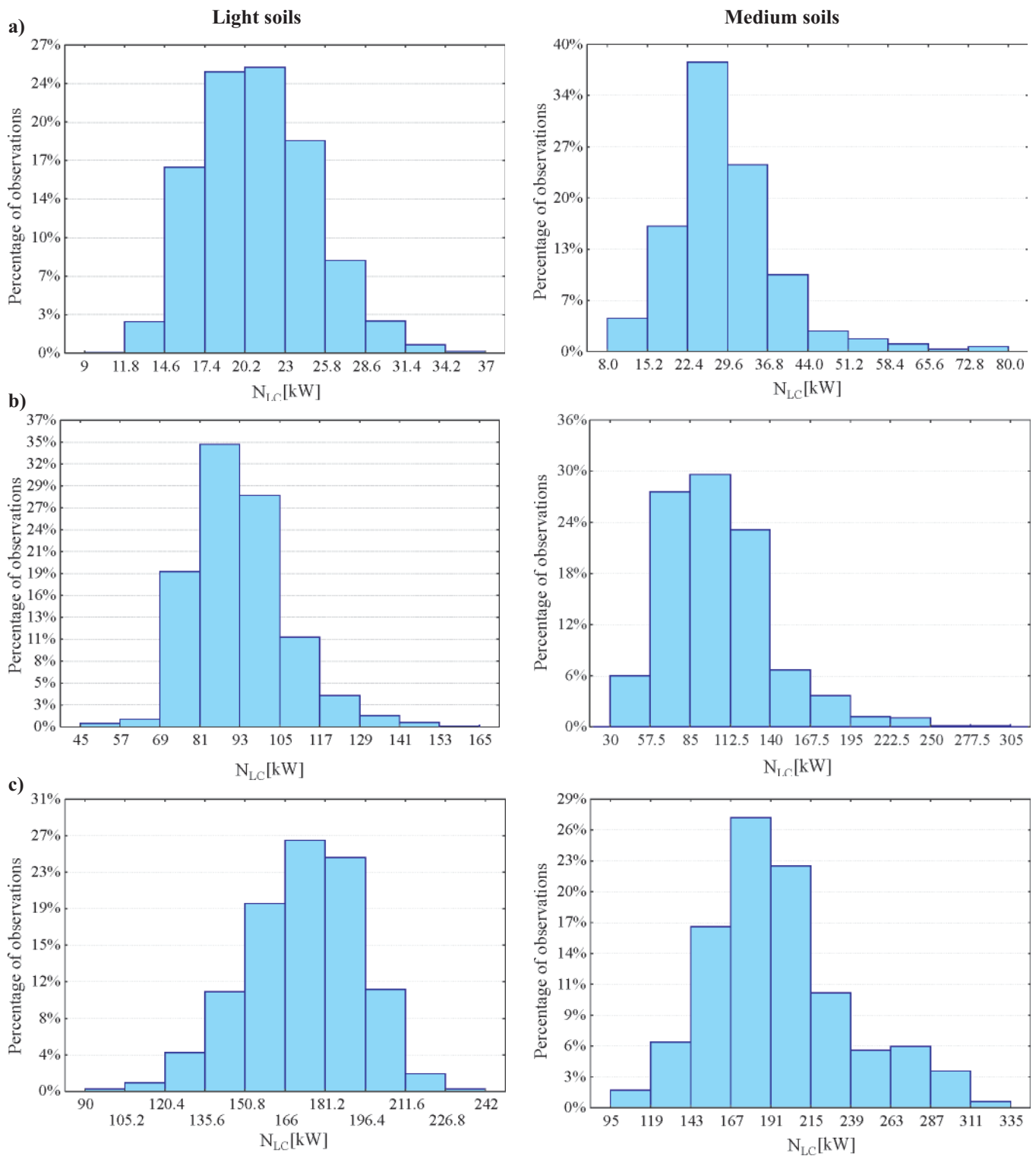


Fig. 1. Histograms of operational bucket chain loads on the multi-bucket dredgers: a) Malż II, b) Inż. T. Wenda, c) Kategats

The measurement results confirm the influence of kind of soil on operational characteristics of bucket chains. Distinct difference can be observed in values of the bucket chain load distribution parameters of the same dredger working in light and medium soils. The values of the mean relative bucket chain loads N_{LC}^{sr} for medium soils are greater by about 15-20% than those for light soils of the same dredger. Differences in values of the variation coefficients of the bucket chain load distribution, v_{LC} , are significant: for medium soils they are contained in the interval of (0.216÷0.432), and for light soils – in the interval of (0.124÷0.189).

The differences in the bucket chain load distribution parameters during dredging the medium soils – regardless

non-cohesive and cohesive – are practically neglectable. The differences in the mean relative bucket chain load values are rather small: in two cases – a little greater during dredging the non-cohesive soils, and in one case – during dredging the cohesive soils. The differences concerning values of variation coefficient of bucket chain load distribution seem a little more significant. In all the three cases the values were greater for dredging the cohesive soil. They amounted respectively to (0.366÷0.432) in the case of dredging the cohesive soils and (0.31÷0.343) - in the case of dredging the non-cohesive ones.

Analyzing the results of Tab. 2 one can clearly observe the differences in values of N_{LC}^{sr} , v_{LC} - especially at dredging medium soils - for the three first dredgers as compared with

three next ones. This situation can be explained by kind of work realized by a given dredger. Generally two types of dredging can be distinguished: investment work and maintenance work. The investment work, as compared with maintenance work, is characterized by a higher effectiveness and in consequence - higher bucket chain loads. Medium and small size dredgers are generally intended for maintenance work. Large dredgers are much more engaged in investment work [5, 6]. Among the investigated dredgers only one, the smallest dredger *Małż II*, was characterized by almost 80% participation in maintenance work; the larger ones: *Rozgwiazda* and *Inż. T. Wenda* were engaged by about 50-60% in investment work. The three largest ones performed only investment operations and for this reason they were characterized by the largest values of the mean relative loads of bucket chains. The carrying-out of investment operations probably results also in somewhat smaller values of variation coefficient of bucket chain load distribution. Worth stressing that the above mentioned percentage values of duration time of carrying-out investment and maintenance work are typical for the multi- bucket dredgers of the investigated size [5,6].

Values of the coefficient λ_{LC}^{cz} are contained in the interval of 0.94÷0.99 and they do not depend on kind of dredged soil.

OPERATIONAL LOADS OF SET OF MANOEUVRE HOISTING WINCHES

The investigations of operational loads of manoeuvre hoisting winches concerned the set of four winches. In manoeuvres also two other winches took part, however they were not considered to be main consumers because of their short-lasting period of work [6].

The results of operational measurements of the set of manoeuvre hoisting winches are presented in Tab.3. They relate to operation of the entire set hence they represent the total load of all hoisting winches in operation. Fig. 2 presents the histograms of operational loads of sets of manoeuvre hoisting winches on two selected dredgers. Like in the case of bucket chains the loads in question were grouped in 10 quantification intervals covering the range ($N_{WM}^{min} - N_{WM}^{max}$).

In Tab. 3 are given the values of distribution parameters of loads of the sets of manoeuvre hoisting winches regardless of kind of soil. The earlier made investigations [6] did not confirm any significant influence of kind of soil on loads of set of manoeuvre hoisting winches.

The performed calculations of the load distribution parameters of the sets of manoeuvre hoisting winches showed that for particular dredgers the mean loads were contained within the interval of 0.072÷0.158 with the mean value of

0.117 and the variation coefficient values in the interval of 0.254÷0.43 with the mean value of 0.372. For greater dredgers a noticeable increase of the mean relative load value can be observed. The fact results from greater values of relative effectiveness (i.e. the ratio of the operational effectiveness and design effectiveness) of greater dredgers as a result of their participation in investment operations. The influence of dredger effectiveness on demanded power of manoeuvre hoisting winches is known and described in many publications, e.g. [11, 12]; this author described his own investigations on the theme in [6]. Values of the coefficients λ_{WM}^{cz} are contained in the interval of 0.94÷0.99 and they are practically identical to those of the coefficient λ_{LC}^{cz} .

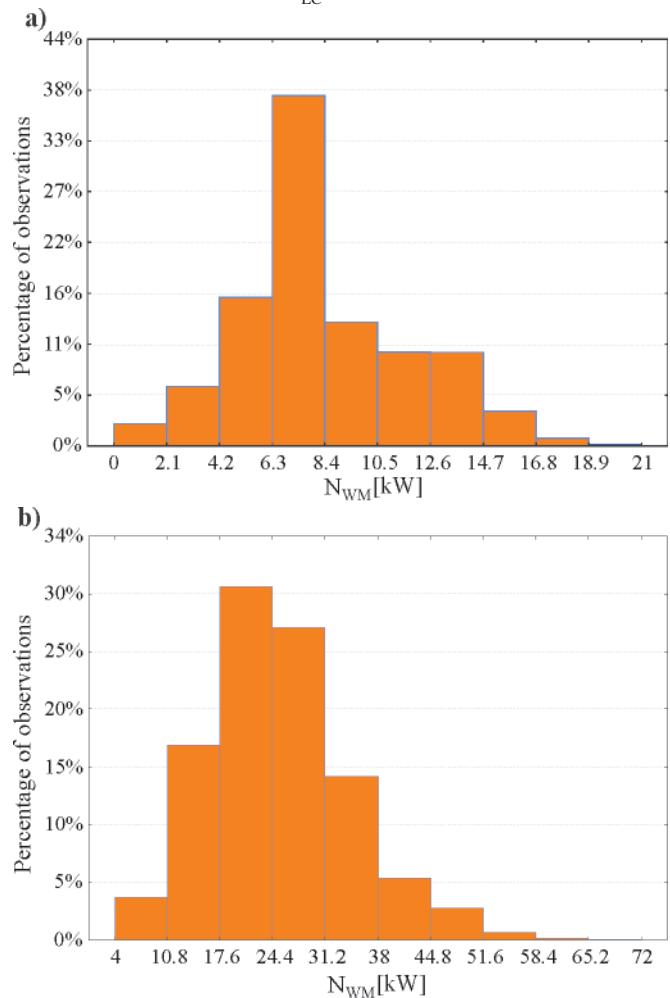


Fig. 2. Histograms of operational loads of sets of manoeuvre hoisting winches on the multi-bucket dredgers: a) *Inż. T. Wenda*, b) *Kategats*

Tab. 3. Characteristics of load distributions of sets of manoeuvre hoisting winches on multi-bucket dredgers

Name of dredger	$\sum N_{WM}^{nom}$	N_{WM}^{sr}	\bar{N}_{WM}^{sr}	σ_{WM}	v_{WM}	λ_{WM}^{cz}	Source of information
	kW	kW	-	kW	-	-	
<i>Małż II</i>	44	3.16	0.072	1.36	0.43	0.96	the author's investigations
<i>Inż. T. Wenda</i>	86	8.33	0.097	3.48	0.418	0.98	ditto
<i>Rozgwiazda</i>	86	7.21	0.084	1.83	0.254	0.97	ditto
<i>Usedom</i>	168	23.18	0.138	8.91	0.384	0.99	ditto
<i>Kategats</i>	168	25.37	0.151	9.23	0.364	0.99	ditto
<i>Ivan Bachalov</i>	168	26.47	0.158	10.04	0.379		[10]
Man values			0.117		0.372	0.98	

The coefficients λ_{LC}^{cz} and λ_{WM}^{cz} given in Tab. 2 and 3 determine duration of working time of bucket chain and set of manoeuvre hoisting winches during dredging the soil onto hopper barge (or silting-up the soil directly to land), respectively. To obtain time relation of the operational state „dredging” it is necessary to use additionally the coefficient λ_{cz}^{sp} (participation of time of dredging only in overall time of dredging operations). For this coefficient the value equal to 0.9 can be approximately assumed [5].

INVESTIGATIONS OF THE RELATIONS BETWEEN MEAN DRIVING LOADS OF MAIN CONSUMERS AND THEIR NOMINAL EFFECTIVE OUTPUT POWER VALUES

The investigations of the relations between the mean operational driving loads of main consumers, N_{GO}^{sr} , and their nominal effective output power values ($N_{GO}^{sr})^{nom}$ is very important for later possible use of their results in preliminary design stages of ship power plant.

As to the main consumers, the effective flux of energy of consumers, being in each case the product of the so called „generalized potential” and the „generalized flow rate”, can be considered [1].

The investigations of the relations between the mean driving loads of main consumers and their nominal effective output power values were already performed for industrial trawlers and typical transport ships (dry cargo ships, bulk carriers) [1, 3].

The performed investigations showed that for all types of main power consumers installed on the considered ships the following linear relation is valid [1,3]:

$$N_{GO}^{sr} = a + b (N_{GO}^{uz})^{nom} \quad (1)$$

where:

a, b – constants

The statement that the relation (1) appear to be linear and the possible determination of the constants a, b is of great importance as it can be used to estimate output power of main engines of ships of the considered types during the offer or preliminary design phase [1, 3, 5, 9].

The effective bucket chain power is determined by the relation:

$$N_{LC}^{uz} = M_{LC} \cdot \omega_{LC} \quad (2)$$

where:

M_{LC} – upper turas torque,

ω_{LC} – upper turas angular speed.

As bucket chain motion is forced by a prismatic rotary drum (called turas) cooperating with the bucket chain, located on a bucket tower, the bucket chain torque is assumed equal to the torque of the above mentioned upper turas. In the case of bucket chains, instead the angular speed, the bucket chain speed expressed by number of buckets passing the upper turas per one minute, as given in technical manuals of dredgers, is used.

In Tab. 4 are presented values of the nominal parameters of the bucket chains on the investigated dredgers as well as parameters of operational driving load distributions for the chains during dredging (on the basis of the data of Tab. 1 and 2). As stated earlier, there are no significant differences between mean values of bucket chain loads during dredging the medium sands and medium silts. Therefore the investigations of the relation (1) were carried out generally for medium soils, without distinguishing non-cohesive from cohesive ones. The investigations in question were performed for bucket chains by using the data of Tab. 4. Their results are presented in Tab. 5 and Fig. 3. The permissible intervals for independent variables of the equations given in Tab. 5, result from the data contained in Tab. 4.

Tab. 4. Nominal parameters of bucket chains and characteristics of their operational loads during dredging for 6 investigated dredgers

Name of dredger	Nominal parameters of bucket chains			Characteristics of operational loads					
	M_{LC}	n_{LC}	N_{LC}^{uz}	Medium soils			Light soils		
				N_{LC}^{sr}	σ_{LC}	v_{LC}	N_{LC}^{sr}	σ_{LC}	v_{LC}
kNm	n.bekts/ min	kNm · n.bekts/ min	kW	kW	-	kW	kW	-	
Małż II	85	24	2040	28.37	9.92	0.349	21.22	4.03	0.189
Inż. T. Wenda	370	19	7030	104.09	37.06	0.353	92.73	14.28	0.154
Rozgwiazda	360	19	6840	96.77	32.92	0.34	90.98	16.91	0.186
Usedom	400	25	10000	183.44	41.62	0.227	158.93	29.93	0.188
Kategats	380	25	9500	195.68	42.35	0.216	172.86	21.48	0.124
Ivan Bachalov	380	25	9500	186.64	46.84	0.251	165.91	28.67	0.173

Tab. 5. Linear regression equations which describe mean loads of bucket chains during dredging the soil of two kinds

Kind of soil	Form of relation	Statistical estimation parameters				
		R	σ [kW]	F	$F_{kr}; \alpha = 0.05$	m
medium	$(N_{LC}^{sr}) = 0.0216(N_{LC}^{uz}) - 29.44$	0.965	23.16	55.35	7.71	6
light	$(N_{LC}^{sr}) = 0.0194(N_{LC}^{uz}) - 27.84$	0.973	18.28	71.15	7.71	6

where: R – coefficient of correlation, σ – standard deviation

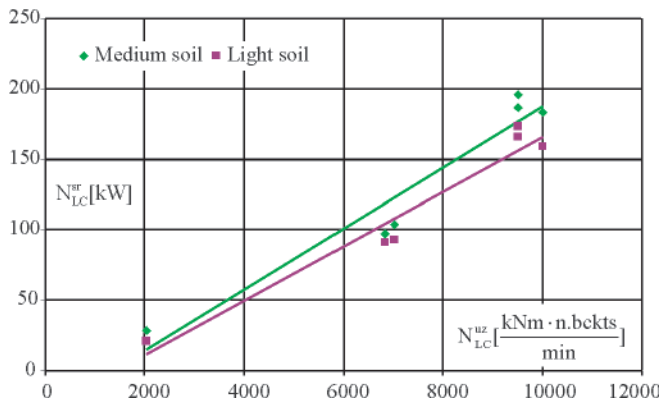


Fig. 3. The relation: $N_{LC}^{sr} = f(N_{LC}^{uz})$ for multi-bucket dredgers

To investigate significance level of correlation coefficient the F test of Snedecor distribution was used. Statistical significance is confirmed if: $F > F_{kr}$ for the assumed significance level α (usually $\alpha = 0.05$) and the degrees of freedom: s_1 and s_2 ($s_1 = 1, s_2 = m - 1 - 1$, where: 1 - number of independent variables, m - number of population).

The nominal effective output power of set of manoeuvre hoisting winches, N_{WM}^{uz} , is described by the relation:

$$N_{WM}^{uz} = \sum_{i=1}^4 (T_{WM} \cdot v_{WM})_i \quad (3)$$

where:

T_{WM} – hoisting winch torque,

v_{WM} – hoisting winch speed.

In Tab. 6 are given the nominal parameters of manoeuvre hoisting winches on the investigated dredgers as well as parameters of operational load distributions of sets of the winches during dredging (on the basis of the data given in Tab. 1 and 3). The investigations of the relation (1) were performed jointly for the whole duration time of the state „dredging” regardless of kind of soil dredged by a given dredger.

By making use of the data of Tab. 6 the following relation was obtained (Fig. 4):

$$N_{WM}^{sr} = 0.2343(N_{WM}^{uz}) - 7.65 \quad (4)$$

for which the values of: the correlation coefficient $R = 0.986$, the standard deviation $\alpha = 2.06$ kW, the test $F = 148.64$ at the population number $m = 6$, and $F_{kr} = 7.71$ for $\alpha = 0.05$, were calculated. The relation is applicable within the range: $38 \leq N_{WM}^{uz} \leq 138$ kW.

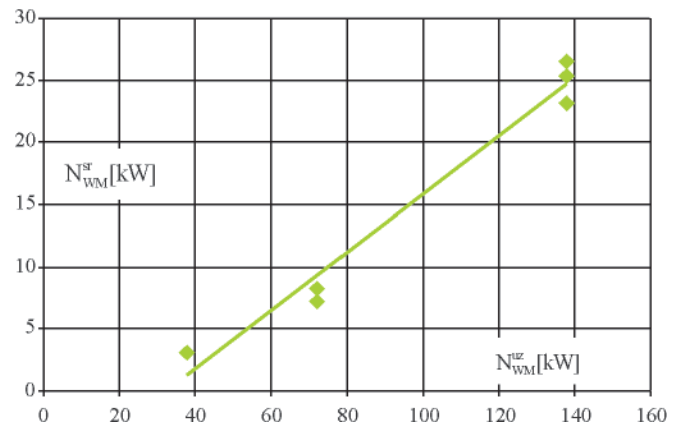


Fig. 4. The relation: $N_{WM}^{sr} = f(N_{WM}^{uz})$ for multi-bucket dredgers

SUMMARY

The performed investigations of operational loads of bucket chains and sets of manoeuvre hoisting winches on multi-bucket dredgers make it possible to offer the following remarks and conclusions:

- the averaged load distribution parameters of bucket chains and sets of manoeuvre hoisting winches, given in Tab. 2 and 3, can be deemed typical for the entire population of multi-bucket dredgers because of the long-lasting period of measurements as well as the broad range of size of the tested dredgers
- the characteristics of operational bucket chain loads, given in Tab. 2, confirm the necessity of taking into account kind of dredged soil
- in both the cases, i.e. of bucket chains and set of manoeuvre hoisting winches, the linearity of the relation (1) was confirmed as in all the considered relations large values (over 0.95) of the correlation coefficient R were obtained
- the achieved results can be used for predicting load distributions of bucket chains and manoeuvre hoisting winches; the relations given in Tab. 5 can be used to determine mean load of bucket chains; the relation (4) can be used to determine mean load of set of manoeuvre hoisting winches; the values of variation coefficients of load distributions of bucket chains and set of manoeuvre hoisting winches given in Tab. 2 and 3, can be used to estimate standard deviations of operational loads of the above mentioned main power consumers
- the presented results can be useful in solving problems during preliminary design phases of power plants for multi-bucket dredgers.

Tab. 6. Nominal effective power of set of manoeuvre hoisting winches and their operational load characteristics during dredging for 6 investigated dredgers

Name of dredger	Nominal effective power	Characteristics of operational loads of set of manoeuvre hoisting winches		
	N_{WM}^{uz}	N_{WM}^{sr}	σ_{WM}	v_{WM}
	kW	kW	kW	-
<i>Małż II</i>	38	3.16	1.36	0.43
<i>Inż. T. Wenda</i>	72	8.33	3.48	0.418
<i>Rozgwiazda</i>	72	7.21	1.83	0.254
<i>Usedom</i>	138	23.18	8.91	0.384
<i>Kategats</i>	138	25.37	9.23	0.364
<i>Ivan Bachalov</i>	138	26.47	10.04	0.379

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