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SELECTION OF DRIVE ENGINES FOR DREDGE PUMPS

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Abstract
This paper presents the principles of selecting drive engines for dredge pumps, formulated by this author. In order to formulate them influence of drive engines on dredge pump characteristics and dredger effectiveness, have been analyzed. Also, an analysis of results of the author's operational investigations concerning energy consumption and parameters of excavated soil transport on board dredgers has been performed.

Keywords*: dredgers, dredge pumps, drive pump*

1. Introduction

The problem of selection of dredge pumps is widely described in the literature [2,7,9, 10,11]. It is different case with selection of drive engines for such pumps. The influence of drive engines on characteristics of dredge pumps is already described in [7,9,10], but recommendations as to their selection are still lacking.

The dredge pumps, in contrast to typical pumps, operate in the systems in which water- soil mixture is forced through. The mixture is characterized by different density and granulation of soil grains that greatly affects characteristics of both pumps and piping. The most important feature of working conditions of dredge pumps is a wide range of pipeline length (e.g. for medium – size cutter suction dredger its pipeline length may be contained in the range from a few hundred to several thousand meters). Power of dredge pumps depends on their function and design assumptions and first of all on dredger's size. It is contained in the wide range from several hundred kW to even a dozen or so thousand kW [1,2,7,9].

Power of dredge pumps and their working conditions show that the problem of correct selection of their drive engines is very important. The selection principles for drive engines should take into account: assumptions as to dredger's capacity as well as changeability of operational parameters which characterize operation of a dredging installation in question.

This paper is an attempt to formulating the selection principles for drive engines of dredge pumps, which take into account the above specified factors.

2. Design capacity of dredger

In owners design assumptions the so called design capacity of a dredger is usually specified. In the case of the dredgers fitted with dredge pump (pumps) the capacity is dependent on possible mining the soil by loosening devices (dredging wheels, cutterheads, excavating dragheads etc) and possible soil transporting by the dredge pump. In the case of pumping the soil the design capacity of dredger decreases along with increasing the pipeline length that results from limitations of the selected engine – pump.

For driving the dredge pumps combustion engines and electric motors are used. Type and size of drive engine seriously affects pump characteristics; therefore we have to speak then about characteristics of the entire engine-pump system. The permissible operational area of diesel engine is limited by the maximum torque line and the limitation resulting from engine – turbo-compressor interaction as well as the maximum rotational speed line (i.e. characteristics of rotational speed governor). In Fig. 1a is presented the permissible operational area of the diesel engine, and in Fig. 1b – the characteristics of the diesel engine – dredge pump [7,9].

The characteristics of electric motor – dredge pump system is somewhat different. It results from that the permissible operational area of electric motor is limited in the range of higher values of rotational speed by maximum power line and the line of maximum torque - in the range of lower values of rotational speed [7,9,10].

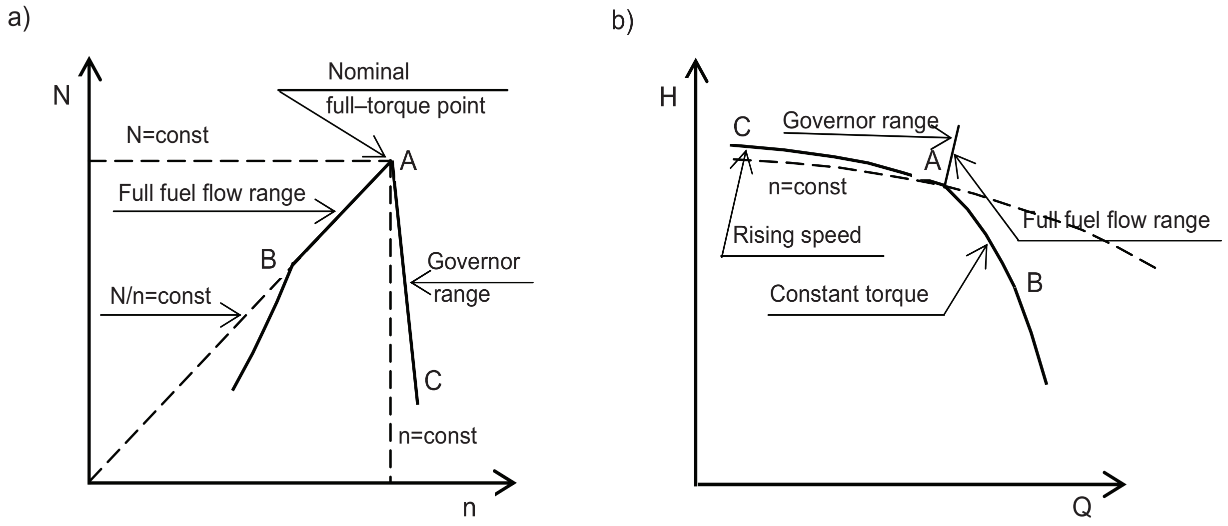

Fig. 1. Limitations imposed on characteristics of dredge pump driven by diesel engine ; a) permissible operational area of diesel engine, b) characteristics of diesel engine – dredge pump

The influence of the selected pump driving engine on the dredger design capacity is exemplified by IHC 175-37,5-75 pump. The rated parameters of the pump are: $H_W = 590\,kPa,\ Q_W = 2{,}3\,m^3/s\ at\ n = 320\,rpm$ - where: H_W - the dredge pump lifting height determined for water, Q_W - the dredge pump volumetric rate of delivery determined for water.

The characteristics of the pump and pipeline are determined for medium-cohesive, grainy soil (medium grainy sand of 0,2 mm mean diameter grains and 1950 kg/m^{3}density in its deposition site). To determine the pipeline characteristics the dredging depth $z = 10m$ was assumed. And, 1300 kg/m^{3}density was assumed for the water-soil mixture. The determined characteristics are presented in Fig. 2. The range of the dredge pump operation (Q_{min} - Q_{max}) was determined by calculating: the critical speed associated with sedimentation of the winning on the piping bottom (Q_{min}=1,5m^3/s), as well as the disposed pump suction head (Q_{max}=2,5m^3/s). The diesel engine drive was assumed. Three values of pump drive power were proposed as follows (pump shaft power): N_1=1460kW (Line 1 is that of constant torque value of $M_1=N_1/\omega$, where ω – pump angular speed), N_2=1840 kW (Line 2 is that of constant torque value of $M_2=N_2/\omega$), N_3=2180 kW (Line 3 is that of constant torque value of $M_3=N_3/\omega$). For the values dredger design capacity characteristics were determined (Fig.3).

From the characteristics presented in Fig. 3 results that drive engine of a lower output will cause, at a given range of pipeline length, the decreasing of the design capacity of the dredger. In the considered case the engine of 1840 kW power output (line 2) will cause the decrease of the dredger design capacity at the pipeline length range of 700÷1300 m, and the engine of 1460 kW power output (line 1) – at the pipeline length range of 500÷1500 m.

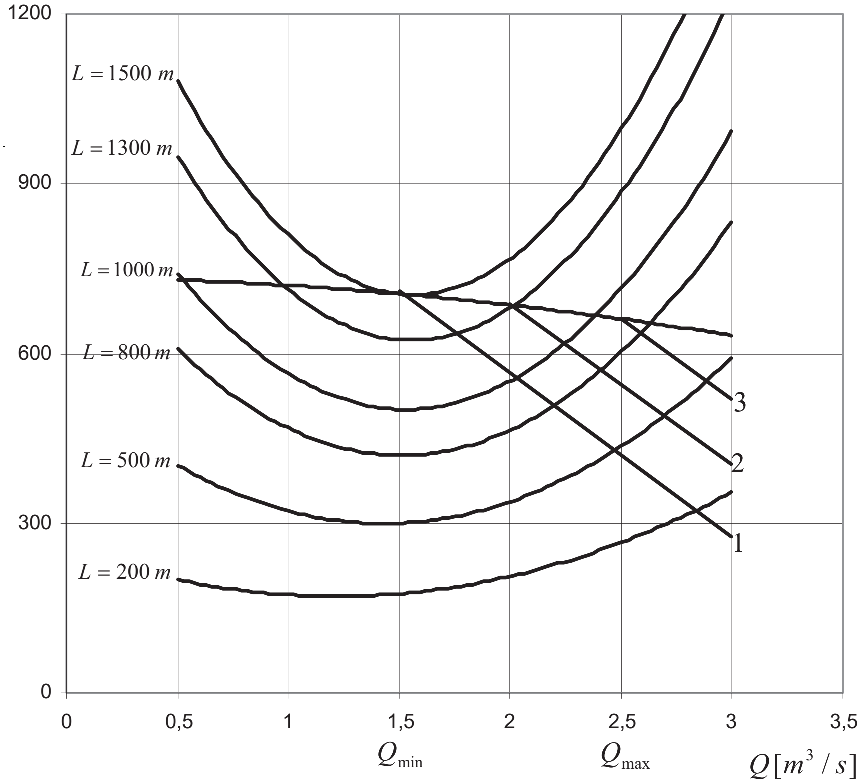

Fig. 2. Interaction between the drive engine - IHC 175-37,5-75 pump system and the pipe lines of different length values ; 1- the system with 1460 kW engine, 2- the system with 1840 kW engine, 3- the system with 2180 kW engine

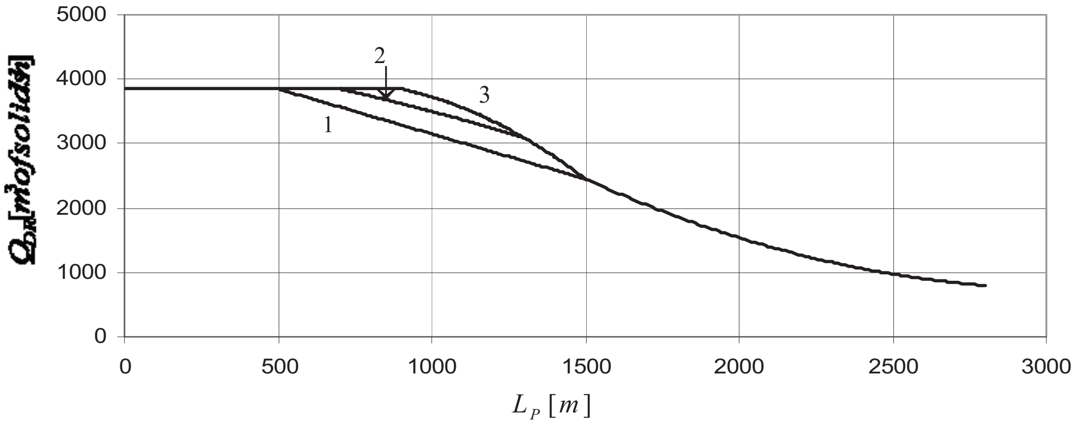

Fig. 3. Characteristics of dredger design capacity for three drive power values for IHC 175-37,5-75 pump

3. Operational parameters of dredge installation fitted with dredge pump

The results of operational investigations carried out by this author [3,4,5], dealing with capacity of dredgers have shown important differences between real capacities of dredgers and assumed design ones. The operational capacities of cutter suction dredgers amount to about 50-

60% of their maximum design capacities [4] that obviously resulted in respectively lower loads exerted onto dredge pumps.

Below, in Tab. 1 are collected the basic rated parameters of the dredge pumps installed on the investigated dredgers as well as the parameters of operational load distributions for the pumps, namely: the average values and standard deviations (N_{DP}^{av}, σ_{DP}), the relative loads $\overline{N}_{DP}^{av}$ as well as the values of the coefficient $N_{DP}^{\max} / N_{DP}^{nom}$ defined as the ratio of maximum operational power of pump and its rated power.

All the results deal with the case of pumping-over the mixtures of water and medium-cohesive grainy soils.

Tab. 1

The basic rated parameters of the dredge pumps installed on the investigated dredgers as well as the parameters of operational load distributions for the pumps

Dredger	Basic rated parameters of the dredge pumps			Parameters of operational load distributions for the pumps			
	P_{DP}^{w}	Q_{DP}^{w}	N_{DP}^{eff}	N_{DP}^{av}	$\overline{N}_{DP}^{av}$	σ_{DP}	$\frac{N_{DP}^{\max}}{N_{DP}^{nom}}$
	kPa	m³/s	kW	kW	-	kW	
TSHD 300	370	0,55	203,5	216,5	0,666	29,6	0,894
TSHD 400	490	0,5	245	189,4	0,451	20,9	0,597
TSHD 1600-1	385	1,6	2×616	832,9	0,757	101,4	0,956
TSHD 1600-2	385	1,6	2×616	828,3	0,753	90,9	0,923
TSHD 7200	430	3,0	2×1290	1815,9	0,769	178,4	
TSHD 9900	560	3,0	2×1680	2194,5	0,708	240,6	0,894
TSHD 13700	1240	4,1	5084	3861,9	0,434		
CSD 1600	600	1,0	600	544,1	0,544	114,1	0,865
CSD 1500	530	0,95	503,5	433,9	0,517	50,4	0,685
UB 750	1160	1,75	2×2030	1204,5	0,371	300,3	0,668
UB 500	440	0,7	308	240,5	0,445	29,5	0,574
BLD 325	410	0,4	164	158,4	0,634	27,1	0,884

P_{DP}^{w} - rated dredge pump pressure for water pumping conditions,

Q_{DP}^{w} - rated dredge pump capacity for water pumping conditions,

N_{DP}^{eff} - effective dredge pump power for water pumping conditions.

The performed calculations of the load distribution parameters of dredge pumps during pumping-over the water-soil mixture showed that for particular dredgers the relative mean loads were contained within the interval of 0,371÷0,769. It manifests that operational conditions of dredgers are very different and they depart from those assumed nominal (design ones). The calculated values of the variation coefficient of pump load distribution $\nu_{DP} = \sigma_{DP} / N_{DP}^{av}$ are contained within the interval of 0,1÷0,25, where the lower values dealt with suction hopper dredgers and the higher values - with suction-cutter and silting-up ones [3]. The magnitude of the coefficient suggests that pump load variability is relatively high. It results from variability of pipeline length. As results from the performed investigations the maximum pipeline length $L_{pipe}^{\max}$ amounted on average to $4{,}46 L_{pipe}^{\min}$ (where: $L_{pipe}^{\min}$ – minimum pipeline length). It's interesting that maximum values of pipeline length amounted to only 70-80% of those specified in the design assumptions [3].

The data presented in the above attached table were used for elaboration of the method for determining operational load distributions of dredge pumps [6]. The following relations were examined:

$$\left.\begin{aligned} N_{DP}^{av} &= f\,(N_{DP}^{eff})^{nom} \\ \sigma_{DP} &= f\,(N_{DP}^{eff})^{nom} \end{aligned}\right\} \qquad (1)$$

The calculation results are given in Tab. 2. The relationships presented in the table are statistically significant. The permissible intervals of independent variables for the equations given in Tab. 2 result from the data contained in Tab. 1.

Tab. 2

Linear regression equations which determine mean loads of dredge pumps

Relations	Statistical evaluation				
	R	σ	t	t_{kr}	m
$N_{DP}^{av} = 0{,}712 \cdot (N_{DP}^{eff}) + 2{,}43$	0,993	136,7	26,6	2,23	12
$\sigma_{DP} = 0{,}076 \cdot (N_{DP}^{eff}) + 22{,}01$	0,868	49,5	5,24	2,23	12

where: R - the coefficient of correlation, σ - the standard deviation, t - the value of the test t-Student, m - the sample number.

4. Formulation of principles for selection of drive engines of dredge pumps

The above presented data were used to formulate principles for selection drive engines of dredge pumps. The general conclusion drawn from Ch. 3 is that drive engine for dredge pump should not be selected for the conditions of maximum pipeline length and design values of water- soil mixture density. As it will lead to selection of an engine of a high power output which will not be practically utilized during dredger operation.

This author has proposed to make use of the results of the above presented operational investigations. On the basis of the data contained in Tab. 2, predicted loads for pumps in operation can be determined; the loads should be then transformed into drive engine loads with taking into account the reduction gear efficiency η_{DP}^{TM} :

$$\left.\begin{aligned} N_{DE}^{av} &= \frac{(N_{DP}^{av})}{\eta_{DP}^{TM}} \\ \sigma_{DE} &= \frac{\sigma_{DP}}{\eta_{DP}^{TM}} \end{aligned}\right\} \tag{2}$$

where: N_{DE}^{av} - the mean values of loads of drive engines, σ_{DE} - the standard deviation of load distribution of drive engines.

In the case of one - engine propulsion system, value of the design (computational) rated power output of drive engine can be determined from the following relationship [3]:

$$(N_{DE}^{nom})^{design} = \frac{N_{SG}^{av}}{(\overline{N}_{DE}^{av})^{design}} \tag{3}$$

The value $(N_{DE}^{nom})^{design}$ in Eq. (3) is determined on the basis of operational values of $\overline{N}_{DE}^{av}$ for the investigated dredge pumps (Tab.1) with accounting for values of the ratio $N_{DE}^{\max} / N_{DE}^{nom}$ and assuming an appropriate value of the drive engine power margin ΔN_{DE} .Value of the margin depends on operational conditions and character of load changeability of power consumers driven by the engine in question. For pumps of a low changeability of instantaneous loads the margin may be assumed on the level of ΔN_{DE}=(10÷15)% N_{DE}^{nom} [8]. Taking this into account one should assume the value of $(\overline{N}_{DE}^{av})^{design} = 0{,}6 \div 0{,}65$ for cutter suction dredgers and silting-up ones, and $(\overline{N}_{DE}^{av})^{design} = 0{,}65 \div 0{,}7$ for trailing suction hopper dredgers.

The other way of determining the value of design rated power output of main engine is to use the following relation:

$$(N_{DE}^{nom})^{design} = (N_{DE}^{av} + \beta_{DE} \cdot \sigma_{DE}) + \Delta N_{DE} \quad (4)$$

where: β_{DE} - the relative maximum load range coefficient; by assuming $\beta = 3$ it is possible to estimate maximum load value with the probability of 0,997;

So selected drive engine for dredge pump ensures that it will operate with the highest operational efficiency. Obviously, it is possible to assume other parameters of predicted load distribution for dredge pump than those determined on the basis of Tab. 2.

Coming back to the example presented in Ch. 2 and applying the above given recommendations concerning selection of pump drive engine we obtain the following values of design rated power output of drive engine for IHC 175-37,5-75 pump :

- $(N_{DE}^{nom})^{design} = 1490 \div 1635 kW$ - acc. Eq. (3);
- $(N_{DE}^{nom})^{design} = 1495 \div 1565 kW$ - acc. Eq. (4).

On this basis we are able to select a diesel engine of power output value contained within the above specified intervals, e.g. 8L20Wartsila diesel engine of 1600 kW rated power output and 1000 rpm rotational speed, as well as an appropriate reduction gear of the ratio n_1/n_2=1000/320.

Examining Fig. 2 we can observe that the selected engine will impose limitations onto pump characteristics, between the lines 1 and 2. The design capacity of the dredger will be also placed between the lines 1 and 2 (Fig. 3).

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