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Design solutions and working conditions of power systems for trailing suction hopper dredgers

SUMMARY

The types of dredgers classified in accordance with their modes of operation are shortly described in the paper. Design solutions of power systems of trailing suction hopper dredgers, the most popular dredger type, are discussed and evaluated.

Working conditions of the power systems are described on the basis of investigations of the dredger „Inż.St.Łęgowski" in operation.

INTRODUCTION

Dredging, regardless of type and construction of a dredger, consists of the following operations :

- loosening or excavating the soil out of the bottom
- lifting the loosened soil from the bottom up to the water surface
- transferring the lifted soil to the dump place.

The dredgers can be divided into several types according to the dredging operation mode.

Three main types of dredgers can be distinguished with regard to an applied mode of loosening and lifting the soil :

- ***The dredgers with hydraulic system of loosening and lifting the soil.*** A dredge pump is the main working facility of the dredgers. This is an impeller pump specially adjusted to pressing through the soil-water mixture. The pump sucks the soil-water mixture prepared in an appropriate ratio, through a suction pipe. The mixture is transferred to a hold or hopper barge. Such dredgers are called the *suction dredgers*.
- ***The dredgers with mechanical system of loosening and hydraulic system of lifting the soil.*** The dredgers are additionally fitted with a mechanical cutter. It usually has the form of a rotating cutter (cutter head). Knives of the cutter cut chips of the soil. The so loosened soil is sucked through the suction pipe to be hydraulically lifted and transferred away. Such dredgers are called the *cutter suction dredgers*.
- ***The dredgers with mechanical system of loosening and lifting the soil.*** The following kinds of dredgers belong to the type :
  - bucket dredgers
  - grab dredgers
  - backhoe/dipper dredgers.

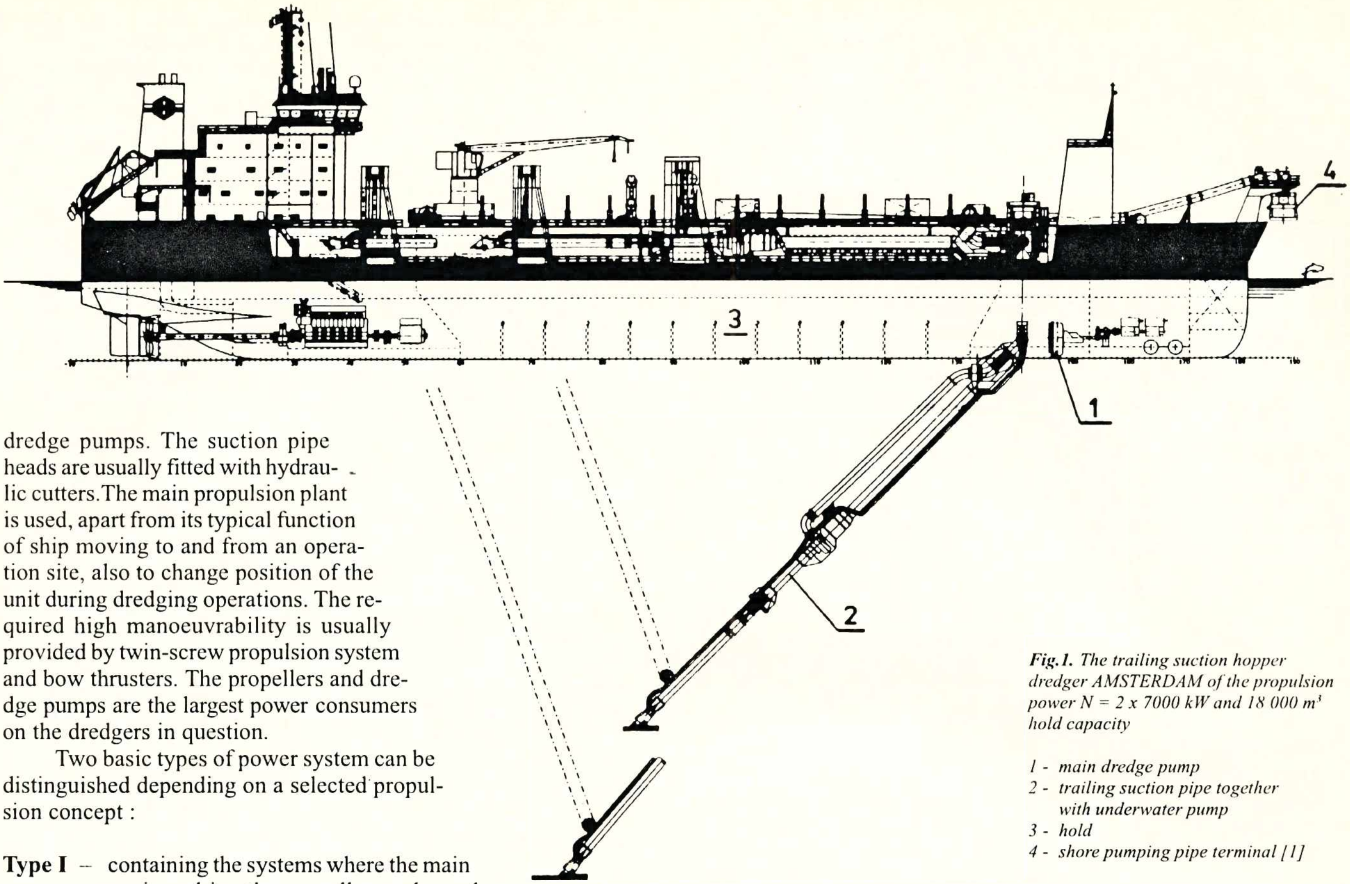
The bucket dredgers loosen and lift the soil by means of a bucket chain; the grab dredgers – by means of a grab or bucket.

The following types of dredgers can be distinguished with regard to an applied mode of transferring away the winning :

- ***The shore pumping dredgers*** which transfer the winning by pumping it through a piping. The dredge pump can silt up the winning directly to a dump (on cutter suction dredgers) or indirectly – by sucking the winning from a hold (on suction dredgers with a hold) or a soil well (on bucket dredgers).
- ***The hopper dredgers*** which are fitted with a soil hold. Its emptying is realized by opening the bottom doors or valves after ship's move to a dump. It can be unloaded also by pumping. All hopper dredgers are self-propelled.
- ***The dredgers assisted by hopper barges to transport the winning.*** The soil extracted from the bottom is loaded into the holds of the hopper barges which transport it to a dump.
- ***The dregders transferring the winning by means of long ejectors.*** They are fitted with a long chute (about 70 to 80 m long) – the ejector or pipe suspended at a special mast and jibs, through which the winning together with the added water directly flows into a dump.
- ***The dredgers transferring the winning by means of belt conveyors.***

POWER SYSTEMS OF THE TRAILING SUCTION HOPPER DREDGERS

The trailing suction hopper dredgers (Fig.1) are usually fitted with two trailing suction pipes, one at each side, and two (or more)



dredge pumps. The suction pipe heads are usually fitted with hydraulic cutters. The main propulsion plant is used, apart from its typical function of ship moving to and from an operation site, also to change position of the unit during dredging operations. The required high manoeuvrability is usually provided by twin-screw propulsion system and bow thrusters. The propellers and dredge pumps are the largest power consumers on the dredgers in question.

Two basic types of power system can be distinguished depending on a selected propulsion concept :

Type I – containing the systems where the main engines drive the propellers only, and the dredge pumps are driven by separate diesel engines

Type II – containing the systems where the main engines drive both the propellers and dredge pumps.

Fig.1. The trailing suction hopper dredger AMSTERDAM of the propulsion power N = 2 x 7000 kW and 18 000 m³ hold capacity

1 - main dredge pump
2 - trailing suction pipe together with underwater pump
3 - hold
4 - shore pumping pipe terminal [1]

Each of the types can be divided into several sub-types in view of e.g. propeller type, engine and pump location, power transmission system etc.

The propulsion systems of type I, most frequently applied, are presented in Fig.2.

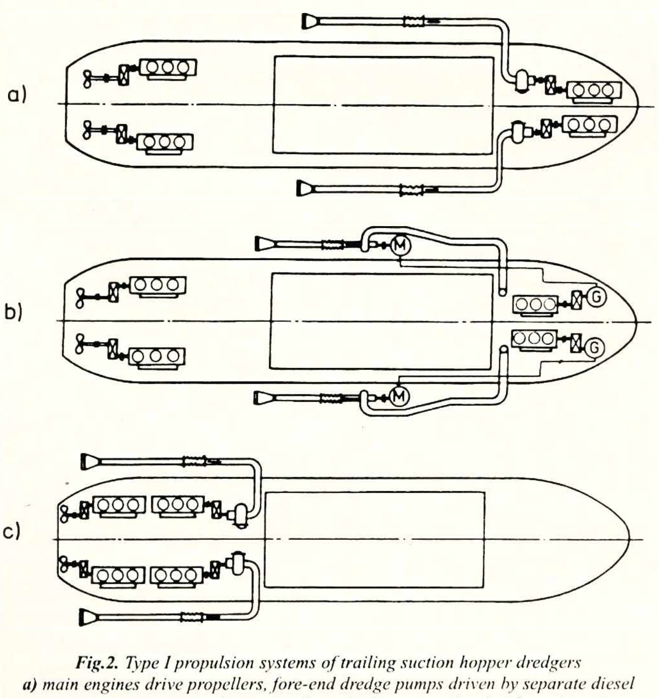


Fig.2. Type I propulsion systems of trailing suction hopper dredgers
***a)** main engines drive propellers, fore-end dredge pumps driven by separate diesel engines, **b)** main engines drive propellers, dredge pumps fitted with suction pipes, driven by diesel-electric sets, **c)** both main engines and suction pump driving engines located aft [1,3]*

The versions substantially differ from each other which influences their dredging ability. Fore end location of the pump room, illustrated in Fig.2a and 2b, makes it possible to apply longer suction pipes enabling to operate at greater depths. The system shown in Fig.2b is especially suitable for that due to application of the underwater dredge pumps. The system with the pump room arranged at the after end, shown in Fig.2c, makes applying shorter suction pipes necessary and therefore it can be used at smaller depths only.

The propulsion systems of type I are characterized by a high nominal power because of the application of separate drives to both largest power consumers. Fixed pitch propellers are used on all versions of the propulsion system as the propellers are driven by the separate engines able to operate with variable rotational speeds. Medium speed diesel engines are applied to drive propellers, dredge pumps and electric generators due to a limited height (3 to 5 m) of engine rooms.

The main engines of type II propulsion systems are utilized to drive the dredge pumps. During dredging operations the loading of the main engines driving the propellers is low (the dredger moves with the speed of 2÷3 knots only while working over the trench) which makes it possible to utilize the then existing power margin of the engines to drive the dredge pumps as well. In Fig.3 designs of type II propulsion systems with mechanical gears are exemplified.

The system versions differ from each other in location of the pump room and drive engines. The designs shown in Fig.3b and 3c, characterized by long shaftlines are applied on large dredgers with separate soil holds. Their main engines are to operate with steady rotational speed as they drive the dredge pumps too, which makes applying the controllable pitch propellers necessary.

In Fig.4 designs of type II propulsion systems with mechanical gears or diesel-electric drive of propellers, as well as diesel-electric drive of dredge pumps are presented.

All earlier comments dealing with propeller types, pump room location, suction pipe length and underwater pumps are also applicable to the considered designs.

Both AC and DC electric motors can be used to drive the dredge pumps. DC motors make operating with variable rotational speed and broad range control possible. The motors can be supplied from DC electric network (Ward-Leonard system, DC loop system), or from

AC electric network through thyristor converters. In the case of application of AC motors the multiple-speed motors with frequency converters are required to cope with a greater power demand during shore pumping than that during soil excavating.

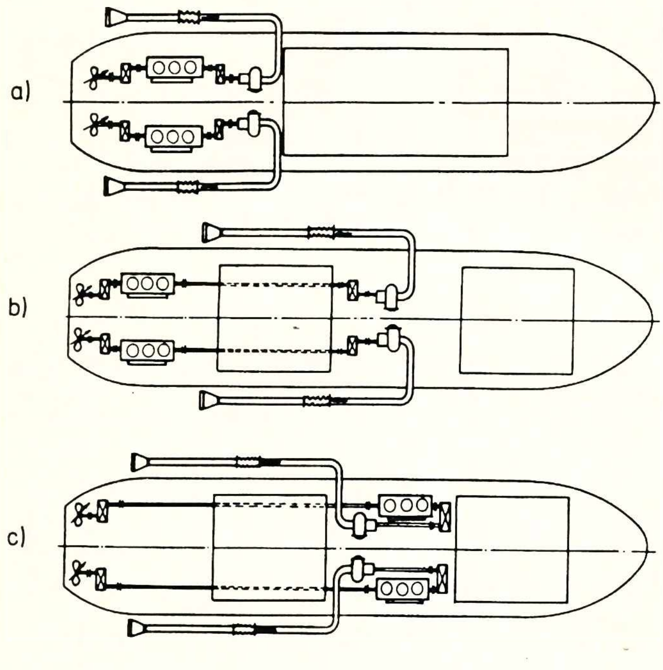


Fig.3. Type II propulsion systems of trailing suction hopper dredgers
a) drive engines and pump room located aft,
b) drive engines located aft, pump room located amidships,
c) drive engines and pump room located amidships [1,3]

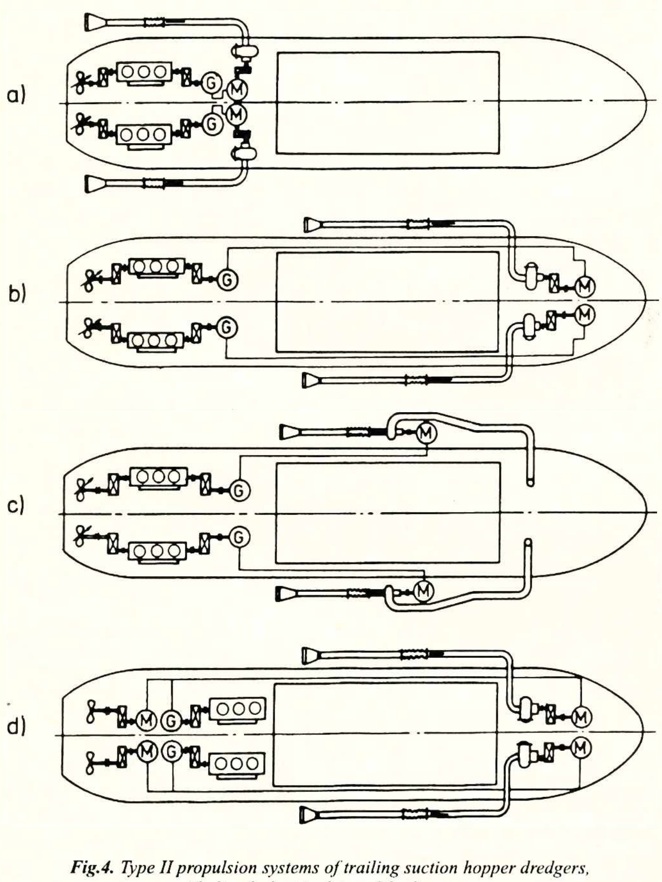


Fig.4. Type II propulsion systems of trailing suction hopper dredgers, with diesel-electric drive of dredge pumps
a) propellers driven through mechanical gears, pump room located aft,
b) propellers driven through mechanical gears, pump room located fore,
c) propellers driven through mechanical gears, underwater dredge pumps,
d) diesel electric drive of propellers and dredge pumps [1,3]

WORKING CONDITIONS OF THE POWER SYSTEMS

The dredger INŻ. ST. ŁĘGOWSKI operated by the PRCiP firm, Gdańsk (Dredging and Underwater Works Company Ltd) is a typical representative of the dredgers in question. Its propulsion system presented in Fig.5 corresponds to that of type II shown in Fig.4d.

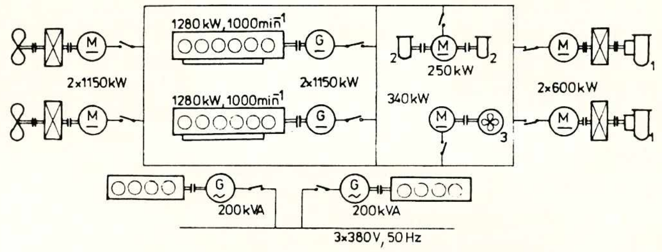


Fig.5. The propulsion system of the dredger INŻ. ST. ŁĘGOWSKI
1 – dredge pumps, 2 – pump of hydraulic cutters, 3 – thruster

It consists of :

⇒ two main electric generating sets of 2 x 1150 kW supplying DC electric network (constant current loop system of I = 1500 A).The electric motors driving propellers, dredge pumps, hydraulic cutters and thruster are supplied from this network

⇒ two generating sets of 2 x 200 kVA supplying the ship electric network of general use (3 x 380 V, 50 Hz).

Full year investigations were carried out on the dredger INŻ. ST. ŁĘGOWSKI in operation [2]. The investigations dealt with a.o. :

✶ duration time of particular operation modes of the dredger
✶ the parameters which characterize the loading upon the propeller drive and dredge pump electric motors.

The investigations consist in filling special recording sheets by crew members and the research project authors. Records were made every half-an-hour, and every 2 min as far as changes of pump operation parameters during single loading and unloading operation of the hold by pumping are concerned.

During the investigations the dredger operated at sea for 4463 hours, i.e. 51.2% of the entire investigation time. Time precentage shares of the particular operation modes were as follows :

✧	dredging the soil	21.5%
✧	transferring the winning by pumping	13.1%
✧	bottom door opening (emptying the hold)	0.6%
✧	moving with the winning, returning to the dredging site	9.5%
✧	passages to and from the port, dredging site changing	6.5%

Loading of the propeller drive motors varied within a broad range depending on the operation mode. Two modes of operation were selected :

● passages and moving with the winning
● dredging (actual dredging and transferring the winning by pumping).

During passages and moving with the winning the maximum ship speed was not greater than 11 knots (max. speed of the dredger : 14 knots without load and 11.5 knots with load).

A histogram of the total propeller drive loading (of both starboard and port-side motors) at this operation mode is presented in Fig.6. Propeller drive loading during actual dredging mainly depends on the suction pipe drag and the dredger hull resistance and speed (of the maximum value of about 2÷3 knots). During transferring the winning by pumping effected always at sea the propellers were used to keep position of the dredger at the silting piping during worsening of the weather conditions only. This is the reason of important differences in propeller drive loading at dredging and transferring the winning. In Fig.7 and 8 histograms of the total propeller drive loading are presented respectively : for all dredging operations together and actual dredging only.

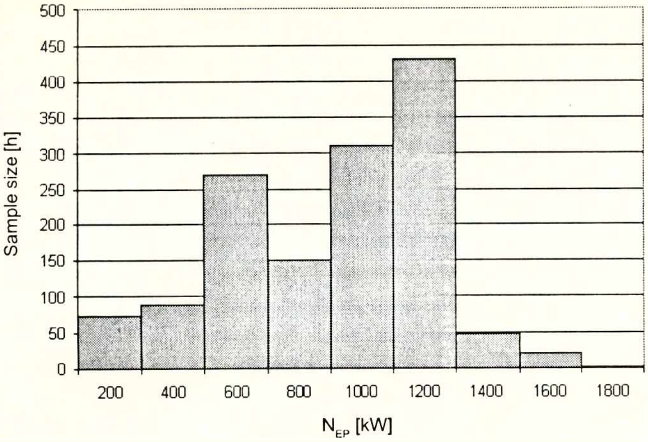


Fig.6. Histogram of the total propeller drive loading during dredger passages and moving with the winning

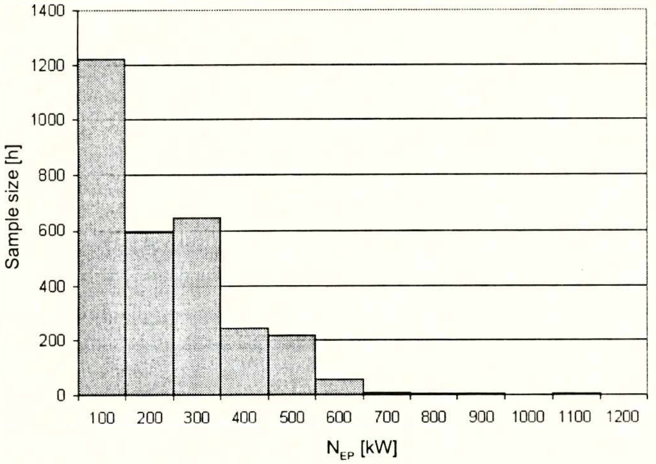


Fig.7. Histogram of the total propeller drive loading during all dredging operations

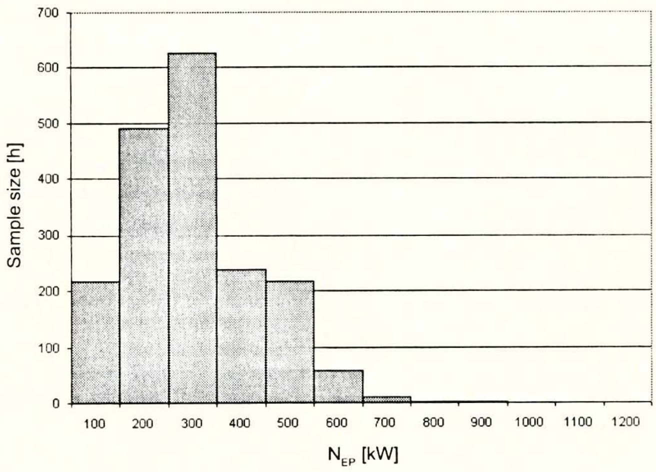


Fig.8. Histogram of the total propeller drive loading during actual dredging the soil

The mean values N^m_{EP} and standard deviations σ_{EP} of the statistical distributions as well as coefficients of variation v_{EP} were calculated. Values of the relative mean propeller drive loading $\overline{N}^m_{EP}$ and relative standard deviation $\overline{\sigma}_{EP}$ related to the maximum propeller drive load recorded during the investigations, N^{max}_{EP}, were calculated as well :

$$\overline{N}^m_{EP} = \frac{N^m_{EP}}{N^{max}_{EP}} \qquad \overline{\sigma}_{EP} = \frac{\sigma_{EP}}{N^{max}_{EP}}$$

where : N^{max}_{EP} = 1740 kW. Results of the calculations are presented in Tab.1.

Tab.1. Total operational propeller drive loading

Operation mode	N^m_{EP}	$\overline{N}^m_{EP}$	σ_{EP}	$\overline{\sigma}_{EP}$	v_{EP}
	kW	-	kW	-	-
Passages and moving with the winning	804.1	0.462	325.1	0.187	0.404
All dredging operations	173.8	0.099	162.0	0.093	0.932
Actual dredging the soil	260.9	0.150	133.6	0.077	0.512

Investigations of the dredge pump drive motor loading were performed at two operation modes :

- actual dredging the soil
- transferring the winning by pumping.

During the performed investigations the dredging depth was contained within the range of 7 to 18 m, length of the winning transfer piping - between 800 and 2000 m, hold loading time -between 40 and 100 min, and time of hold unloading by pumping the winning to dump site - between 50 and 90 min.

During single operation of hold loading the changes of drive motor loading were rather not large (Fig.9.) and mainly dependent on density of the soil-water mixture. The similar situation was observed during transferring the winning by pumping (Fig.10).

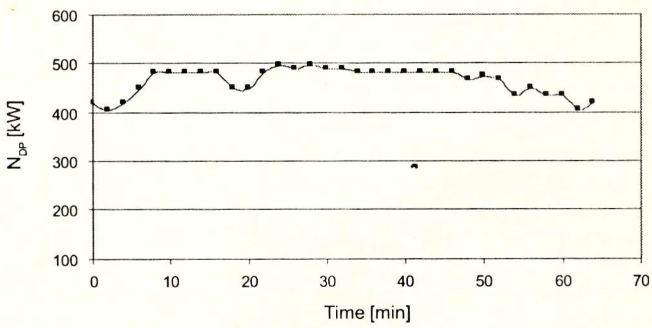


Fig.9. Loading changes of the starboard dredge pump drive motor during single hold loading operation (N^m_{DP} = 461.4 kW ; σ_{DP} = 27.3 kW)

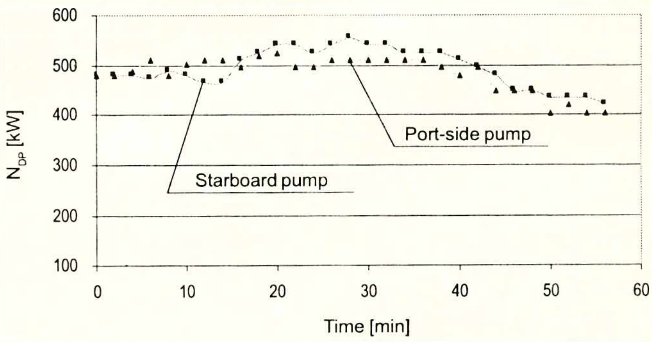


Fig.10. Loading changes of the dredge pump drive motors during transferring the winning by pumping (serial operation of the pumps)
Starboard pump : N^m_{DP} = 497.1 kW ; σ_{DP} = 37.9 kW
Port-side pump : N^m_{DP} = 483.3 kW ; σ_{DP} = 34.3 kW

Values of the mean loading of the dredge pump drive motor during single hold loading operation were contained within 135÷515 kW range and mainly dependent on the kind of the dredged soil and actual output of the pump.

Values of the same loading during transferring the winning were contained within 310÷565 kW range, and most influenced by the silting piping length and silt transferring capacity.

Histograms of the dredge pump drive motor loading recorded during the entire investigation time are presented in Fig.11 and 12.

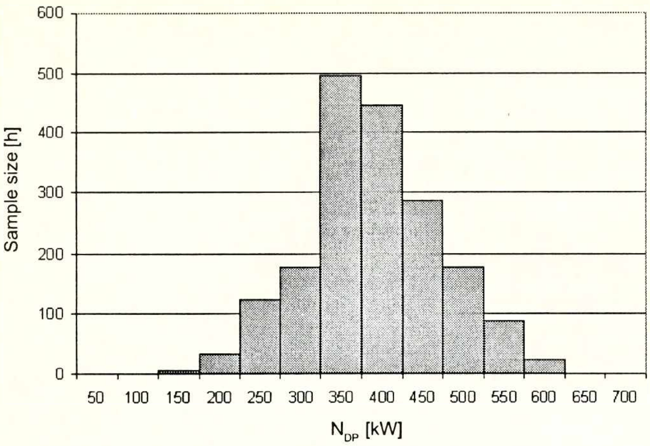


Fig.11. Histogram of the dredge pump drive motor loading during actual dredging the soil

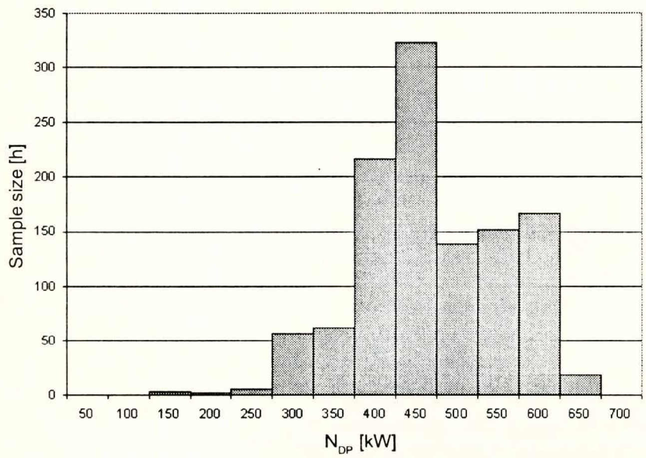


Fig.12. Histogram of the dredge pump drive motor loading during transferring the winning by pumping

Similarly, the mean values N^m_{DP} and standard deviations σ_{DP} of the statistical distributions as well as the coefficients of variation v_{DP} were calculated. Also, values of the relative mean dredge pump drive loading $\overline{N}^m_{DP}$ and relative standard deviation $\overline{\sigma}_{DP}$ related to the rated power of the dredge pump drive motor, N^{nom}_{DP}, were calculated :

$$\overline{N}^m_{DP} = \frac{N^m_{DP}}{N^{nom}_{DP}} \qquad \overline{\sigma}_{DP} = \frac{\sigma_{DP}}{N^{nom}_{DP}}$$

where : $N^{nom}_{DP} = 600\ kW$. Results of the calculations are presented in Tab.2.

Tab.2. Loading of the dredge pump drive motors in operation

Operation Mode	N^m_{DP}	$\overline{N}^m_{DP}$	σ_{DP}	$\overline{\sigma}_{DP}$	v_{DP}
	kW	-	kW	-	-
Actual dredging the soil	367.2	0.612	83.2	0.139	0.226
Transferring the winning	401.2	0.668	95.3	0.159	0.237

CONCLUDING REMARKS

- The most popular power systems, out of all presented design solutions, are : that of type II whose main engines propel, through mechanical gears, screw propellers as well as dredge pumps (Fig.3a), and the other also of type II but with screw propellers driven through mechanical gears and diesel-electric drive of dredge pumps (Fig.4b).
- The statistical distribution of the propeller drive loading during passages and that during moving with the winning greatly differ from each other. The operation mode „dredging" is characterized by the much lower mean propeller drive loading and greater coefficient of variation simultaneously. On the contrary, the mode „passages and moving with the winning" reveals the higher mean propeller drive loading and lower coefficient of variation.
- The statistical distributions of the dredge pump drive motor loading are of a similar character and scatter (similar values of the coefficient of variance : 0.226 and 0.237). Somewhat larger values of the mean loading are found for the mode „transferring the winning by pumping".
- The investigations performed on the dredger INŻ.ST.ŁĘGOWSKI in operation demonstrated that working conditions of its power system are very changeable which is connected with cyclic character of dredging operations, variability of soil type, environmental conditions and other operational factors.
- Traditional design methods of ship power plants as well as dredger power systems are mainly based on deterministic models. The performed investigations indicated that probabilistic models can approximate real operational conditions better than deterministic ones. Therefore further development of the power system design methods for the trailing suction hopper dredgers should be based on probabilistic models of their operation.

NOMENCLATURE

N	-	power output
$\overline{N}$	-	relative power output
v	-	coefficient of variation
σ	-	standard deviation
$\overline{\sigma}$	-	relative standard deviation

Indices

DP	-	dredge pump
EP	-	engine propulsion
m	-	mean value
max	-	maximum value
nom	-	nominal value

Appraised by Andrzej Balcerski, Prof., D.Sc.,M.E.

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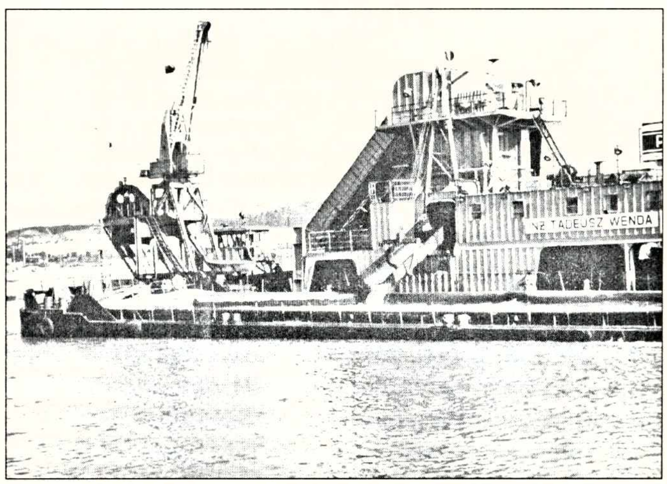

Bucket dredger INŻ.T.WENDA