THE ANALYSIS OF DRIVE SYSTEMS IN UNMANNED UNDERWATER VEHICLES TOWARDS IDENTIFYING THE METHOD OF DRIVE TRANSMISSION – PART 2

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ABSTRACT

This is the second part of material concerned with the analysis of drive systems in remotely controlled underwater vehicles. The first part involved the problem of classification of unmanned underwater vehicles, mainly remotely controlled, as well as the nomenclature used in relation to various components of the discussed drive systems and thrusters. The functionality of particular drive systems was discussed along with the advantages and disadvantages of the analysed design technologies. This material presents the method of conducting an analysis of drive systems, its methodology and results.
Keywords: sea engineering, underwater vehicle, underwater work technology.

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INITIAL ANALYSIS OF DRIVE SYSTEMS IN UNMANNED UNDERWATER VEHICLES

The analysis was conducted on 173 ROVs of various classes on the basis of information contained in the available literature listed in the first part of the publication. The following groups of vehicles were distinguished for the purposes of analysis:

- vehicles with thrusters equipped with electric motors with direct drive on the propeller,
- vehicles with thrusters equipped with hydraulic motors with direct drive on the propeller,
- vehicles with thrusters equipped with electric motors and magnetic drive transmission or with electro-magnetic motors.

Quantitative division of vehicles selected for analysis acc. to class (Norm NO-07-A118:2015) and the adopted division into groups is shown in Table 1.

Tab. 1

The number of analysed ROVs according to their class and type of drive used in thrusters.

Vehicle class	Number of vehicle [pcs]			
	Thruster drive type			Total
	with electric motor	with hydraulic motor	with electric motor and magnetic coupling	
Micro	5		5	10
Small	16		13	29
Medium	15		14	29
Large	27	63	15	105
Total	63	63	47	173

COMPARATIVE ANALYSIS OF BASIC TECHNICAL PARAMETERS OF UNMANNED UNDERWATER VEHICLES

The tables below provide a summary of the data related to particular classes of analysed underwater vehicles with regard to thruster type and drive transmission, as well as such basic operational parameters as: mass in the air [kg], operational depth [m], horizontal velocity (forward) [kn] and installed capacity [kW]. Vehicles with thrusters equipped with electric motors with magnetic drive transmission are marked as "mg". The remaining vehicles with electric or hydraulic thrusters with direct drive transmission were marked as "other".

VEHICLE CLASS "MINI"

Tab. 2

Mass in the air [kg]		
Thruster type	mg	Other
min	3	2
max	5	6
average	4	4
median	4	4
min ÷ average	80%	60%
average ÷ max	20%	40%
number	5	5

Tab. 3

Depth [m]		
Thruster type	mg	Other
min	75	50
max	3000	152
average	690	101
median	150	76
min ÷ average	80%	60%
average ÷ max	20%	40%
number	5	5

Tab. 4

Horizontal velocity [kn]		
Thruster type	mg	Other
min	2	2
max	3	4
average	2	3
median	2	2
min ÷ average	40%	60%
average ÷ max	60%	20%
number	5	5

Tab. 5

Installed capacity [kW]		
Thruster type	mg	Other
min	0.2	0.2
max	0.5	1.0
average	0.3	0.4
median	0.3	0.3
min ÷ average	40%	80%
average ÷ max	60%	20%
number	5	5

VEHICLE CLASS "SMALL"

Tab. 6

Mass in the air [kg]		
Thruster type	mg	Other
min	12.00	11.00
max	47.00	42.00
average	26.46	28.56
median	20.00	28.00
min ÷ average	62%	50%
average ÷ max	38%	50%
number	13	16

Tab. 7

Depth [m]		
Thruster type	mg	Other
min	100	46
max	4000	6000
average	593	834
median	300	300
min ÷ average	85%	81%
average ÷ max	15%	19%
number	13	16

Tab. 8

Horizontal velocity [kn]		
Thruster type	mg	Other
min	3.00	2.00
max	4.20	10.00
average	3.41	3.36
median	3.00	3.00
min ÷ average	58%	36%
average ÷ max	42%	64%
number	12	14

Tab. 9

Installed capacity [kW]		
Thruster type	mg	Other
min	0.20	0
max	3.60	5
average	1.73	2
median	1.50	1
min ÷ average	55%	73%
average ÷ max	45%	27%
number	11	15

VEHICLE CLASS "MEDIUM"

Tab. 10

Mass in the air [kg]		
Thruster type	mg	Other
min	50.00	50.00
max	140.00	132.00
average	84.71	79.56
median	75.00	82.00
min ÷ average	64%	47%
average ÷ max	36%	53%
number	14	15

Tab. 11

Depth [m]		
Thruster type	mg	Other
min	50.00	300.00
max	1500.00	6000.00
average	607.50	865.00
median	500.00	425.00
min ÷ average	64%	86%
average ÷ max	36%	14%
number	14	14

Tab. 12

Horizontal velocity [kn]		
Thruster type	mg	Other
min	2.00	1.50
max	4.50	3.50
average	3.13	2.72
median	3.00	3.00
min ÷ average	58%	36%
average ÷ max	42%	64%
number	12	14

Tab. 13

Installed capacity [kW]		
Thruster type	mg	Other
min	2.50	2
max	10.00	15
average	4.78	6
median	3.00	5
min ÷ average	67%	54%
average ÷ max	33%	46%
number	12	13

VEHICLE CLASS "LARGE"

Tab. 14

Mass in the air [kg]		
Thruster type	mg	Other
min	150.00	165.00
max	2700.00	15000.00
average	606.33	2830.50
median	330.00	2540.00
min ÷ average	73%	54%
average ÷ max	27%	46%
number	15	89

Tab. 15

Depth [m]		
Thruster type	mg	Other
min	600.00	200.00
max	7000.00	11000.00
average	2350.00	2639.46
median	2000.00	2750.00
min ÷ average	73%	50%
average ÷ max	27%	50%
number	15	90

Tab. 16

Horizontal velocity [kn]		
Thruster type	mg	Other
min	1.50	1.6
max	3.50	5.0
average	2.93	3.03
median	3.00	3.0
min ÷ average	18%	50%
average ÷ max	82%	50%
number	11	90

Tab. 17

Installed capacity [kW]		
Thruster type	mg	Other
min	4.00	5
max	74.00	600
average	18.71	129
median	13.00	115
min ÷ average	71%	58%
average ÷ max	29%	42%
number	14	89

COMPARATIVE ANALYSIS OF SELECTED PARAMETERS OF DRIVE UNITS OF UNMANNED UNDERWATER VEHICLES

The comparative analysis of selected parameters of the drive units of unmanned underwater vehicles was based on two indices:

- W_{Tj} – index of use of unit thrust in horizontal movement forward $[m^2 \cdot kn/kg]$,
- W_N – drive transmission index from the motor to the propeller in horizontal movement forward $[kg/kW]$.

The index of use of unit thrust (W_{Tj}) is defined by the product of vehicle frontal area and its forward velocity obtainable with 1 kg of thrust, calculated from the following equation:

$$W_{Tj} = \frac{B \cdot H \cdot v_H \cdot i_H}{T_H} \left[\frac{m^2 \cdot kn}{kg}\right] \quad (1)$$

where:

B	vehicle width [m]
H	vehicle height [m]
v_H	vehicle forward speed [kn]
i_H	number of thrusters in movement forward [pcs]
T_H	total thrust produced by vehicle thrusters [kg]

The above index accounts for the resistance of the vehicle, thus it may be used to determine the velocity obtained by a similar vehicle of a defined frontal area equipped with a thruster producing a defined amount of thrust.

Drive transmission index (W_N) is defined by the quotient of thrust and power supplied to the thruster and is calculated from the following equation:

$$W_N = \frac{T_p}{N_p} \left[\frac{kg}{kW}\right] \quad (2)$$

where:
P – thrust [kg]
P – power supplied to thruster [kW]

Using this indicator we may compare thrusters with electric motors ensuring direct drive transmission to the propeller with thrusters equipped with magnetic drive transmission or electro-magnetic motors.

The tables below present the results of calculations of particular indices in the analysed classes of unmanned vehicles. For the purposes of the conducted analysis thruster drive types were classified as follows:

- hydraulic – vehicles with thrusters equipped with hydraulic motors with direct drive on the propeller,
- electric – vehicles with thrusters equipped with hydraulic motors with direct drive on the propeller,
- magnetic – vehicles with thrusters equipped with electric motors and magnetic drive transmission or with electro-magnetic motors.

Tab. 18

Average W_{Tj} index acc. to vehicle class and thruster drive type.

Vehicle class	Thruster type			
	electric	hydraulic	magnetic	all
MICRO	0.16		0.12	0.13
SMALL	0.03		0.04	0.03
MEDIUM	0.05		0.06	0.05
LARGE	0.06	0.05	0.08	0.06
all	0.06	0.05	0.07	0.06

Tab. 19

Average W_N index acc. to vehicle class and thruster drive type.

Vehicle class	Thruster type		
	electric	magnetic	all
MICRO	50.0	62.5	58.3
SMALL	17.9	25.0	21.5
MEDIUM	23.3	30.0	27.8
LARGE	18.0	18.8	18.5
all	25.4	34.1	30.8

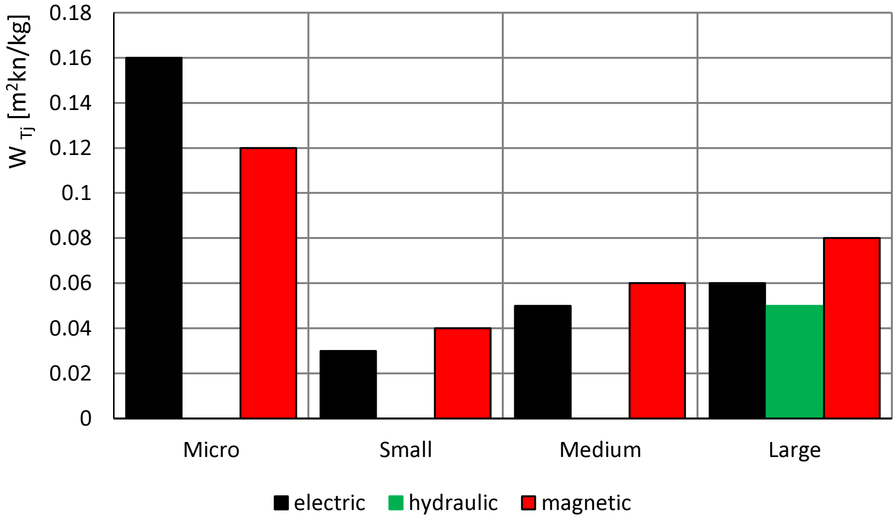

Fig. 1 The average index of use of unit thrust in horizontal movement forward (W_{Tj}) acc. to vehicle class and thruster drive type.

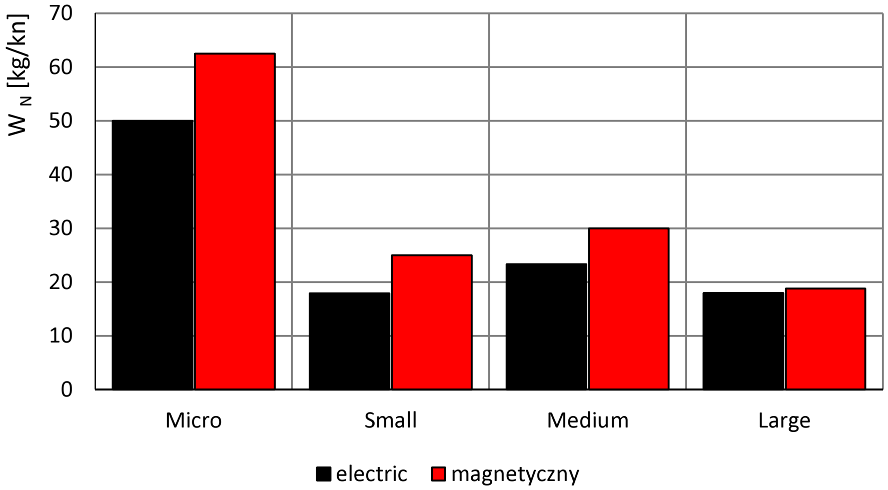

Fig. 2 The average index of drive transmission from electric motor to the propeller in horizontal movement forward (W_N) acc. to vehicle class and thruster drive type.

CONCLUSIONS

The two parts of the article titled *The analysis of drive systems in unmanned underwater vehicles towards identifying the method of drive transmission* discussed a number of issues related to the problem of classification of this type of devices, the nomenclature concerned with particular components of analysed drive systems, as well as advantages and disadvantages of analysed solutions.

Two most common solutions of drive transmission froman electric motor to the propeller were analysed: traditional, consisting in direct placement of the propeller on the shaft of the motor, and magnetic, with the use of magnetic coupling. The second part of the article contained a comparative analysis of the discussed design technologies. The analysis was based on technical data of 173 ROVs which were divided into three groups:

- group 1: vehicles with thrusters equipped with hydraulic motors with direct drive on the propeller,
- group 2: vehicles with thrusters equipped with hydraulic motors with direct drive on the propeller,
- group 3: vehicles with thrusters equipped with electric motors and magnetic drive transition or with electro-magnetic motors.

The classification of analysed constructions results from the provisions of the norm NO-07-A118:2015. The number of vehicles along with the division into classes and groups of analysed drive types is presented in Table 1. Data divided into vehicle class, drive type and basic operational parameters such as: mass in the air, depth, horizontal velocity and installed capacity are presented in Tables 2 to 17. The data show that in the case of "Micro" vehicles there is the greatest difference between operational depth of analysed constructions. In this case, vehicles with magnetic drive transmission the operational depth is nearly seven times greater than compared with the remaining constructions. In the remaining classes the trends are opposite, however not as significant.

Considering the horizontal velocity of vehicles, the values of this parameter are similar for all analysed constructions, whereas installed capacity in vehicles with direct drive is greater than in vehicles using magnetic coupling. This could suggest a greater efficiency of a system with magnetic drive transmission, however such a conclusion is too far-reaching at this stage of research and requires experimental confirmation.

Further system analysis was carried out with the use of unit thrust index in horizontal movement forward (W_{Tj}) and drive transition index (W_N). The method of determination of particular indices was illustrated with the use of mathematical equations (1) and (2). The analysis of index W_{Tj} may again indicate a greater efficiency of a system with magnetic drive transmission. The values of this parameter for this group of systems are higher as compared with the remaining constructions (Table 18). A similar situation is observed in the case of drive transmission index W_N (Table 19). Opposing tendencies occur only in the class of "Mini" vehicles, as shown in Fig. 1.

The conducted analysis provides a clear indication for the need of further research aimed at comparing the efficiency of both analysed design technologies. However, next research phase should be based on laboratory tests with the use of both drive systems.

References analogous to that in the previous article of the authors

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