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Application of internal power sources to supplying the remotely controlled submersible vehicle

SUMMARY

Problems connected with the modernization of KORAL underwater system (Remotely Operating Vehicle - ROV) by applying an internal power source are described. The paper shortly presents system's characteristics, selection of accumulator battery, technical collaboration aspects of electric cells and system's propulsion. It also presents in a systematic way the collected data on alternative power sources and compares their features from the point of view of possible use in underwater technology.

The paper presented at II Drive and Steering Systems'96 Seminar, Gdańsk, February 1996

DESCRIPTION OF KORAL-AT UNDERWATER SYSTEM (ROV)

Growing demand for underwater TV monitoring services and other similar control works was the reason to undertake, by the team of Ship Research Institute, Technical University of Gdańsk, design work on a relatively cheap submersible device, mobile and adaptable to very complex tasks, which brought to completion the KORAL and its next version, KORAL-AT. The system's modular structure makes it possible to arrange either a simple underwater system of limited number of functions and smaller gabarites or a more complex system aimed at more sophisticated missions. The complete system for underwater inspection works is shown in Fig.1. The main executive element of the system is the submersible vehicle (ROV) shown in Fig.2. It consists of the set of operation instruments and the motion system supplied from the set of transformers to lower supply voltage.

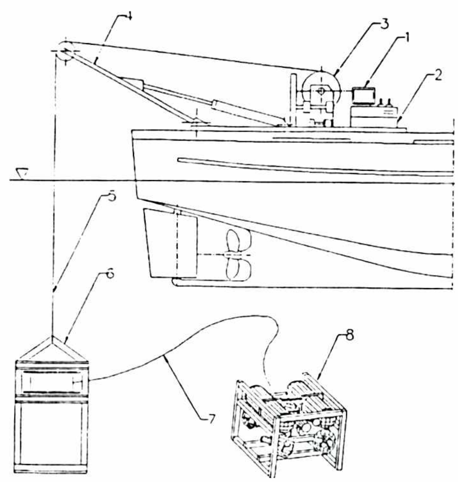

Fig.1. The complete KORAL underwater system:
1 - Steering console, 2 - Feeder, 3 - Cable-line winch , 4 - ROV's davit,
5 - Heavy umbilical cord, 6 - ROV's garage, 7 - Light umbilical cord, 8 - Submersible vehicle

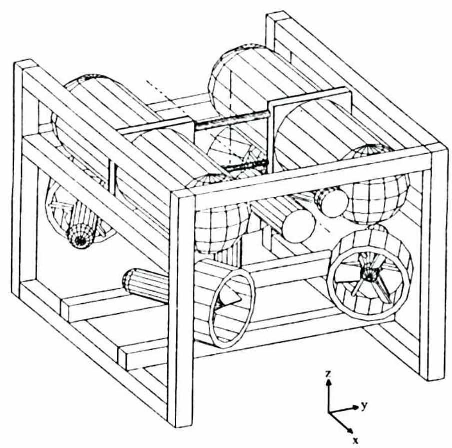

Fig.2. Sketch of the original version of KORAL submersible vehicle

The overwater part of the system is connected with the underwater vehicle by the umbilical cord of zero buoyancy, which contains supplying cables and fiberoptic communication link. The feeder is installed to change one - phase voltage from 220 V/ 50 Hz to about 800 V/ 1000 Hz and to make the cable used to transmit the assumed amount of energy relatively thin.

An important part of the KORAL is the control sub-system. It decides on system's capabilities, and an overwhelming part of system's design costs is spent on its designing and programming.

The control post contains a special microcomputer with two input joysticks and a keyboard. Results of system's operations and images transmitted from TV cameras are simultaneously displayed on the monitor screen. The post can be supplemented by the overwater part of sweeping sonar, i.e. the steering console equipped with a monitor. A hydro-acoustic underwater navigation system can be also added.

The system's devices are located in two objects: submersible vehicle and overwater operator cabin. Each of them is equipped with the autonomous microcomputer mutually connected by means of the fiberoptic link by which signals from the underwater TV camera and signals from the interface provided for sending commands and feed-back information between the computers, are transmitted.

The ROV's components are fastened to the frame which consists of the GRP multi-layer beams filled with the pressure resistant polyurethane foam of closed pores.

The buoyancy containers with the electronic devices: computer, compass and impulse motor feeders are placed in the upper part of the frame. Between the containers the vertical propeller and cable-line yoke are arranged. Four propellers to move the ROV in the horizontal plane are located just beneath. They are arranged as shown in Fig.3, which makes it possible to generate thrust or/and torque vectors in an arbitrary direction. The propellers and umbilical cord yoke are placed in such a way as to locate the geometric centre of thrust as close as possible to the centre of hydrodynamic resistance.

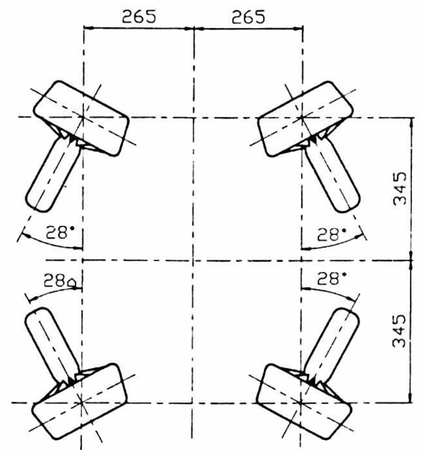

Fig.3. Location of four propellers to move the ROV in the horizontal plane

Modern brushless motors with permanent rare earth magnets, and sinusoidal field oscillation are applied. The motors are fed from inverters without feed-back, i.e. they work as synchronous machines.

Technical specification of KORAL-AT SV

- *Main Particulars:*
  ROV gabarites: 910 x 760 x 700 mm
  ROV mass: 76 kg
  cable-line length: 150 m
  cable-line diameter : 14 mm
  propeller power: 5 x 375 W
  (thrust: 5 x 190 N)
- *Basic equipment:*
  colour TV camera (6 W)
  lamps (2 x 150 W)
  electronic magnetic compass
  echo sounder (2 W)
  pressure depth-meter
- *Optional equipment:*
  photo camera with flash lamp
  sonar
  ultrasonic thickness meter
  structure cathodic potential meter
  manipulator

AIM OF INTERNAL SUPPLY SOURCE APPLICATION

The physical connection between the ROV and the accompanying surface unit generates many, often underestimated, structural and operational problems, e.g.:

- danger of locking the vehicle or even loss of it
- substantial hydrodynamic resistance (especially in the case of towed devices or those working in current)
- umbilical cord vibrations, their influence on steering process and additional resistance of the system
- surface unit heaving which can generate additional load onto the umbilical cord and lead to its failure, and also induce cable-line vibrations
- system's mass increase (sometimes multifold) which makes transportation and operation of the system more difficult
- problems linked with designing the umbilical cord: ensuring its relevant durability, strength, buoyancy, electric parameters, and disturbance limitation.

The above specified drawbacks gave impulse to search for a more autonomous ROV design. It can be obtained in several ways; one of them is minimizing the cord diameter and optimizing its cross-section shape. Evolution of the method has led from the increased voltage of input energy to the application of buffer energy supply from an accumulator battery or even to a ROV design alternative with the energy supply exclusively from an internal source connected with the surface vessel by means of a link to transmit control signals only (e.g. by a cheap, thin, single-use fiberoptic linc).

KORAL RESISTANCE CHARACTERISTICS

The frame structure of KORAL is fitted with many appendages. An approximate resistance characteristics of it are presented in Fig.4. Values of the force components due to the cable-line are shown in Fig.5.

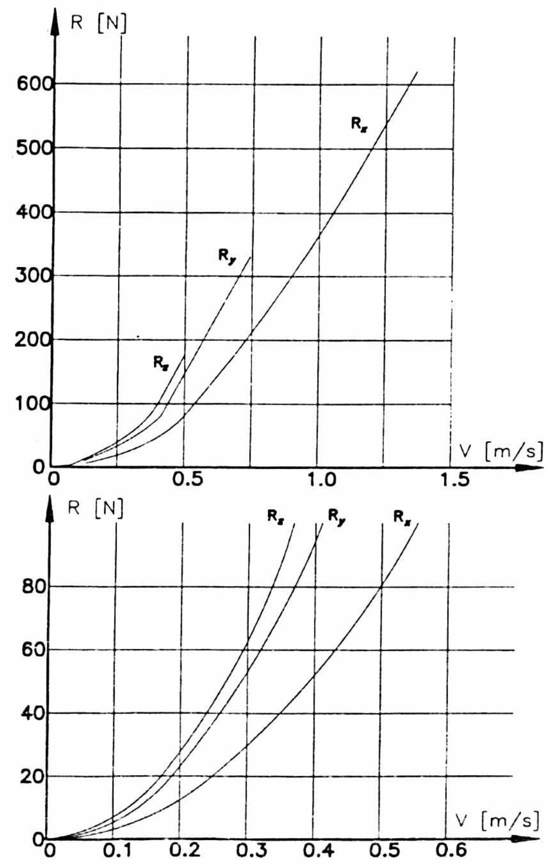

Fig. 4. Resistance characteristics of KORAL

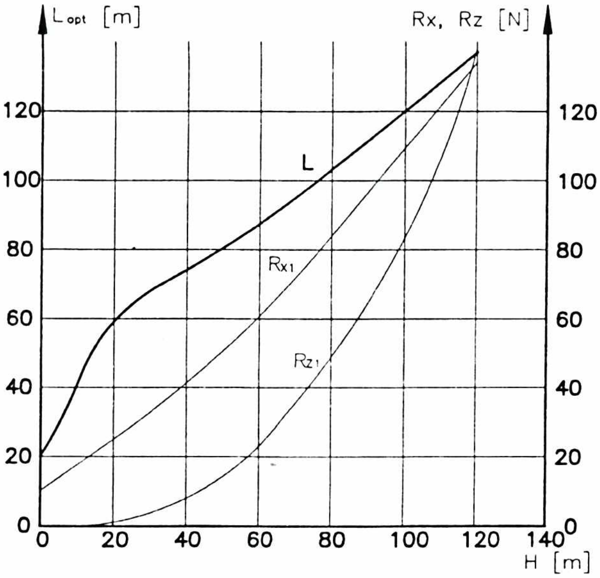

Fig.5. Resistance characteristics of the umbilical cord

It is difficult to determine the umbilical cord characteristics as many its parameters can be changed during design process. Therefore some limitations are imposed upon them in advance. The calculated values are valid only for a given mission of the vehicle, described later. Values of the force components R_x and R_y are presented in function of the water depth H while assuming an optimum length of the line to be laid out. The umbilical cord length L was optimized under the criterium of the minimum values of the forces introduced to the system and the limited sag of the cord curve. Keeping the sag of no more than 20 m ensures that the cord will not be entrapped by structural elements of a serviced platform.

The propeller characteristics are shown in Fig.6.

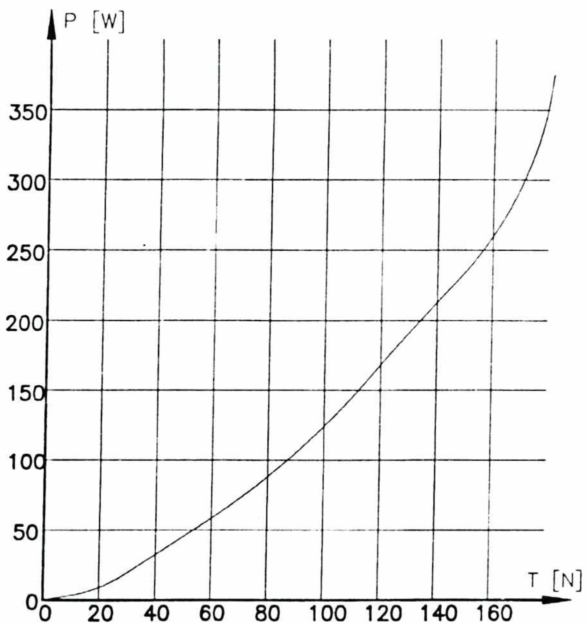

Fig.6. KORAL propeller characteristics

INTERNAL POWER SOURCES

The internal power source used for the ROV is an important element of energy supply sub-systems. Its parameters are highly decisive of the parameters of the entire system. Its mass can reach even 50 to 60 % of the entire vehicle mass.

The application of internal sources to supply the ROVs is more and more advantageous firstly due to advances in improving the features of the power sources and lowering the share of their costs in system's costs (which grow as more and more expensive equipment is installed in the ROVs) and secondly due to smaller and smaller energy demand of the equipment and higher and higher propulsor efficiency.

Feasibility of the common, cheap accumulator batteries for supplying the ROVs is limited because of specific demands of underwater technology. In the recent years however great progress can be observed in the area of electric energy application to ecological propulsion of vehicles. It concerns also the application of the electrochemical energy sources to underwater vehicle propulsion (e.g. submarines).

Only a few of many available solutions can be applied to supply the submersibles. Recently the lead-acid cells are most used. So far, more sophisticated sources are applied first of all to the underwater vehicles of research or military applications [5]. Some features of the considered energy sources are compared in the table beneath.

Comparison of some features of alternative energy sources

No.	Type of source	Energy/mass density [Wh/kg]	Power/mass density [W/kg]	Durability [cycles, hours or other time units]	Relative investment cost [$/kWh]
1.	Lead - acid L-A cell (LIS)	30 - 40	800	200 1500[1)]	120
2.	L-A cell (traction use)	25 -35	20	1000 8000[1)]	250
3.	L-A cell (no leak)	30 - 55	150	200 - 600 5000[1)]	320
4.	Ag-Zn cell	70 - 130	800	100	4000
5.	Ag-Cd cell	45-75	150	500	6000
6.	Ag-Fe cell	110	800	300	lack of data
7.	Ni-Cd cell (PET)	15-30	45 300[2)]	2000	800
8.	SPC cell	22-37	800	2000	1400
9.	Ni-Fe cell	20-35	35	4000	< 1600
10.	Ni-Zn cell	35-70	750	200	1600
11.	Ni-H2 cell	47	100	300	20 000
12.	Water activated cells	100-150	80	1cycle 30s - 72 h	lack of data
13.	Fuel cells	130-175	20-150	3 years	10 000
14.	Li cells	100-440	50	1cycle	400-1300
15.	Semi-fuel cells	950	450	1cycle 10 years	500-2000
16.	Diesel engine	340[3)] 110	150-250	3-10 x1000 h	lack of data
17.	Stirling engine	340[3)] 110	lack of data	lack of data	lack of data
18.	Nuclear reactor	4500	0.2-1	~ 3 years	lack of data
19.	THULIUM-170 isotope	31000[4)]	82[4)]	$t_{1/2}$ = 128 days	lack of data
20.	Heat generators	800-4200[4)]	lack of data	1 cycle	lack of data

Notes:

1) - *at slight discharge of < 50 %*
2) - *high current version*
3) - *stored liquefied oxygen*
4) - *heat energy*

Dimensionless characteristics of the most important types of electrochemical cells are compared in Fig.7a to 7d in com-pliance with the following enumeration:

1. Lead-acid cells:
1.1 High current cells
1.2 Traction cells
1.3 Serviceless cells
2. Silver-zinc cells
3. Siver-cadmium cells
4. Nickel-cadmium cells:
4.1 Pocket type electrode
4.2 Sintered plate
5. Nickel-iron cells
6. Nickel-zinc cells

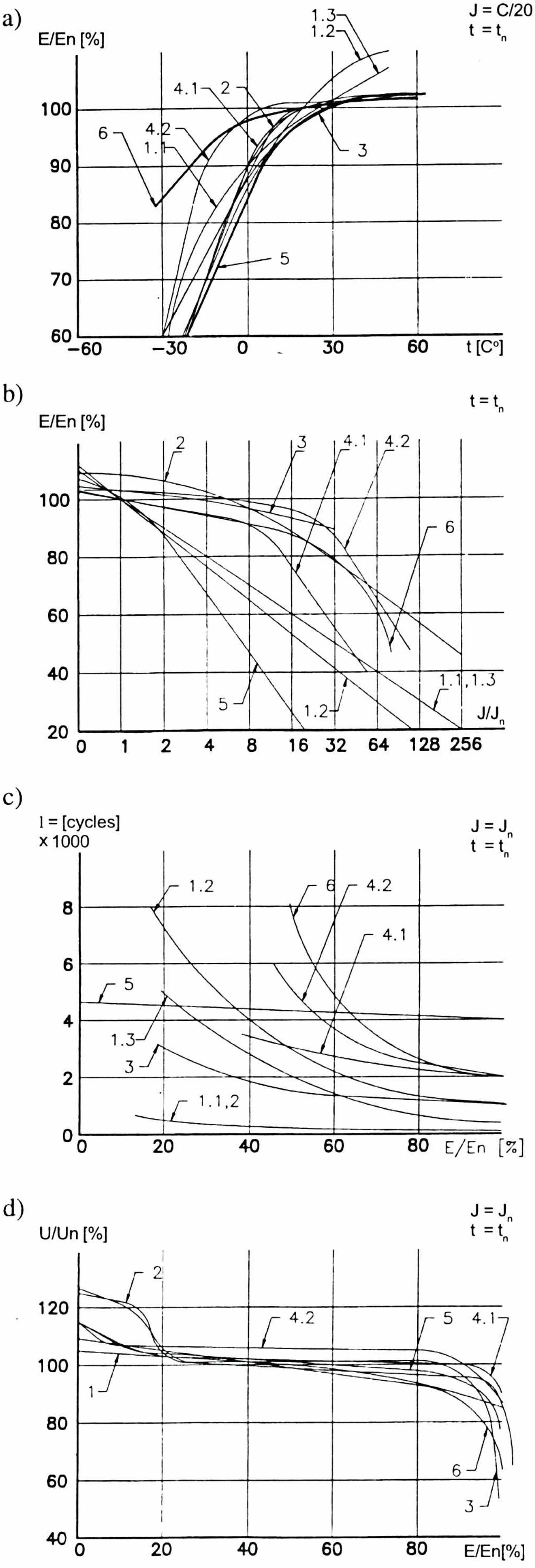

Fig.7. Characteristics of the most important types of electrochemical cells

ANALYSIS OF ACCUMULATOR BATERY - INVERTER COLLABORATION

Collaboration of the brushless DC motor of the rectangular supply voltage characteristics with the electrochemical cell does not cause any problem. The cell is loaded by an almost constant current. Possible disturbances during commutation are compensated by a condenser. Constant load of the electric source is guaranteed by inverter manufacturers.

A room for doubt can be attributed to loading the cell by the sets composed of the inverter and synchronous motor with permanent magnets, which were applied to KORAL. This results from the way, in which sinusoidal course of motor supplying current is obtained, and from influence of load on cell's capacity. As the applied EUROTHERM inverter is usually supplied by 220 V AC, its producer does not indicate any recommended load course at the DC end where supply batteries are to be connected.

In practice the motor is fed from the inverter with the impulse voltage of constant amplitude and modulated impulse width. The impulses are simultaneously triggered in all three phases. Therefore a high current impulse load exceeding several times the average value can be expected to be applied to the cell. This operation mode is highly disadvantageous to the cell as it lowers cell's capacity (Fig.7b) and also increases gas emission. Oscilloscopic observations were utilized to reveal a real load course.

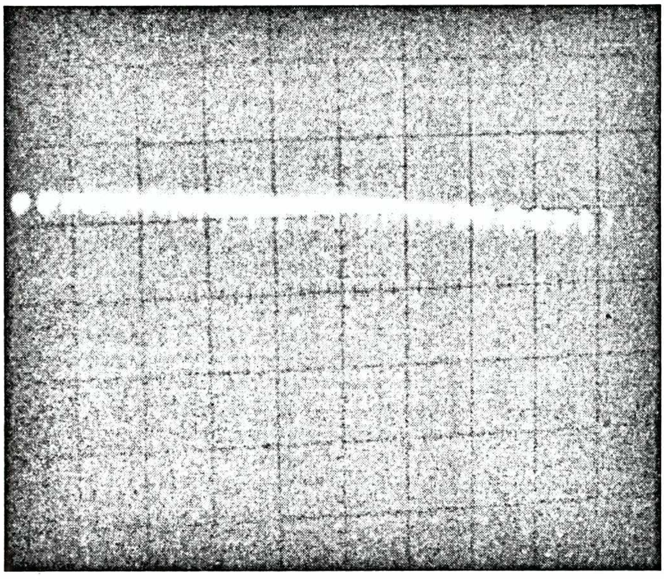

Fig.8. Oscillographic image of the supply voltage course of the motor

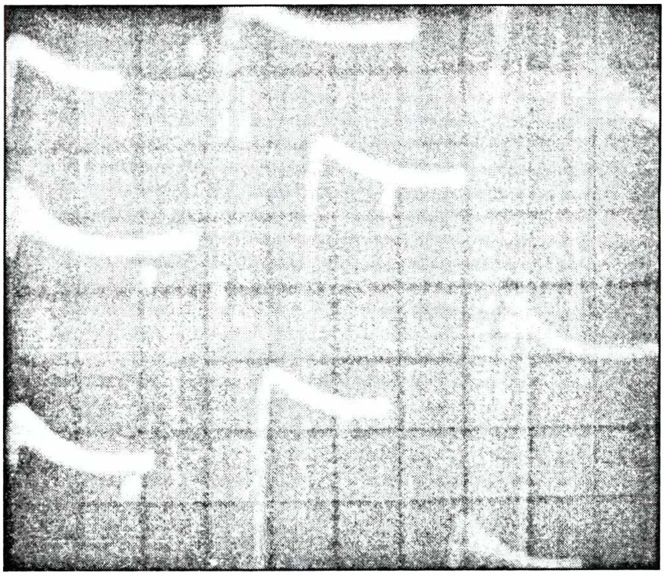

Fig.9. Oscillographic image of the inter-phase supply voltage course of the motor

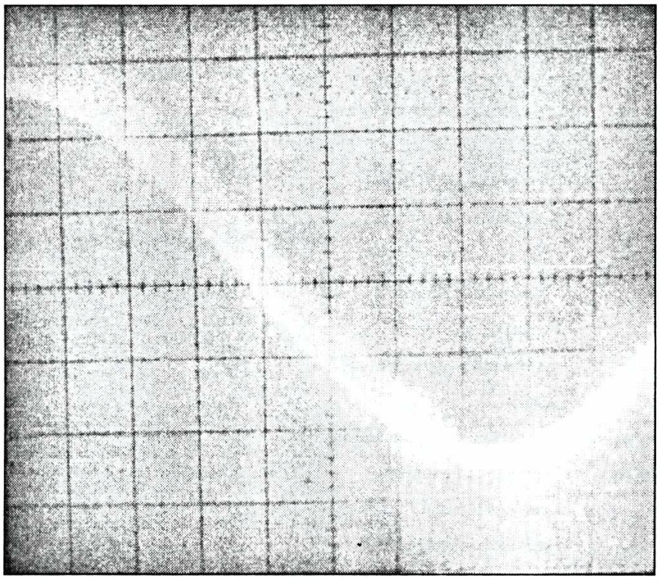

Fig.10. Oscillographic image of the input current course of the motor

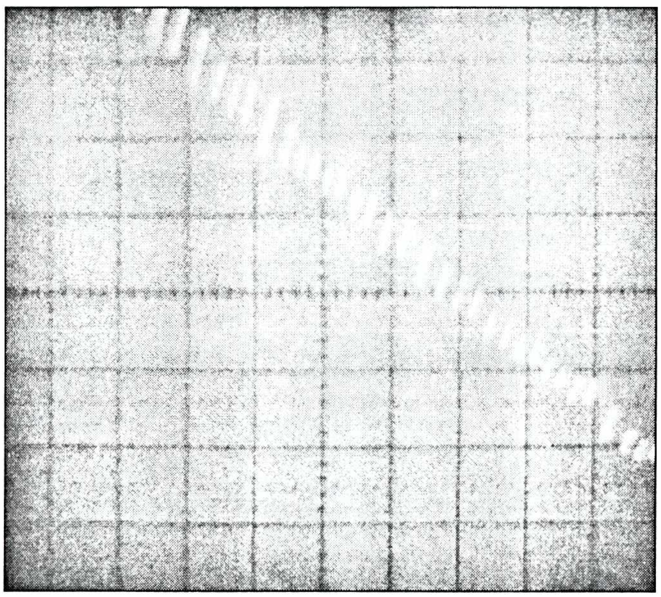

Fig.11. Oscillographic image of the input current course of the motor

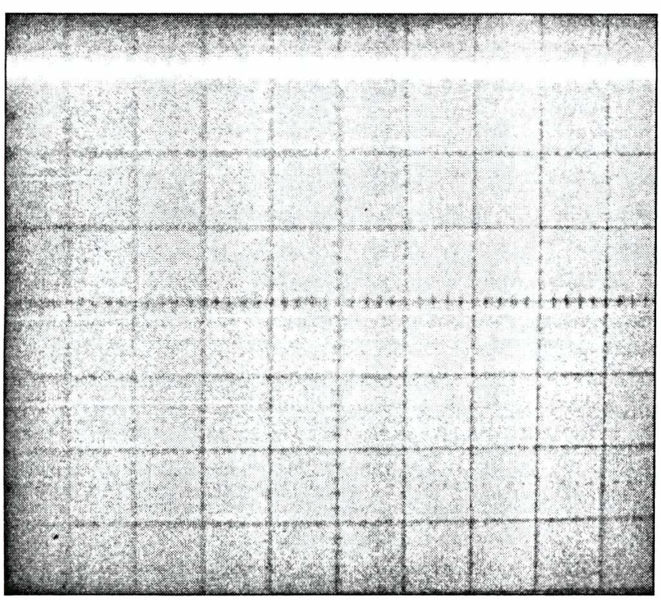

Fig.12. Oscillographic image of the course of current input from the rectifier

The supply voltage course of the motor is shown in Fig.8 and 9.Two inter-phase voltages, vertically shifted to make the image more distinct, were simultaneously observed. Simultaneous impulse release in both phases was clearly revealed (see Fig.9).

The current input course of the motor is shown in Fig.10 and 11.The sinusoidal course of the current due to motor winding inductance can be observed.

Fig.12 shows the course of current input from the rectifier which represents the cell in the system in question. The constant value run obtained due to smoothing by motor winding inductance and the applied condenser of 470 mF/ 400 V can be observed. Minute disturbances did not exceed 0.2 % of the mean value.

In result one can be sure that the applied system can collaborate with an electrochemical energy source without any negative impact on its features.

ADVISABILITY EVALUATION OF KORAL MODERNIZATION

An ideal solution would be to choose power source size in such a way as to satisfy the power demand of ROV during its mission with an appropriate margin, i.e. not to overdimension it. Unfortunately it is not possible to select the ideal size because of KORAL versatility and many its possible missions. Statistical data collected during missions of other ROVs are of no use because of their sporadic character and great differences in their size, equipment or mission profile.

Therefore the power demand which is to be covered by a battery installed on board KORAL was determined on the basis of its hypothetical mission of inspecting the underwater part of PETROBALTIC offshore drilling platform. The mission consisted in inspecting each of its three legs and two risers on both opposite sides of each of them and planar move between subsequent survey stands. Fig.13 presents the mission course.

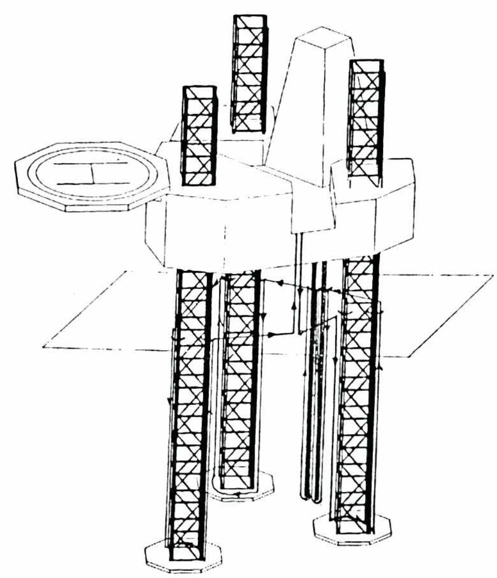

Fig.13. KORAL SV hypothetical mission of inspecting the PETROBALTIC offshore drilling platform

The most unfavourable operation conditions, i.e. current action perpendicular to ROV's axis and of velocity calculated with 30% margin, were assumed. The vehicle velocity V = 0.2 m/s was selected to obtain the entire image, observed from 1 m distance, moving across the monitor screen in about 3 to 4 seconds.

The characteristics of currents within the considered sea region are dependent first of all on meteorological conditions. Literature source data indicated that the current velocity of more than 0.5 m/s could not be expected even after long storms.

Results of the relevant calculations performed on the basis of these data are presented in Fig.14, which illustrates the course of power demand of KORAL during the mission. They were used to determine the required capacity of the electrochemical cell battery.

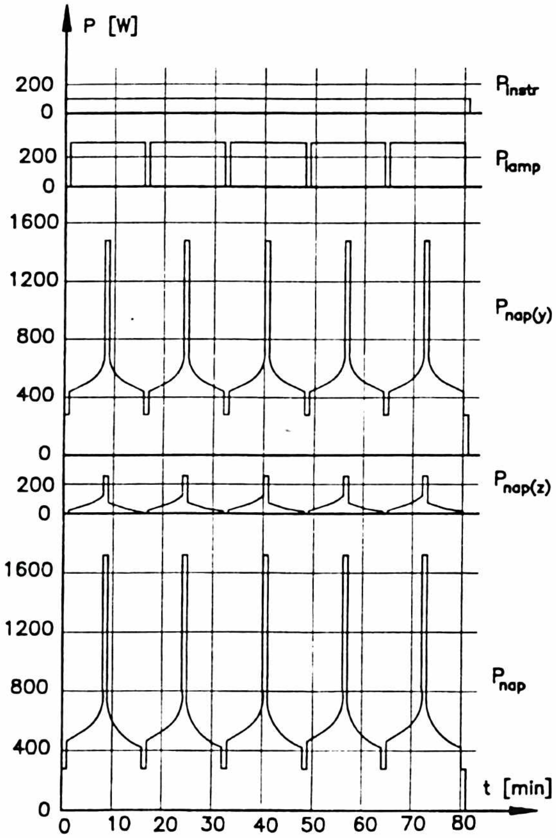

Fig.14. Course of KORAL power demand during its hypothetical mission

Analysis of the results showed that the ratio of the energy required to overcome umbilical cord resistance, to that required to overcome the entire system resistance is about linearly dependent on the ROV working depth. The ratio is as high as 28 % for ROV vertical motion and 40% for ROV horizontal motion at the assumed working depth of 80 m. The values were reduced to 14% and 26% respectively when replacing the original umbilical cord (of ϕ = 16 mm) by a new one (of ϕ = 5 mm). This makes it possible to reduce the capacity of the propulsion battery by about 23%, i.e. the entire capacity of all batteries by about 12 %.

The modernized ROV equipped with accumulator batteries, drafted in Fig.15, can be compared with its original version shown in Fig.2.

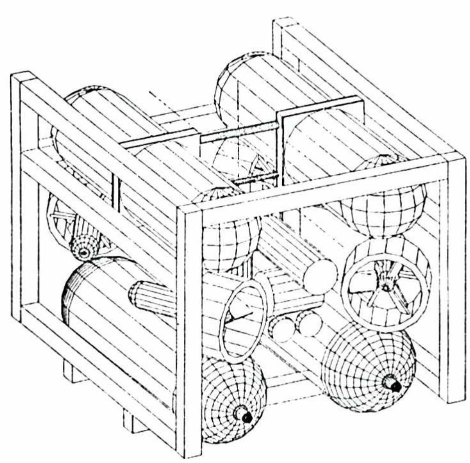

Fig.15. Sketch of the modernized KORAL equipped with accumulator batteries

It seems purposeful, when analysing the load course shown in Fig.14, to take into consideration a compromising solution where the accumulator batteries work in the buffer mode and the umbilical cord is provided to ensure energy transmission to charge them and supply the ROV during its low input power demand.

NOMENCLATURE

C	-	capacity of electric battery acc. to producer's specification
E	-	real capacity of electric baterry
E_n	-	nominal capacity of electric battery
H	-	submersible working depth
J	-	charging current
J_n	-	nominal current
l	-	battery durability
L	-	umbilical cord length
L_{opt}	-	optimum umbilical cord length
P	-	power
P_{instr}	-	power absorbed by instruments
P_{lamp}	-	power absorbed by lights
$P_{nap(x,y)}$	-	power of horizontal propellers
$P_{nap(z)}$	-	power of vertical propeller
P_{nap}	-	propulsion power [$P_{nap} = P_{nap(x,y)} + P_{nap(z)}$]
R	-	hydrodynamic resistance
$R_{x,y,z}$	-	hydrodynamic resistance components
$R_{xl,zl}$	-	umbilical cord hydrodynamic resistance components
t	-	operation temperature
t_n	-	nominal operation temperature
T	-	hydrodynamic thrust
U	-	voltage
U_n	-	nominal voltage
V	-	vehicle velocity

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