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Measuring systems applied in the Engineering Objects Detection System (SWOT)

SUMMARY

In this paper an autonomous, mobile, multi-purpose measuring system designed as an integral part of the SWOT Engineering Objects Detection System applicable in deep water exploration is presented.

Its measuring characteristics related to some possible tasks of the underwater instrument carrier, KRAB, are described. Motion qualities of the vehicle are determined more precisely with regard,in particular, to motion parameters stabilization.

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INTRODUCTION

Underwater operations during which divers descend to deep waters are extremely expensive and time-consuming. Amount of equipment, number of divers and supporting personnel and transportation means increase with water depth and in consequence the needed financial expenditures grow dramatically. Simultaneously the effective time which can be used for underwater works decreases.

Economic demands and duties put on users of sea and inland water engineering infrastructure require an alternative organisation system of underwater works. The alternative could be a system in which all the preparatory operations , preparation of photographic and factual documentation and eventually other auxiliary works would be transferred to the underwater Engineering Objects Detection System, called SWOT („SWOT" acronim comes from first letters of its Polish name), viz. its part, KRAB-underwater instrument carrier. The SWOT system was developed on the basis of the Underwater Monitoring System designed earlier in Faculty of Maritime Technology , Technical University of Szczecin.

SWOT'S TECHNICAL SPECIFICATION

SWOT system consists of two components:

- Mobile Test - Control Stand
- KRAB-underwater instrument carrier

Mobile Test-Control Stand

The stand is placed in a two-axle car trailer. It consists of the following sub-assemblies:

- ❑ KRAB carrier's control unit
- ❑ monitoring data recording and retrieving system
- ❑ image recording and reproducing system
- ❑ analytical and testing mini-laboratory
- ❑ autonomous supply system (and other similar systems).

KRAB underwater instrument carrier

The carrier is built of anodized aluminium tubes. The instruments are placed in pressure vessels. The similar vessels serve as displacement modules.

KRAB's technical specification

- year of completion 1992
- operating depth 50 m
- gabarites 1220 x 1070 x 590 mm
- mass 62 kg
- speed 1,5 m/s
- cable-line length 150 m
- cable-line buoyancy abt.0 N/m
- number of propellers 5
- configuration of propellers: 2 longitudinal, 2 transverse, 1 vertical
- electric energy supply 220 V/50Hz

Basic equipment

- 2 TV cameras: colour, black-white
- adjustable supporting platform for cameras and 4 x 150 W halogen lights
- single-function jaw manipulator
- compass
- pressure water-depth meter

Optional equipment

- measuring head
- magnetometer
- water-sample-taking device
- echo sounder for determination of vehicle distance from bottom and water surface

Deck equipment

- control console
- magnetometer console
- control desk
- keyboard
- monitor
- monitoring data stabilization and visualization systems.

POSSIBLE SWOT'S APPLICATIONS

The underwater instrument carrier can be fitted, if necessary, with various measuring systems and devices. This feature makes it possible to use the carrier in very different missions. Some possible SWOT's applications in cooperative tasks with a diver or when substituting him in more hazardous operations are presented below.

Examination of hydraulic engineering underwater constructions

Overhaul or examination of hydraulic engineering constructions in their underwater part are bound usually with failures or damages suffered by them (for instance those of a quay, navigation mark, bank protection, wave breaker, dry dock etc). Accident investigation must be proceeded quickly, within 72 hours only, as it is required by the Polish maritime law to make preliminary loss assessment and evaluation , which makes it possible to arrest in this time the ship suspected guilty of an accident. Application of the SWOT can simplify and accelerate the process of the preliminary loss assessment making simultaneously its results more objective. Fault location and its video-tape records can accelerate subsantially further divers' works indicating places in which a more exact inspection should be done, and simplifying determination of methods applicable in further action.

Location and removal of obstructions to navigation

The preliminary location of obstructions to navigation obtained solely from hydrographic data is insufficient to make decision about methods applicable in further action or about range of works to protect and remove the obstruction. At this proceeding stage, direct observation results, complex investigation to detect and locate possible additional hazards (e.g. leakage of active substances), determination of dimensions and other data important for techniques applicable in further action, become indispensable.

Application of the KRAB vehicle during obstruction removal works can provide suitable lighting of working site and factual documentation which enables to rationalize and accelerate further works and to ensure visual contact with a working diver.

Drawing up inventory of cables, pipelines and other installations

The KRAB equipment makes it possible to search for and to determine routes of cables, pipings and other engineering installations. Preliminary detection and determination of possible failures, line route and laying depth location can help in further examination of the installation by divers.

Searching for metal elements in bottom sediments

The KRAB equipment is able to detect metal elements in bottom sediments. Detecting metal elements such as wrecks, scrap, lost cargo etc should be one of the basic identification operations (apart from trawling and sounding) required to obtain the bottom cleanliness certificate.

Technical state examination of quays and other engineering structures

All owners of port and hydraulic engineering structures are obliged to overhaul and examine periodically their technical state prior to repairing them. Among others, these are the following operations :

- sounding 10 m wide strip of bottom adjacent to a quay to control bottom profile
- trawling to detect possible obstructions
- quay structure examination (a.o. wall tightness control)
- surface failure detection in concrete structures (wastage, pinholing, state of expansion joints, concrete reinforcement laggings and quay equipment fittings)
- examination of pile structures (corrosion, wastage, state of joints between piles and load carrying plate)
- other equipment control (ladders, cathodic protection systems etc)

Most of the above mentioned operations can be done in a conventional way or supported by the SWOT. Video tape records possible to be made in the latter case may be used in qualitative and quantitive technical state assessment of the examined objects.

MOTION QUALITIES OF THE KRAB - UNDERWATER INSTRUMENT CARRIER

The instrument carrier is fitted with 5 propellers, 2 of which are longitudinally, 2 transversely and 1 vertically orientated. The longitudinally orientated propellers are able to produce forward or astern thrust, the vertical one - up or downward thrust, and the transverse ones - rotative moment and port or starboard thrust. The vehicle motion ability is high due to the applied propellers' configuration and the assumed power distribution between them . Moreover the vertical propeller is included into the vertical motion stabilization system of the vehicle and the transverse propellers into the direction stabilization system of it.

Stabilization of vehicle's immersion depth and its distances from bottom and surface of water

KRAB vehicle is equipped with a computerized system of vertical motion stabilization, used usually in such vehicles. The vehicle motion is controlled by the PID discrete regulator designed as the „ tough" one. This choice was done to account for variability of controlled object's parameters, viz. of its speed, mass, resistance etc. Tough regulators are characterized by very stable work, high steering quality in every situation, and weak dependence on object parameter values.

Operating procedure of the applied regulator is very simple. The switch „hand control - automatic control" is fitted in the operator's control desk. Even if it is set to „automatic control" hand control can be also executed without any trouble, but if the potentiometer is left at „0" position then motion stabilization of the vehicle at its actual depth (i.e. its distance from bottom or water surface) is activated. The next turn of the potentiometer causes transition to hand operation. The following measured values can be used as an input (set) signal:

- depth measured by pressure gauge
- distance from bottom measured by echosounder
- distance from water surface (ditto)

Vehicle course stabilization

KRAB's performance was highly improved by the application of the course stabilization system.

The transverse propellers of the vehicle are used to stabilize its course. Propellers torque is set on the control desk by setting an appropriate voltage signal. An analogue signal of vehicle's course measured by the magnetic compass is sent also to the control console.

The applied propulsion configuration of the vehicle made convenient conditions to use the course stabilization system, with necessary changes introduced to vehicle's design kept at a minimum.

The simplified linear description of the vehicle's motion in horizontal plane was assumed because of the low vehicle's speed and the choice of the tough regulator for which more exact object's motion modelling is not required as a rule.

The course stabilization system parameters were chosen in the same way as in the case of the immersion depth control system. Computer simulation of the system's behaviour under different external disturbances was performed to recognize thoroughly the course control quality of the vehicle.

The investigation of the PID discrete regulator was carried out with propellers' constraint and insensitivity parameters taken into account. This was aimed at checking to what degree a nonlinearity of the propeller characteristics influences performance of the course stabilization system designed with all its elements assumed to follow linear response characteristics.

The investigated system revealed very advantageous performance as it was able to accept very large variations in the controlled object's characteristics, maintaining high steering quality.

UNDERWATER NAVIGATION SYSTEM

KRAB vehicle was equipped with a short-base hydroacoustic navigation system. The system is comprised of a transmitter and a set of three correlative range-finders. Its spatial coordinates are determined by means of the triangulation method and using the distances, measured by the range-finders, from a transponder placed on the bottom or fixed at the vehicle. The transmitter sends an interrogation signal coded by a sequence of impulses. The transponders receive and decode it. After some assumed time-lag needed the reverberation to cease, the transponder which has recognized its own code generates a response signal.

The deck station is provided with a digital range meter which counts signal generators impulses in the time passing between interrogation signal sending and response receiving instants. The counted impulse number is proportional to the measured distance provided sound velocity in water is assumed constant and its propagation linear.

The deck station and transponders are built with the application of 8051micro-computers which carry out all the information processing during the consecutive vision signal sampling.

System's technical specification

• max. range	1000 m
• sub-ranges	10, 20, 30, 50, 100, 200, 500, 1000 m
• number of transponders	4
• electric supply voltage	220V AC/ 24V DC
• interrogation signal (time/frequency)	10 ms/60 Hz
• response signal (time/frequency)	10 ms/57 Hz
• way of co-operation with PC	by the motherboard serial communication controller via RS232 socket
• distance accuracy	1 m
• vizualization methods in rectangular or polar coordinate systems	
• permissible water depth	300 m
• station-transmitters cable length	50 m
• transponders' gabarites :	2 pieces ∅ 65 mm, 400 mm height 2 pieces ∅ 120 mm, 600 mm height
• transponders' material - anodized aluminium	

The system is contained in the POLON type cassette.

MEASURING SOUNDER

The measuring sounder is installed in the KRAB vehicle to collect and send measurement data to a PC type computer, and to switch on 8 vehicle's devices.

The measuring sounder module is a micro-processor-based, measuring-controlling system. It makes possible to carry out measurements of 8 analogue magnitudes (their equivalent electric current or voltage values, depending on configuration) and 8 binary ones. Analogue inputs are of the multiplex type (i.e. one measurement is allowed to be done at a time). A measurment track is seperated from the micro-processor by electroplating. Measurements are carried out on the basis of voltage-to-frequency conversion and inpulse number counting in a time unit. A current loop, seperated by electroplating, provides serial communication with CPU. The software installed in the micro-processor makes it possible to set a demanded input/output operation option. An autonomous operation of the measuring sounder is also available (at the switched-off CPU).

Available software-provided options

- binary output control
- real time clock setting
- input read-out program setting
- buffer memory read-out
- buffer memory erase
- analogue and binary input/output read-out

Device technical specification

• electric voltage supply	8 to 20 V DC
• max. watch-time current demand	60 mA
• max. measurement current demand	300 mA
• number of analogue inputs	8
• seperation from digital system	by electroplating
• multiplex inputs	provided
• available measurement input setting ranges: of voltage inputs: 0 to 1V, 0 to 5V, 0 to 10V of current inputs: 0 to 1 mA, 0 to 10 mA, 0 to 20 mA, 4 to 20 mA	
• number of binary inputs/outputs	8/8
• output type	TTL/OC
• current loop length	150 m
• current loop transmission rate	4,8 kbaud
• nonvolatile memory	24 kB
• calendar and real time clock	provided

WATER-SAMPLE-TAKING DEVICE

It was decided to provide the KRAB optionally with a device for water sampling from different water depths because of a variety of the water physical-chemical parameters, required to be determined but difficult to be predicted during thorough examination of waters, as well as due to vehicle size limitations and connected with it but reduced ability to provide it with an appropriate set of gauges. The water samples can be analysed in a chemical laboratory.

The device is composed of four 500 ml containers, which can be closed automatically from both sides with the use of spring snap fasteners released by electro-magnetic releases. A release control system is placed in the vehicle's pressure vessel. It is controlled from the central control unit via the cable sounder (where its binary outputs are used). Command signal for sample-taking can be generated with the use of an algorithm established in advance taking into account water depth and time instant, or by the operator.

Device technical specification

• water-sample containers	4 x 500 ml
• electric supply voltage	12V DC
• release power demand	10W

VERTICAL ECHO SOUNDERS

The vertical echo sounders may be installed in the KRAB to measure distances of the vehicle from local water bottom and surface. The complete device contains:

- measuring device
- echo sounder converter
- converter's cable

Apart from the above elements the set is fitted also with a digital tester.

The measuring device is the modified Ye-43 yacht echo sounder equipped with a crystal converter. Measuring impulses are released by the computer when it is demanded . Impulse reception, processing and interpretation is performed also by the computer. Measurement results may be also displayed graphically on monitor's screen or used in the vehicle's automatic system of distance stabilization from the bottom or water surface.

The test-control device (tester) serves for calibration and operation correctness control of the measuring device. The tester is placed in a small, portable, weather-proof casing fitted with a cable 1,5 m long and terminated with a suitable connection.

Echo sounder's technical specification

• electric supply voltage	10 to 20V DC
• max. current demand	20 mA
• range of distance measurement	0,7 to 150 m
• allowable ambient temperature	-10 to +40°C
• gabarites	europacard

MAGNETOMETRIC DETECTION SYSTEM

The KRAB may be equipped optionally with a metal objects' detection system, PULSE 10, produced by J.W. Fishers Inc.,USA. The system consists of a sending-receiving coil connected with the control desk through a cable link. The coil generates a high power magnetic impulse with constant parameters. Having generated the impulse the coil starts to operate as a receiving antenna. The magnetic impulse, when hitting a metal object, generates in it electric current that causes magnetic field deformation. The phenomenon is registered by the coil, then amplified and displayed at the control desk. Parameters of such a signal depend on object's size, its distance from the coil and of an environmental material in which the object is sited (sand, mud, rock waste).

The main advantage of the system is that in spite of its high detection sensitivity it does not detect even materials of high metal concetration; this is especially suitable for sea bed penetration where such deposites can be met in big quantities. The system ignores such clusters and detects solid metal objects only.

Magnetometer's technical specification

• penetration range	3,3 m height x 5,1 m breadth
• operation depth	up to 90 m
• operation speed	1 to 3 knots
• electric supply voltage	24V DC
• electric power demand	7W
• measuring coil diameter	18"
• detection ability	metal objects
• detection indication	indicator, loudspeaker/ headphones

• mass of coil/150m cable/central unit: 5kg/15kg/2,5 kg

MEASURING HEAD

The KRAB may be fitted with a head for measuring water physical-chemical parameters.

The measuring head is an autonomous device designed to carry out programs of measurements and registration of their results. The measuring sounder module,described earlier, is placed in the head.

Six transducers connected with inputs of the sounder are provided to measure the following parameters:

- water temperature
- water conductivity
- solubilized oxygen content in water
- hydrogen ion concentration (pH) in water
- water depth (pressure)
- battery voltage

Any measuring transducer of a standard output compatible with that given in the system technical specification can be connected with the measuring head (e.g. ionosonde transducers, transducers of oil product content measuring sounders). The measuring sounder module is connected with the computer's serial connection through current loop interface. Operation of the measuring head is controlled by a PC resident software.

The software makes the following operation possible:

- real time clock setting
- output reading-out program setting (e.g. according to an assumed depth or time)
- measurement execution - on request
- buffer memory reading-out
- buffer memory erasing
- analogue inputs reading-out

Other technical data (of the measuring sounder itself) have been given earlier.

Temperature transducer

Temperature may be an important parameter in diving works as physical-chemical properties of matter (its state, viscosity etc) depend on its degree of heating.

Thermometric resistors were applied in the temperature measuring system. The transducer comprises an electronic bridge system which converts the resistance variable value (of the thermometric resistor) into the electric current signal of a unified value. The unbalanced-bridge voltage is put into a multistage amplifier which controls range of output current. The installed temperature transducer is of N 5360 type which cooperates with Pt100 thermometric gauge. This transducer is a part of AQUAMER 551 Water Quality Monitor produced by TEL-EKO S.A.

To apply the N 5360 transducer gabarites of its printed-circuit board were changed and electric supply systems separated. The temperature transducer output was connected with the measuring sounder module in the measuring head.

Temperature transducer's technical specification

• temperature measuring range	-5 to + 45°C
• measurement resolution	0,2°C
• measurement accuracy	0,2°C

Oxygen content measuring system

Oxygen content is one of the basic water quality indices. In waters polluted by organic substances the solubilized oxygen is consumed in biochemical decay processes and its content drops. At 30÷40% oxygen saturation level biocenose disturbances appear. Water corrosive agressiveness varies with oxygen content in it, especially in the presence of carbon dioxide.

In the measuring head an oxygen measuring transducer of N 5260 type is applied which is a part of the AQUAMER 551 Water Quality Monitor. It cooperates with an electrochemical measuring gauge.

The electrochemical method consists in measuring electric current which is generated in oxygen reduction process which proceeds on the gauge, forming a galvanic cell electrode. The measured electric current is proportional to the concentration of the oxygen solubilized in water.

The gauges are coated by teflon membranes. Concentrated KCl solution was used to fill the void space between electrodes and the membrane. When the gauge is immersed in water the oxygen solubilized in it penetrates the membrane and is reduced on the cathode. Oxygen diffusion through the membrane depends on speed of the water surrounding the gauge. Measurement of the solubilized oxygen content is also dependent on temperature, therefore a temperature gauge is installed close to the oxygen content measuring gauge to compensate influence of temperature on measurement results.

Oxygen content measuring system's technical specification

• oxygen content measuring range	0,5/10/20 mg/l
• measurement accuracy	± 2%
• temperature compensation	inherent within 0 to 40°C
• output signal	0 to 5 mA

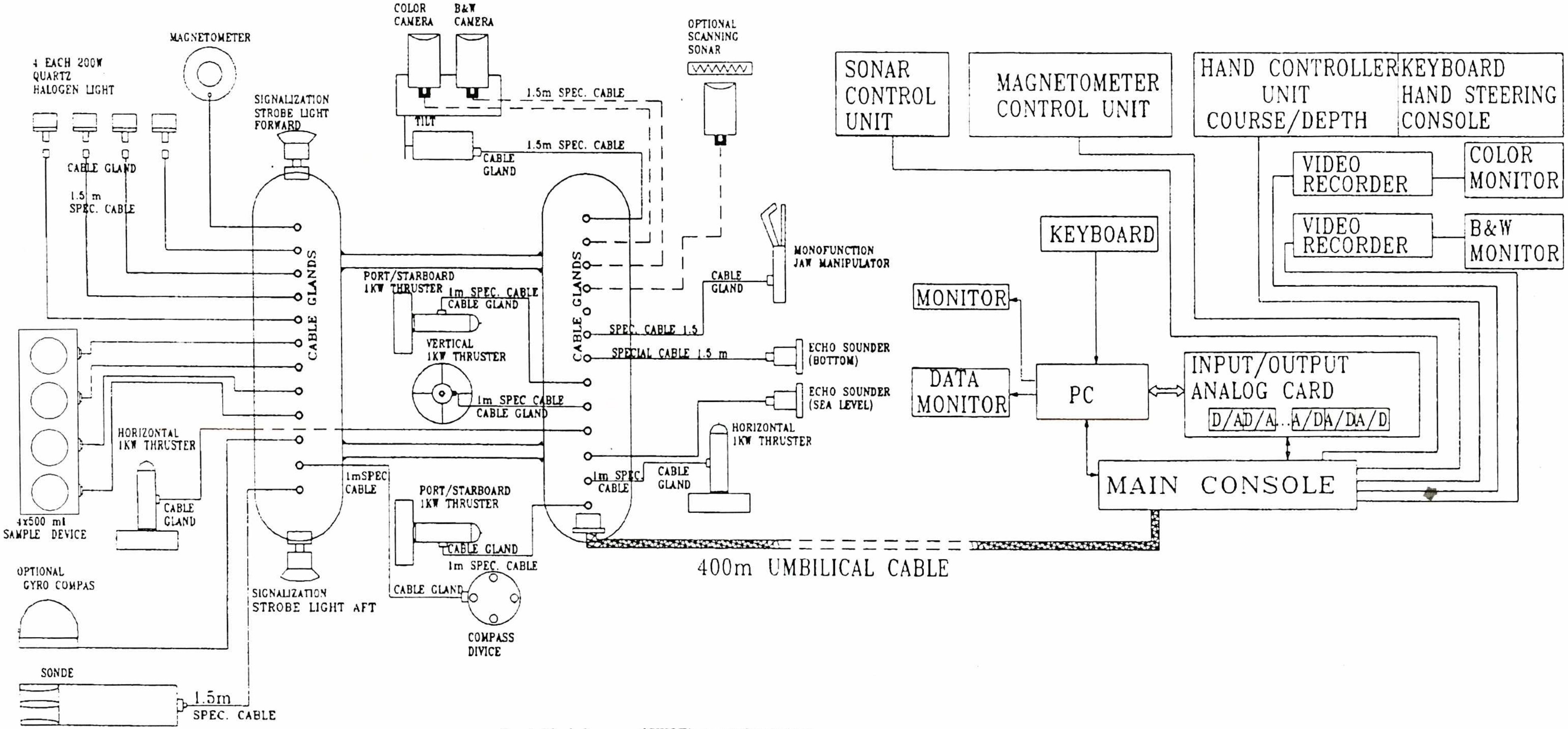

Fig. 1. Block diagram of SWOT's measuring systems
(a new version supplied additionally with sonar and strobe lights)

Water conductivity transducer

Water specific conductivity increases nearly proportionally to content of the salts solubilized in it; but conductivity of the water which contains different salts is equal to the sum of conductivities of the component solutions. Conductivity of water increases if its temperature increases.

A conductometric transducer of N5760 type together with four-electrode gauge, produced by TEL-EKO S.A.,was adapted to measure conductivity of water.

The four-electrode measurement method consists in regulation of electric current generated between the voltage electrodes. Voltage drop on a standard resistor, included in the current circuit being regulated, is proportional to the conductivity of water. A temperature compensation system was provided as temperature highly influences water specific resistance.

Water conductivity transducer's technical specification

- measuring range — 0 to 100 mS/cm
- measurement accuracy — 0,15 mS/cm
- measurement resolution — 0,4 mS/cm

Pressure transducer

An electronic pressure transducer coupled with a strain gauge is one of the devices installed to measure water depth. A strain gauge signal measured by an extensometric bridge, after being amplified in a measurement amplifier is sent to a measuring sounder. After transformation into digital form it is sent to the PC computer through the cable-line. Its scaled value is displayed on the computer monitor's screen or used to stabilize vehicle's immersion depth. The signal can be also used for other purposes too, a. o. steering of measuring or sample-taking operations, etc. Gauges of different measuring range can be installed in accordance with an expected working depth.

Pressure transducer's technical specification

of the transducer:

- electric supply voltage — 10V
- measuring error — <0,2% of range
- output signal — 0 to 20 mA
- gabarites — 160 x 75 x 75 mm
- mass — 1,3 kg

of the gauge:

- measuring ranges — 0,1; 0,5; 1; 2,5 MPa
- made of anodized PA7 aluminium alloy

Hydrogen ion concentration (pH) transducer

Hydrogen ion concetration is one of the basic properties of water. To measure it a galvanic cell with pH-sensitive electrode is provided for installation in the measuring head. Electro-motive force of the cell is proportional to pH value. A temperature gauge is provided additionally to ensure inherent temperature compensation of measurements. Potential of the measuring cell, when applied to a high-resistance current amplifier, is amplified and transduced into a standard, current output signal which is linearly proportional to the measured parameter's value.

In the vehicle in question a slightly adapted measuring transducer of N 5131 type, produced by TEL-EKO S.A., may be installed.

pH-transducer's technical specification

- electric supply voltage — 12V DC
- output signal — 0 to 5 mA
- pH measuring range — 4 to 14
- pH measurement resolution — 0,04
- accuracy class — 0,5
- temperature compensation (with application of Pt100 gauge) -10 to +80°C

Voltage control transducer

An electronic voltage transducer was installed in the measuring head to control electric supply voltage and alarm in the case of an excessive battery voltage drop.

Voltage control transducer's technical specification

- measuring range — 5 to 18V DC
- measurement resolution — 0,05V

IMAGE RECORDING AND PROCESSING

Two video-recording cameras, the colour and black-white one, were installed in the KRAB vehicle. An image sent through the cable-line can be displayed on monitor screens and recorded simultaneously by a video recorder.

An image field taken by the cameras is lighted by four halogen projectors with possible stepless adjustment of light intensity. Incidence angles of light from the projectors are adjustable too. An image obtainable from the cameras is thus fully satisfying.

Two following video recorders are used for image recording:

- a medium-class, two-head video recorder (produced by Panasonic)
- a high-class, digital, four-head video recorder (produced by Sony)

The four-head video recorder provides very high image stability which makes it possible to take good quality shots by applying the „frame-by-frame" mode.

An image taken by the cameras can be observed on two Sony colour monitors: 25" or 12", the latter is a special one, insensitive to voltage variability in a very wide range.

The images as well as separate, tape recorded shots can be stored and processed by the computer. Image processing is meant here as ability of image blowing-up and image sharpness improving. Image printing is also possible.

CONCLUDING REMARKS

Growing industrial development and higher and higher demands of environmental protection, especially that of sea and inland water resources, make undertaking of underwater operations more and more necessary and frequent. Application of divers' operations at higher depths are limited by growing financial expenditures, man-hostile enviroment and growing need to improve personell working conditions.

Some operational abilities of unmanned underwater vehicles, examplified by those of the SWOT vehicle in this paper, indicate that the traditional methods of arranging underwater operations can be improved substantially. It seems that wider application of unmanned, remotely controlled underwater vehicles to support and even substitute divers should be recommended as advantageous and necessary in some tasks at least.

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