Monitoring of the submarine atmosphere composition

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Abstract

The paper reports research on control and maintenance systems of the submarine atmosphere. The results obtained during pressure and temperature tests of the gas analyser sensors will be discussed.

1 Introduction

At present, implementation of the new monitoring system of breathing gas with elaboration of the computer data acquisition and analysis data system is the standard not only on the submarines. Maintenance of the proper submarine atmosphere composition is essential for the mission and the crew safety. The most important parameters of submersible atmosphere should be continuously monitored. Besides assurance of life support in the confined space, it enables automatic work of the life support systems and evaluation of naval facilities hazards. The systems that have been used up to now in the Polish Navy were not suitable to perform the continuous and simultaneous local measurements at different measuring points. The system was based on centrally located measuring position (stand), where gas suction was realised with the aid of the pipe system. As the gas analysers became less expensive at the present time, therefore it is possible to install the measuring facilities on the whole submersible. The local measuring system has the advantage that measurements are achieved at the stand where they are necessary. The only analytic signals are transmitted to central
Computer. Computer data acquisition system enables to analyse the situation. Obviously, data transmission is considerably faster than sampling of gas but modernisation of the measuring system does not have to be directed towards elimination of the existing measuring pipes system. In this case it is possible to use the mixed system. Implementation of the new gas analysers requires fitting the special procedure. The number of laboratory tests that enables beginning of the implementation research phase may be different and may be reduced if the gas analyser has been earlier tested and now was only modified or it has been certified by acknowledged laboratory. In case of the new gas analyser, the number of laboratory tests must be sufficient to reach the proper confidence level. Ministry of Defence – Armament Policy Department (APD) takes decision on laboratory research phase termination and the beginning of the implementation research phase. The implementation research phase relies on the observation of the measuring system in the real operating conditions. During the implementation research, gas analysers are only tested. In order to control submarine atmosphere, the other gas analysers set is used. The implementation stage may be stopped at any moment, when some problems occur. If there are no problems during implementation phase, APD takes the decision on implementation of gas analysers to the usage. However, research is not finished yet. During normal operational use, the results obtained from the gas analysers are periodically analysed by the special activities from Polish Navy Headquarter – Search and Rescue Department (SRD). If some troubles with the use of the system occur then the implementation phase must be repeated. When it is decided to take out of use or modernise the measuring system, the whole research process starts from the beginning.

2 Laboratory research

Laboratory research includes selection of gas analysers (based on the technical data) fulfilling the technical requirements of The Polish Navy and laboratory research aimed at checking the technical requirements. Introductory technical requirements for the gas analysers are presented in Table 1. Gas analysers should fulfil the technical requirements for the facilities assembled on the navigation bridges and marine power plant. Hence, in respect of work site environmental properties all mentioned above facilities should fulfil the requirements of the acknowledged marine classification societies. Time between servicing (maintenance service) should not be less than six months. All facilities must keep the working parameters at special environmental conditions:
- the pressure: 80-160 kPa (during 3 hours 300 kPa)
- tilts: 3 min-30°, 9 s-45°
- resistance for disturbances caused by chemical pollution of the working environment, specification of contaminants like: oxygen (19 to 25 %), hydrogen (< 4 %), carbon dioxide (< 1.5 %), carbon monoxide (< 15 mg/m³), hydrocarbons (< 100 mg/m³), antimony hydride (< 0.15 mg/m³), Freon-12 (< 500 mg/m³), sulphur dioxide (< 0.4 mg/m³),
Initially, the different types of gas analysers that originated from various manufacturers were investigated. Experiments were limited to analysis of the technical parameters determined by the manufacturer and to the basic metrology features of gas analysers that had been selected and purchased. In the next stage, the selected manufacturers were asked to submit gas analysers for classification research (free of charge) in special conditions (low and high temperature and increased pressure). The manufacturers, who submitted gas analysers for research or declared the will of later participation in such research at the manufacturers’ costs took part in the call for tender. The tender concerned the delivery of gas analysers set for the real operation conditions. Drägerwerk AG Lübeck has won call for tender because this manufacturer presented the coherent set of gas analysers that fulfilled technical requirements. Gas analysers were equipped with the universal heads enabling elaboration of the measurement results and its transmission. Moreover, the manufacturer presented very advantageous quotation and declared technical assistance during research. The results of some investigations will be presented further. Particularly, special emphasis will be put on situations where the tests results revealed exceed of permissible parameters determined by the manufacturer or resulting from assumptions that have been made Table 1. Research on gas analysers was performed at the computer test stand that had been built for measurements of basic metrology features, Figure 1. The control desk of the research stand was equipped with computer controlled rapid electromagnetic valves and flow regulators that were used to control the standard gases’ flow. The system of the signal and controllable transducers was placed inside the electric control box. The test stand was equipped with the computer controlled climatic chamber, as
well. The following parameters were investigated: discrimination threshold, dead
time, reaction and response time, reproducibility of measurement, reproducibility
of scaling and adjusting (calibration repeatability), reversibility of indications
(hysteresis), effect of the high and low temperature, long-term deviation, drift,
reaction on some contaminants of the monitored atmosphere (cross sensitivity)
influence of other physical quantities, frequency of metrology certification, etc.
Experiments were also performed under increased pressure in the hyperbaric
diving complex and during simulation of the system operation at manned
submersible Figures 2.3.

Figure 1: Computer test stand for research of selected metrology features of gas
analysers, general view.
1 - the climatic chamber for the environmental measurements
2 - the control-measuring desk
3 - monitor
4 - control computer
5 - power pack with battery support
6 - the electric control box equipped with measuring transducers.

The following gas analysers were tested: Dräger Sensor O₂LS, Dräger Sensor
O₂LS, Dräger Polytron IR CO₂. Gas analysers were tested with the respect to
their basic metrology features i.e.: long-term reading out of the stable parameters
of the reference atmosphere, temperature tests, reaction time, measuring error at
the use of 5÷7 sets of standard samples, drift, discrimination threshold, dead
time, hysteresis. repeatability of the measurements, correctness of calibration and
adjustment procedures, effect of pressure and other parameters, resistance for
disturbances resulting from contaminants (metabolic gases, technical pollutants)
that may occur in atmosphere of submersible. Some of above mentioned
parameters were investigated in the preliminary phase.
Figure 2: Experimental diving complex DGKN-120 at Diving Gear and Underwater Work Technology Department, The Naval Academy of Gdynia

Figure 3: Investigated sensors placed inside the decompression chamber.

2.1. The preliminary test

The test was aimed at measurements of sensors’ stability indications and determination of the effect of pressure and temperature on the results. The results
were compared with the parameters given by the manufacturer. In order to determine sensors’ stability indications, the test of duration 150 hours was performed. During the test, where the sampling time was 1 min, the following parameters were continuously measured:
- atmospheric pressure $p$, with the aid of the Honeywell sensor of the type PPT-
  maximal limiting error $\pm 0.2 \text{kPa}$,
- ambient temperature $t \, ^{\circ}\text{C}$ with the aid of the Vaisala sensor of the type
  SOU/SOY-
  maximal limiting error $\pm 0.8 ^{\circ}\text{C}$.
In order to design the measuring system, the investigated sensors were applied. The measuring set was placed inside the tank of outside diameter $d_e=2000 \text{ mm}$ and the length $L=3751 \text{ mm}$. By that means, the measuring system was protected against atmosphere motion and instantaneous fluctuation of temperature, humidity etc.

2.2 The temperature tests

The first kind of tests was aimed at determining the effect of temperature variations on indications of investigated gas analyser. In order to determine the effect of temperature on the gas analyser indications, gas analyser was placed inside the environmental chamber, which is the part of computer stand presented in Figure 1. The climatic chamber enables regulation of the temperature within temperature range $15 + + 40 ^{\circ}\text{C}$ (temperature measurement with the aid of temperature sensor of the type Vaisala 50U/50Y, maximal limiting error $\pm 0.8 ^{\circ}\text{C}$) and measurement of relative humidity within the humidity range 10 to 90 % (measurement with the aid of humidity sensor of the type Vaisala Humiter 50U/50Y, maximal relative error $\pm 1\%\text{rh}$). Each of sensors was investigated separately, test duration 7 hours. The aim of the other tests was to determine the effect of the slow temperature changes on the indications of the investigated gas analyser. The tests were performed with the use of the stand that has been described earlier. Investigated gas analysers were placed inside the climatic chamber, the mean temperature inside the chamber was approximately maintained at the level of $34 ^{\circ}\text{C}$. Duration of tests over 100 hours.

2.3 The pressure tests

The test was aimed at determination of the pressure effect on gas analyser indications. Gas analysers were placed inside the hyperbaric complex presented in Figure 2. Series of expositions of duration approximately 2 hours for the depths $10\text{mH}_2\text{O}$, $30\text{mH}_2\text{O}$ and $60\text{mH}_2\text{O}$ were performed. During experiments the pressure (pressure sensor of the type Rosemount Alphaline Pressure Transmitter (maximal absolute error $\pm 0.3 \text{m H}_2\text{O}$), temperature and humidity (humidity sensor of the type Vaisala 50U/50Y – maximum limiting error $\pm 0.8 ^{\circ}\text{C}$) were measured.
3 The results

3.1 The results of the preliminary tests

During test, gas analysers of the type DrägerSensorO₂ and DrägerSensorO₂-LS have shown a slight exceeding of the limiting value of systematic error determined by the manufacturer. Gas analyser of the type Dräger Polytron IR CO₂ has not shown such deviations.

3.2 The results of the temperature tests

The tests have shown that indications of investigated oxygen sensors (oxygen percentage) are temperature dependent. In case of oxygen sensors the decrease of the temperature influenced sensors' indications. Indications of the DrägerSensorO₂-LS not exactly exceeded the permissible measuring error determined by the manufacturer. Only in case of humidity variations the permissible measuring errors were negligibly exceeded. In case of DrägerSensorO₂ the permissible measuring error was negligibly exceeded during the temperature Figure 4, whereas indications of Dräger Polytron IR sensor didn’t exceed the permissible measuring errors. During faster temperature variations, for example from 15°C to 30°C within the time range 15÷40 min (observations up to 5 hours after change of temperature), the permissible measuring errors were not exceeded. The test has shown that indications of the DrägerSensorO₂ negligibly exceeded the permissible measuring errors during the temperature changes Figure 4. In case of the other investigated sensors the effect of the temperature and humidity changes on exceeding of the permissible limits of errors determined by the manufacturer was not observed. Indications of the DrägerSensorO₂ have not shown exceeding of the permissible errors with the humidity changes. The tests performed within the temperature range 5÷7°C during approximately 50 hours have shown that indications of the DrägerSensorO₂-LS negligibly exceeded the permissible measuring error, while the indications of the other sensors were correct.

3.3 The results of the pressure tests

Indications of all investigated sensors except Dräger Sensor O₂-LS are dependent upon the variable partial pressure of the measured quantities. Examples of the investigated sensors' indications during the pressure increase (red line) corresponding to the depth of 60 m H₂O are presented in Figures 5, 6, 7. Functioning of the DrägerSensorO₂ is typical for the membrane sensors, Figure 5. The principle of operation relies on reaction on partial pressure of the measured gas concentration. Dräger Sensor O₂-LS is equipped with the light-gauge channel that is penetrated by the gas of concern. For this reason it doesn’t react on the oxygen partial pressure but on the percentage of oxygen. Hence, its indications are not dependent upon the external pressure except disturbances that occur at the beginning of the pressure increase. It leads to increase of the measuring error Figure 6.
Figure 4: The relationship between the oxygen percentage and the temperature $c(O_2) = f(t)$ for Dräger Sensor $O_2$

Indications of the Dräger Polytron IR CO$_2$ show the significant deviations from the appropriate contents of carbon dioxide in the investigated atmosphere, Figure 7. It is typical behaviour. In infrared technique, the change of the component partial pressure or change of the total sample pressure can intensify or weaken the intensity of the corresponding band without maintaining the proportionality to the changes in gas concentration. Increase of pressure may lead to so-called pressure band transfer. It causes poor resolution and false contour of the absorption band and finally the incorrect results. Further research will be focused on the problem mentioned above. The results of the residue experiments confirmed the parameters given out by the manufacturer. Later, the Dräger Sensor $O_2$-LS was withdrawn from the use because the hydrogen contents in the investigated atmosphere effected on the gas analyser accuracy.
Figure 5: Indications of the Dräger Sensor O₂ during increase of the pressure.

Figure 6: Indications of the investigated sensor of the type Dräger Sensor O₂-LS during increase of the pressure.
4 Conclusions

Based on the laboratory experimental results, the following gas analysers have been admitted to further research:

- DrägerSensorO2
- Dräger Polytron IR CO₂
- DrägerSensor H₂

In order to prepare an experimental measuring system, gas analysers that have been tested were employed. Measuring system is additionally equipped with Adwantech (ADAM 4013, 4520, 4521, 4017) transducers, self made transducers and standard Adwantech computer of the type PPC-120E. In order to perform further experiments in real operating conditions, the system will be assembled at KILO class submarine.

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