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RESCUE DEVICE CONCEPT FOR THE ARGO PROFILING FLOAT

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ABSTRACT

The material presents the development work carried out by the ARGO-Poland scientific consortium related to the design of rescue systems for ARGO profiling floats used for in situ exploration of the world oceans. The article describes the principle of operation of the Argo float and the theoretical basis of the rescue system and six alternative design solutions for such a system.

Keywords: oceanology, underwater technology, unmanned underwater vehicles, mechanical engineering, automation and robotics.

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INTRODUCTION

For more than two decades, the world's ocean system has been monitored using a fleet of Argo profiling floats [1,2,3,4]. At present, there are approximately 4,000 floats in operation (Fig. 1).

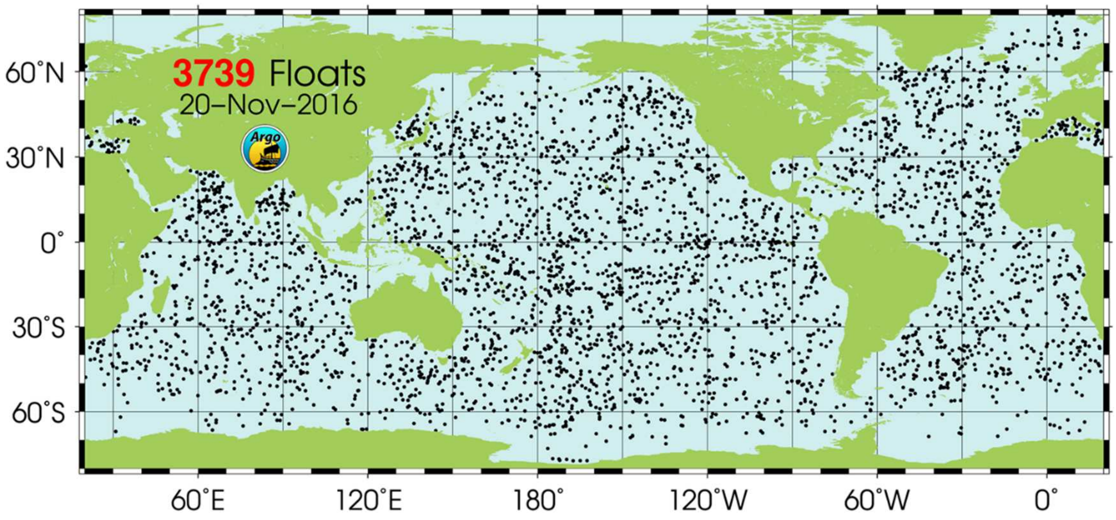

Fig. 1 Positions of Argo profiling floats in use as at 20.11.2016 [5]

The Argo float (Fig. 2) is a measuring device designed to collect physical data of the marine environment such as salinity, temperature, depth, and optionally the oxygen content of the water. Its maximum operational depth is 2000 m [6]. Measurements of the parameters above are made in so-called measurement cycles, i.e. during a single immersion and ascent of the float to the surface. During a single cycle, measurements are made during immersion, drifting in the depths, and during ascent. A single cycle (Fig. 3) consists of the following steps [6]:

- immersion – a measurement of the immersion profile to a set depth is taken;
- drift in the water – a measurement of the drift profile at a preset depth (usually 1000 to 2000 m) is made;
- immersion at the depth from which the measurement of the ascent profile will start;
- measurement at the depth from which the ascent profile measurement will start;
- ascent – a measurement of the ascent profile is taken. In the final phase of ascent, measurements are taken "in the air" of the surface layer;
- GPS position update and satellite transmission of the float's technical data and measurement results.

The float power system allows to perform up to 300 cycles during a single mission. If the float is reused during consecutive missions, the number of cycles during a mission should not exceed 300 (this depends primarily on the type of batteries installed, the amount of measurement data collected and transmitted).

The user has the possibility of programming two groups of cycles during a single mission performed consecutively. For each group, the user sets the duration of a single cycle, the drift depth, and the ascent initiation depth. Furthermore, depending on the conditions in the mission area, the user can define how the buoy will behave depending on the situation:

- if the bottom is encountered during a dive, it is possible to define a change in the drift depth of the buoy, or to leave the buoy on the bottom for the duration of the current cycle (Fig. 4);
- if ice is detected on the surface during ascent, it is possible to abort the cycle (i.e. ascent) and proceed to the next cycle without the ascent stage and data transmission. Data transmission will occur during subsequent cycles where no surface ice threat is present. (Fig. 5).

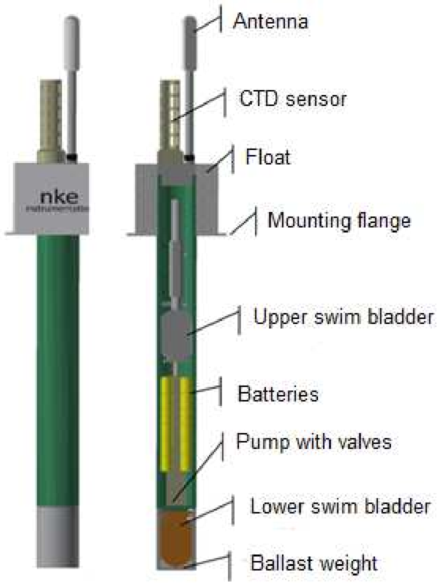

Fig. 2 Argo profiling float based on [6].

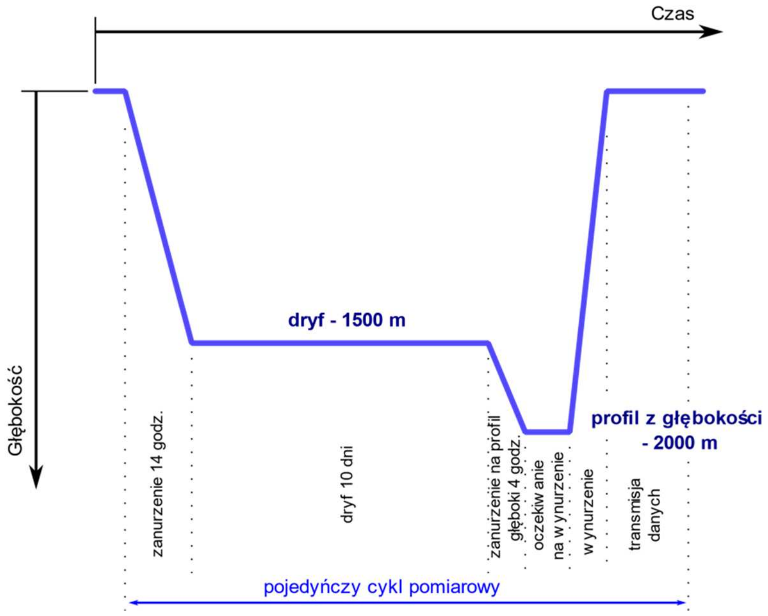

Fig. 3 Single measurement cycle of the Argo float, based on [6].

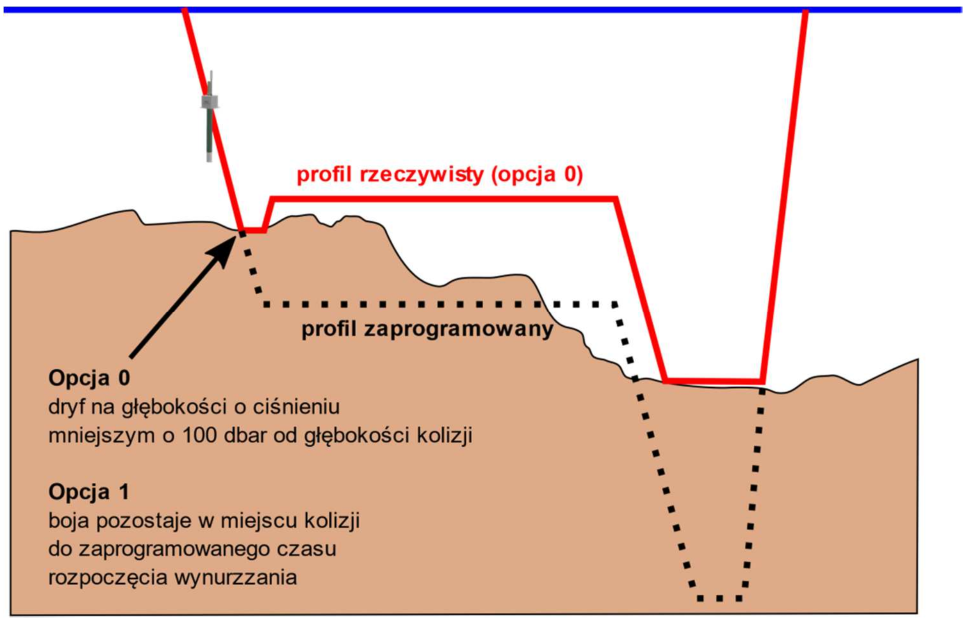

Fig. 4 Variants for the continuation of the float cycle when the bottom is encountered during immersion, based on [6].

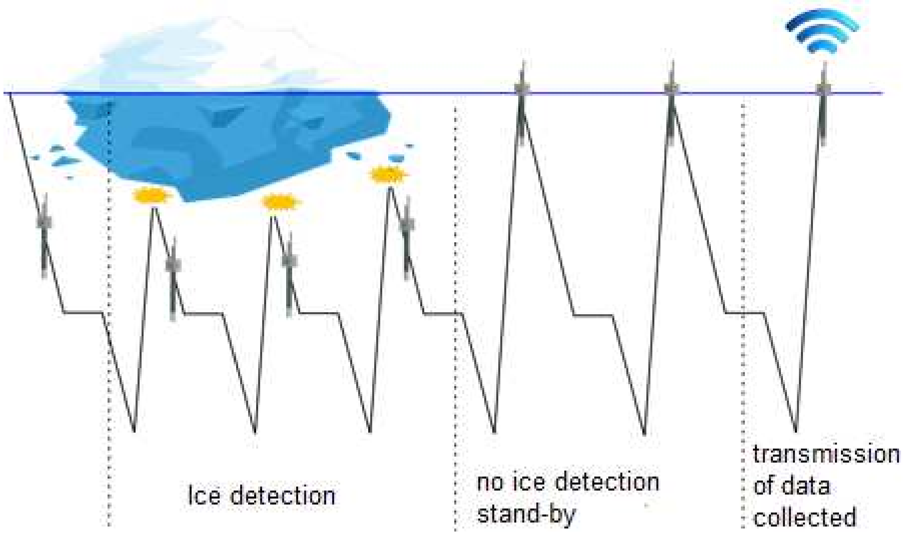

Fig. 5 Transmission of measurement data when ice is detected on the surface, based on [6].

The subject under consideration is the development of a rescue device for the Argo float, which is to enable the float to surface automatically from the water's depths and initiate the transmission of an alarm signal. The rescue of the float is to be triggered when the appropriate combination of time and depth parameter limits for the various stages of the mission are exceeded. In addition, once the float has been brought to the surface, the device should be capable of initiating the transmission of an alarm signal to an external satellite communication device. Moreover, the rescue system for the ARGO float should meet the following tactical and technical conditions:

- power supply independent of the Argo float;
- neutral buoyancy at rest;
- the device is to ensure positive buoyancy of the Argo float in the event of activation of the rescue system;
- the device is to ensure that the Argo float can be brought to the surface regardless of the position of the float on the bottom;
- compact design;
- the device is to ensure easy integration with various types of Argo floats (different diameters);
- resistance to low-temperature seawater operation (below -0. C);
- maximum operating depth of 300 m water column.

The main requirement for the design is the postulated ability to bring the float to the surface in an emergency, regardless of its position on the bottom. In this context, it should be emphasised that an emergency is understood to be any deviation from the designed immersion profile which is manifested by the float not reaching the surface. This is only possible if the float is provided with an additional buoyancy reserve, which is initiated once the emergency situation has been established. The way a body immersed in a liquid behaves (what buoyancy it has) is the result of a function of the difference between its gravity and buoyant force:

$$F_g > F_w \rightarrow \textit{body sinks}$$

$$F_g = F_w \rightarrow \textit{body has neutral buoyancy} \qquad 1)$$

$$F_g < F_w \rightarrow \textit{body has positivie buoyancy}$$

From which it follows that the change in buoyancy of the body will depend on any change in the ratio between its mass and volume (Fig. 6)

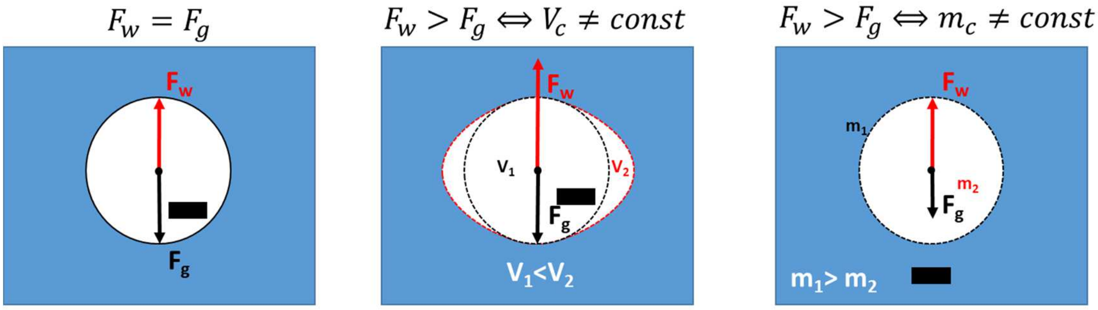

Fig. 6 Change in body buoyancy due to changes in volume or mass [7].

For the above reasons, the further consideration of the concept of a rescue system for the ARGO float took into account two ways of changing buoyancy in an emergency situation: by changing its volume and by changing its mass - differing in their design approach to the issue under consideration. Following the above approach, six initial design variants of the rescue device were developed, four related to changing the volume of the float, and two to changing its weight [7]:

1. Design variants for changing buoyancy by altering the volume of the float:

- Variant 1: volume augmentation by means of sliding plungers,
- Variant 2: volume augmentation by means of filling a buoyancy bag,
- Variant 3: volume augmentation by pumping water between tanks,
- Variant 4: volume augmentation by means of filling the flexible hose.

2. Design variants for changing buoyancy by altering mass:

- Variant 5: change in mass by discarding concrete ballast,
- Variant 6: weight change through discarding stainless steel ballast.

DESIGN VARIANTS OF THE ARGO FLOAT RESCUE DEVICE

VARIANT 1 VOLUME AUGMENTATION WITH SLIDING PISTONS

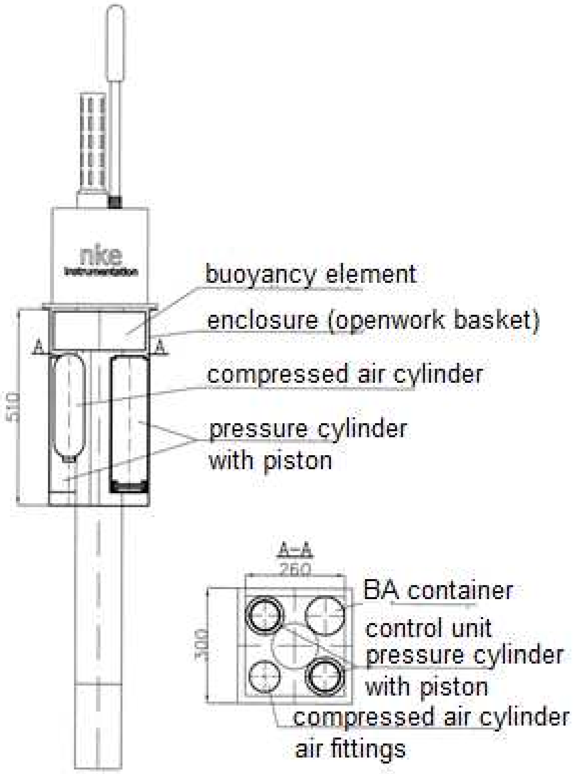

Fig. 7 Proposed technical solution for variant 1

The technical solution plan for variant 1 is shown in Figure 7.

The components in this version of the design include:

- control and power module with a BA unit in a container,
- cylinder with piston: dwc = 94 mm; lc = 360 mm; Vc = 2.5 dm3 – pcs. 2,
- compressed air storage cylinder: pb = 20 MPa, Vb = 1.0 dm3,
- pressure regulator: 20/6 MPa, dn = 3 mm,
- electrically operated shut-off valve,
- relief valve,
- piping and other necessary fittings,
- casing in the form of an openwork basket slid on the ARGO float from the bottom,
- buoyancy elements to counterbalance the weight of the rescue device in the free spaces of the openwork basket.

The base component consists of two vertical cylinders open at the top and flooded with water in the underwater position. At the bottom of the cylinders there are pistons. When pressurised with compressed air under the pistons, they will start to move upwards and push the water out of the cylinders. This increases the underwater volume of the float and the buoyancy force exerted on it. Compressed air is supplied from a storage cylinder via a regulator and valve, which is actuated from the system control module. A relief valve is located on the feed line to maintain a constant pressure difference between the water tone and the inside of the cylinders during ascent. The cylinders do not need to be resistant to the pressures resulting from the depth of immersion.

VARIANT 2 VOLUME AUGMENTATION BY MEANS OF FILLING A BUOYANCY BAG

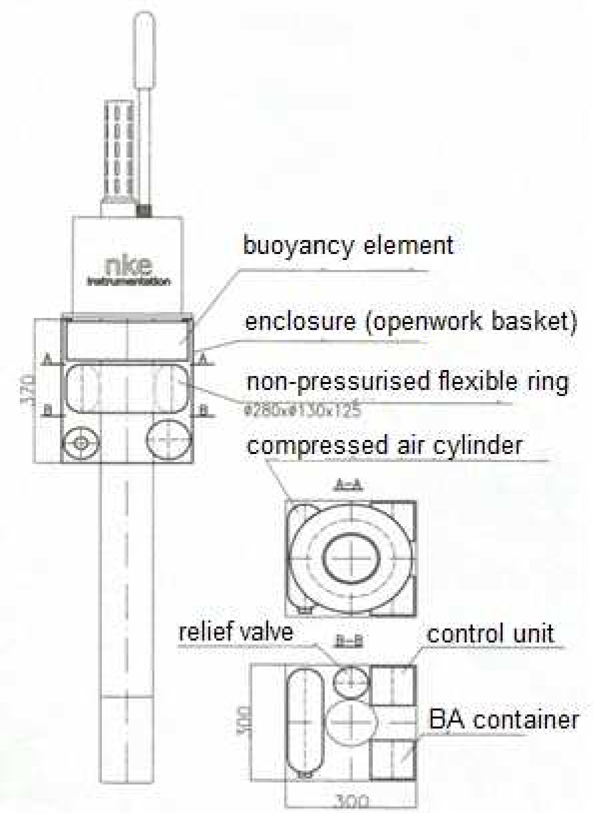

Fig. 8 Proposed technical solution for variant 2.

The technical solution plan for variant 2 is shown in Fig. 7.

The components in this version of the design include:

- control module in a container,
- rechargeable power batteries in a container,
- flexible ring-shaped bag with dimensions: dz = 280 mm; dw = 130 mm; h = 125 mm; V ≈ 5.25 dm3,
- compressed air storage cylinder: pb = 20 MPa, Vb = 1.25 dm3,
- pressure regulator: 20/6 MPa, dn = 3 mm,
- electrically operated shut-off valve,
- relief valve,
- piping and other necessary fittings,
- unit casing in the form of an openwork basket slid onto the ARGO float from below,
- buoyancy elements to counterbalance the weight of the rescue device in the free spaces of the openwork basket.

In this variant, the core element is a flexible bag which, when filled, is ring-shaped. It is placed in the water depth in a casing that is adapted to its shape, which protects the bag from mechanical damage. When compressed air is injected into the bag, it begins to fill to the shape of the casing and increases its volume and the buoyant force of the float. Compressed air is supplied from a storage cylinder via a regulator and valve, which is actuated from the system control module. A relief valve is located on the feed line to maintain a constant pressure difference between the water tone and the inside of the bag during ascent. Subsequently, the bag does not need to be resistant to pressure variations due to changes in depth of immersion.

VARIANT 3 VOLUME AUGMENTATION BY WATER CIRCULATION

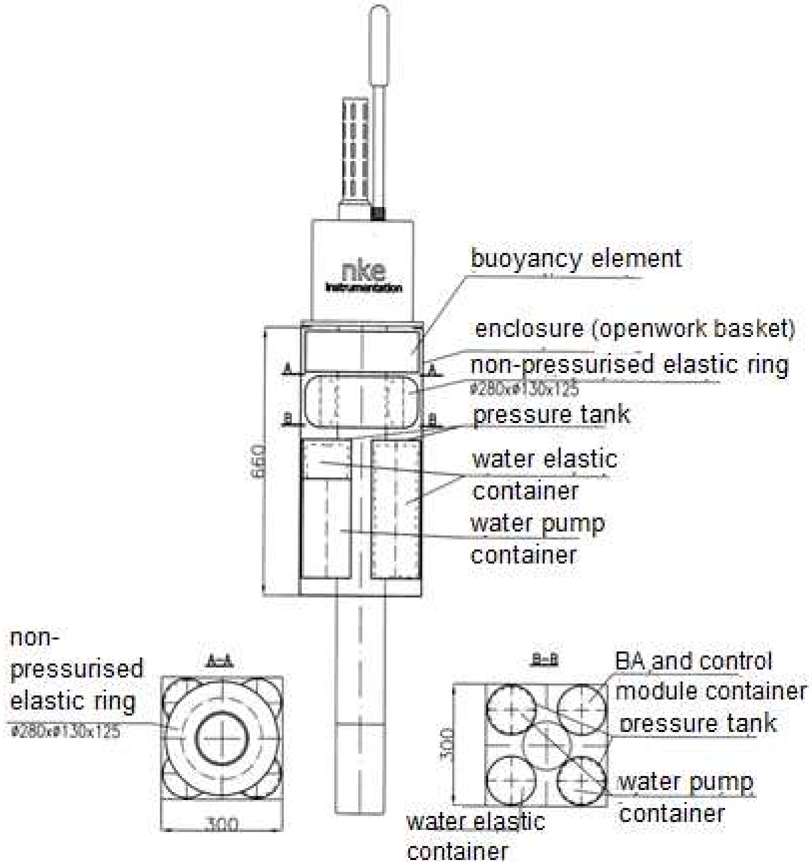

Fig. 9 Technical solution proposed for variant 3.
dla wariantu 3.

The technical solution plan for variant 3 is shown in Figure 9.

The components in this version of the design include:

- control module and rechargeable batteries for the power supply in a container,
- flexible ring-shaped bag with dimensions: dz = 280 mm; dw = 130 mm; hw = 125 mm; Vw ≈ 5.25 dm3,
- pressure vessel containing a flexible bag with a volume V ≈ 2.64 dm3 filled with water – pcs. 2,
- water pump with electric drive in the container,
- piping and other necessary water fittings,
- enclosure in the form of an openwork basket sliding on the ARGO float slid from the bottom,
- buoyancy elements to counterbalance the weight of the rescue device in the free spaces of the openwork basket.

In this design variant, the main components are two cylindrical, flexible bags filled with water located in pressure vessels and one empty bag which, when filled, takes the shape of a ring and is placed in the water depth in a casing adapted to its shape, thus protecting the bag from mechanical damage. When activated from the system control module, the water pump is used to pump water from the bags in the tanks to the bag in the water depth, which begins to fill to the shape of the casing and increases its volume and the buoyant force of the float. The installation does not require a relief valve as the medium in the installation is incompressible water. The bags are not required to withstand the pressures resulting from the depth of immersion.

VARIANT 4 OF VOLUME AUGMENTATION WITH FLEXIBLE HOSE FILLING

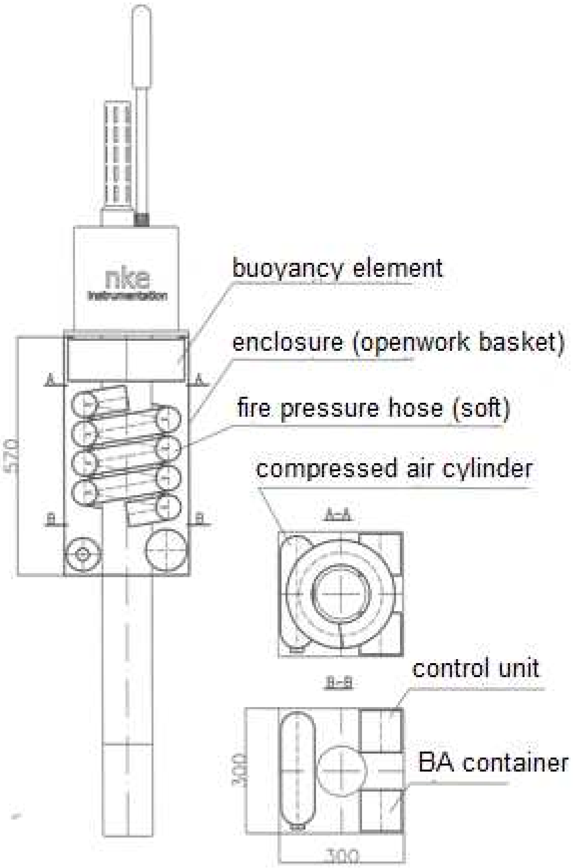

Fig. 10 Proposed technical solution for variant 4.

The technical solution plan for variant 4 is shown in Fig. 10.

The components in this version of the design include:

- control module and electrically controlled inlet valve in a container,
- rechargeable batteries for power supply in the container,
- flexible hose: dw = 52 mm; l = 2500 mm, Vw ≈ 5.0 dm3 – pcs. 1,
- compressed air storage cylinder pb = 20 MPa, Vb = 1.0 dm3,
- pressure regulator 10/6 MPa, dn = 3 mm,
- piping and other necessary air fittings,
- casing in the form of an openwork basket slid on the ARGO float from below,
- buoyancy elements to counterbalance the weight of the rescue device in the free spaces of the openwork basket.

The main element is a flexible hose of sufficient length, placed in the water in a special openwork casing. The hose is arranged in a spiral shape around the ARGO float body. The hose has adequate resistance to high internal pressure. When compressed air is injected into the hose, it will begin to inflate and increase the volume and buoyancy force of the float. The compressed air is supplied from a storage cylinder via a regulator and valve, which is operated from the system control module.

VARIANT 5 MASS CHANGE BY DISCARDING CONCRETE BALLAST

The technical solution plan for variant 5 is shown in Figures 11 and 12.

The components in this version of the design include:

- ballast module – a ballast weight made of a material with a specific gravity considerably higher than that of seawater,
- electronics module – containing sensors and electronics along with a power source,
- release module – an electromechanical device that discards ballast,
- buoyancy module – the element that balances the weight of the rescue device.

The modules will be located in 2 groups. The buoyancy module will be placed directly under the flange at the top part of the Argo float. The electronics and ballast release modules will be located in the bottom section of the Argo float. Such placement of the device elements will not significantly change the position of the buoyancy centre of the float, but will lower the centre of gravity, which should increase vertical stability in the water. The purpose of the buoyancy module is to ensure neutral buoyancy of the device. Due to the varying density of seawater resulting from variations in salinity, temperature and pressure, the buoyancy element will be calibrated for the expected average density of seawater in the mission area. The calibration of the buoyancy element is aimed at minimising the effect of the difference in the variable buoyancy of the device on the buoyancy of the Argo float. The buoyancy element will be made of robust syntactic foam with an additional protective coating. The mounting of the buoyancy element will allow its easy removal/mounting in order to locate a bluetooth communication device under the Argo float to programme its mission.

The electronics module is a component that controls the mission parameters, with the task of possibly triggering the ballast release in the event of diagnosed deviations of the depth and/or time parameters according to the values set by the operator. The operation of the module consists in continuously measuring the depth and time of the mission and comparing these parameters with the values of the programmed research profiles of the Argo float. Given the possibility of programming a variety of missions, it will be necessary to programme the rescue device separately by entering the appropriate mission parameters, depending on the user-defined emergency situation. In addition, the module will power the ballast release actuators.

The release module will be responsible for releasing the ballast (Fig. 12). Its actuator will be a DC motor powered by the electronics module, which will deflect the lever releasing the ballast valve head through a worm gear. Once the ballast has been discarded, the module will be flooded with seawater. Prior to the next mission, it will undergo regeneration consisting in the replacement of the actuators. The ballast module, on the other hand, will consist of a concrete cylinder with an embedded stainless steel valve head.

It is planned to use heavy concrete to minimise its volume against weight. Concrete as a ballast material is non-hazardous to the marine environment, which is important in terms of environmental protection.

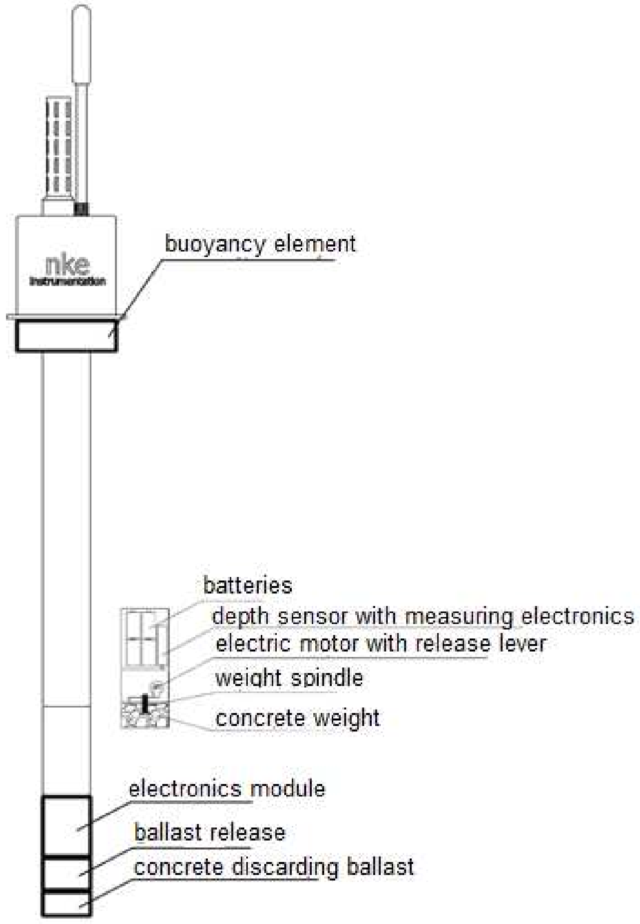

Fig. 11 Proposed technical solution for variant 5.

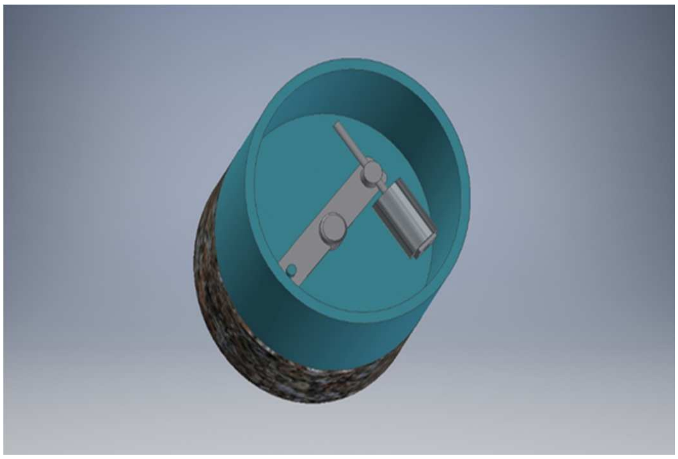

Fig. 12 Ballast release module.

VARIANT 6 MASS CHANGE BY DISCARDING LEAD BALLAST

The technical solution plan for variant 6 is shown in Figs. 13 and 14.

The components in this version of the design include:

- buoyancy module – a buoyancy element balancing the weight of the rescue device,
- release module – integrated module containing electronics, power supply and ballast with release device.

The modules will be arranged in 2 groups. The buoyancy module will be located directly under the float. The ballast release modules will be located in the bottom part of the Argo float. The buoyancy module will be made of syntactic foam as in variant 5. It will be placed under the flange in the upper part of the Argo float.

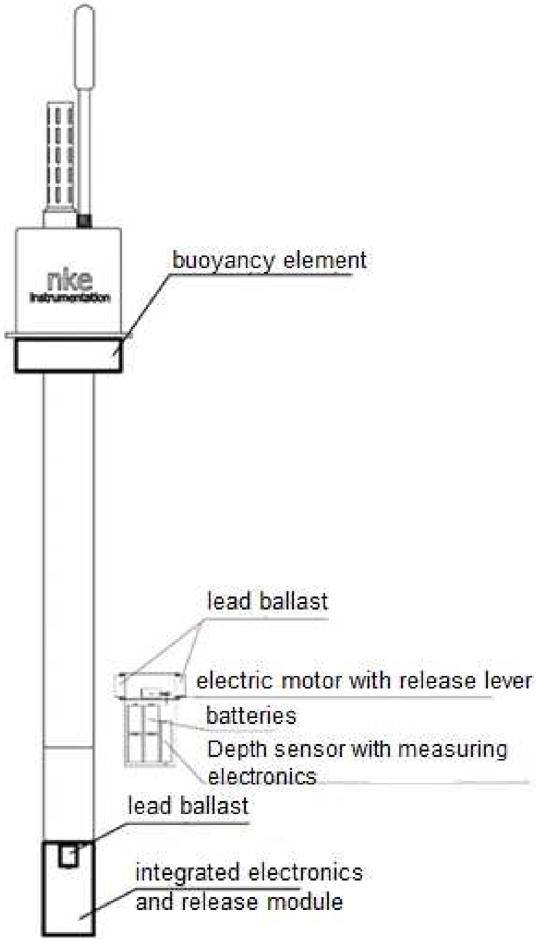

Fig. 13 Proposed technical solution for variant 6.

The release module is responsible for analysing the Argo's motion parameters and releasing ballast in the event of an emergency. It consists of the following sub-modules:

- The electronics unit is a module which analyses mission parameters to trigger the ballast release in the event of an emergency. Its operation consists of continuous measurement of the depth and time of the mission and comparing these parameters with the values of the programmed ARGO research profiles. Due to the possibility of programming a variety of missions, it will be required to separately programme the rescue device by entering the appropriate mission parameters. In addition, the module will power the ballast release actuators. The electronics assembly will contain components and elements similarly specified in variant 5.
- The release module consists of stainless steel ballast weights positioned opposite to each other on the outer side of the enclosure. The weights are located on the enclosure in special holders (upper and lower). The upper grips are fixed elements of the release module housing. The lower grips are made in the form of a movable bolt. On release of the bolt, the spring between the steel weight and the body of the module pushes the weight outwards causing it to be released.

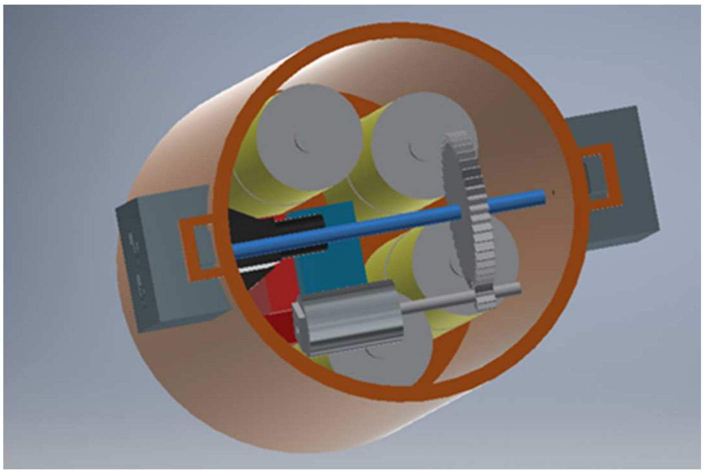

Fig. 14 Release module with electronics, power supply and ballast unit.

CONCLUSION

The developmental work described in this material is being carried out within the framework of the Argo Polska scientific consortium comprising the Institute of Oceanology at the Polish Academy of Sciences in Sopot, the Institute of Geophysics at the Polish Academy of Sciences in Warsaw and the Polish Naval Academy in Gdynia (Department of Underwater Works Technology). Simultaneously, Argo-Poland is a member of the European research infrastructure EURO-Argo ERIC, which is a component of the global network of world ocean observations based on Argo autonomous floats. In this undertaking, the task pursued by the Department of Underwater Works Technology at the Naval Academy consists in the design, construction and verification under laboratory and real conditions of rescue systems for Argo profiling floats. As presented in in this material, 6 variant designs of such solutions have been developed. The solutions described are registered with the Polish Patent Office. In the course of further research steps, the constructions were subjected to multi-variant analysis towards the selection of a solution for implementation. These issues will be the subject of subsequent publications by the team.

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