Pressure Tolerant Systems for Deep Sea Applications

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Abstract - **The present paper deals with new approaches concerning pressure tolerant submerged technology. Different designs of pressure tolerant systems, which are characterized by the absence of pressure hulls, are discussed. Advantages and disadvantages of this novel technology are demonstrated. The overall pressure tolerant test platform *DNS Pegel* is introduced along with the main vehicle components and subsystems that highlight the pressure tolerant design. The vehicle includes an adjustable payload section. The current work discusses the sophistication of pressure tolerant systems. The goal is autonomous test dive cruises with the vehicle in the Atlantic Ocean.**

I. Introduction

The present paper focuses on the design of a new underwater vehicle "DNS Pegel". The vessel was created under a publicly funded project, supported by the German Federal Ministry of Economy, to test pressure tolerant devices for permanent submerged applications. Since no pressure hull is used to protect any part of the vehicle against the hydrostatic water pressure, specific design aspects must be taken into account, some of which are described in this paper. Most importantly, the application of pressure tolerant design principles will lead to a considerable reduction of construction costs and enable almost any dive depth for the vehicle. A number of research cruises and dive tests were successfully passed in the Baltic Sea. Thereby the design of an overall pressure tolerant vessel showed excellent performance.

II. Pressure Tolerant Systems

One of the major challenges for deep sea devices is the rising hydrostatic pressure with increasing depth. The use of pressure hulls for maintaining ambient pressure for enclosed components is state of the art technology. Pressure hulls for deep sea applications have to be thick-walled in order to withstand the extreme pressure, making them heavy and bulky. In contrast, pressure tolerant devices avoid all pressure hulls, and therefore, no gas filled cavities can be found in these systems. By transmitting the pressure onto all components, no pressure differences exist between the surrounding sea water and pressure tolerant components. Therefore, each component must individually withstand the pressure.

Pressure transmission can be achieved by use of either liquid or solid materials, whereas gases are inappropriate due to their high compressibility (see fig. 1). If fluid compensated pressure tolerant systems are employed for pressure equalisation, the design must allow for volume adjustments due to volume shrinkage of liquids under increased pressures. Therefore, assemblies typically contain flexible walls or pressure adjustment is accomplished with flexible bags or compensators. Examples can be found in [1], [3], [4] and [5].

In casted pressure tolerant systems, pressure transmission is achieved with a solid material. Hereby, it is possible to choose between hard and soft castings. Materials used for embedment are plastics like polyurethane or silicone elastomers. Since no housing is required in these cases, the project team chose to use this innovative approach for most components of the vessel in this project.

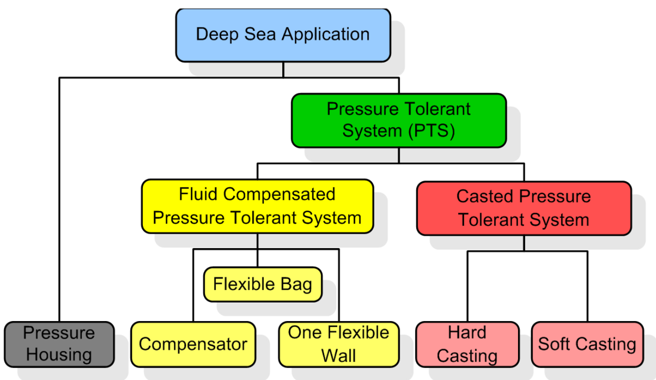

Figure 1. Classification of pressure tolerant systems

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Pressure tolerant submerged systems offer offshore engineers new opportunities and advantages for designing deep sea applications. Once a component is designed for pressure tolerant application, it can be used in almost any water depth. The elimination of pressure hulls, feedthroughs and penetrators helps to reduce production costs and weight. Also, the required space can be optimized. Without pressure differences between the inner submarine components and its surroundings, the risk of leakage or even dangerous pressure hull implosions is significantly reduced.

However, with the absence of pressure hulls, offshore designers have to consider some new challenges. Most mechanical components will have contact with sea water. It is therefore imperative, that all materials such as the mechanical parts of an electric motor running in sea water are corrosion-resistant.

III. A Pressure Tolerant AUV - DNS Pegel

The unmanned under water vehicle DNS Pegel ("DNS" stands for the German abbreviation of "pressure tolerant system") was developed by a joint research team consisting of the German company ENITECH GmbH, the Leibniz Institute for Baltic Sea Research and the Department for Electromechanical and Optical Systems at the Technical University Berlin (refer to [2]).

The main design target of the DNS Pegel was the creation of a test platform for pressure tolerant components necessary for operation of underwater vehicles. The vehicle has a total length of 3.1 m, a diameter of 55 cm and a dry weight of 350 kg. Its design supports the overall pressure tolerant architecture and includes a length-adjustable payload section usable for installation of different equipment. The current payload section is 60 cm in length and is utilized to support tests in the Baltic Sea. Detailed information about the Baltic Sea tests can be found in [2].

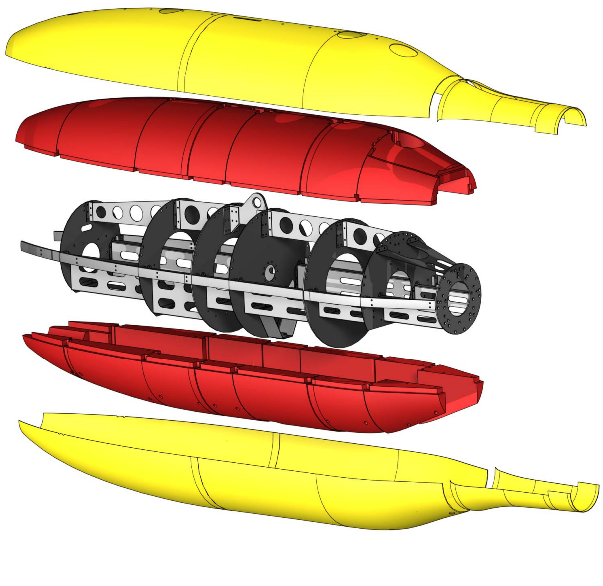

Figure 2. Main structure of the DNS Pegel

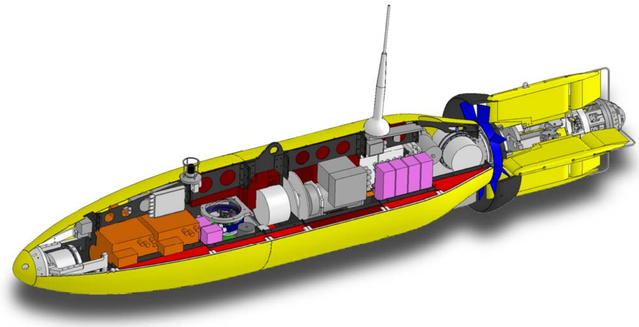

Figure 3. Internal view of DNS Pegel

To give DNS Pegel sufficient structural stiffness a space frame made out of two and five mm thick titanium sheet metal is used (see fig. 2). To achieve necessary flexibility, flanges, boxes and strengthening plates of the frame are interconnected by screws. The cylindrical middle section of the stream body can be adjusted in length depending on the actual payload. The built-in parts are placed in the free flooded compartments formed by the frame. The frame is surrounded by syntactic foam necessary to ensure neutral buoyancy. The outer shape of the foam blocks forms the streamlined shape of the DNS Pegel. To guarantee low flow resistance the syntactic foam blocks are covered by a thin plastic fairing (see fig. 2 and 3).

A. Design Aspects for Pressure Tolerant Underwater Vehicles

Application of the pressure tolerant concept does not necessarily change the way of designing underwater devices, but different shapes and properties of pressure tolerant systems demand specific assemblies and configurations reflecting this new approach.

The absence of pressure hulls leads to the loss of buoyancy force. Consequently, remaining gravity force must be compensated by the application of buoyancy producing materials such as syntactic foams. Also, a light-weight construction of all subcomponents is imperative.

Without pressure hulls, most subcomponents have direct contact with corrosive sea water and, therefore, all parts must be corrosion-resistant. The use of existing special metal alloys for sea water resistant applications is necessary. Regardless, if different metal parts are connected, electrochemical corrosion can occur.

Several autonomous underwater vehicle (AUVs) or remotely operated vehicle (ROVs) are available, which use massive cylindrically or spherically shaped pressure hulls to protect electronic equipment, sensors or electric motors, for example. These voluminous components force the designer to place them in specific locations within the vehicle resulting in an inappropriately shaped vehicle with high flow resistance. Alternatively, the pressure tolerant design allows for a more flexible distribution of components within the underwater vehicle. As a consequence, a more compact and streamlined configuration can be achieved.

In vehicles like the DNS Pegel, many of the heavy components such as the main engine and rudders are located near the stern of the vessel where there is no possibility of placing syntactic foams. To maintain a horizontal trim angle of the vehicle some heavy components e.g. the accumulator, have to be placed near the bow.

B. Propulsion and Maneuvring

The main propulsion is designed as an outrunning electric DC ring motor. Pressure tolerance is given through the embedment of rotor and stator within a customized cast. The rotor with its eight blades functions as the driving propeller. Because of the large outer diameter of the rotor, it is possible to cause a high thrust at a low rotational speed of the propeller. Consequently, the loss of efficiency due to friction of rotating elements in water is significantly minimized. To enhance the propulsion efficiency the propeller rotates within a duct. Thereby, the DNS Pegel can reach cruising speeds up to three meters per second.

The underwater vehicle is steered by four control planes: two elevators, or rather, roll-ailerons as well as two interconnected side rudders. They are arranged behind the main propulsion. This alignment is advantageous since the steering effectiveness of the fins is enhanced by the high flow velocity around the rudders. Thus, small radius vehicle turns are possible. The control planes are actuated by three actuator modules which are arranged at the rear end of the DNS Pegel. They are composed of three pressure tolerant servo motors in conjunction with three spindle-type gear transmissions.

An additional pressure tolerant maneuver system allows the DNS Pegel to successfully turn around its vertical vehicle axis as well as to perform sidelong movements. The maneuver system enables the vehicle to maintain a fixed position relative to the sea floor even under the influence of cross currents. It can also be used to perform docking maneuvers at docking stations for data transfer or charging for example. The propulsive force is generated by two water jets at bow and stern. These high velocity jets are created by two centrifugal pumps integrated within both vehicle tips. It is possible to revolve the water jet nozzles 360 degrees around the longitudinal vehicle axis. Since the nozzles are small-sized, the contribution of the thruster system to the flow resistance of the DNS Pegel is almost negligible. Both thrusters exhibit a seawater resistant and compact design. The electric servo motors for the propulsion of the pump impellers as well as the electric step motor for the adjustment of the jet nozzles run directly in sea water. The pressure tolerance as well as the protection against corrosion is guaranteed through the embedment of stator and rotor within a customized cast.

Furthermore, the vehicle is equipped with a pressure tolerant trim system for adjustment of the static angle of pitch. This enables the vehicle to perform efficient dive and emersion maneuvers, especially during low vehicle forward speeds where the rudders are ineffective due to low water flow velocity. For this reason, precisely executed docking maneuvers in conjunction with the above mentioned maneuver system can be accomplished. Another area of application is the vehicle balancing in case of changes in trim e.g. while using manipulators. The pitch adjustment is achieved through the shifting of a trim fluid with a density different from sea water via tubing between two containers in bow and stern. Since the compressibility of the deployed fluid, and thereby its volume shrinkage, is no longer negligible at pressures of 600 bar, the containers exhibit a flexible design. The transport of fluid is achieved by a gear pump, and possible unintended redistribution is inhibited by an electromagnetic valve. The pump and its driving motor, as well as the valve are made pressure tolerant through the embedment within a soft cast.

C. Energy

A lithium polymer battery setup, which combines good pressure tolerant properties with a high energy-to-weight ratio, is used as the primary electrical power source for the DNS Pegel. Each battery block consists of single cells which are embedded within silicone as a soft cast to assure a pressure tolerant assembly (see fig. 4).

The vehicle's main energy source contains four battery blocks with an output voltage of 110 V and a total capacity of 5.2 kW / h. Each block is equipped with voltage monitoring and cell balancing systems.

The main propulsion is connected to a 110 V power bus. Furthermore, because several other electrical and electronic vehicle devices require voltages of 24 V, a 750 W pressure tolerant energy converter is also included. The converter is characterized by an efficiency of 95 percent.

For redundancy reasons an additional 24 V battery is incorporated in the underwater vehicle. The low self discharge and good self-leveling properties of lithium titanate cells make them an excellent choice for the emergency battery system.

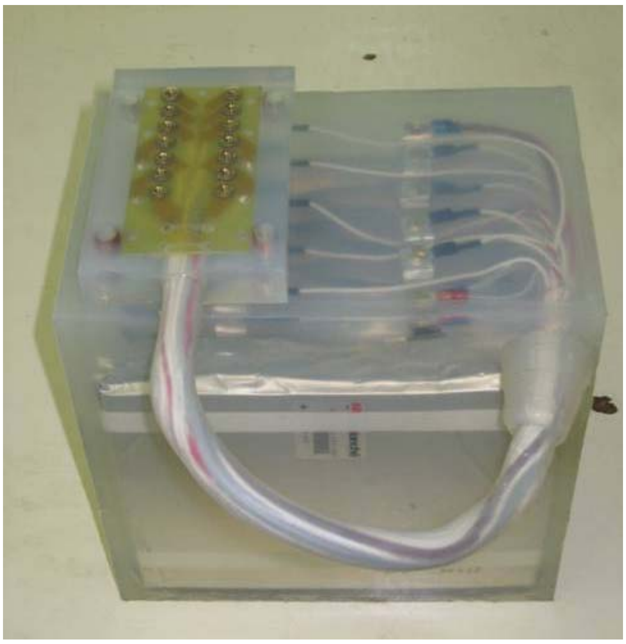

Figure 4. Lithium polymer main battery block

D. *Long Term Test*

The DNS Pegel was anchored at a depth of 20 meters in the Baltic Sea for a period of six weeks (see fig. 5). Thereby, every pressure tolerant component was exposed to saltwater as well as to bioorganisms. Immediately after the test duration all components were visually examined and their function validated. No system showed severe degradation due to sea water exposure. Despite their different degrees of hardness, none of the castings showed any damage at all. The encased electronic circuits, power supply electronics, accumulators and sensors remained fully functional.

Also, other pressure tolerant and in-sea-water operated components such as the servo motors for the adjustment of the rudders as well as the main propulsion did not show any sign of damage. Similarly, sliding bearings with different tribological pairings composed of metals and plastics showed superior operability. As expected, the titanium frame structure showed no corrosion at all. However, a few regions of crevice corrosion in metal parts were found, even where material combinations of stainless steel and plastic existed.

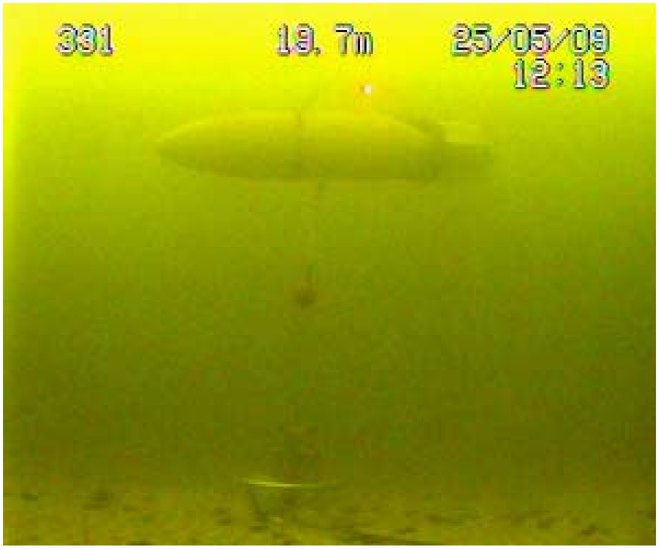

Figure 5. DNS Pegel moored to an anchor on the Baltic Sea bottom

IV. Future Work

At the end of the year 2009 a follow-up project was started. During the three year project duration a new pressure tolerant test vessel will be designed. The goal is autonomous diving cruises at ocean depths of 6000 meters. For the achievement of autonomous behaviour, the vessel will be equipped with a variety of additional sensors (e.g. acoustic modem with USBL technology, doppler velocity log, altimeter and side scan sonar). Together with a new research team member, the German company EvoLogics GmbH, an underwater acoustic data and navigation network will be established in the Atlantic Ocean. It will consist of several acoustic beacons on the sea floor bordering a large area within which the vehicle will be able to navigate accurately.

V. Conclusion

The work presented in this paper shows the excellent applicability of pressure tolerant components in deep sea applications and for unmanned deep sea vehicles. The offshore design of complex pressure tolerant configurations e.g. batteries, electronic motors, electronic circuits or pumps is possible today. The offshore engineer achieves new opportunities with the deployment of pressure tolerant components and consequently reduces the risks of pressure hull failure.

The follow-up project enables our team to optimize components and test the vehicle in a deep sea environment. Several commercial applications were derived from this work by project partners and will be available to the markets.

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