Development of Research Submersible ICTINEU 3

Carme Parareda, Pere Forès
ICTINEU Submarins SL
cparareda@ictineu.net, pfores@ictineu.net, http://www.ictineu.net

Abstract *– This article will give an overview to the development, manufacturing process and certification of the manned submersible ICTINEU 3, a work class vehicle with high capabilities for research, ocean observation and underwater intervention, but also suitable for filming and leisure. It has been designed for 1.200 meters depth and a crew of three: one pilot and two observers (passengers) with certification and classification by Germanischer Lloyd. The challenge was to achieve a very small and lightweight but at the same time versatile and highly operational vehicle, with the aim to improve the capabilities of existing submersibles in this depth rate. The result is a new generation of manned submersible, a compact vehicle of only 5300 kg, with no need for syntactic foam, that can be easily operated from most research vessels and incorporates outstanding innovations such as a lithium-ion-polymer battery system that will provide the vehicle with a high power capacity.*

Keywords *– Manned Submersible, Research Platform, Ocean observation and intervention*

I. INTRODUCTION

Ictineu Submarins SL was founded in 2007 to develop and built the ICTINEU 3 manned submersible. The vehicle was named ICTINEU 3 as a tribute to Narcís Monturiol that built the first modern submersible in history, the Ictineu or Ictíneo in 1859, and the second in 1864.

The aim was to build a new generation of manned submersibles that would improve the observation and operation capabilities, as well as versatility and easy of operation. This should be done by incorporating outstanding innovations with respect to the other submersibles that are currently on the market, in terms of design, construction materials, and in particular its energy system and automation.

The challenge was not easy, a lot of technology review was needed, a lot of research and a big determination to go further. It might seem only a few goals, but difficult to accomplish them all together. It has taken 8 years of development and construction. The result is far satisfactory as the main goals have been achieved: high observation capabilities, very low weight (<5,3 tones), easy to transport and operate worldwide, highly operational with a high power and efficient system, and passenger access from sea.

Fig. 1. ICTINEU 3 research submersible

II. DEVELOPMENT AND INNOVATIONS

In order to achieve the mentioned goals, many challenges had to be solved during the design phase of the Ictineu 3, but there are three particular areas where most effort hat to be put on:

Weight reduction. A big effort on design and research on new materials was needed in order to drastically reduce weigh in several systems. And extensive calculation was done by FEM as well as design optimization and research in new materials, mainly in the pressure hull. Innovation in stainless-steel materials and design have lead to an unparalleled volume to weight ratio of the pressure hull, that weighs only 2714kg (including the two acrylic domes, 540kg) for 3,089 cubic meters of internal volume. Composites (CFRP) have been largely used as structural and constructive material, both in exterior (exostructure, tanks, pressure-tolerant containers) and interiors. The exostructure and the fairings have been built as a sole body, withstanding the requirements of the certification authority. Many years of experience have allowed to work with different materials and properties, achieving lightweight, high-resistance, fire-proof parts, suitable for interior and exterior. The development of a pressure-tolerant li-ion-polymer battery system have been definitive in the final weight reduction. As a result, the vehicle does not need syntactic foam at all.

Improvement of performance in navigation. The aim was to built an easy to pilot, safety improved vehicle, with fine control on navigation systems. Apart from diving tanks with 600l capacity, interior buoyancy tanks have been provided with a capacity of 220 litres. They will allow a fine control of the ascent-descent as well as trimming of the vehicle. If we add 8 powerful thrusters, 2,5kW each, to the system, we have a vectorial propulsion system on full 6 degrees of freedom. Custom-made, pressure-tolerant motor drivers have been designed. They allow for a proportional control on the thrusters and for a pilot-configurable navigation board. The whole must be an efficient and easy to pilot system.

Improvement of performance in operation. A high power and high energy system has been developed based on lithium-ion-polymer technology. The result is a compact, lightweight and safe battery system that will provide endless capacity to work at a normal load for longer missions (up to 10 hours) and enough power to respond to an emergency high power requirements. An optimal selection and configuration of thrusters, the proportional motor drives and the architecture of the whole electric system will add efficiency to the vehicle. Power and communications system has been dimensioned so they can adapt to any task and mission requirements with capability to upload any instrument from the client in an easy and quick way.

Improvement in safety. Three different safety systems (manually actuated) have been implemented in the vehicle: diving tanks with 345 litres capacity at 1.200m depth, drop-weigh system (200 to 500kg), emergency buoy with 1.800m high-resistance rope. Design has been used also to improve hydrodynamics and to avoid as much as possible entanglement areas. If we add an electrical system distributed architecture, and and powerful and efficient energy system, the vehicle gains in autonomy, performance and finally: safety.

III. CERTIFICATION AND TESTING

The ICTINEU 3 submersible is being certified and will be classified by Germanisher Lloyd authority. Rules for classification and construction of submersibles, 1989 and 2009 are applied, as well as other international standards depending on the system (ASME, UN, UL, etc).

An extensive testing program was agreed with GL that ranges from factory approvals for manufactured parts (pressure hull, composites, etc), welder approval for pressure hull manufacturing, laboratory testing for metallic and CFRP parts (destructive), non-destructive and dimensional testing on pressure hull, type approvals and factory acceptance tests for connectors and equipment, and manufacturing local inspections to pressure cycling under GL inspector supervision.

More than 80 different tests have been run, counting all the mandatory by the certification authority and those done by self initiative in order to proof technology for new parts and systems. Final functional tests, factory acceptance test, harbour acceptance test and sea acceptance test have still to be run, that will make a sum of around 105 total tests. Up to date a whole of 10.000 cycles in autoclave have been done, counting those in water for pressure hull, external equipment and pressure containers, and those in oil for pressure-tolerant electronics.

IV. VEHICLE MAIN FACTS

Main facts and performance of the vehicle are described next. The pressure hull is 1.7 meters in diameter and it has two acrylic domes, one on top (entry hatch) and one in front, 1.5m external diameter. The position of the front dome has an inclination of 10 degrees forward in respect of the vertical, so the vision on the sea floor is improved. This allows the three passengers a large field of view and excellent capabilities for ocean observation, as well as the possibility to take high quality photography and video recording from inside the pressure hull. An important effort has been done in design for optimisation of space and ergonomics have also been taken in account in order to make submersibles a comfortable place to travel and work.

The weigh of the vehicle will be about 5.300kg, a very reduced weight for a 1.200m and 3 people rated submersible, so it can be operated from most research vessels. As it has a very reduced size it can fit in a 20 feet open-top container, so it's easy to transport to the work place by road, ship or air worldwide.

Due to shape and diving tanks capacity,passengers can go in/out from water surface in good sea state, what makes easier the exchange of passengers, without the need of lifting and recovery operations from mother ship every time a shift is needed. It can also be towed from harbour if working area is near the coast.

The power system is based on last generation lithium-ion-polymer batteries, which give the vehicle a high power capacity: 3kW continuous, 42 kWh (10 hours full autonomy at normal load capacity). This means that it is able to work for more than 8 hours with thrusters, lights and all instruments and sensors simultaneously, and can travel up to 20 nautical miles underwater. The whole range of parameters of the power system can be monitored all time, and values are recorded for the whole mission automatically. An alarm system will advise for critical parameters that might compromise a mission performance or safety.

Fig. 2. Large field of view trough the front acrilic dome.

Propulsion and manoeuvring are based on a complete 6 controllable degrees of freedom system. The configuration of the 8 thrusters, 2,5kW each, provide a vectorial propulsion system on 5 axis: 3 translation (XYZ), 1 yaw, 1 roll. Trimming (pitch) is provided by internal buoyancy tanks, that also provide the buoyancy system, so that Z axis is redundant (thruster and ballast). Piloting is done by a PLC- assisted console: 1 joystick, 3 axis (advance, lateral translation and yaw), plus 12 manoeuvring control buttons (buoyancy, pitch, up/down).

As it has been said, it has always been a must the versatility and capacity of operation of the vehicle. In this sense the power and communications system has been dimensioned in order to be able to adapt to any task and mission requirements. A sensors platform has been designed in a way that it is capable to upload any instrument or sensor from the client in an easy and quick way. This is done through an oil filled, pressure tolerant junction box, with 18 extra shielded twisted pairs for connections, and a choice of 12VDC or 24VDC in series for power. Inside the pressure hull, direct access to distribution board is allowed.

The payload of the submersible is 300kg that can be distributed between instrumentation, samples collection or any tools or markers to be placed on the sea floor. A basket will be available for that purpose in front of the vehicle. Front protection bars pay also the role of masts and support for cameras, flashes and other instrumentation that can be easily fixed on them.

As basic equipment the vehicle will have: an underwater telephone, VHF for surface communications, flux-gate compass, GPS, sonar, altimeter, redundant depth control, Doppler velocity log, 6 LED lights and a couple of 6-function hydraulic manipulator. Additionally, a CTD and multi-parametric probe will be always mounted on board, continuously logging data. Information recorded during the mission and during the ascent and descent along the water column will be available to the scientific community after each dive. The Doppler velocity log, a Teledyne Workhorse Navigator, can be used also as a current profiler.

V. SUMMARY

The design of ICTINEU 3 submersible started in 2004, engineering and pressure hull calculations started in 2008 and main construction works in 2009. Eight years later the vehicle is about to be finished. All engineering has been finished, as well as the construction of pressure hull, exostructure and subsystems. All equipment is ready for final assembly and testing. Final certification, sea trials and classification are expected for spring 2013. One of the main steps in the construction of a submersible is the pressure test of the pressure hull, that for ICTINEU 3 was successfully completed in summer 2011.

Once the vehicle is finished, the company itself will operate the submersible and offer diving services. Operation of ICTINEU 3 submersible can be adapted to any need of the client, either for long campaigns on a mother ship or on a daily basis with the need of only a small surface support vessel. A daily mission of 8 hours can be run, and a time lapse of 5 hours is needed to re-charge the batteries. As the implementation of instrumentation and sensors can be done easily it can be used as a test platform for new equipment and applications.

The ICTINEU 3 team is eager and open to proposals for cooperation to the improvement of the oceans knowledge. New models are being explored to fund research and exploration projects.

Table 1. Technical specifications of the ICTINEU 3 vehicle

General Specifications		**Propulsion**	
Max. Operating depth	1200 m	Stern thrusters	4 x 2,5kW, 43Kg
Weight in air	5300 kg	Manoeuvring thrusters	4 x 2,5kW, 43Kg
Length	4800 mm		
Beam	1950 mm	**Batteries**	
Height	3000 mm	Main group 150V, 42kWh	Lithium-ion-polymer
Hatch diameter	540 mm	Service and Emergency group	24V, 1,3kWh
Main (front) acrylic window diam.	1200 mm	Working autonomy	10h
Hatch acrylic window diameter	540 mm	Emergency autonomy	5 days
Crew	1		
Passengers	2	**Dynamic Characteristics**	
Payload	300 kg	Maximum surface speed	2,5 Knots
Classification authority	Germanischer Lloyd	Maximum submerged speed	4,2 Knots
		Cruising submerged speed	1,5 Knots
Life Support		Autonomy range at cruising speed: 20 nautical miles	
Daily life support	24 hours for 3 people		
Emergency life support	+ 96 hours for 3 people	**Equipment**	
Atmospheric control by 2 digital O_2 and CO_2 analysers		Underwater telephone	
		VHF for Surface communication	
		Flux-gate compass	
Buoyancy and trimming		GPS	
Diving tanks	600 L	Sonar	
Buoyancy tanks	240 L	Altimeter	
Trimming	+/- 3 deg	Depth control by two analogue depth gauges and one digital pressure sensor	
		Doppler Velocity Log	
Safety devices		8 LED Lights of 6,000 Lumen each	
Emergency drop weigh	500 Kg	6- function hydraulic manipulators	
Diving tanks	600 L	Basket for sampling	
Emergency buoy	1800 m long rope	CTD multi-parametric probe with pH sensor, ORP (Redox) sensor, Dissolved Oxygen sensor, Fluorometer.	
Total buoyancy generation of	800 Kg at max. Depth		

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