PRESSURE HULL DESIGN AND CONSTRUCTION OF THE MANNED SUBMERSIBLE ICTINEU 3

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Abstract – *This paper describes the design and construction of the pressure hull of Ictineu 3, a manned submersible with a maximum operative depth of 1200m. The design and manufacturing process of a pressure hull is a cumbersome engineering challenge because of the extreme pressure conditions and extremely low tolerances required by the certification agency. The pressure hull has been calculated and designed under the ASME PVHO-1-2007 and Germanischer Lloyd rules, and Finite Element Method (FEM) simulations have been performed. It will be tested in an autoclave at a test pressure corresponding to 1440m. The pressure hull is composed of an stainless steel body with two acrylic spherical sectors, one is the top hatch and the other is a large front window that will provide the crew an exceptional wide field of view. The steel has been spefically selected due to its excellent mechanical properties and its high corrosion resistance.*

Keywords – *pressure hull, austenitic-ferritic steel, pressure test, deep drawing, heat treatment*

I. INTRODUCTION

Ictineu 3 is the first project of Ictineu Submarins S.L., a scientific manned submersible designed to operate at a maximum depth of 1200m and carry three people. The most critical part in the design of a manned submersible is the pressure hull, which must hold the external pressure, and therefore, its design must be done accordingly to strict rules. In this project Germanischer Lloyd has been chosen as the certifying agency so whole submersible has been designed under their rules and the ASME PVHO-1-2007ones. Moreover, every step of the construction process must be certified and subject to strict quality controls that will provide high precision allowing to meet very low tolerances. Two major difficulties have had to be solved in this project: from one side the selection of the right material and the calculation of the pressure hull; on the other side the definition of the manufacturing process for the two spheres to satisfy the tolerances required.

II. THE PRESSURE HULL

A preliminary study was realized to select the most suitable shape and material with the aim to obtain the lightest possible pressure hull maintaining the safety. The sphere is the solid with the minimum surface/volume ratio, hence the most suitable geometry to withstand an external pressure with a minimum weight:
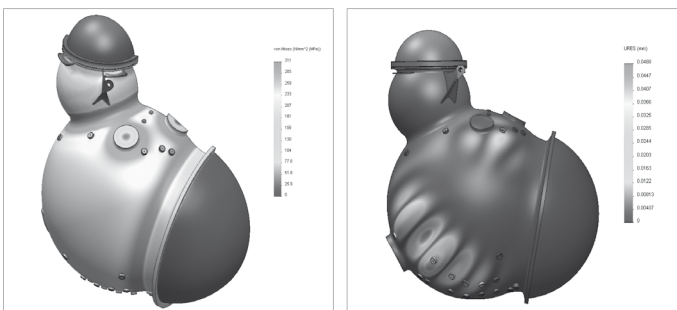
this is why a sphere has been chosen to host the three crew members. On top of the main sphere (Ø 1700mm) there is a second one (Ø 800mm) with an acrylic hatch, through which people can access and leave the submersible. At the front of the main sphere, a large PMMA window (Ø1200mm) enables the crew with a wide field of view. For the spheres, a special steel was selected after a thorough research and calculation among different materials such as two different titaniums, six different steels and two types of carbon fiber/epoxy composites. Finally the selected material is an austenitic-ferritic steel with high Cr, Ni and Mo content compared to a standard austenitic steel (e.g. AISI 316), suitable for marine application because of its high corrosion resistance. This chemical composi-

tion gives the material special properties: high yield strength (Rp0,2 ≥ 530MPa), high ultimate tensile strength (Rm ≥ 730MPa), high elongation (A5=35%). From the mechanical point of view this material is comparable to a high strength steel (e.g. HY-80) but with far superior corrosion resistance. Another advantage is that it is not magnetic, with no interferences with the surrounding equipments (e.g. compass).
The calculation via FEM (Fig.1) has been performed for the design pressure (12,1MPa) and as well for the collapse pressure (20,9MPa). A buckling analysis showed a high safety factor under the collapse pressure.

The Steel Spheres.

The manufacturing of the pressure hull of the Ictineu 3 is being carried out among several specialized factories with previous experience in pressure hulls construction. The selection took many months as there are few workshops in Europe that were able to do manufacture the different parts and most of them were not able to guarantee the specified tolerances. To obtain the two spheres, a steel plate 46mm and 30mm thick respectively was used. After the deep drawing and the heat treatment of the dished heads (Fig.2), a machining process is necessary to meet the "out of roundness" tolerance. The sphere is obtained welding together two heads along the equatorial line. The welding process has to be carried out by certified welders, with low heat input and very low interpass speed, in order to avoid deformation of the steel along the welding line. Once the reinforcing flanges and penetrators are welded, the two spheres are assembled together through a reinforcing ring: this object, closed with the two acrylic windows, represent the pressure hull of the Ictineu 3. The mechanical tests and dimensional checks are carried out under the strict supervision of a Germanischer Lloyd Surveyor.

The Acrylic Viewports

The acrylic is a thermoplastic with excellent environmental stability and low water absorption (0.25% in 24h). It is almost completely transparent (92% light transmission) and it has a lower density (1.19kg/dm3) and an impact strength higher than the glass. For all these reasons it has been used for underwater applications for the last 60 years with excellent results. An extensive study for the acrylic windows has been performed, according to [1], [2], [3]. The aim was to design suitable windows for external view, able to withstand the design pressure (12,1MPa) in a wide range of conditions: from cold to hot regions, with a considerable temperature variation (-15/+50ºC).
The design temperature is 18ºC, considering the mean value in between internal (24ºC) and external temperature (12ºC) at the design pressure. The design service life is 20 years or 10,000 pressure cycles [1], [2]. The two windows are spherical sectors, with opening angles of 150º (main dome) and 160º (top hatch). They weigh 500kg and 45kg respectively and they will be tested together with the steel structure at 14,5MPa inside a hyperbaric chamber, with a 1,2 safety factor compared to the design pressure (12,1MPa).
The Ictineu 3 will be the first submersible for 1200m with such a big acrylic window, all the submersibles for similar or higher depths have only small portholes up to Ø200mm.

III. SUMMARY

Thanks to extensive search in materials, calculations and FEM simulations, a very light pressure hull has been achieved. This will result in a very lightweigh submersible with capabilities for three people and a big acrylic window under 6 tones, compared to the 8 to 12 tones for similar vessels. The construction of the pressure hull is due to be completed at the end of 2009. After the pressure test in an hyperbaric chamber, all the submersible systems will be fitted and the outer hull will be mounted. The first sea trials of the Ictineu 3 submersible are scheduled in the second half of 2010.

IV. ACKNOWLEDGEMENTS

Fig. 2. Deep drawing of one hemispherical dished head

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ANT COLONY OPTIMIZED PLANNING FOR UNMANNED SURFACE MARINE VEHICLES

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THE PROBLEM:

This paper presents some results achieved from a preliminary study on the use of the Ant Colony Algorithm to plan feasible optimal or suboptimal trajectories for an autonomous ship manoeuvring. The scenario, for this preliminary work, comprises only open sea manoeuvres. The goal involves obtaining the least time consuming ship trajectory between to points, departing from the start point with arbitrary initial speed and attitude values and arriving to the end point with predefined speed and attitude values.

The specific dynamic of the ship imposes typical restrictions to its manoeuvrability. In the present case, the non-holonomicity, the rate speed/turn radius, and the imposed forward-only propulsion of the ship make up the main restrictions to the ship movement. For long distances, the problem could be tackled as a classical navigation problem, in which, for the most part of the ship trajectory, techniques such inertial navigation should be enough. The problem arises at short distances when it becomes a manoeuvring problem. In this case to obtain a optimal, --in some cases just a feasible--, trajectory could be a difficult problem.

A WAY OF SOLUTION:

In recent years, several innovative optimisation techniques, based on heuristic search methods have been developed and proved in very different scenarios. Among them, the so called bioinspired algorithms, such the Ant Colony Optimisation or the Artificial Bee Colony Algorithm result particularly attractive by their capacity to solve complex optimisation problems in which, other classical techniques are unfeasible or difficult to implement.

The aim of the present work is to prove the viability of one of these techniques to obtain the trajectory of an autonomous ship in the manoeuvring scenario described above. To accomplish this goal, a simplified dynamical model of a ship, considering only three degrees of freedom (surge, sway and yaw) was employed. The propulsion was modelled as a trimable waterjet system, which plays also the role of the rudder. Both, speed and course are controlled by a classical PID system, which stabilizes the course and speed, according to preset values of the PID constants. A more complete description of this model will be provided in the full paper.

Ant Colony Optimisation algorithms are based in the way in which ants are capable of finding the shortest path from a food source to their nest. Ants deposit a certain amount of pheromone while walking. When any ant searches a path to follow in its search for food, it prefers, in a probabilistic sense, the trails rich on pheromona. As far as shorter paths can be followed faster, the shorter the path the larger the number of ants that cover it by unit time. As a result, the shortest (optimum) path becomes more and richer on pheromona, and more a more ants follow it. Although the process tends to converge with time to the best way found by the ants, the probabilistic nature of the ants path election, makes easier to avoid get trapped in local minima far from the optimal solution and it allows, once the algorithm has found a feasible solution, to improved it towards the optimum.

In the robotics context it is usual to divide the problem of robot motions into two steps: first to get an optimal path (path planning), according with certain cost criteria, and then making the robot follow the path (path following). It may be difficult for the robot to follow the path, due to the dynamic characteristics and restrictions of the robot itself.

In our case we propose to solve the motion problem in one step, so the path planning includes the robot dynamics and restrictions.

Now, the original ant colony algorithm doesn't consider any particular dynamics for the ants' movements. It just assigns an elapsed time proportional to the length covered by the ant in its movement towards the goal. Our contribution here is to add dynamics -the dynamics of the ship- and restrictions to the algorithm. In this way the trajectories obtained are feasible. The ants behave as ships. In the original algorithm, the ant colony is composed by an arbitrary number of ants. They are sent from the nest, which represent the starting point of the quest, in random directions. The ants follow straight paths until they reach an obstacle, then a new random direction is selected. When any ant reaches the