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STUDY OF UNDERWATER THRUSTER (UT) FRONT COVER OF MSI300 AUTONOMOUS UNDERWATER VEHICLE (AUV) USING FINITE ELEMENT ANALYSIS (FEA)

M. Sabri[1, 2], T. Ahmad[1], M. F. M. A. Majid[1] and A. B. Muhamad Husaini[2]
[1]Mechanical Section, Universiti Kuala Lumpur MSI, Kulim Hi-Tech Park, Kulim, Kedah, Malaysia
[2]System Engineering and Energy Laboratory, Universiti Kuala Lumpur MSI, Kulim Hi-Tech Park, Kulim, Kedah, Malaysia
E-Mail: msabri@unikl.edu.my

ABSTRACT

The Ocean's living resources are a treasure for current and future generations of humankind. To sustain the valuable resources, the scientists start to develop unmanned underwater vehicles such as Remotely Operated Vehicle (ROV) and Autonomous Underwater Vehicle (AUV) to seabed mapping and sampling. This underwater vehicle propelled by underwater thrusters (UT), which consists of electric motor and propeller fix at the shaft. However, most of the available UT is not specifically meet the requirement such as the size and the power output. A new UT for an AUV has been designed to suit in. The study focused on new design front cover which is one of most important component in UT and using Aluminum 6061-T6 as material. Finite element analysis on the front cover of the UT reveals that it can withstand the pressure up to 1000 meter operating depth. Another crucial part need to be investigated is the gap between shaft and front cover. It was found that the gap needs to be increased from preliminary design 0.005 mm to 0.008 due to deflection occurred in most critical area is 0.0073 mm. It is important to determine this gap in order to avoid the water leak into the thruster if the gap too big or the shaft contacted the casing if the gap too small.

Keywords: autonomous underwater vehicle, underwater thruster, motor casing, finite element analysis and aluminium 6061-T6.

INTRODUCTION

Autonomous Underwater Vehicle (AUV) is the underwater vehicle that has been developed without crew or pilot and has the ability to operate without manual inputs, tethers or remote control. It is an intelligent vehicle for surveying underwater purposely in military, scientifically, and etc. It consists of processor, sensors, motor, propeller, and other supporting part that make AUV to work successfully [1], [2]. AUV was propelled by the thruster which is located at the rear part of AUV. Figure-1 shows example of AUV design and develop by the group of researcher from Republic of Korea[1]. The thruster was consisting of electric motor and the propeller connected through a single shaft. The electric motor was covered by casing to prevent from leakage. This type of propulsion system was utilized by most of AUV system available in world nowadays. AUV has a various shape and operate at hazardous environment, thus the UT need to be designed within replaceable component when failure occurred and should be easily fitted at any AUV. High pressure and leakage is the main factors contribute to failure of the UT.

Figure-1. ISiMI AUV [1].

The trivial challenge in designing the underwater thrusters was the operating pressure and weight. Because of the basic requirement of underwater thrusters design is lightweight with high strength, the material selection and stress distribution must be properly justified with numerical evidence. Finite element analysis (FEA) can be applied in design process in order to analyse the stress distribution and deformation of component during the operation. A group of researcher from UniKL MSI has design and develop an AUV for sea bed mapping and underwater sampling. This newly develop AUV was named as MSI300 regards to UniKL MSI. The AUV system performance in term of power consumption depends on thruster design because thruster system drained most of AUV power.

The conceptual design for MSI300 was adopted from ISiMI AUV which was develop for Korea Ocean Research and Development Institute (KORDI) [1]. This AUV has 1200mm length and 170mm diameter. The thruster dimension was designed so that can fix in the MSI300 geometry. The MSI300 was designed to operate at 300 meter depth or pressure at 3 MPa. This pressure is considered high enough to make the thruster cramp and failure in term of stress on casing. In this research work, finite element analysis has been conducted to study the stress in the casing component. FEA is proven to give the real picture of component's stress due to variable load. Figure-2 shows the first ilustration of MSI300.

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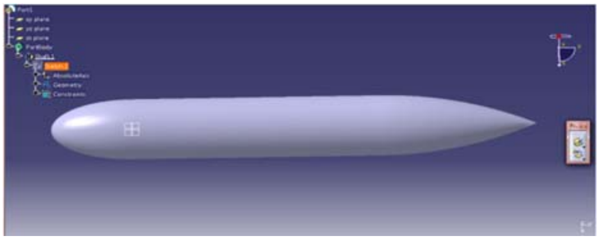

Figure-2. Illustration of MSI300 in solidworks interface.

METHODOLOGY

Design and modelling

The MSI300 UT casing has been modelled by using SolidWorks software. It consists casing, rear and front cover, motor, shaft and etc as shows in the Figure-3. This thruster casing has ability to travel until 300 meter depth under sea water. It is quite deep for human to go at this depth with bare protection. At this depth, the pressure is 3.1 MPa which is equal to 31 bars. This pressure is quite high for living things to survive. The design was compact and simple and quite reliable. The difference between ISiMI and MSI300 thruster is the motor. They build their own motor so that they can build the motor as compact as they can to fit in the casing. MSI300 motor will be choose from off-the shelf because the objective of this paper is to design the underwater thruster casing only. The modular concept was adapted in the design. The purpose is to make the thrusters suit for each customer requirement in terms of size, power motor and the operating condition. Moreover, this thruster new design can be easily disassemble and change the motor or other component if failure occurs. For this type of casing, it can endure the pressure up to 10.1 MPa which equal to 1000 meter depth underwater.

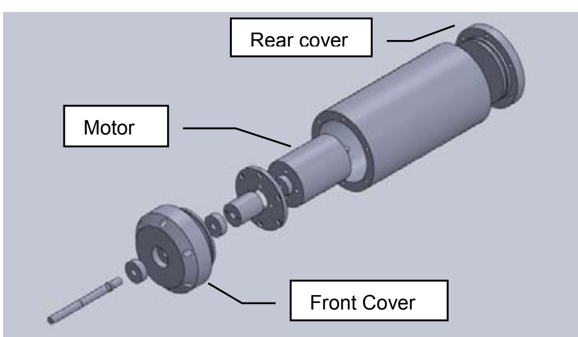

Figure-3. Exploded view of MSI300 UT motor casing.

Figure-4 shows the 3-dimensional model of the UT front cover in SolidWorks software. It is the most important part in the casing. It is because the front cover consists of rotating the shaft that connect to the propeller. Due to this configuration, the tolerance for the shaft fitting need to be analyze in order to get the optimum tolerance for the shaft fitting. Moreover, the front cover can be a reference to the other part of the thruster casing. The shaft will be 10 mm in diameter.

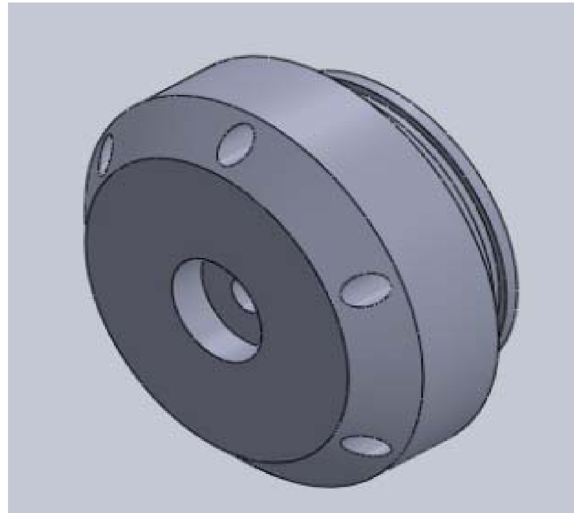

Figure-4. Front cover of MSI300 UT.

Finite element analysis

In the pre-processing stage, the thruster casing model with a scale of 1:1 was imported into ANSYS Workbench 14 for the meshing process. UT front cover model was saved as a para-solid file in SolidWorks to ensure that the casing profile is maintained when exported into Workbench. Another option was to save as STP, IGES or STL file format. But this option is not suggested because it will lead to some geometry lost. If the file is in IGES, imported files will have numbers on the edge that are not required in the mesh process. This edge finally needs to be reconnected in ANSYS. This process consumed unnecessary time for the grid process. ANSYS was used as the pre-processor for geometry modeling due to several of its advantages. ANSYS is very user friendly in terms of generating a mesh. Besides that, this software has broad options for CAD modeling that it accepts. Important considerations when selecting the pre processor software were that the generated mesh file must be accepted by the solver that will be used. Figure-5 shows the fine meshing of the UT front cover. The element size was set to 0.001 which created 23685 nodes and 148427 elements. The result will be more accurate if the meshing finest is greater.

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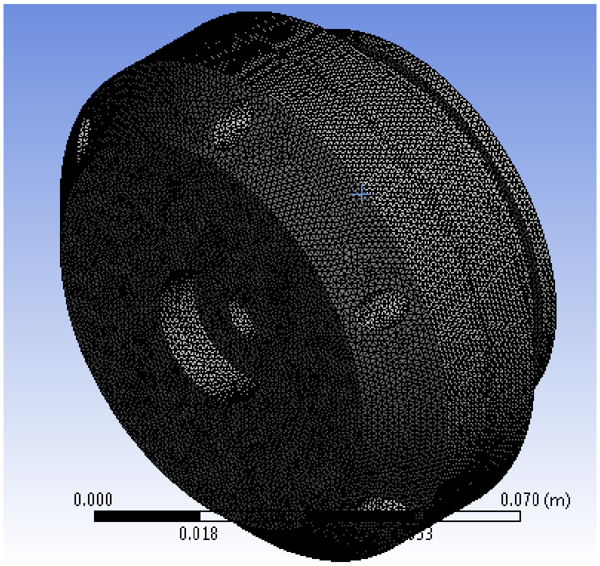

Figure-5. Fine meshing front cover of MSI300 UT.

Material properties

The ANSYS Workbench 14 demands material properties that are defined using module Engineering Data. The material used for thruster front cover is Aluminum 6061-T6. Table-1 shows the properties of the material.

Table-1. Aluminium 6061-T6 attributes. [3]

Mechanical Properties	
Tensile yield strength	276 MPa
Ultimate tensile strength	310 MPa
Modulus of elasticity	68.9 MPa
Shear strength	207 MPa
Poisson's ratio	0.33
Density	2.7 g/cc

Boundary condition

Boundary condition plays an important role in FEA. Therefore, it must be carefully defined to resemble the actual working condition of the component being analyzed. There are two type of boundary which is the fix support and load distribution. Figure-6 and Figure-7 show the location of the fix support and the load distribution. The fix support was located at the screw holes of the UT front cover and the inside tower of the UT front cover. This area was assumed to be the static area while the load or pressure was set around the outer face of the front cover.

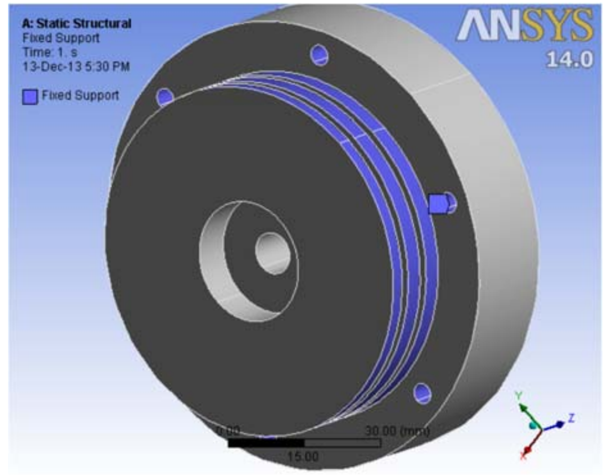

Figure-6. Fix support was set at all screw holes and inside tower.

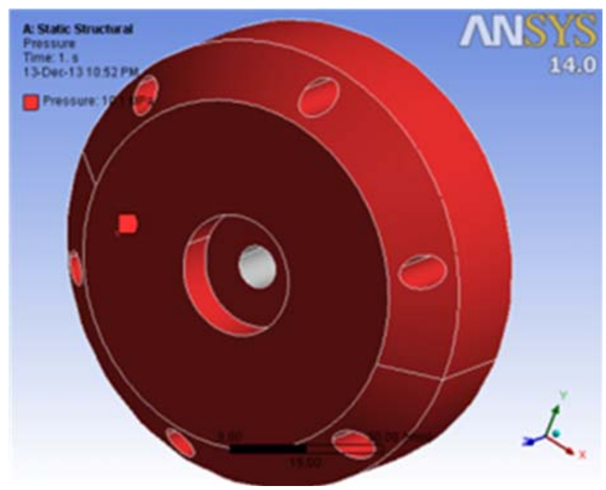

Figure-7. Load was distributed to all outer face of the UT front cover.

RESULTS AND DISCUSSIONS

In real applications, the UT will be fitted in the AUV hull. Due to experimental limitations, finite element analysis was run to gain an understanding of the structural behavior during its application. The analysis was run at the UT front cover only as a references to the other part of the UT. The front cover was the crucial part because it has the rotating part or shaft which is connected to the propeller. The shaft might cramp during application under high pressure [4].

Von mises stress

The results shows in Figure-8 and Figure-9 indicated the maximum stress is developed at the tip of the screw mounting. At this point the screws tend to force back the incoming stress. If the material is not strong enough, it will start to break from the screw mounting and the thickness between the screw hole and the surface of the casing is the most critical compare to the other area.

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Aluminium 6061-T6 is ductile and it can endure the pressure. Aluminium 6061-T6 starts yielding at 250 MPa. Below this value, it can endure the stress and it will return to its original shape. FEA proved that the maximum yielding value is 74.621 MPa which is smaller than 250 MPa. The material will not fail at 1000 meter depth underwater. Figure-10 shows the stress that occurs at the tip of the screw hole due to stress concentration.

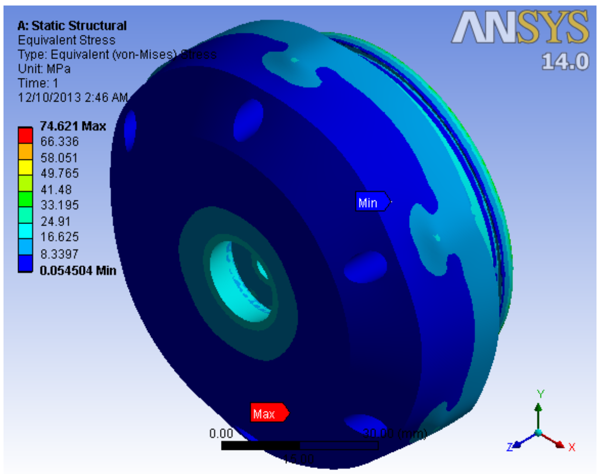

Figure-8. Equivalent stress at front area.

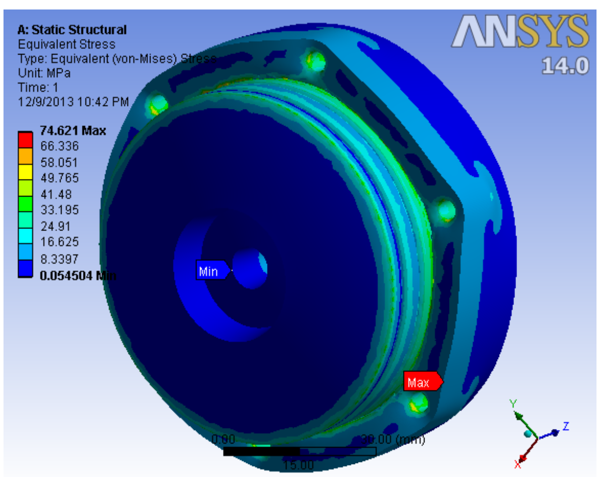

Figure-9. Equivalent stress at rear area.

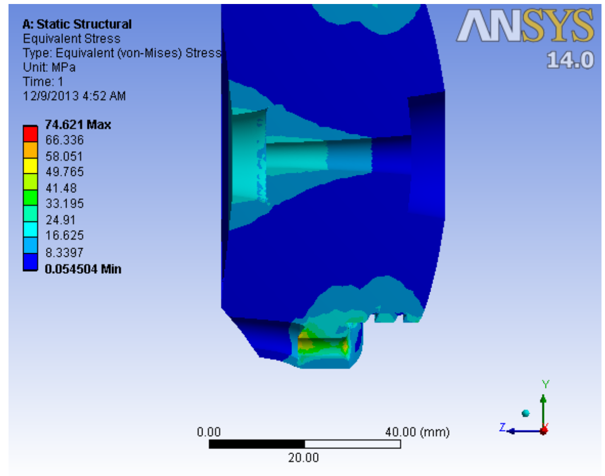

Figure-10. Equivalent stress at cross section area of screw hole.

GAP TOLERANCE

The other objective is to determine the tolerance needs to be set in gap between shaft and front cover. This value is important in order to avoid the water leak into the UT. If the clearance of gap is to big the water will flow in and fail the system. However if the gaps is too small the shaft will contacted into the casing and the propeller is rotating smoothly because of the friction. The FEA results show the value of maximum deflection was 0.0073592 mm and occurred at the tip of the hole as shown in Figure-11 and Figure-12.

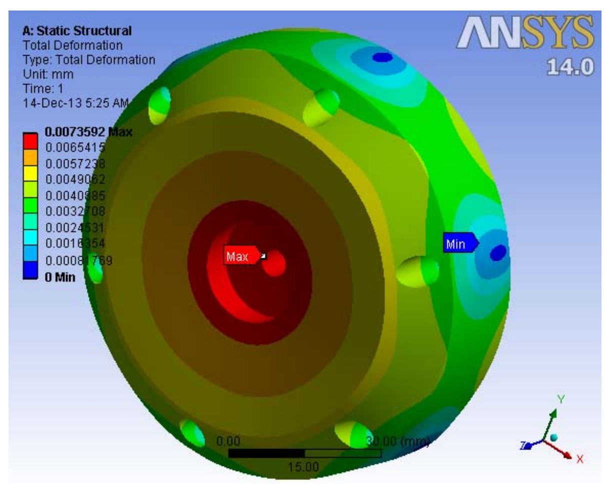

Figure-11. Total deformation at front area.

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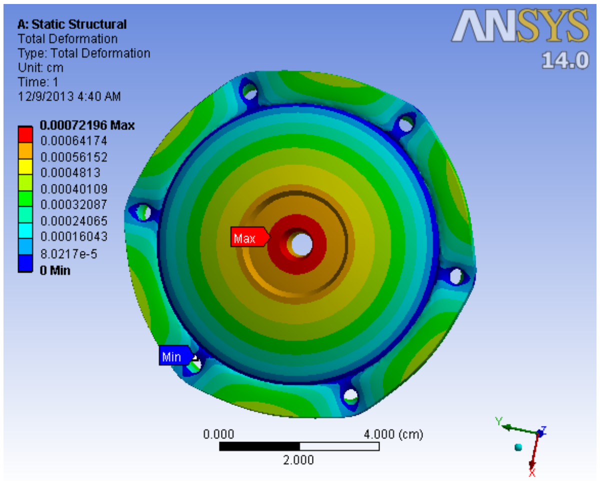

Figure-12. Total deformation at rear area.

Premilinary design set the gap between shaft and the front cover was 0.005 mm. Thus the current design consider fail because of maximum deflection finding from FEA is 0.0073592. Thus the gap size for future design is set bit larger from previous design which is 0.008 mm. FEA shows the stress distribution inside the casing as shown in Figure-13. The maximum deflection mostly occurs at sharp edge of the casing. The stress is increase due to the unsufficient area to absord the pressure. Beside that, at the corner the stress is difficult to flow and start to develop stress concentration.

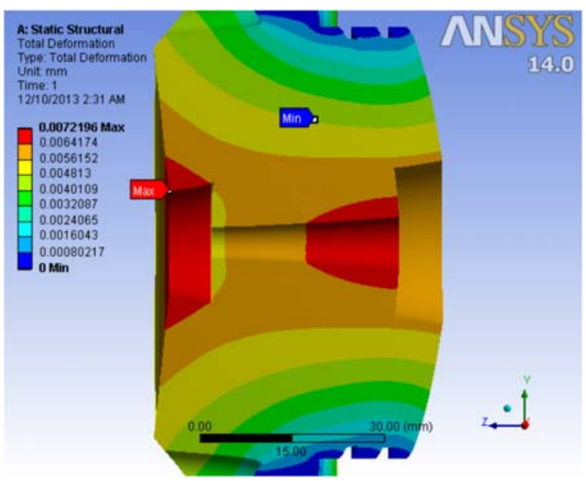

Figure-13. Total deformation at cross section of screw holes.

CONCLUSIONS

FEA on UT front cover shows that the maximum deflection is not exceed than allowable yielding stress. At 1000 meter operating depth which is equal to 10.1 MPa, the maximum yielding stress developed is only 75 MPa while the allowable yielding stress for Aluminum 6061-T6 is 276 MPa. Although the factor of safety is set to be 3.5, 75 MPa is still not more than 79 MPa. The stress can be clearly seen developed at the tip of the screw hole. It is because at this area, the screw will try to hold the casing from deflecting and deformation. If the pressure is too high, the UT front cover will start to fail within the screw holes area. The UT front cover is not fail at 10.1 MPa, but at this condition, the propeller shaft might cramp during application. After the analysis was successfully done, the maximum tolerance for a 10 mm shaft is 0.008 mm. If the value is lesser than 0.008 mm, the shaft will touch and contact the front cover inner holes and get stuck and if the tolerance is too wide, the water will easily leak into the UT motor casing.

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