Modeling, Stress Analysis and Design of an Underwater Remotely Operated Vehicle (ROV)

Ahmad Bagheri
Shahed Aliakbar
Salar Basiri

Mechanical Eng. Department
Guilan University, Rasht, Iran
E-mail: bagheri@guilan.ac.ir

Keywords
ROV, Finite Elements Analysis, Underwater Robot

Abstract

In this paper, firstly the modeling of the robot has been performed and then the analysis of stress and displacement has been carried out using CATIA finite element techniques. The body of the robot is under pressure due to the amount of water above it. The design and construction of an underwater has been considered for transferring the information about alive organisms under the sea.
The purpose of the construction of this ROV is recording visual data from the seabed. The camera has been installed on the frame connected on the base. The base and the engine are connected to the ROV's main body. Inside of the main body consists of electrical equipment and a vessel that balances the buoyant force.
According to the analysis increasing the thickness of the body is recommended.

Introduction

The progress made in the field of underwater vehicles, either autonomous (AUV) or teleoperated (ROV), has been very important in the last years [1,2].

This progress, based mainly on the use of new sensors or improved environment perception systems in these vehicles, has also carried with it an outstanding increase in their cost.
This cost can restrict in some cases their applicability, hence, some researchers have been involved in the design and development of low-cost underwater robots [3,4].

Due to cost restrictions and with the aim to provide a biologists' team with a system able to perform long observations over the flora and some determined undersea fauna, we were entrusted to study and develop a low-cost prototype.

The underwater robot that has been constructed in Giulan University is for study on behave of fishes and discover not useful organism in Caspian Sea so it is an explorer ROV.

The situation of the body of the robot poses significant problems in the accurate fabrication of ROV because the stresses that perform in the body may lead to fracturing body or damaging electrical equipment are into the vessel. Therefore, estimating the magnitude of stresses and displacement and characterizing the effect of pressure of water on the body are deemed necessary.

In this work the amount of the von misses stresses and displacement of the body have been achieved using CATIA finite element techniques.

Design and Construction of Underwater Robot

This robot includes a vessel to produce the power and also there are the electrical equipments inside. The body of underwater robot combines of two half part of thin wall vessel. It is made from steel.
There are five engines in the bottom part of robot. Two of them for the vertical movements of robot and two of them are being used for horizontal movements of robot. Under the robot there is an engine to produce the vibrating of robot to take place on the Flore of the sea[5].

The engines has been connected with the pins that has been used on the handles of engine. This robot includes of three projectors and one camera in closed circle form on the part connected to the base of the robot for taking picture which the pictures transfer to the operator in the ship.

The height of robot is 80 cm and the diameter is 30 cm. also the diameter of base ring is 60 cm. The Top of the robot is connected to a cable which, is connected to the ship. In conclusion, according to the analysis the thickness of the body is recommended**.**

Figure 1: Underwater remotely operated vehicle constructed in Guilan University

Theoretical consideration

Von mises stress and displacement is calculated by CATIA finite element techniques, that for both component of the stress tensor within the part cylindrical axis uses:

$$\sigma_{rr} = p\ \frac{a^2}{(b^2-a^2)}\left[1-\frac{b^2}{r^2}\right]$$

$$\sigma_{\theta\theta} = p\ \frac{a^2}{(b^2-a^2)}\left[1+\frac{b^2}{r^2}\right]$$

Where a, b are the inner and outer radiuses.

And for the component of the displacement using the same axis uses:

$$u_r = \frac{p}{E}\ \frac{a^2}{b^2-a^2}\ r\left[(1-\nu)+(1+\nu)\frac{b^2}{r^2}\right]$$

Where υ is the Poisson ratio and E is the Young's-module[6,7]. p is the pressure of hydrostatic power that is the amount of weight of water above the robot that according this formula:

$$P = P_0 + \int_0^h \rho\, g\, dh = P_0 + \rho\, g\, h$$

Where P_0 is the atmosphere pressure, ρ is density of water and h is the height of water above the robot.

Finite Elements Analysis of Underwater Robot

the cylindrical body and the frames around it have been designed like sheet by 1mm thickness to choose shell element for them, and it cause to possibility for testing different thickness for the body and finally select the best thickness.

It has been tried that analyze occur in critical condition. The speed of this robot is so low because for best condition of recording film, (the speed is about 0.5 m/s).

It cause to dynamic forces like drag and tension force of the rope above the robot be negligible, also the effect of the pressure of the water is more than these dynamic forces in this speed. So analysis occur in the static conditions.

Finite Element Analysis consist of three steps:
1- Preprocessor 2- Solving 3-Postprocessor

At first step (preprocessor), these procedures will be done:
1- Selecting the kind of elements
2- Adjusting the property of the elements
3- Appling the material and etc.

In this process of construction the model, the thickness of body is equal 1mm, because we want to choose Shell element for the body, to changing in the property of the shell element and we can test different thickness for the body until find the best thickness for it[8].

It has been tried to model all the connections and analyze all the details. However this is the advantage of CATIA software and it is almost impossible in other soft wares so it is the reason of using this software in this work[9].

In this way the meshing of the model is prepared and now we can solve the problem whit the determining of body conditions(Figure2).

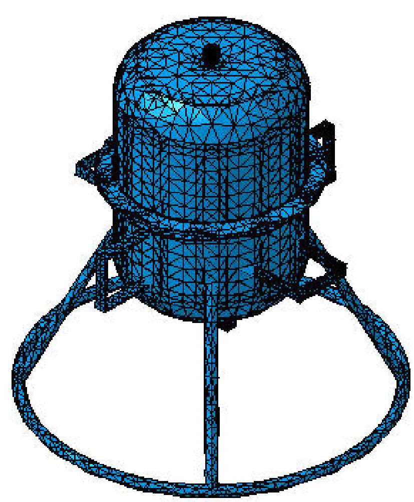

Figure 2 : Meshing the model

After meshing, this is time for Solution the problem which in this level loading the model, the time adjusting and solving problem has happened.

The first body condition of the pressure of hydrostatic power is the amount of water above the robot that according this formula:

$$P = P_0 + \int_0^h \rho\, g\, dh = P_0 + \rho\, g\, h$$

Where p_0 is the amount pressure of atmosphere of above the surface of water and ρ is the density of sea water and g is the gravity and finally h is the height water on the top section of Robot.

Since this critical height is most important condition in the robot, the depth that has been considered is 300 meters. And we can find out the atmosphere pressure in the above formula.

Then we model the reflective power from the weight of the engines in case theses are effective.

For solving this problem, in theses kind of software, we should consider a place on the model to be fixed that we chose the circular base of robot for it.

Result and discussion

Here shown the exit results such as Von Mises stress and displacement that these have been got from the CATIA:
As it seen the amount of stress is from 25MPa until 3750MPa, according to the yield strength for the safety factor it has been recommended that be 1.And also according to some places on the body that the von mises stress are more than ultimate strength so the thickness of body should be increase.

Figure 3 is shown critical zone that it can be found out, from the changing of the color.

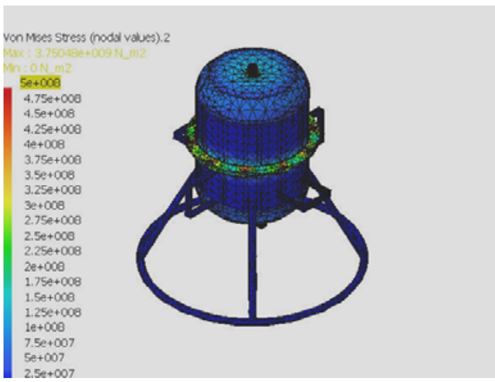

Figure 3 : The graph of the von mises stress

Another part of model have been brought in below figures to recognize the effect of pressure in each zone.

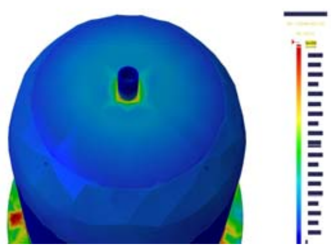
Figure 4 : Top of the robot (caps)

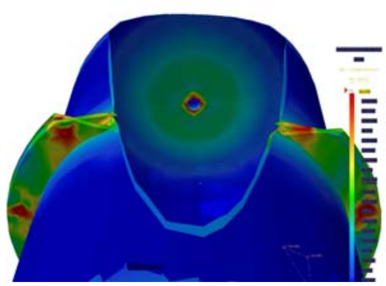
Figure 5-a : The cut view of the body is shown at the center of cylinder

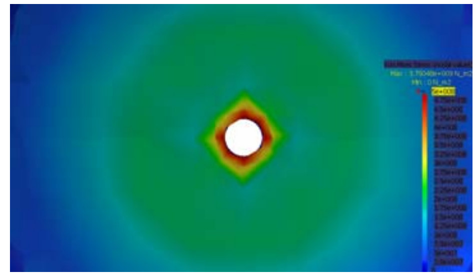
Figure 5-b : The cut view of the body is shown at the center of cylinder

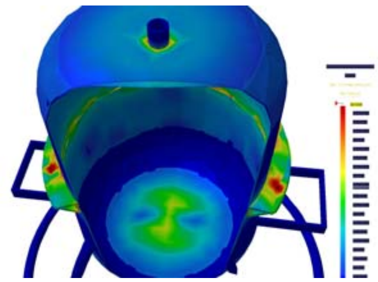
Figure 6 : View of the center of bottom half body

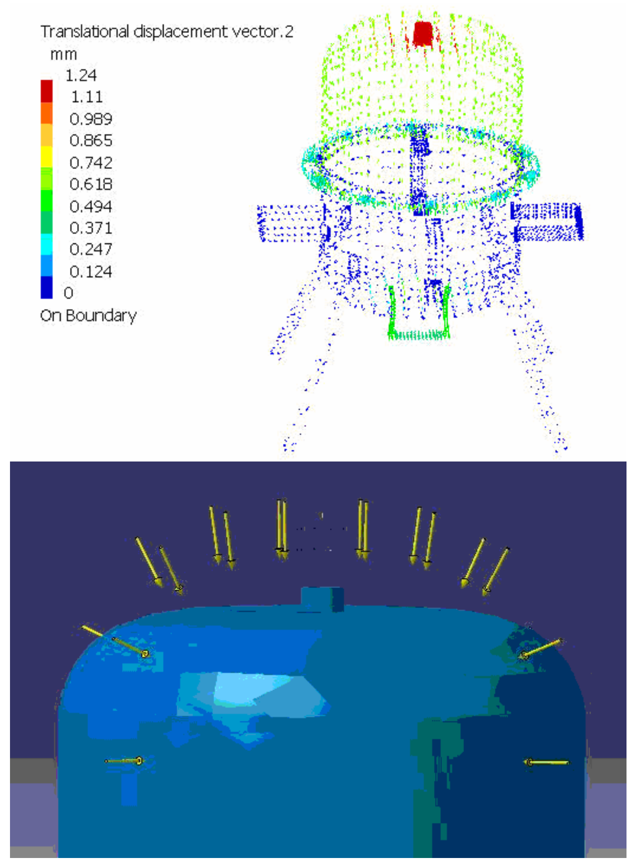

Figure 7 : Graph of displacement

From this figures it will be clear that where zone should be repaired.

Conclusion

Based on the above result of analyzing and also according to the achieved data of stress & displacement of the robot's body, the design should be optimized.

The yield stress is 250MPa, never less the maximum stress is on the frame around the body and is equal 3750MPa, and the safety factor has achieved 0.066 which needs to be more than 1, so the design should be changed until the safety factor be more than 1. At first the thickness of frame and also the circle of bolts can be changed.

So after testing different thickness and different amount for bolt's circle finally thickness is better than be 10mm and the circles be 8 mm and also the distance between center of bolts and center of the cylindrical body is better than be 163mm.

But now this time the maximum stress is on the top center of the body and is equal 656MPa. Now according to this formula $\sigma_l = \frac{pd_i}{4t}$ for thin wall vessel by increasing the thickness of the body the amount of the stress decreases.

So the thickness of the body have been increased, the first thickness that cause to the maximum stress be lees than yield strength is 8mm, that the maximum stress achieved to 237Mpa and again it has occurred on the frame.

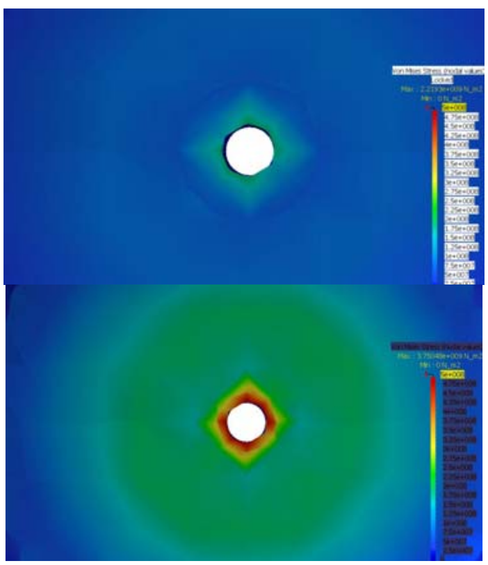

Figure 8 : Stress at the center of cylinder before and after modification

This time it is less than yield strength and the safety factor is equal 1.05 that is reasonable. If the thickness of body be equal about 1/20 of its circle it can be called thin wall vessel, and this body obey from this low by 8mm thickness.

But if instead of steel ASTM-A36 use from steel ASTM-514 that is plated baked because its yield strength is 690MPa it causes to there is more limit for maximum stress until the thicknesses and bolt's circles don’t be increased.

By using of this steel the thickness of frame and the bolt's circle can be both 6mm, and the thickness of the body can rest 4mm.

Figures 8 to 10 compare robot before modification and after.

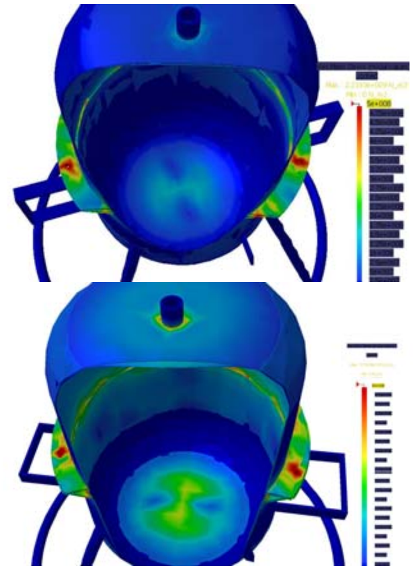

Figure 9 : Stress at the center of cylinder before and after modification in View of the center of bottom half body

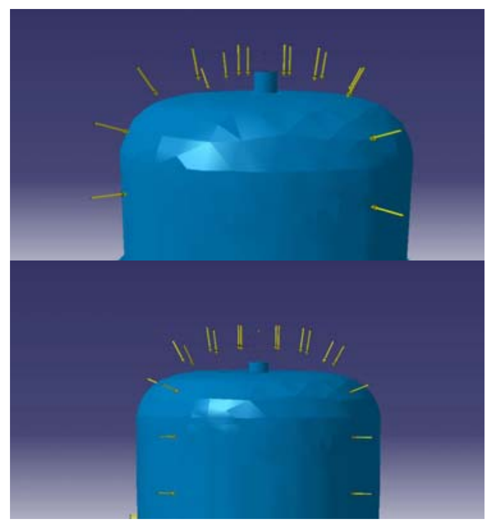

Figure 10 : Graph of displacement before and after modification

REFERENCES

[1] V. Rigaud, Robotics state of the art versus subsea intervention, Report of the UNION project D1.2, ESPRIT-BRA, 1994.

[2] I.D. Bonnon, Rov intervention for effective cable burial-an overview of recent achievements, Oceans 94, vol. 2, Brest, France, 1994, pp.515–520.

[3] J. Amat, et al., Garbı´: The UPC low cost underwater vehicle, Undersea Robotics & Intelligent Control, A joint US/Portugal Workshop, 1995, Lisbon, Portugal, pp. 19–24.

[4] S.M. Smith, Modular low-cost AUV systems design, Undersea Robotics & lntelligent Control, A joint US/Portugal Workshop, Lisbon, Portugal, 1995, pp. 153–157.

[5] J. F. Lots, D. M. Lane and E. Trucco. Application of 2 ½ D visual servoing to underwater vehicle station keeping. Proc. of the IEEE Oceans Conference, Providence, USA, September 2000.

[6] Beer. F.P, Johnston. E.R, 1998, "Mechanics of Material", Mc Graw-Hill

[7] Shigley. J.E, 1998, "Mechanical Engineering Design", Mc Graw-Hill

[8] Saeed Moaveni, 2007, " Finite Element Analysis Theory and Application with ANSYS", Prentice Hall, 3 edition

[9] Zamani. N.G, 2005, " CATIA V5 FEA Tutorials, Release 14", Schroff Development Corporation