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Analysis of the Birns Lights

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ABSTRACT

MBARI's new ROV *Tiburon* has a problem with their deep-sea lights, the lenses continue to break under pressure. The cause of these failures is unknown, but it is thought that a design flaw might be the cause. After analyzing the lenses using a computer modeling program, it was determined that the lenses were probably breaking due to a high stress gradient. Some new lenses were designed on the computer and were analyzed for improvements in the stress gradient. Most of the models did not significantly reduce the stress, although one of them did show a lot of promise. A wider bottom made a large difference in decreasing the stress and the possibility exists that a new lens will need to be created to fix the current problem.

INTRODUCTION

The Monterey Bay is one of the greatest areas in the world for deep-sea research. Canyons as deep as 3,000 meters lie just over 70 km east of Moss Landing, the home of the Monterey Bay Aquarium Research Institute (MBARI). Since 1988, MBARI has owned the Remotely Operated Vehicle (ROV) *Ventana*, which has been used up to four times a week to do deep-sea research in the canyons of the Monterey Bay. *Ventana* has an operating depth of 1,850 meters, a rating that allows the *Ventana* to explore a good portion of the ocean floor in the Monterey Bay.

In 1994, MBARI decided to build another ROV, one that would be able to operate at a depth of 4,000 meters, approximately the average depth of the ocean (Encyclopedia Americana 1997). The ocean floor is a desert of darkness at this depth, as sunlight can only "penetrate perhaps 300 to 400 meters below the surface of the sea before it [becomes] too weak to support vision" (Robison 1995). Because of this, bright lights are required for operations in the ocean. MBARI wanted to use lights on their ROV that would illuminate not just what was directly in front of the lights, but the surrounding environment also. Unfortunately, most of the lenses that were being used at the time were relatively small and worked much like a spotlight, illuminating a small area in front, but not much else (Kirkwood, 1997). MBARI

was able to find a company willing to make a lens to suit their needs, Birns was that company. Birns said they could develop a lens that was much wider, and would then be able to shine light not just in front of the lens, but in the surrounding environment as well. MBARI liked what they saw, and chose to go with Birns.

The ROV *Tiburon* was completed in 1996, and in early 1997, the first ocean test dives began. As with any new equipment, some flaws were detected, and solved, but one problem continued to surface throughout testing. The Birns HMI Lights on the *Tiburon* were not working properly (Scholfield 1997).

The original Birns lights continued to leak during testing, and eventually a new lens design was implemented. Unfortunately, these new lenses did not fare any better than the originals. Because MBARI wanted to get the ROV fully operational as soon as possible, an immediate analysis of the lights and lenses was needed. My research involved analyzing the failures of the Birns lenses to determine if a design flaw existed, and if one did, to either develop a solution to the problem, or design a workable model to replace the one currently in use.

MATERIALS AND METHODS

In order to analyze why the lenses were failing, I used the finite element analysis program created by ANSYS^(R) to model the Birns lights. Unfortunately, the complete model of the Birns lights was very complex, and required more memory than I had available, so I was unable to apply loads to the entire system. Instead, I took apart the model, and analyzed just one piece at a time. I started by modeling the Birns lens.

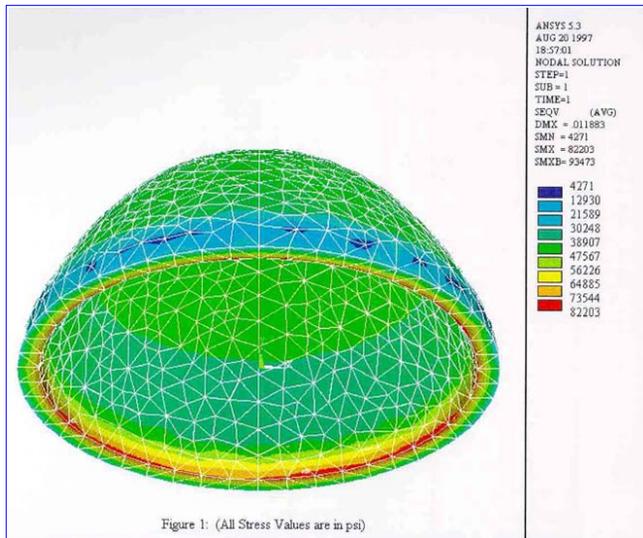
I created half of a hollow sphere by setting the inside radius to 6.414 cm (2.525 in.), the outside radius to 7.048 cm (2.775 in.), and the starting and ending angles to 0 and 180 degrees respectively. I then allowed the computer to mesh the solid model with a free mesh. When this was done, I constrained the model by picking keypoints along the bottom of the sphere. I expanded them to the nodes to constrain the computer model like the lens was constrained by the retaining ring: the lens was simply constrained on the inside (no movement in the vertical plane allowed), and completely constrained on the outside (no movement allowed). A load was applied to the surface of the lens equal to the pressure at 4000 meters under seawater, or 4.83×10^7 N/m² (7000 psi). After completing the model for the Birns lens, seven new designs were created, with different constraints applied to each of the designs. All of the designs were loaded with the same pressure of 4.83×10^7 N/m² (7000 psi), and the computer then solved the model. The details of each of the new designs are explained under the appropriate Model heading.

RESULTS

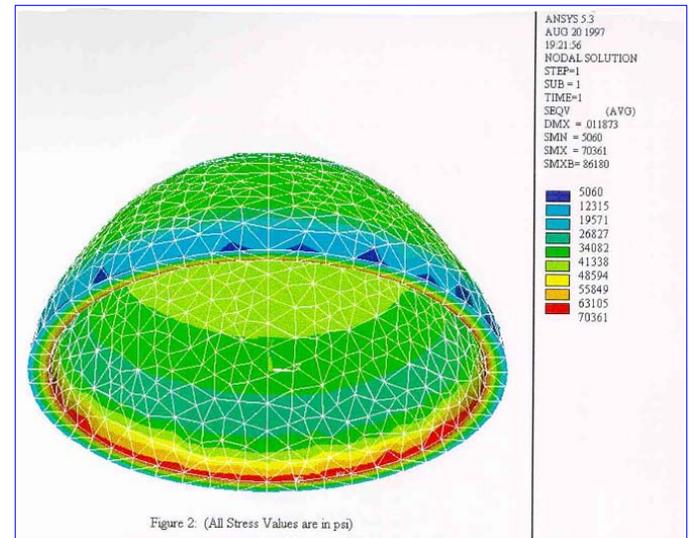
The HMI Lights were tested by Birns at 5.17×10^7 N/m² (7500 psi), and without fault, the lights passed every time. Similar results were found when MBARI tested the lights in their pressure chamber. Although Birns Co. tested these new lenses under pressure, they neglected to test them with the lights on. This was a problem, because when the lenses were tested with the lights on, they failed. MBARI did conduct such testing, and on April 23, 1997, the lens fractured when a pressure of 4.83×10^7 N/m² (7000 psi) was applied. The exact point where the lens fractured was not known, so another test on April 27

1997 was run. The lens cracked at 2.41×10^7 N/m² (3500 psi), a pressure well under the working pressure of 4.03×10^7 N/m² (5840 psi), the pressure at 4000 meters under seawater, and not even half of the required testing pressure (Birns Failure Notes). Similar failures were found during field operations and other "hot tests."

Because of these failures, a computer analysis of the lens was needed. The Von Mises plot of the modeled Birns lens, with a 4.83×10^7 N/m² (7000 psi) pressure applied was created ([Figure 1](#)). There was a very high stress point of 5.65×10^7 N/m² (~82K psi) and gradient, 4.83×10^8 N/m² (70K psi), found in the inside portion of the lens. Changing the constraints of the lens did not significantly affect the results of the stress levels ([Figure 2](#)), so a search for a better lens design began. All of the designs attempted will be shown for completeness.



[Figure 1](#)



[Figure 2](#)

MODEL 1

The first model created was a truncated sphere, with the same constraints as the current Birns model. The bottom 0.52 radians (30 degrees) from the center of curvature was removed. When a 4.83×10^7 N/m² (7000 psi) load was applied to the model, no improvement in the stress levels was seen when compared to the current Birns model. Attempts to decrease the stress gradient by changing the constraints were ineffective.

MODEL 2

For this design, 0.14 radians (8 degree angle) of the lens, with respect to the horizontal, was removed from the bottom of the lens. The same pressure and constraints as in MODEL 1 were applied and again the stress levels were not significantly different from the current lens. Changing the constraints did not help either.

MODEL 3

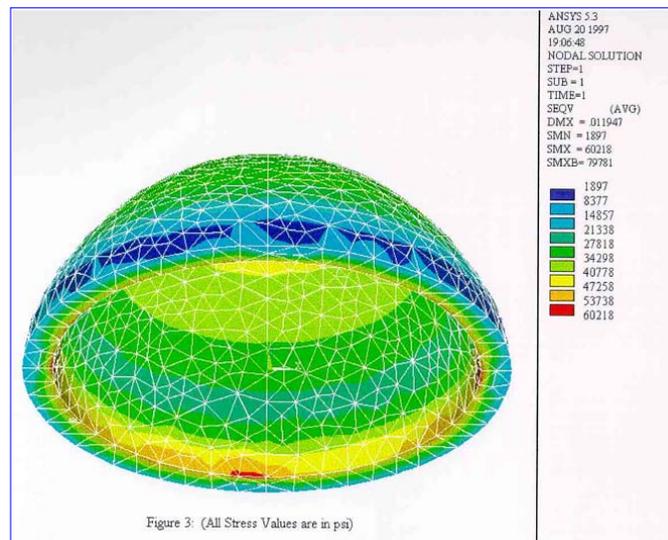
This model was created the same way as *MODEL 2*, but instead of 0.14 radians, 0.26 radians (15 degree angle) was removed from the bottom. The constraints were kept the same, and, like in the previous models, no significant changes in the stress levels appeared when tested at a pressure of 4.83×10^7 N/m² (7000 psi).

MODEL 4

This model had the same inner radius as the Birns model, and in an attempt to improve the area over which the high stress gradient existed, the outside of the lens was pushed out. The result was that the outer radius was 7.684 cm (3.025 in.) with respect to a center that was 0.64 cm (.25 in.) below the center of the inner radius. What this did was create a thickness of 0.64 cm (0.25 in.) at the top of the sphere, the same as the Birns model, and nearly 1.25 cm (~ 0.50 in.) at the bottom of the sphere. The constraints that worked the best were when the lens was simply constrained on the outside, and completely constrained on the inside. The high stress values not only decreased to below $3.45 \times 10^8 \text{ N/m}^2$ (50K psi) from $5.72 \times 10^8 \text{ N/m}^2$ (83K psi), but the gradient along the bottom of the lens was nearly cut in half, from $4.83 \times 10^8 \text{ N/m}^2$ (70K psi) to $2.62 \times 10^8 \text{ N/m}^2$ (38K psi).

MODEL 5

The difference between this design and *MODEL 4* is in the thickness at the bottom. Instead of 1.25 cm (~.50 in.), the thickness at the bottom was 0.95 cm (0.375 in.). The thickness at the top was still 0.635 cm (0.25 in.), and the inner radius was still 6.414 cm (2.525 in.). The radius of the outside was 7.373 cm (2.903 in.) from a center that was 0.3246 cm (0.1278 in.) below the center of the inner radius. For this model, completely constraining the inside and outside of the lens produced the best results when a pressure of $4.83 \times 10^7 \text{ N/m}^2$ (7000 psi) was applied ([Figure 3](#)). The high stress was about $4.07 \times 10^8 \text{ N/m}^2$ (59K psi), and the gradient was approximately $3.52 \times 10^8 \text{ N/m}^2$ (51K psi).



[Figure 3](#)

MODEL 6

This design is similar to *MODEL 5* in all respects but one. The top of the lens had the same thickness as did the bottom, but the radii changed. The outer radius was the same as in the Birns model, 7.048 cm (2.775 in.), and the inner radius was the same from 0.31 radians (~0.18 degrees) to 2.83 radians (~0.163 degrees), measured from the horizontal. At the points where the curvature stops, the lens dropped vertically with a fillet radius at the intersection of 0.64 cm (.25 in.). Depending on where the constraints were applied, the lenses ranged from $3.86 \times 10^8 \text{ N/m}^2$ (56K psi) to $4.76 \times 10^8 \text{ N/m}^2$ (69K psi) for maximum stress, and had a gradient range from $2.14 \times 10^8 \text{ N/m}^2$ (31K psi) to $2.90 \times 10^8 \text{ N/m}^2$ (42K psi).

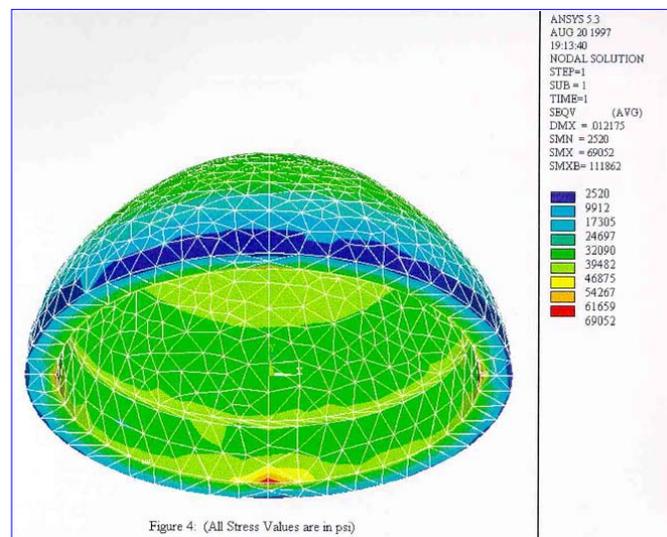
MODEL 7

In an attempt to alleviate the stress at the inside bottom portion of the lens, a lens was designed with rounded edges at the bottom instead of a sharp corner. When a pressure of $4.83 \times 10^8 \text{ N/m}^2$ (7000 psi) was applied, the stress levels were actually higher than in the Birns model.

DISCUSSION

The Von Mises stress plot of the original Birns lens showed the stresses in the lens to be on the high side, especially along the inside bottom portion of the lens. When coupled with the results of our lens failures, which showed heavy spalling in the same area as the computer model, it was determined that there could be a design flaw in the lens. For that reason, seven new models were created to try and lessen the stress in the lens. Models 1, 2, and 3 did not show any significant change from the values in the Birns model. Model 7 did not do what was expected, and was actually worse than the current Birns lens. Model 4 looked good, but its design purpose was to see what would happen if the area was increased at the bottom of the sphere, not to be used in a real design, basically because the lens was too thick at the bottom to be effective. However, this model did serve its purpose, as it led to the creation of Models 5 and 6.

Model 5 had significantly lower stress values than the Birns lens, but because the outside radius was larger than the current Birns lens, the entire structure of the lens would have to be redesigned in order to use this model. Model 6 on the other hand, had the same outside radius, and had lower stress values than Model 5. For this reason, Model 6 would be a good candidate as a new lens prototype. When this model was simply constrained on the outside, and completely constrained on the inside, the results looked the most promising ([Figure 4](#)). Even though the value of $4.76 \times 10^8 \text{ N/m}^2$ (69K psi) looked like it was not very different from that of the Birns model, or even better than Model 5, a close examination of the stress plot showed that this high value was caused by a computer anomaly.



[Figure 4](#)

When the computer meshed the lens, it created more segment intersections in a couple of places around the bottom of the lens. Because of this, when the computer tried to create the stress plot, it was forced to put an abnormally small stress value on the outside of the lens, and a large stress value on the inside. By examining the portion of the lens where these anomalies did not exist, it was found that the high stress

value was actually somewhere between $2.76 \times 10^8 \text{ N/m}^2$ (40K psi) and $3.10 \times 10^8 \text{ N/m}^2$ (45K psi) while the stress gradient dropped to about $2.07 \times 10^8 \text{ N/m}^2$ (30K psi). The "thick at the bottom" lens looks like the type of lens that will work the best.

RECOMMENDATION

At this time, there is still quite a bit that needs to be done before we can say this problem has been solved. First of all, a comparison of the stress plot of a working lens would be good. Because we are also using the Deep Sea Power and Light (DSPL) HMI lights, a comparison with this lens would be good. In order to do this, a model of the DSPL lights needs to be created in ANSYS^(R) with the same pressure load applied. Comparing the two Von Mises stress plots might show if we are on the right path to finding a solution.

A computer model with a thermal load is also needed. There might be more than just a structural problem, so it would be good to apply a thermal load and analyze those results for structural problems. Once a thermal model is working, a combination of the thermal and structural loads would be beneficial. After these models are completed, a review of the results will be necessary to determine how best to proceed.

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RELATED LINKS

- [ROV Ventana](#)
- [ROV Tiburon](#)
- [Birns Company](#)

- [ANSYS\(R\)](#)
- [Deep Sea Power and Light](#)