Under Pressure: Testing Before Deployment is Integral to Success at Sea

Rigorous Pressure Testing Can Uncover Problems Before They Become Costly

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"Nature sides with the hidden flaw" is a fitting corollary to Murphy's law. Success below the high seas comes largely from detailed planning and careful preparation. Capt. Don Walsh, pilot of the bathyscaphe Trieste I, in its historic two-man dive to the floor of the Challenger Deep in the Mariana Trench, recently said, "Successful operations depend upon a skill-to-luck ratio. While luck is important, you always want skill to be more than 50 percent."

Pressure testing has a long and storied history and remains one of the most useful tools designers have available. It is a critical part of preparation, but often one of the first steps to be cut when resources get stretched. With the limited availability of ship time, combined with the high cost of ship operations and equipment and long lead time of grant and project funding, it makes financial sense to validate system integrity before deployment. Equipment should not see pressure for the first time on its first deployment. External pressure testing is a critical environmental test that is part of routine mechanical testing protocols. Ideally, pressure testing should simulate the actual conditions of operation and complement a full systems test that includes electronics and software validation.

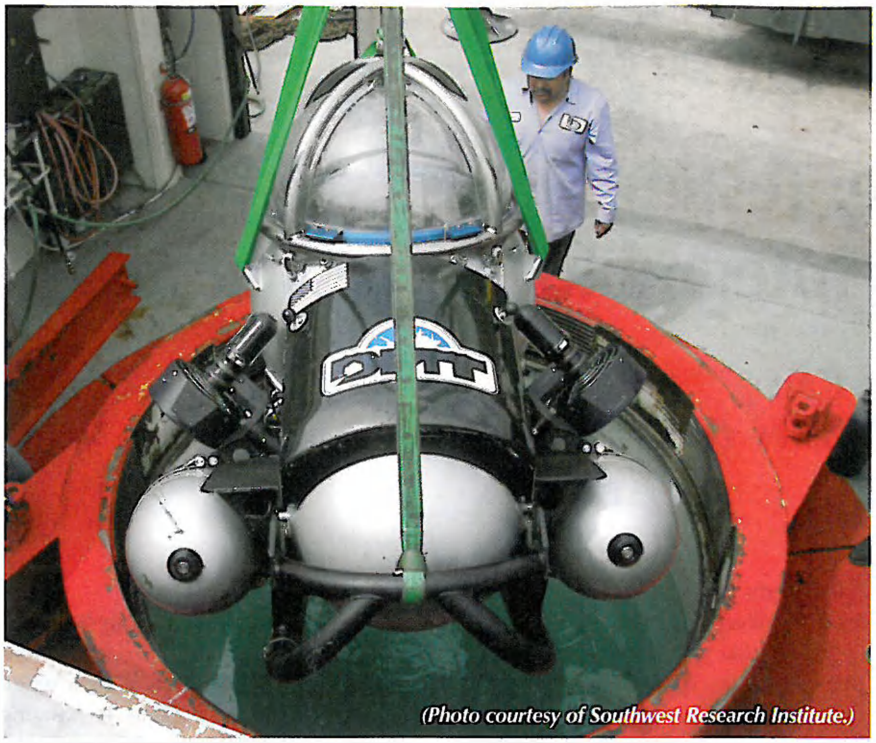
This article will summarize current pressure testing paradigms and protocols used with pressure testing facilities, based on the experience of operating the DeepSea Power & Light high-pressure chambers, some of which operate to 30,000 pounds per square inch under computer control. This article is limited to a discussion of external hydrostatic pressure testing.

(Above) A new pressure housing design was intentionally taken to crush depth to confirm the expected failure mechanism.

(Right) Steve Weston poses with this new American Society of Mechanical Engineers-certified 20-inch chamber at DeepSea Power & Light, which can operate to 20,000 pounds per square inch and includes multiple feedthrough ports.

Advantages

There are distinct advantages to pressure testing. "It should work" are not words an end user wants to hear when his instrument or vehicle is hanging below a quick release over some very deep water. Pressure testing is the best means to validate housing integrity before expensive electronics are placed inside. It can reveal hidden mechanical flaws such as extruded aluminum tubing with an unfused seam or an unacceptably thin wall section that was created during the extrusion process. Molded nonmetallic pressure-resistant connector parts can have assorted flaws. Even soft rubber-molded cable



Southwest Research Institute prepares a submersible for a hydrostatic test. The facility operates ocean simulation chambers with diameters up to 90 inches and pressures to 30,000 pounds per square inch.

terminations and urethane overmolds can have voids that show up only under pressure when the void collapses and the wires short out. Pressure compensation systems might have problems with component bulk modulus that compromise smooth operation when needed most.

While pressure testing can appear to be time-consuming and adds some cost, in practice it saves time and adds confidence for a successful operation by eliminating failure modes, some potentially catastrophic. A tenured faculty member recently sent a borrowed instrument with a stated six-kilometer-rated housing to 8.4 kilometers, guessing there was sufficient safety margin in the design. Pressure testing was not a convenient option. The device made it to the bottom, and it is still there.

Pressure testing is useful at three key junctures of development: component validation, system validation and proof testing. Component validation qualifies a part for integration into a system. System validation tests the full assembly to the maximum defined static pressure of the "design depth," and it should include cyclic testing to be certain the material can survive repeated deploy-

Rules of Thumb

1. Expect at least a half day to set up and breakdown, depending on test requirements.
2. Failure is an option; that is why we pressure test things. Have a plan to cope with failure. If expensive components do not need to be inside the housing for the initial test, save the aggravation.
3. If there is something that is delicate, should not be touched or needs a little extra care, let the operator know. They appreciate your directness. For one, DeepSea encourages customers be present for complex test plans or to operate their external test equipment.
4. Wet things can be slippery. Use gloves that maximize grip strength, and pay careful attention to handling. Use of pressure facilities is at your own risk. Operators do not assume any liability for damage to your equipment.
5. Operators do not allow clients to operate the pressure system. However, most welcome on-site detailed direction and assistance in testing.
6. It is recommended that a witness be present for any test. Simple pressure testing may be dropped off and picked up later.
7. Review any liability waivers for clarity.
8. Discuss the training and experience of the facility operators.
9. Agree on payment terms before coming to the facility. Understand that most quotes for pressure testing are estimates based on your desired testing protocol. Delays are inevitable as procedures get more complex.
10. Provide a well written plan, including a bill of materials and checklists. Do not make the operator guess. If not present, review the plan with the operator before the test day to prevent a needless delay while the operator tries to determine exactly what was intended.

ment. A test to "crush depth" confirms failure mode. At DeepSea, at least one article of every new housing design is validated by taking the part to implosion—which can be quite exciting for the operators. This may be a costly test, but important information can be gleaned by analyzing the failure mode and comparing calculated versus actual implosion pressures. Proof testing is an in-process quality control test to "rated depth" after manufacture or overhaul.

Also on the plus side, pressure chambers are run by knowledgeable and experienced technicians. Should a part fail, it is easy to pick up the pieces for forensic engineering. Feedthroughs allow data logging and external power supplies. It is a lot easier to get in and out of a chamber than to access the deep sea—and a lot less expensive.

Limitations

There are limitations to pressure chambers. Sometimes the ocean is the only place large enough to pressure test a fully assembled system. Jacques-Yves Cousteau tested the integrity of his new two-man diving saucers by lowering them into the Mediterranean Sea.

Tests of sympathetic implosion require the "infinite" volume of the sea, as pressure chambers rapidly lose pressure with the loss of any amount of volume due to the largely incompressible nature of water. The chamber walls may also artificially cause interactions that could dampen or amplify the shock wave.

Pressure pumps are often positive displacement piston pumps powered by compressed air.

The action is reciprocal, and pressure is added in incremental increases. It is not smoothly linear, even under computer control.

CAE

Computer-aided engineering (CAE) programs, such as DeepSea Power & Light's freeware UnderPressure, provide designers a first-order analysis of simple housing integrity against the affects of external pressure. Advanced users will want to study the program for opportunities to modify default material properties to match their actual material. Other simulation programs, such as COMSOL Inc.'s (Burlington, Massachusetts) COMSOL 3.5 and SolidWorks Corp.'s (Concord, Massachusetts) COSMOS, provide motion, stress or thermal models, but are costly and are not routinely available to the average designer.

Testing Paradigms

Pressure testing should simulate the actual conditions of operation. Dwell time at the surface before a dive may produce a low-pressure leak that seals with increased pressure. Zooming rapidly to high pressure in a chamber may mask this weakness. Alternately, a high-pressure test may cause a void or other weakness around a seal to collapse. The high pressure will maintain the seal, but the housing will leak during a low-pressure soak test following the proof test. One should also keep in mind that an undulating autonomous underwater vehicle (AUV) or a wire-lowered conductivity, temperature, depth instrument package sees cyclical pressure stresses, while plastics may creep under long-term exposure to high pressure. Pressure testing should model the most extreme of expected conditions.

Testing Protocols

When working with a testing house, it is important to define the test plan in writing. The plan should be offered to

Roster of Pressure Facilities

If your firm offers a pressure chamber for outside testing, readers will benefit from knowing about it. Please send information on your facility to Marine Technology Society fellow Brock Rosenthal at brock@o-vations.com, who has offered to post it to his Web site and maintain it. Please include:

- Contact info (company, contact name, address, phone, e-mail, Web site)
- Chamber size(s)
- Pressure capabilities
- Other features, such as manual or automatic control, feed throughs, data logging, temperature, working fluid and if your site is a secure facility

the testing facility with enough time for them to carefully review and comment on the testing. They have lots of experience, and they are, after all, their chambers. One should include the proposed test dates and be sure to discuss their in-house shop loading to ensure his or her desired window fits within their availability.

The testing protocol should outline the following items.

Purpose. What are the important variables to measure? What defines a pass or fail? Is this component validation, system validation or proof testing?

Standards and Certifications. Are there defined standards to be tested against, such as those of the American Bureau of Shipping, Underwriters Laboratories or U.S. Government specification? If so, be sure to provide a copy to speed up the process.

Safety Factor. What are the design limits, including the safety factor? How were these determined? Safety factors are a matter of choice.

For example, Woods Hole Oceanographic Institutions' deep submergence vehicle Alvin requires testing to 50 percent over its rated depth. Unmanned systems may only require testing to 10 percent over their rated depth.

> ***"When working with a testing house, it is important to define the test plan in writing. The plan should be offered to the testing facility with enough time for them to carefully review and comment on the testing."***

Can Blocking be Used? If this is the first time an empty housing is being taken to the design depth, the interior implodable volume should be filled to 90 percent or more with an incompressible material or hard wood to limit the amount of energy released by a failure. A 98 percent fill may be required if the system is being taken intentionally to failure.

Measurement Techniques. How are variables to be measured? The test may look to simply confirm that no seals leak, but other tests may measure volumetric displacement, strain gauge deflection, acoustic emission or count pressure cycles. Define the test equipment that will be needed and where it will come from. Ask the operator what equipment they might have or suggest.

Calibrations. Are gauges, meters and other measurement devices in current calibration?

Environmental Simulation. Define the rate of pressurization and depressurization, number of cycles, hold times at pressure and at sea level, water temperature, fresh or saltwater and test pressure.

Electrical Interface. Specify the voltage and current requirements for any power-on testing and specify the required connectors the test house may need to interface to the project. Note that this may incur additional costs and preparation time if the test facility has to procure special nonstandard connectors to support the test or fabricate a custom adapter plate.

Pressure Compensation. Is there oil or other hazardous material that may need to be dealt with? How will it be contained? Provide the material safety data sheet to the operators. Is there compressed air to deal with? Specify the venting plan intended during depressurization.

Hazards. If the housing fails and water gets inside, are there materials, like lithium batteries, that will react vigorously with water? If a seal fails and the interior becomes positively pressurized, is there a way to relieve the interior pressure safely?

Sample Size. How many tests are needed for the statistics sample size?

Conclusions

Pressure testing is a critical part of preparation and a key to success at sea. It is a critical environmental test that should always be part of routine design and manufacturing validation. Pressure testing should simulate the actual conditions of operation. It provides the operator and deck crew confidence in the system being deployed.

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References

For a full list of references, please contact Kevin Hardy at Kevin_Hardy@deepsea.com. For further information on DeepSea Power & Light's pressure test facilities, please contact Edward Vega at Edward_Vega@deepsea.com, or for information on Southwest Research Institute's chambers, contact Jesse Ramon at jesse.ramon@swri.org. ■

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COVER—A Nortek acoustic Doppler velocimeter, as seen through a fisheye lens, is used to measure currents and waves in Mallorca, Spain. (Photo courtesy of Eduardo Infantes Oanes.)

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