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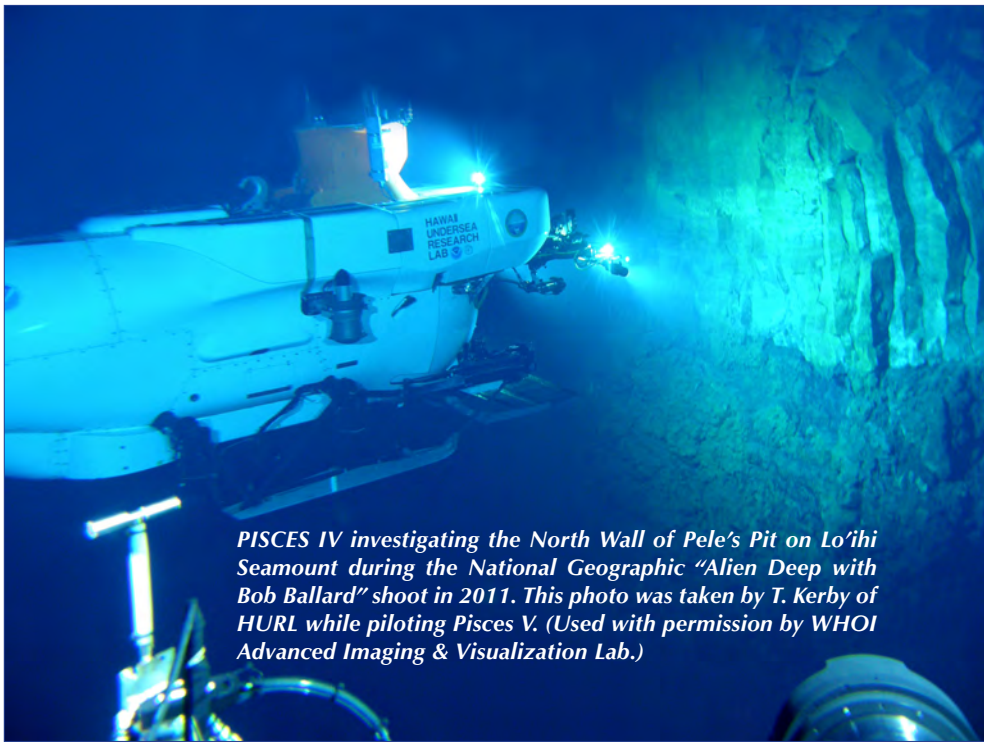
Cable Assemblies for Manned Research Sub

6 Km-Rated Connectors for Main Power Cable of Pisces IV

By Amy Brown • Maximilian D. Cremer

For 35 years, the Hawaii Undersea Research Laboratory (HURL) in Oahu, Hawaii, has specialized in providing scientists across the globe with the tools and expertise they need to investigate the undersea environment, using its two manned submersibles, as well as ROVs. HURL is now an Organized Unit under the School of Ocean and Earth Sciences and Technology (SOEST) at the University of Hawaii, and was part of NOAA's Office of Ocean Exploration and Research until March 2012, when federal funding ended.



PISCES IV investigating the North Wall of Pele's Pit on Lo'ihi Seamount during the National Geographic "Alien Deep with Bob Ballard" shoot in 2011. This photo was taken by T. Kerby of HURL while piloting Pisces V. (Used with permission by WHOI Advanced Imaging & Visualization Lab.)

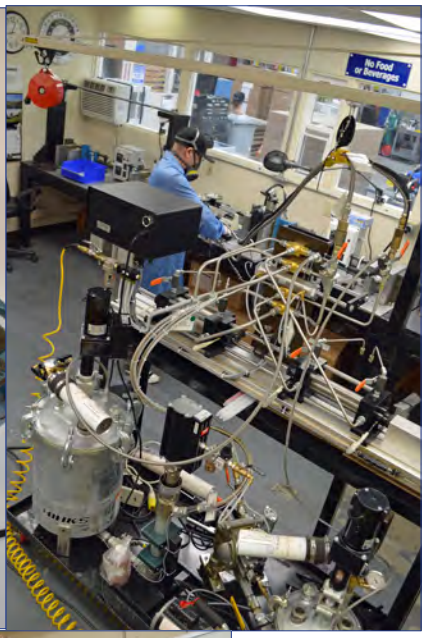
In early 2016, the team at HURL was preparing for a busy dive season, including more than 60 scheduled dives in the South China Sea, with its manned submersibles Pisces IV and Pisces V when an urgent need to replace the Pisces IV's 11-year-old, 24-V main power cable arose. This critical item needed to be stripped down to bare metal, as the outer cable jacket had outlived its expected service lifetime (due to years of prolonged exposure to seawater and sunlight) and needed to be repaired and received back in just one week—an extremely short turnaround time.

HURL asked BIRNS, Inc. of Oxnard, California, a manufacturer of high-performance connectors, cable assemblies and lights for the marine industry, for a solution that could help them meet the narrow window for the repair. BIRNS was also asked to create a new, identical, complete cable assembly to eventually replace the repaired cable to remain in line with HURL's dive season project deadlines. BIRNS determined that it could meet the required turnaround time and first repaired the cable to keep HURL on schedule.

Pisces Background

The Pisces IV is a 20-by-10-by-11-ft., three-person, battery-powered, 13-ton submersible with a depth rating of 2,000 m. It has been widely used for research in the subsea scientific community since 1972. It has three acrylic viewports, as well as an extensive array of operational capabilities, including sample collecting, environmental sensing and instrument placement.

The Pisces IV and Pisces V drew worldwide attention in 2011 by successfully executing the first two-sub dive series inside an active volcanic pit crater, "Pele's Pit" on Lo'ihi Seamount, Hawaii, for a 3D HD National Geographic documentary with the oceanographer Bob Ballard. During their tenure at HURL, the two submersibles have performed more than 1,100 successful deep ocean science missions throughout the central and western Pacific. Other notable achievements include, but are not limited to: 12 "first descents" to active submarine volcanoes in the Kermadec Back-Arc, north of New Zealand; an 18-consecutive-year investigation of Lo'ihi Seamount, an active submarine volcano south of the Big Island of Hawaii; the first dives on the enigmatic Necker Ridge in Papahanaumokuakea Marine Reserve in



(From top to bottom) A J-STD-001 Class 3 certified technician electrically terminates the penetrator end of one cable. The terminated connectors and penetrators are overmolded in BIRNS's NAVSEA S9320-AM-PRO-020 certified facility, with a custom double acting meter mix and dispense system. A BIRNS technician uses a custom Kikusui system to subject the final assembly at 707-VDC/500-VAC minimum, with a requirement of greater than 200 megohms between pins and shell. 6km-rated BIRNS Primum cable plug (CP) with two 8AWG conductors (MSSL-2-CP-CA) terminated and overmolded to 12 in. of 14/4 polyurethane cable and a 1-14 threaded stainless steel penetrator body and 48-in. inboard flying leads. View of Pisces IV upper battery pod with removed lid. Visible are 18 of 60 cells of the 120-VDC battery and all 12 cells of the 24-VDC battery.

the northwestern Hawaiian Islands; the discovery of three giant, top-secret, Japanese World War II submarine aircraft carriers on the seabed south of Oahu, Hawaii; and the discovery of the near mythical "Ward's Midget", an 80-ft. small attack sub operated by two crew, which was sunk by the Navy destroyer USS *Ward* 1 hr. prior to the Japanese air raid on Pearl Harbor, Hawaii, on December 7, 1941. The sinking of "Ward's Midget" marked the very first shot fired by the United States in the Second World War and thus possesses enormous symbolic historical significance.

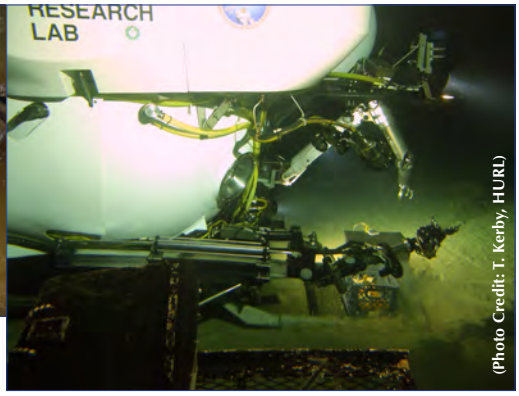
Initial Cable Assembly Repair

The cable assembly needed for the Pisces IV was a straight 6 km-rated BIRNS Primum cable plug (CP) with two 8AWG conductors (MSSL-2-CP-CA) to be terminated and overmolded to 12 in. of 14/4 polyurethane cable and a 1-14 threaded stainless steel penetrator body and 48-in. inboard flying leads. First, BIRNS focused on repairing the assembly with the degraded cable jacket that had been installed and used on the Pisces IV since early 2000. BIRNS technicians stripped back the polyurethane to expose the wire and isolate the short on the inboard side of the connector. Once the short was found, the team cleaned around the wires and reconnected them. Next, it was tested for insulation resistance (IR), new polyurethane was reapplied on the reworked assembly, and final inspection and another round of IR testing were conducted. The BIRNS team worked diligently and successfully completed the entire job and shipped the reworked cable to HURL within a mere one-week time period. The cable repair was intended to keep Pisces IV going for about 25 dives until it could be replaced by the new assembly during a scheduled battery service.

New Assembly

BIRNS then focused on developing a new cable assembly to eventually replace the repaired cable. While the repair work was essentially stripping the damaged unit down to bare metal and then rebuilding it, an entirely new assembly was built to be part of the main 24-V power feed from the vehicle's sealed battery pod through to the command sphere of the Pisces IV sub. Because of the demanding subsea environment and the need for lengthy life expectancy of the cable and connectors, BIRNS Primum connectors, which are designed for extremely heavy-duty use, were used. The robust connectors are made of 316 stainless steel passivated per ASTM A967 and provide high open-face pressure resistance.

First, BIRNS created the inserts for the CP and for the penetrator on each end of the cable. The BIRNS Primum MSSL-2-CP connector end of the cable would mate with the main 24-V power cable coming from the command sphere of the sub. Its insert had a diameter of 1.026 in. and its two sockets were 0.150 in. (gap) and 0.400 in. (center to center) apart. The CP's engaging nut had a diameter of 2.43 in. The other end of the cable featured a BIRNS custom 90° ABS Product Design Assessment (PDA) certified penetrator that was developed with a modified BIRNS Primum MSSK BCR sub assembly with a unique double-ended insert. The insert was designed to permit attachment of cable from both sides,



(Photo Credit: T. Kerby, HURL)

(Left) Rebuilt BIRNS 24-VDC cable assembly with 90° penetrator installed. (Right) Pisces IV exercising its robotic manipulators during a 1,500-m test dive off the coast of South Oahu October 2014.

and would also serve as a last-line-of-defense pressure barrier; even if the cable and overmolding were inadvertently sheared off, the penetrator wouldn't leak. By making the insert double-ended, as opposed to having wires pass through it, it provides an impregnable pressure barrier that nonetheless retains the ability to pass electrical power. This double-ended insert is 0.875 in. in diameter and its two pins are 0.066 in. (gap) and 0.300 in. (center to center) apart from one another.

Pisces IV's lead-acid 120-VDC at 330-ampere hour (Ah) capacity/24-VDC at 220-Ah capacity batteries are housed in two interconnected, oil-filled pods, so BIRNS selected materials for the assembly that would survive long-term immersion in oil. BIRNS technicians would terminate cable to inboard leads of the battery and to the outboard CP. The 90° penetrator, which featured two jam nuts to provide good anti-turning security, would be installed on the battery lid, with the 8AWG conductors being the positive and negative lead coming from the serially connected, 12-each, 2-V/220-Ah battery cells. The 120-VDC battery bank supplies power to the sub's major power users; the vehicle is capable of 3 kt. and dive durations up to 9 hr. Propulsion for the sub is provided by two tiltable side-mounted reversible thrusters. Both the 120- and 24-VDC battery banks consist of tall, narrow mining truck type cells, connected in series. This design helps to avoid electrolyte spillage during extreme tilts. HURL still relies on lead-acid technology mainly for economical and reliability reasons. For example, the annual battery budget of less than $20,000 is an order of magnitude (10x) lower than alternative, more modern power plants such as silver-zinc, lithium-ion or fuel cell technologies that are also being used in deep-sea vehicles.

The 24-V battery supplies power to the smaller, but still very important applications inside and outside of the submersible, including vital life support functions inside the 7-ft. diameter sphere, such as the carbon dioxide control system. The Pisces IV also has nonpowered redundancies in place in case of vital system failures. The 24-VDC battery also provides power to critical communications functions, including its surface marine VHF and underwater acoustic telephone, necessary to provide constant contact with the surface support team aboard the mother ship, and the sub's hydraulic control, used to manage the circuitry running the 120-VDC hydraulic system. The 24-V battery powers the Pisces IV's tracking transponder, a TrackLink 5000HA USBL submersible tracking system, used to pinpoint the sub's position and follow its progress on the seabed. The vehicle's battery system additionally supports the operation of a wide range of nonvital—but still important—systems, from the sub's main onboard computer, video system and manipulator arm control, to its scanning sonar system and dive data sensors that provide depth, altitude and compass heading.

Some of the most demanding environmental and performance challenges for the cable system include preventing seawater from intruding into the batteries, penetrators, cables and connectors, withstanding hundreds of pressure cycles from 14 to 3,000 psi and back, and providing load to the applications as opposed to generating heat. Therefore, special care was needed in the development of all components of the cable assembly. To fabricate the inserts, BIRNS technicians carefully placed the pins and sockets into precision mold cavities; the molds are precisely located in the press, and then GRE is thermally liquefied and injected into the molds.

BIRNS used a new custom Grimco 40-ton hydraulic GRE transfer press, in which carefully controlled high temperature (302° F) and pressure were applied to cure the inserts. The Plug Insert Socket (PIS) inserts for the CP required 3 min. to carefully inject into their molds and then 5 min. to cure, while the Receptacle Insert Pins (RIP) for the penetrator end of the assembly took 3 min. to inject and 3 min. to cure. The inserts were then inspected using a Mitutoyo direct computer-controlled coordinate measuring machine. BIRNS Quality technicians inspected both inserts to the tightest tolerances with 9-micron accuracy and 3-micron repeatability with this device, which allows computerized geometric inspection of connector pins, shells and other key components. Next, the inserts were electrically terminated per J-STD-001 Class 3 in their respective CP and penetrator shells, and then comprehensive in-process termination inspections per WHMA-A-620, Class 3 were conducted. Next, IR testing was performed at 707-VDC/500-VAC minimum, with a requirement of greater than 200 megohms between pins and shell.

Then the terminated connectors were overmolded with polyurethane to the cables in BIRNS's NAVSEA PRO-020 certified molding facility. The overmolding process included the application of epoxy adhesive, the application of primers, and a two-part polyurethane mixture heated and mixed in BIRNS's custom precision double-acting meter mix and dispense system and then injected into a mold, which was then electronically heated to a controlled temperature for each connector. Once the overmolded assembly had cured, BIRNS technicians conducted a comprehensive visual examination of the assembly to ensure that no voids, gas bubbles, flash (ridges on the exterior of the molding larger than 1/32 of an inch/0.7938 mm) or other imperfections existed. Subsequently, the team performed bend and nondestructive tests per PRO-020, and then a final round of IR testing was successfully performed on the assembly.

Installation

HURL's team has a precision installation procedure for the cable assembly. Prior to sealing the battery, the cable connecting it to the outside of the sealed containment will be installed. First, the battery inside the normally oil-filled containment will be tested for proper voltage, polarity and adequate capacity. Then, after a thorough visual inspection and preparation of the sealing surfaces, the 90° penetrator with the 8AWG leads will be carefully fed through its hole in the battery lid. Next, the backing nut will be installed and

"BIRNS was also asked to create a new cable assembly to eventually replace the repaired cable."

the penetrator tightened to about 25 ft.-lb., taking care to maintain proper orientation of the outside cable assembly. Once installed, the voltage will be tested again to ensure correct polarity and potential. Finally, the battery will be sealed up, leak tested and installed in the Pisces IV. The new cable assembly will be installed this July.

Conclusion

The BIRNS team was proud to have been able to meet the demanding deadline for repairing the original cable and developing the new cable assembly to eventually replace the repaired cable to keep HURL's activity time frame on track. At the time that this article was written, the repaired cable installed on Pisces IV was working well. So far, three test dives, one maximum depth certification dive to 2,000 m (6,500 ft.), and one contract dive have been completed in March with the repaired cable.

Unfortunately, the much anticipated, $4.6 million, four-month expedition to the South China Sea was cancelled virtually at the last moment due to concerns about the escalating geopolitical tensions in the area. Negotiations are underway to restart the project if and when the tensions subside. HURL is looking forward to diving both subs on a number of deep-sea projects around the Hawaiian Islands this coming fall. **ST**

Amy Brown is the director of corporate communications for BIRNS, Inc. and is responsible for developing and managing a comprehensive set of strategic external marketing, media relations and internal communications programs.

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