Robust open-ocean AUV launch and recovery systems

Walton, Jim

Simple Systems Have Proven Reliable and Cost-Effective, Logging Hundreds of Safe AUV Launches and Recoveries

Much of the launch and recovery (L&R) of developmental autonomous underwater vehicles (AUVs) is accomplished with simple harnesses and fixtures similar to rigging used in terrestrial equipment lifts. Small boats, riggers, swimmers and divers are normally required in support.

These techniques work well in calm waters but become significantly more difficult and dangerous as remotely operated vehicles (ROVs) and AUVs venture offshore into high sea states. Many of the solutions to the open-ocean L&R of vehicles have employed sophisticated compensators attempting to automatically control the forces of the L&R. Many of these sophisticated solutions result in large, highcost, low-reliability systems.

The Ocean Systems Division at Space and Naval Warfare Systems Center San Diego (SSC-SD) has a long history of launching and recovering open-ocean buoys, autonomous oceanographic equipment, ROVs and AUVs. In fact, SSC-SD has developed over 30 manned and unmanned submersibles and their L&R systems over the last four decades.

The L&R systems have ranged from complex motion-compensated cranes and winches for ROVs to simple sea-state tolerant ramps and cocoons for AUVs. Based on this experience, SSC-SD has settled on simple and robust approaches as the preferred option for open-ocean L&R of AUVs. AUV L&R techniques developed by SSC-SD are now in use throughout the industry.

SSC-SD Ramps Set a Standard

SSC-SD fielded a system in the early 1970s that employed many of the features that have become standard for high sea-state AUV L&Rs. The system, Sonodiver, employed an unmanned, untethered deep diving vehicle (a simple AUV). It provided a quiet platform for gathering acoustic data at predetermined depths. Sonodiver was launched and recovered through a "garbage chute" device, the predecessor to AUV ramps developed at SSC-SD. Once Sonodiver left the garbage chute, it descended, released its descent weight hovered, took data, released its ascent weight and returned to the surface. Upon surfacing, Sonodiver released a floating line that was grappled using a line-throwing gun. The Sonodiver was then hauled aboard via the garbage chute.

SSC-SD also developed two L&R systems associated with its Advanced Unmanned Search System (AUSS) AUVs. One system was developed for the AUSS prototype (late 1980s) and the other for the fleet-delivery AUSS (1990s). After the Sonodiver approach was analyzed along with other approaches, an L&R ramp system was devised for the prototype AUSS. The design further evolved for the fleet-delivery AUSS system. The tail of the ramp floats on the surface of the ocean as the support ship moves forward. The vehicle is released to slide down the ramp for launch. Both AUSS vehicles deploy floating lines upon surfacing (similar to Sonodiver), which are grappled and brought on-board where they are attached to a line pre-fed into the ramp. The vehicle is then taken in tow and recovered up the ramp.

The AUSS approach satisfies most of the optimum AUV L&R criteria: no swimmers, divers or small boats are required; the vehicle transitions to a ramp, the motion of which is first matched with the surface of the water that the vehicle is riding, and then is transitioned to the ship’s deck motion as it comes on board. The complexities and size of automated compensation systems are avoided by using this method.

Both AUSS ramp systems are focused on simplicity, ease of use, durability, reliability and low cost. These systems are completely me-
chanical except for electric motors driving standard deck support equipment (winches, capstans, etc.). The value of these simple, inexpensive features are validated by the fact that 134 AUSS L&R evolutions have been accomplished with no vehicle damage and no loss of operational time associated with the ramp systems.

The prototype ramp design employs a cart held in place at the aft end of the ramp. The cart provides docking and centering of the vehicle as it approaches from astern. The vehicle is pulled via its nose-line up to the cart using a capstan. The cart is released from its secured position once the vehicle contacts it, allowing the cart and the centered vehicle to be pulled to the front of the ramp. Air hoses are then inflated against the vehicle from the sides of the ramp. The air hoses hold the vehicle in place while the ramp is brought aboard. The fleet-delivery AUSS ramp operates in a similar fashion to the prototype ramp except that the vehicle mechanically latches into the cart, and the cart and vehicle are winched up the ramp. Both AUSS ramps are brought on deck using a cable winch system. Once on board, the vehicles are moved forward out of the ramp and into a maintenance shelter. Both ramp designs are simple and are all that is required for high sea-state L&R as long as the vehicle structural design is adequate to transfer the load at the nose attachment through its body.

Cocoon Lightens AUV Structures

Another evolution in AUV L&Rs has been the SSC-SD cocoon approach. The cocoon replaces the ramp and provides a shelter for the AUV as it is brought aboard. The cocoon may be used with standard handling equipment aboard a ship. In addition, use of the cocoon lessens the structural design requirements on the AUV.

The cocoon sequence is similar to the ramp sequence in that a pre-fed line goes through the cocoon and out to the vehicle in tow. The vehicle is pulled into the towed/floating cocoon using a capstan.

The cocoon was conceived at SSC-SD when an AUV requiring L&R was not compatible with the ramp approach. The vehicle’s outer finish was not amenable to the rigors of mating and sliding up a ramp, and the vehicle could not structurally tolerate the stress of being pulled up the ramp by its nose. It was decided to pull the vehicle into a floating cylinder and then bring the cylinder and its contents aboard the ship using a U-frame.

Unfortunately, it was not possible to provide a line permanently attached to the nose of the vehicle. A nose cage with a pre-fed line back to, and through, the cocoon was determined to be the best solution for this shortcoming. The nose-cage installation at sea required the use of a small boat and swimmers.

The Navy Oceanographic Office (NAVOCEANO) and SSC-SD cooperated in development of a cocoon system for L&R of vehicles associated with the NAVOCEANO AUV program. Planning meetings between the two organizations and a design trade-off study resulted in a system approach that employs the AUSS type deployment of a floating line from the AUV that is grappled and then attached to a line that is pre-fed through the cocoon. This requires a deployable line stored in the vehicle but eliminates the need for a small boat and/or swimmers. The vehicle is taken in tow, but in this case it is towed behind the deployed cocoon. The vehicle is pulled into the cocoon where it is captured by large air hoses (similar to those used by the AUSS prototype ramp). Once the vehicle is secure in the cocoon, the cocoon is two-blocked into the U-frame and rotated aboard the surface craft. This was first accomplished with a low-freeboard coastal ship operated by NAVOCEANO (a converted landing craft). A greater challenge has been developing the cocoon capability for the NAVOCEANO T-AGS 60 Navy ships, which have about 10 feet of freeboard astern.

T-AGS 60-Class and Cocoon

The motion of the nose of a cocoon-recovered vehicle will first be matched to the motion of the cocoon's tail, and the vehicle gracefully transitions to match all motions of the cocoon while it is pulled into the system and captured. The cocoon, with the vehicle inside, adjusts to the motion of the ship by first being two-blocked (pulled as far as it will go) to the U-frame and then laid against a stern roller. It is important that the tail of the cocoon remains submerged and the nose of the cocoon remains two-blocked until the
cocoon body is hard against the stern roller to keep the cocoon from swinging.

Finally, the cocoon is laid over center where it is placed upon a saddle or cart while still two-blocked to the U-frame. This is easily accomplished on a ship with little freeboard and a standard U-frame with reasonable angular throw.

Some new issues arise with a ship of significantly greater freeboard such as the T-AGS 60. It is tempting to violate the two-block criteria at either the aft extent or the forward extent of the U-frame throw on the larger ship, since this seems to allow the use of a standard U-frame. Violation of the two-block criteria means that the cocoon line has been paid out at some point in the process. The nose of the cocoon in this circumstance is allowed to swing rather freely, resulting in a dangerously under-restrained system.

The SSC-SD/NAVOCEANO team concluded that there are two design criteria that best address the higher freeboard challenges. The first design requirement is for a U-frame that rotates nearly 180[degrees] (from horizontal aft to horizontal forward). The second need is for an extension in the length of the cocoon to assure its tail remains in the water until it is laid into the stern roller. An extension module was added to the cocoon. The U-frame design employs rotary actuators to accomplish the large angular rotation without taking excessive amounts of deck space forward. SSC-SD designed and delivered the cocoon and the U-frame (after undergoing the rigors of ABS approval) and assisted NAVO-CEANO in the installation and early testing of the system aboard the T-AGS 60 USNS Bruce C. Heezen. NAVOCEANO has taken the system to sea and has reported safe/reliable operation during high sea-state L&R.

Commercial Applications

One very simple AUV L&R approach is the Ocean Workers patented system. Ocean Workers states that their system benefits from features of two proven Navy system approaches (the ramp and the cocoon). The Ocean Workers system requires a vehicle that deploys a float for grappling and has the structural integrity to be pulled out of the water by its nose onto a small ramp with rollers. One of the major advantages is that the U-frame, winch and line used in the cocoon approach are replaced with a cable and trolley system integrated into the maintenance van itself. The other piece of equipment that must be transported and installed at the stern of the ship is the small ramp that the vehicle rolls over for launch and lays into for recovery.

Conclusions

An AUV that can be taken in tow with a nose-line deployed upon surfacing, and furthermore withstand the rigors of loading and being hauled out of the water over rollers, can benefit from a simple, easily transportable system such as the Ocean Workers design.

A launch ramp smoothly transitions the AUV from the water to the deck of the boat by stepwise matching of the AUV motions, first to the ramp and then to the ship. A properly implemented ramp may decrease the amount of force that must be carried through the shell and body of the vehicle. Ramp installations can be quite involved if the ship interface is not carefully considered during system design.

A cocoon L&R system can be the most protective for the AUV and least structurally demanding on the AUV. This may lead to a lighter AUV using lighter materials and having less structure-born weight. The cocoon approach can, in some cases, be accomplished with existing ship handling equipment but usually an integrated U-frame design is required.

In the case of the NAVOCEANO T-AGS 60-class ships, a design/tradeoff study supported the cocoon approach when high sea-state, high-freeboard and AUV-vulnerability issues were taken into account.

Robust AUV L&R systems for the open ocean have been in use for the last two decades, although their evolution has been underway during most of the last four decades.

Prudent AUV developers may want to take advantage of this evolution and experience, identify L&R system features that are
important to their specific AUV at the beginning of vehicle design process and design a simple integrated system that satisfies those features. /st/

By Jim Walton

Head, Ocean Systems Division Space and Naval Warfare Systems Center

San Diego, California

Jim Walton heads the Ocean Systems Division at SSC-SD. Expertise within his organization includes undersea robotics, fiber optics, electro-optics, targets, acoustics, nuclear sensors, diving, and maritime test and evaluation. He has over 25 years experience in designing and leading the design of prototype and fleet-delivery underwater systems. He has patents in acoustic sources, ROV tool systems, and AUV launch and recovery. Walton has led over 200 sea tests, most of which involved undersea vehicles, and led over 100 successful AUV launches and recoveries. Systems he has designed have been used for over 800 successful open-ocean AUV launches and recoveries.

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