AN EVALUATION OF DIVING AND SUBMERSIBLE SYSTEMS[1]

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HISTORY

One of the first written records of man's ability to work underwater is found in the writings of Herodotus in the 5th Century B.C. He tells of a diver named Scyllis who worked to recover sunken treasure for King Xerxes. There are many other accounts of divers working underwater by holding their breath for two to three minutes but it was not until 1500-1800 A.D. that any significant advancements were made which could be attributed to present day diving technology.

During the period after 1500, a device called a diving bell came into the forefront as a practical tool to explore the underwater world. The device was called a bell because it resembled a typical church bell of the times. The first account of such equipment being used was in 1531. Bells did not advance much until the 1680's when an adventurer named William Phipps from Massachusetts supplied air to a bell by lowering inverted, weighted buckets of air to the divers. The famed astronomer, Edmund Halley, also developed a bell and demonstrated his system in 1690.

Other inventions by various people were developed but were all like the first diving bells limited by the fact that air could not be continuously supplied to the divers. It was not until the turn of the 19th Century that a hand operated air pump was developed which could deliver a continuous supply of air. This was the first major breakthrough in the advancement of diving technology.

During the 19th Century, numerous inventors continued the development of new and more practice equipment. Among these were John and Charles Dean's "smoke apparatus" and Augustus Siebe's "closed" diving dress and helmet.

A new problem became evident after the advent of the caisson, a French word meaning "large box," which permitted men to work underwater in a pressurized air environment for extended periods of time. Workmen subjected to the pressure in the caisson needed to keep the water out for an extended period of time experienced various painful physiological maladies when they returned to the surface. This ailment was initially called "caisson disease" and was first described by a French physiologist, Paul Bert, in 1878. Workers on the Brooklyn Bridge, using caissons, gave the sickness a more descriptive term, "the Bends". This gave rise to investigations as to the cause of the Bends and the ultimate development of rudimentary slow ascent, "Decompression tables".

J.S. Haldane, an English physiologist in 1907, after having worked with Navy divers, theorized that part of the "Bends" was due to insufficient ventilation in the diver's helmet and, consequently, high levels of carbon dioxide. He then developed the first "stage" decompression tables which remain the basis of modern day tables. The result of Haldane's discoveries was an extention of depth for air divers to 200 ft.

From this time, diving technology slowly progressed at an arithmetic rate until the late 1950's and early '60's.

At this point, technology began advancing at a exponential rate leading to the state-of-the-art diving systems of 1978.

MANNED DIVING SYSTEMS

Diver in the Water

S.C.U.B.A.

SCUBA is a acronym which stands for Self Contained Underwater Breathing Apparatus. A diver using this system is untethered and normally has no back-up life support.

There are three basically distinct SCUBA systems. The first is open circuit SCUBA whereby compressed air is regulated from high pressure to a low pressure demand regulator. Once the diver exhales this air, it is lost into the environment. The second system is a semi-closed one where exhalations are partially recovered and "scrubbed" of carbon dioxide. Fresh air is provided to the diver at a predetermined rate. Divers can conserve air in this mode that is lost using simple open circuit. The third and most sophisticated SCUBA system is the closed circuit unit. A diver's gas is entirely retained and none escapes from the unit accept during ascent. Carbon dioxide is scrubbed from the gas envelope and oxygen is automatically added as needed upon demand by an electronic signal from oxygen sensors. The only gas consumed is oxygen and a few cubic feet of diluent gas needed to keep the breathing gear inflated to ambient pressure during descent.

The most obvious advantages of using SCUBA are the relative simplicity of equipment and the freedom of movement experienced by the diver. The major disadvantages are that the diver is limited to the amount of time he can spend in the water and the maximum depth at which he can safely work. SCUBA is mainly used by the sport and scientific community and is not recommended past 180 ft.

Surface Supplied Diving

This is a method of supplying a breathable gas (air or mixed gas) to a diver via an umbilical system from the surface. The diver's umbilical always consists of at least the following: gas supply hose, communication line and pneumo fathometer line for topside diver depth indication. His umbilical may also contain other gas lines for pneumatic tools and hoses for hot water supply to the diver's suit. A bailout bottle or high pressure gas storage cylinder is generally worn for emergencies if normal umbilical gas supply is interrupted. In addition to the diver's gear, topside support is also required. This equipment consists of a vessel or barge suitable for the type of work involved. The vessel must be equipped, in addition to normal shipboard gear, with low and high pressure air compressors, deck decompression chambers, control van for communications, high pressure gas storage banks, oxygen transfer pumps and gas regulator controls. The vessel or barge must also be equipped with multi-point mooring. Usually at least three points are needed.

Besides SCUBA, this is the second simplest form of diving. The diver is in constant communications with the surface and can receive an unlimited amount of air or gas via his umbilical. With this method, the diver is limited to a maximum depth of 350 feet. This limitation is based on safety and the length of decompression required in the water.

Bell Systems

Submersible Decompression Chambers (SDC's) were introduced to the diving community in the early 1960's by Edwin A. Link. For the first time, it was possible to place man on the bottom in a dry environment adjacent to the work site. SDC's typically carry at least two men. SDC's allow divers to descend to bottom depth and return in the comfort and safety of a sealed pressure vessel. Bell systems consist of an SDC, Deck Decompression Chamber (DDC), handling method (to move the bell from the mated position on the DDC to a position where it can be lowered in the water), control van (for communications and life support monitoring), high pressure gas storage banks, umbilical storage/handling system and other related support equipment such as transfer pumps, high and low pressure air compressors,etc.

For the most part, these systems can be divided into two types, short duration and saturation. The two systems are almost identical with regard to overall conceptual design and number of components; however, the saturation system is more complex and larger in physical size to support extended decompressions in comfort. In saturation type diving, divers are usually pressurized on deck under strict control in the DDC to bottom depth. Normally as many as six to eight divers are exposed at one time. Two or three divers enter the SDC through a transfer trunk and are lowered to the bottom. Usually one diver remains in the bell to act as a tender and safety back-up while the remaining diver/divers lock-out (leave the SDC) and proceed to the work site. As much as eight hours can be spent at the work site in this manner while the other members of the diving team rest topside in the DDC. At the end of a work shift, the divers return to the SDC, secure the hatch and are brought to the surface and mated to the DDC where they are reunited with the rest of the team. At this point, the second shift is freed to descend to the work site in the same manner while the first off duty shift rests.

This type of diving is conducted when there is a need to spend considerable bottom time in an area to complete a series of tasks. The method is restricted in time only by the human limiting factors of the divers themselves. Saturation exposures of over 30 days have been performed safely utilizing this technique. The divers need only decompress once at the end of the mission. This decompression profile, however, is quite lengthy and can last as long as a week or more depending on depth. Dives to a 1000' and deeper in the open sea have been performed safely utilizing saturation diving techniques.

A short duration bell system uses many of the same principles as the above with a few changes in operating sequence. In this system, divers are usually lowered to the bottom inside the SDC at atmospheric pressure. Once on the bottom, the divers prepare for their mission prior to pressurization. Normally two divers are present in these smaller SDC's, one working in the water and the other acting as tender inside the bell. At the end of the dive, the diver and tender secure the hatches and initiate an ascent to begin decompression. The SDC is recovered and mated allowing the divers to transfer to the DDC. Decompression for these dives is usually less than twelve hours (depth dependent) and dive depth is normally limited to about 500 ft.

The major advantage of using a Saturation System as compared to Short Duration Bell Diving is only one decompression schedule is used at the end of the mission. The working depth of a Saturation System is limited only by present technology while Short Duration work is generally limited to 500 ft. Also, while saturated, the divers can spend unlimited time at the work site without affecting the decompression schedule.

Bell diving, as compared to Surface Supplied Diving, allows greater safety in that the SDC is close to the diver's work site. Also, no decompression is required in the water.

Submersible Lock-Out Systems

There is only a semantic distinction made between the terms "submarine" and "submersible". The main difference is one of size, a submersible being considerably smaller than a submarine. The term submersible implies a small vessel, capable of submerging with a limited number of crew members. Physical configurations, depth limitations and equipment can vary greatly under the definition of submersibles. When not diving, a submersible is usually hoisted aboard a mother ship where maintenance can be performed while its batteries and gas supplies are replenished. Internal space is limited to accommodate only the passengers and support equipment. Most submersibles carry a crew of two to four persons with one of them being a trained and qualified operator or pilot. When using lock-out submersibles, there is also a trained tender and lock-out diver in the dive chamber. In most cases, the pilot and divers are in separate compartments during a lock-out dive so the pilot and electronic support equipment are not subjected to pressure. After the diver has locked-out and is in the water performing a task, his life support is provided via an umbilical using the submersible's gas supply.

The general advantage of utilizing submersibles lies primarily in placing the human eye and brain at the point of three dimensional observation in the water. The submersible support ship does not require an elaborate multiple point mooring system to maintain precise position during a lock-out dive. Instead, both the submersible and the support vessel are free to maneuver independently of one another. The surface vessel must have electronic tracking equipment capable of monitoring the submersible's relative position at all times. This leaves the submersible free to navigate in order to locate the lock-out area and position it in direct view of the pilot or operator.

The greatest disadvantage of using a lock-out submersible is the limited gas and power supply available to operate all systems and support the diver. In extreme cold water environments, where a diver must be heated, duration of his exposure is limited somewhat as sufficient heat to warm him cannot be supplied for an indefinite period of time.

Manned Atmospheric Systems

Bell Systems

This section covers pressure vessels that have been designed to keep man physically out of the water. He is still at the work site, however, he is in the comfort and safety of an enclosed capsule operating remotely controlled external tools and manipulators to achieve his work task. The shortcomings of these to date have been primarily in the total design concept. Manipulators have proved to be very useful tools if used in conjunction with tasks that have been designed around the manipulator's capabilities. Unfortunately, not many existing underwater structures have been designed to be repaired with manipulators. Therefore, the effectiveness of such systems is limited. Attempts are being made to design bottom hardware that can be serviced with manipulator units.

Basically these systems are bell configured and are equipped with trim and thruster controls. They fall between true submersibles and diving bells. These vehicles derive their power from the surface via an umbilical and are, therefore, limited in maneuverability and bottom area coverage. They have the advantages of being able to supply unlimited amounts of power at the work site. Some of the newer systems are equipped with expensive and sophisticated force feed back manipulators. This type of manipulator so far is the most advanced and functional for performing underwater work. At least one of these can also be used as a diving bell thereby combining the advantages of a manned atmospheric system with those that a diver can personally accomplish.

Other vehicles of this sort are used for entirely different reasons than performing bottom work with manipulative devices. This type of bell was designed to transport personnel to a bottom pressure vessel to mate and achieve an atmospheric seal. Technicians are then transferred into the bottom structure to perform work at atmospheric pressure. The systems are mainly used by the oil industry and are called one atmosphere satellites. Exactly the same technology is used by the U.S. Navy if recovering crewmen from a downed submarine. Basically these systems consist of a surface vessel in a multi-point moor, bell handling system, bell equipped with a special mating flange/seal arrangement, control van and other topside supporting equipment. (Free swimming submersibles have also demonstrated their capabilities in this type of work and, therefore, eliminate the costly and restrictive requirements of having the topside support vessel in a moor).

The advantages of using an atmospheric Bell lie primarily in the use of an umbilical from the surface vessel. The umbilical provides unlimited power to the Bell and real time monitoring to topside personnel. Because man is in the comfort and safety of a one atmosphere environment, safety levels are higher than in man-in-the-water systems. This method is, however, limited somewhat in the tasks which can be performed by manipulators. It is also limited in maneuverability and the area on the bottom which can be covered. The support vessel is required to effect a multi-point moor and cannot readily change position from one area to another.

<u>Submersibles</u>

Once again the description of a manned submersible is more aptly defined as a free swimming, untethered, manned vehicle. A one atmosphere manned submersible is generally thought to have a single spherical or torpedo shaped compartment housing 2-4 persons. The accent on this class of submersibles is on external, remotely operated tool and manipulation systems. Their depth capabilities are generally far greater than lock-out submersibles, some of them being able to reach the greatest depths in the oceans.

The overwhelming advantage using this system as compared to tethered bells is in the greater degree of maneuverability. If one wants to transfer his detailed view from one area to another in a planned or opportunistic manner, the manned submersible permits this. As compared to unmanned remote controlled vehicles, the salient advantage lies again in being able to place the human eyes, brain and integrated reflexes at the point of observation. The third dimension, present only when man can utilize his stereoscopic vision to make decisions is indispensable to maximizing the use of remotely operated tools and manipulators.

This system can be operated at depths where man has not yet reached. Remote controlled tools and manipulators will, however, never be able to replace man's hand; the most versatile tool known to him. In relatively shallow water, accessible to a diver, most tasks can be more expeditiously accomplished by utilizing a lock-out vehicle. These one atmosphere manned submersibles are considered somewhat impractical unless they can perform tasks requiring more strength than man can apply using power assisted tools or if they can work at depths deeper than those to which a diver can be exposed.

Atmospheric Diving Suits

Atmospheric diving suits (ADS) have stimulated inventors and diving enthusiasts for the past century. The basic design concepts were to create an armored diving suit which would free the diver from any and all problems of pressure. With such a suit, he could breath air at normal atmospheric pressure and, hopefully, descend to great depths without any ill effects. The utility of such armored suits was questionable until very recent times. The early models were very clumsy and difficult for the diver to control.

Recently these suits have been redesigned with modern technology and are finding a place in the commercial market. Several models are now available that will allow the diver to descend as deep as 2000 ft. to perform limited tasks. They must, however, be operated with a tether to the surface.

The advantages of using Atmospheric Diving Suits are that the suits are small, lightweight and are easy to handle and transport. Relative size and complexity of the topside support system is greatly reduced. Tasks which can be performed and the work area which can be covered using this method are, however, quite limited.

UNMANNED REMOTE CONTROLLED SYSTEMS

Tethered Systems

The term unmanned submersible generally refers to relatively small, self propelled vehicles which are tethered to a surface craft from which they derive their power and direction. Man, at the control and display console on the surface vessel, is still the most vital link in this system.

These systems range in size, from the smallest, which are slightly larger than a basketball, to large tracked or wheeled vehicles weighing as much as 90,000 lbs. These vehicles vary in degree of sophistication and instrumentation. All are equipped with at least some method of viewing and transmission to the surface in real time. The popularity of these systems can best be described with the following statistical information: It has taken the diving industry approximately three years to develop about 80 of these unmanned systems where it took about 25 years to develop 130 manned submersibles.

<u>Observation Systems</u>

The simplest of the Remote Controlled Vehicles (RCV) are equipped with a television camera and thruster control. Most of these vehicles are very small (100-300 lbs.) and serve a limited function. These vehicles have the advantage of being able to work in very tight places, such as the inner structure of a drilling platform. Because of their size, the handling system and total topside support hardware is also kept to a minimum. They are generally best suited to simple observation. They are not designed to accomplish tasks requiring manipulation, search or salvage.

<u>Intermediate Work Systems</u>

This leads us to the second type of RCV, those designed for intermediate work applications. These are larger (500-3000 lbs.) and are equipped with such items as T.V. still cameras, sonar, manipulator(s), echo sounders, magnetometers, etc. These vehicles provide T.V. monitoring but it is generally used in conjunction with the other vehicle mounted systems to accomplish a particular task. Most RCV's operate from a current deflection device lowered to the bottom and attached to the umbilical system. This arrangement frees the vehicle of potential current drag acting on the entire umbilical length. Generally at least 100 ft. of excursion tether is used between the vehicle and deflection weight.

For the most part, currents are normally found near the surface and become relatively weak at the bottom. Utilizing the deflection weight allows the vehicle relatively free motion near the bottom and de-couples surface vessel heave effect from the vehicle. This system is similar in principle to a lead weight attached to a fishing line to keep the hook in one place or from dragging the bottom. The disadvantage of the system is that one must place the weight relatively close to the work site to allow the vehicle enough excursion tether.

Full Work Systems

Generally speaking, the larger and heavier unmanned RCV's do not operate with deflection weights. These systems are large enough that once they are on the bottom, umbilical drag is of little worry. It should be pointed out that these vehicles are usually used in one area for a considerable time and unlike their mid-water counterparts operate only on the sea floor. These vehicles serve mainly as underwater construction units engaging in heavy manipulator tasks, bull-dozing, pipe line servicing, bottom sampling and reconnaissance, cable burying,etc. Each of the three types of unmanned vehicles have a specific role to play. The eventual choice of which system to use depends on the nature of the mission and the work involved. There is no all-purpose aircraft, ship, automobile or manned/unmanned vehicle.

The major advantage utilizing unmanned remote controlled vehicles is removing man from the water environment. These vehicles can also operate in hazardous areas without endangering personnel. Operational endurance at the work site is unlimited because of the cable link to the surface, but the support ship must be able to maintain station during operations. Crews can easily be changed without disrupting the mission.

All unmanned systems are limited in the kinds of work they can perform when compared to man's capabilities. Because of the required umbilical to the surface, they are limited to the area they can cover and added power is necessary for maneuvering. Many of the manipulative tasks require three dimensional viewing which is not available with existing television systems. Control and monitoring demand intense concentration and limits optimum operator time to about 2 to 3 hours.

Untethered Systems

Untethered remotely controlled systems were in the design/concept stages in the 1960's. The 1970's saw at least two units in limited operation. The vehicles can descend to a preset depth and operate on a programmed course recording some data. One system is equipped with an obstacle avoidance sonar system. These vehicles operate on pre-programmed information. Back-up systems can be activated if the vehicle ceases operation. The most common of these back-up systems is to release a weight so the unit can surface for recovery. These vehicles are still in the design stages and presently have little use, if any, in the working environment. The overall concept is excellent in that you finally rid the vehicle of its number one problem, the umbilical. Present technology, however, does not exist to accurately control the RCV in real time and receive real time video presentations to the surface operator. Data transmission methods, through the water column, need to be designed to allow topside to control and track the vehicle accurately in real time.

The power source for these crafts is also a problem area. Until this area of concern is remedied, untethered RCV's will be very limited in the tasks they can effectively accomplish.

Using untethered Remote Controlled Vehicles versus tethered vehicles removes the umbilical from the control loop and allows a greater freedom of movement. These systems have the advantage of being small, lightweight and easy to handle and the surface vessel requires no mooring or station-keeping system. RCV's, however, have a limited onboard power supply and tasks it can perform are limited. At the present time, technology does not exist to accurately control these systems.

SUMMARY

Numerous types of diving and submersible systems exist today. The eventual choice as to what type to use will depend on the nature of the work involved. In this age of specialization, the user is no longer confined to just a one method approach.

The various methods that exist of placing man in the water presently are limited to present day physiological technology. This places depth and time restrictions on the working diver.

Unmanned submersible systems extend man's depth capability but so far have not advanced to the point of duplicating or replacing human abilities. This indeed may never take place. As one who has been actively involved in the commercial and scientific diving area for the past sixteen years, I dread the thought of removing man entirely from the water environment. I believe he will always have a role to play and that technological advancements will place him deeper and deeper in what continues to be our last frontier.

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