

SUBMERSIBLES FOR OCEAN SCIENCE AND ENGINEERING

B. U. Nayak
Head, Ocean Engineering Division
National Institute of Oceanography
Dona Paula, Goa-403 004

A. K. Suryavanshi
Scientist
Ocean Engineering Division
National Institute of Oceanography
Dona Paula, Goa-403 004

ABSTRACT

Until about 1970, various underwater tasks associated with offshore activities related to exploration and exploitation phases of the offshore oil industry were mostly carried out by divers. Subsequent development of diving bells made it possible for divers to extend their depth of operation and their endurance. Their movements from the diving bell, however, were restricted by the length of the umbilical cables whose lengths normally did not exceed 30 m. Further development in underwater technology led to more versatile submersible crafts which could carry divers giving them the flexibility of being able to move along intricate installations such as pipelines and platforms. Diver lock-out submersible allowed the diver to lock out from the submersible and on completion of their tasks, the diver could be transferred back under pressure to the decompression system located in the mother ship. Because of the high operating cost of the manned submersible in terms of trained manpower, sophisticated equipment and surface support vessel, unmanned submersible systems were developed for undertaking certain underwater tasks. An appraisal with a historical review giving relative advantages and disadvantages of the manned and unmanned submersibles for oceanographic and ocean engineering studies has been presented in the paper.

INTRODUCTION

Historically it was man himself, holding his breath accomplished many underwater tasks. He gradually added crude open-bottom habitats, where he could go for a breath of air and rest without surfacing. Later, he added pumped air, the HARD HAT, the complete pressure suits, the SCUBA gear, the saturation diving and finally unused gases. With each step forward in sophistication due to technological developments, the manned and the unmanned submersibles emerged as the present day underwater work systems. These submersibles with pressure hulls provide protection to divers from cold and pressure and have made it possible to travel to the deepest ocean depths. The recent technological improvements have aided in building robot submersibles (tethered and untethered remotely operated vehicles) eliminating the intervention of human beings. A brief

review on manned and unmanned submersibles highlighting their relative advantages and disadvantages has been presented here.

MANNED SUBMERSIBLES

The first self propelled one-man submersible on record is TURTLE designed by American inventor David Brushnell for use against the British fleet during the revolutionary war of 1775. Vickers Oceanics PISCES II was the first manned submersible used for commercial applications in North Sea. This was built primarily as observational chamber with facility to perform simple mechanical tasks using hydraulically operated manipulators having six degrees of freedom.

Salient features

Manned submersibles are superior devices for offshore inspection, monitoring and fault detection etc. Minor leaks in offshore pipelines have been detected immediately by the manned submersibles whereas the Remotely Operated Vehicles (ROV's) with video systems have been unable to detect such leaks from offshore pipelines. Thus the presence of a man at the work site has been of very great value. Manned submersibles are designed to provide a means to take one or more human beings to depths beyond that approachable by divers, while retaining inside the comfort of dry 1-atmospheric environment. Majority of the manned submersibles are designed for operating in deeper depths. The manned submersible TRIESTE designed by Anguste and Jacques Piccard has in 1960 descended to the record depth of 11,000 meters at the bottom of the deepest known point in the oceans, the Mariana Trench.

Manned submersibles are free from tether problems. Submersible underwater activities are dependent on the storage batteries. Thus the electrical power available is limited by the capacity of the batteries and hence submersible operation endurance comes into picture.

Designing and building of manned submersible is an astonishingly expensive venture. The low production volume of the subsystems of the submersible, the dual life support systems provided, and the need of surface support system have substantially contributed towards the high purchase and the operating cost of these submersibles. Need of sophisticated technology and facilities to build have further contributed to their high purchase cost. Till today only a few industrialised countries have know-how and facilities to build manned submersibles.

Safety of operators/divers and equipment is viewed very seriously in offshore operations. A major statistical assessment of the safety of the submersible operations is carried out by world's leading insurance companies. Today the insurance charges for manned submersibles are significantly cheaper than those for unmanned submersibles, due to too many losses of ROV's. The tighter discipline in manned submersible operation and safety measures adopted is one of the reason for this. All manned submersibles incorporate safety backups in the form of dual life support systems, cable jettison, manipulator and thruster jettison, back-up power supplies and dual communication systems. The manned submersibles are often too large to enter the confined areas like the centre of steel jacket etc.

Accurate navigation, correct approach to the required work site, high reliability of work are some of the additional advantages of manned submersibles.

Manned submersibles with diver lockout:

Manned submersibles with diver lock-out (DLO) were introduced first in 1970's. A DLO submersible has two separate crew compartments --one for the divers which can be pressurised and the other for the pilot/supervisor maintained at atmospheric pressure. Thus the diving supervisor/pilot can supervise with close visual contact of the divers' work by sitting in the 1-atmospheric chamber. Use of DLO submersibles in offshore inspection work has increased because of the ease of transporting the underwater inspection engineer down to the work site in a warm dry 1-atmospheric pressure environment for inspection. The person sitting inside the compartment can take on-spot decisions and guide the divers there at the work site. These submersibles are suitable for carrying out under-water complex jobs. DLO submersibles have better accessibility to the subsea parts of offshore platforms compared to the diving bells. The other advantage of DLO submersibles is it can be used as compression chamber for divers. DLO submersibles lack the power requirements to support the divers for long operating periods against hypothermia. However the DLO submersibles are not expected to become obsolete anytime in near future because of their superior work capabilities.

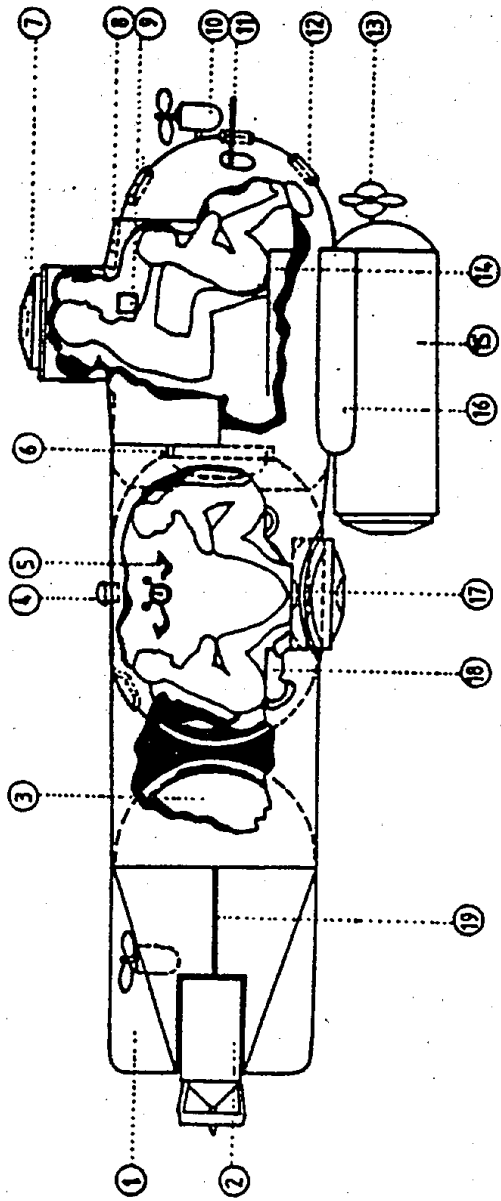
The two-manned DLO submersibles MAKAL11, (operated by the Harbour Branch Foundation based at University of Hawaii) and the Woods Hole Oceanographic Institution's ALVIN have been used by Scientists for research and exploration in deeper depths. ALVIN is known for its excellent manoeuvrability and propulsion. It has transported personnels between stations 32 kilometers apart at 1670 m of water depths. Fig. 1 shows a typical schematic layout of a manned DLO submersible.

Tethered diving observation chambers.

To overcome the restrictions in electrical power available to the free swimming manned submersibles, several manned tethered diving observation chambers with restricted mobility have been developed for offshore applications. The tether from the surface station supplies power required for the long-time operating subsea divers. These systems are used for inspection and few manipulated tasks. Perry Oceanographers introduced the Diver Lock Out Systems in the tethered observation chambers called as Mobile Diving Units (MDU). Thus the MDU supplies unlimited power unlike the DLO submersibles for the divers for carrying out longer dives. The maximum operating depth of MDU will probably remain at approximately 1000 meters. These systems continue to increase but not as rapidly as ROV's because of a few disadvantages like longer time period involved in building, more deck space and their high cost.

Applications of manned submersibles

The manned submersibles have been used for a variety of tasks ranging from detailed sea-bed surveying, diver/rig support, pipeline laying/repairs, inspection, non-destructive testing (NDT), measurement of ocean physical variables, sea bed sampling and underwater welding etc. One of the most demanding jobs in offshore industry is picking up and repositioning of items on the sea bed in a cross current. The manned submersibles have proved their ability in this regard. DLO submersibles are more suitable in search operations involving objects or inspection of pipeline/structures, wherein the actual dive site is not known until an observer finds and locates the object or the faulty location. Using DLU submersible under these circumstances means that the transit speed



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|-------------------------------------|----------------------------|------------------------------------|------------------------------|
| 1. VERTICAL STABILIZERS. | 4. INTER COMPARTMENT HATCH | 11. BOW PLANKS. | 14. HIGH PRESSURE AIR. |
| 2. 10° MAIN MOTOR | 7. HATCH | 12. VIEW PORTS | 17. DIVER EGRESS HATCHES. |
| 3. LIFE SUPPORT GAS STORAGE SPHERE. | 8. MAIN BALLAST TANKS. | 13. HORIZONTAL BOW THRUSTER. | 18. VARIABLE BUOYANCY TANKS. |
| 4. MEDICAL LOCK | 9. CONTROL BOX | 14. TRIM TANK. | 19. HORIZONTAL STABILIZERS. |
| 5. EMERGENCY BREATHING APPARATUS. | 10. VERTICAL BOW THRUSTER. | 15. DROPPABLE BATTERY COMPARTMENT. | |

FIG. 1. A TYPICAL DRIVER LOCK OUT SUBMERSIBLE.

during search mode is that of the vehicle rather than that the swimmer, thus enormous time is saved.

Manned submersibles have contributed significantly in scientific exploration and oceanographic research applications (Woods-hole Oceanographic Institution's ALVIN). Manned submersibles have been used in surveys for polymetallic nodules, polymetallic sulphides and also in the discoveries of hot water vents. For countries placing heavy emphasis on fishing industry manned submersibles can be very useful as survey devices, thereby aiding the fishing fleets. Manned submersibles have been used in military sector as offensive weapon. Table 1 gives a list of a few leading manned DLO submersibles built during 70's and 80's.

TABLE I A FEW LEADING MANNED DLO SUBMERSIBLES

Model/manufacturer	Weight (tonnes)	Length (meter)	Energy capacity (KWh)	Crew pilots/ divers	Life support duration (hours)	Remarks
I Bruker-Physik- West Germany a. Mermaid IV	13.5	7.5	36	2 + 2	600	These manned DLO Submersibles have work capabilities for performing scientific surveys, site surveys inspection, installation, construction, tasks and underwater repairs.
b. Mermaid VM	14.0	6.5	*	*	*	
II Perry Oceanographics, U.S.A. PC 1803	12.2	7.3	41	2 + 2	172	■ Diver lockout with rescue facility. * Not known.
III Vickers slingsby, U.K. LR 5 ■	20.0	10.5	52	3 + 2	600	
IV Comex, France SM-358	12.5	7.5	45	2 + 3	360	
V Hyco, Canada Taurus ■	24.0	10.7	134	2 + 3	500	

UNMANNED SUBMERSIBLES

The US military was the first in committing significant funds and efforts for the R & D in ROV's. The first major activity took place at the Naval Ocean Systems Centre (then the Naval Electronics Laboratory) beginning in the early 1960's with the tethered free swimming vehicle CURV (Controlled Underwater Research Vehicle). The CURV was launched in the year 1965 and in the following year it was instrumental in retrieving a lost US hydrogen bomb off Spain in 600 M of water depth. Later Hydro-Products, a US based company introduced its first ROV in 1974 (RCV-125 and later RCV-225) on commercial basis.

Salient features

With minimal danger to human life ROV's perform certain tasks like inspection and monitoring more economically than devices on manned submersibles. Specialized ROV's have been built to perform operations such as in-situ repair of sea floor telephone cables etc. (AMETEK Strazas SCARAB). Many autonomous untethered acoustically controlled ROV have been built for operating upto 6000 m depth for photographic and bathymetric surveys of sea bed (FREMER's Epaulard system).

Tethered ROV's weakness lies in its umbilical cable. There are vast chances of fouling of the umbilical cable on the structures. Also the cables are prone to damage/break on contact with the structures. Various suggested procedures to minimize the umbilical vulnerability such as by entering a structure on a horizontal plane from down current side and placing a TV camera so it can scan the umbilical cable, but none of these are found to be foolproof.

When it comes to the operating costs, the cost of operating the unmanned submersible is very low compared to that of manned submersibles. The operating cost of manned submersible works out very high because of the high cost of life support facilities involved.

ROV's suffer from poor quality of video data, even when compared with the pilots/divers vision through a distorting acrylic view port. High reliability and better interpretations are possible with pilot's/diver's inspection. Thus in case of ROV's the operations necessary to be performed at the work site will be done only after viewing the recorded video tapes. Hence the decision work at the work site is delayed.

The safety record of ROV in offshore industry is too inferior compared to that of manned version. Many ROV's have been lost during their operations. Hence, the insurance charges for ROV's are significantly high compared to that of manned submersibles. The other advantage of unmanned vehicle is that it is easily transportable and can be deployed either from a medium size vessel or from a fixed platform. ROV's other assets are easy manoeuvrability and ability to enter restricted places and work round the clock if necessary without danger to the personnel. Fig. 2 shows a schematic view of a typical ROV.

ROV configuration and gear

Most tethered ROV's weigh less than 500 kg. All have slightly positive buoyancy when submerged. At the sea surface ROV's float with about 10 cm or less free board. All tethered ROV's run on surface supplied AC power, either from ship's power or from a dedicated diesel generator. Umbilical cables which carry power and communication links usually are single units with one or three co-axial conductors. Some time additional floats are attached on the umbilical cable to offset its negative buoyancy. Most of ROV's have electric or hydraulic thrusters. The top mounted vertical thrusters which maintain the vehicle at a required depth do not disturb sea bed sediments and thus provide good visibility. ROV's maximum speed ranges upto 4 knot with an average less than 2 knots. Commonly ROV's are equipped with B & W television cameras, Quartz Iodide Malogen lights, 35 mm still cameras, (some have stereophotography camera) and one or two manipulators. Standard gear includes Echosounders, Scanning sonars, Sub-bottom profilers and Directional hydrophones. Special tools for corrosion potential measurement, ultrasonic

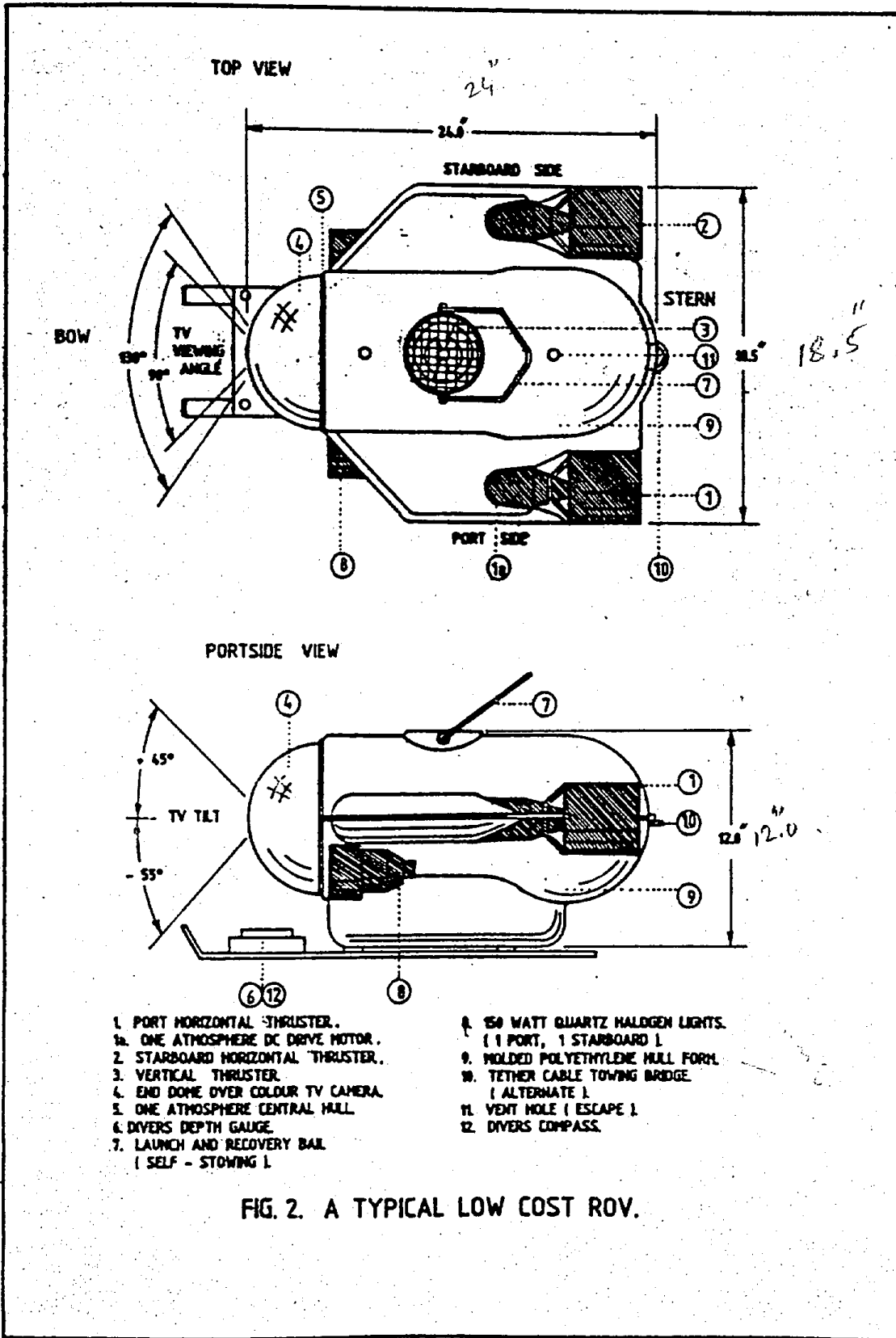


FIG. 2. A TYPICAL LOW COST ROV.

thickness measurement, radiographic testing and for cleaning can be mounted on ROV's as per the requirements. Acoustic navigation gear in ROV is either bottom or surface based similar to the gear employed in manned submersibles.

ROV's with GARAGE system

When umbilical cable drag approaches the submersible thrust, some form of device must be used to enhance the performance of the submersible by decoupling the main umbilical from the submersible. Hydro products' RCV-225 is a typical example, wherein the effect of the main umbilical drag on the ROV is reduced by adopting a 'Garage'. The Garage carrying the submersible is lowered through the main umbilical cable to the inspection spot using a suitable handling system on board the vessel. On attaining the proper location the ROV is drawn out of the Garage on its separate umbilical to perform its task. On completion of the job the ROV returns to the Garage on its own umbilical cable. Such system can be operated to any depth provided the handling system is uprated to cope up with the increased length of the umbilical cable. During inspection of large offshore structures the Garage defines the depth with the depth sensors installed in it and allows the ROV to enter the structure horizontally taking behind its umbilical cable. The use of non-garage ROV becomes difficult in deeper depths. Other benefits are accessories like transformers, power packs for various instruments and water jetting power packs can be accommodated on the Garage itself, thereby releasing space/weight on the vehicle for additional manipulators/sensors.

Untethered autonomous acoustically controlled ROV's

The untethered autonomous acoustically controlled ROV's have overcome the umbilical cable problem of the tethered ROV's. These vehicles are practically free from the umbilical cable problems in terms of drag and depth limitation. The tethered ROV's compared to untethered autonomous ROV's can be easily launched/retrieved even in high seas because of the presence of umbilical cable. The other disadvantage of these vehicle is that they are inflexible and are only suitable for dedicated repetitive tasks. The Centre National Pour l'Exploitation Des Oceans (CNEOX presently known as IFREMER) are pioneer in these type of submersibles. IFREMER's Epanlard Submersible is primarily designed for deep ocean manganese nodule survey work.

The present day untethered ROV's operate in two different operating modes. The first operating mode is the preprogrammed or autonomous in which a task is given to the vehicles microcomputer, which directs the vehicle in terms of depth, course, speed, data to be collected, dive period etc. All these operations are carried out without surface intervention. In the second operating mode the underwater vehicles course, depth, speed, data to be collected, dive period etc. are controlled via an acoustic link from the surface station. Currently most data collected is recorded in the vehicle and reviewed after the vehicle is retrieved. The most promising avenue at present is the use of fibre optic link for communication and data transmission purposes. Ten Kilometer transmissions without amplifiers have been achieved. Offshore Systems Engg Ltd's (OSEL) ROV Hornet has a 7 mm dia optical fibre cable. This cable serves for transmitting high quality colour TV signals, digital control signals etc.

Low cost ROV (LCROV)

The earlier ROV's were significantly expensive to maintain plus they were difficult to use and mobilize. For handling/deploying/retrieving purposes a medium size crane or forklift was necessary. It takes a few years to write off an investment on ROV at the usual utilization rate. This situation stimulated interest in the design of lower cost vehicles now known as low Cost Remotely Operated Vehicles (LCROV). These vehicles are truly portable. They can be hand deployed, retrieved from any vessel and can be transported as an usual luggage to any distant place. With efficient hull and thruster designs they can operate in currents well over 1 knot and can handle long tethers. Deep Sea Systems International (DSSI) is pioneer in LCROV's. Their Mini Rover weighs only 22.7 kg with a total thrust of applications of unmanned submersibles.

Applications

ROV's are classified into three main categories depending upon their applications as observational ROV's, inspection ROV's and work ROV's. Observational ROV's are equipped with TV cameras for simple inspection purposes. Inspection ROV's are capable of more sophisticated works such as colour video, stereophotography etc. Work ROV's are large powerful vehicles fitted with one or more manipulators and other special equipment for rig support, pipeline surveys, platform cleaning and other operations.

One of the most promising segment of the industry for ROV application is in the area of drilling support. With drilling operations moving to deeper waters, the ROV finds itself as the only viable tool for subsea operations. Application of ROV's have been extended to icy regions wherein severe climatic conditions upset the divers most of the time.

Modern specialised ROV's are capable of performing tasks such as pipeline inspections, anode replacement, underwater retrievals, cable burial and cleaning operations. Non-destructive testing (NDT) techniques such as corrosion potential measurement, ultrasonic thickness measurement have been performed to a limited extent from tethered submersibles. AMETEK's new ASD/620 is a fourth generation ROV equipped with high pressure water jetters and wire brushes for cleaning offshore structures even at deeper depths for long durations. ROV's finds a major application in military sector specially in mine inspection and neutralization. Mine Neutralization System (MNS) by US Navy, Advanced Development ROV (ADROV) by Hydroproducts are a few examples of ROV's application to military sector.

The ROV's are expected to find increased use in the field of search and identification operations in deeper water. The AMETEK straza's SCARAB was in news recently for its search and recovery of Air India's air craft "Kanishka" wreckage off Ireland. The International Submarine Engineering Ltd (ISE) has developed an Acoustic Remotely Controlled Survey Submersible (ARCS) for supporting the drilling operations in arctic regions. The untethered ROV's are widely used in military sectors for operations such as search, identification, survey, broad area reconnaissance, mine counter measures, and also serving as model for submarine hydrodynamic studies.

The LCROV's are widely used for reconnaissance or inspection and specific work tasks with the aid of manipulators. Many inspection

TABLE II A FEW LEADING ROV'S OF THE WORLD

Model and working depth	Garage or tether management system	Standard features	Manipulator type	Normal duties
I Ametek, California, USA				
a) Scorpio 914 M	Optimal Bottom entry	Continuous transmission frequency modulated (CTFM) sonar, low light level (LLL) television, TV monitor, auto heading and auto depth.	5-function 7-function (Optional)	Drill support, inspection
b) ASD/620 914 M	Cage system (Optional)	Vehicle status display unit (SDU), auto depths heading, auto pitch and roll stabilizer.	5-function (Optional)	Inspection, Non-Destructive Testing (NDT), intermediate work tasks.
c) Scorpi 3000 ft.	Side entry (Optional)	LLL TV, auto depth, heading, pitch and roll.	4-function (Optional)	Inspection, NDT, light work.
II Benthos Inc, Massachusetts, USA. RPV-430	Protective cage for launch and recovery	B & W Video, still camera and flash.	3-function (Optional)	Inspection survey light work.
III IFREMER, Paris, France Epanard 6000 m.	None	Untethered autonomous vehicle (acoustically controlled) still camera with flash, auto navigation.	None	Photographic and bathymetric surveys.
IV Hydro products California, USA				
a) RCV-150 (2000 ft)	Side entry cage	Video annotated with auto depth and heading control, LLL TV	None	Inspection
b) RCV-150 (2000 ft)	Bottom entry cage	Pan and tilt TV, altimeter, depth sensor.	3-axis manipulator	Inspection, limited access work
V International submarine Engineering Ltd, Port Moody, Canada. Autonomous Remotely Controlled submersible (ARCS)				
a) 1200 ft. and b) 3000 ft.	None	Gyro compass, depth sensor	Optional	Survey under arctic ice.
VI Offshore systems engineering Ltd, (OSEL group) Great Yarmouth, England.				
a) Underwater flying observer (U.F.O.) - 1400 ft.	Standard cage available	Cathodic protection probe, SIT video camera.	3-function	Inspection.
b) Duplus II 5000 ft.	Standard Cage available	Operates in remote and manned modes. Upto 2300ft as a 1-atmosphere tethered submersibility	Two hydraulic manipulators with 7 degrees of freedom.	Inspection, light work.
VII Deep sea systems Internationals Inc, Falmouth USA. Deep sea minirover 121 M	None	Low cost ROV with light weight, LL colour TV camera with tilt mechanism, quartz halogen lamps.	None	Inspection, under ice survey (Optional) biological studies & sampling (Optional)

jobs have been carried out with LCROV's at a range of only 15 cm from the structures revealing details such as cracks, damages etc. on the offshore structures. They are also capable of performing manipulative operations such as grabbing, cutting, positioning underwater cables, lines and objects etc. Table II lists a few leading ROV's of the world giving some of their standard features, normal duties etc.

CONCLUSIONS

Manned and unmanned submersibles have been playing an important role in oil and gas industry. The manned submersibles still hold upper hand over ROV's in offshore oil and gas industry because of their superior dexterity and work capabilities. There is no room for complacency on part of operator/divers with regard to safety in manned submersibles. But technological improvements are being incorporated in the unmanned submersibles making them more attractive economically. The cost of life support system inside the submersible is the key economic element that distinguishes the manned from the unmanned version. With improvements in power sources, communication and control and vehicle intelligence the untethered ROV's are expected to replace tethered ROV's for many tasks in future. There is an urgent need for developing capabilities in India for the application of these modern underwater systems for various submarine tasks.

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