Deep water ROV design for the Mexican oil industry

T. Salgado-Jimenez, J. L. Gonzalez-Lopez, L. F. Martinez-Soto, E. Olguin-Lopez, P. A. Resendiz-Gonzalez and M. Bandala-Sanchez
Center for Engineering and Industrial Development (CIDESI)
Av. Playa pie de la cuesta 702. Col. Desarrollo San Pablo
Querétaro, QRO, CP.76130, MEXICO

Abstract-**This paper describes both the design and technical integration of a deep water ROV (Remotely Operated Vehicle) that is able to employ visual inspection in deep water, as well as to take samples with an underwater arm. Visual inspection is the essential application for a ROV, which is useful for; underwater structure inspection, underwater oil production systems inspection and underwater pipeline inspection. This paper mainly describes the ROV design, and explains in general manner other elements; such as the SCU, LARS and TMS. It is important to mention that the design phase is complete and it was financed by PEMEX (Federal Mexican Oil Company). The project has stalled, since we are waiting for the financial support from PEMEX for the system construction. A future objective is the design and construction of Work-Class ROVs, which can be used to perform PEMEX specific tasks.**

I. Introduction

Mexican main oil reserves are in deep water of the Gulf of Mexico (between 500 - 3000 meters). PEMEX (Federal Mexican Oil Company) is looking for the deep water technology to explore and operate deep water fields. PEMEX is turning to the international companies and Mexican research and development (R&D) centers to acquire and develop deep water technology.

ROVs are a little part of the necessary technology for deep water oil production, due to the high water pressure that makes it impossible to use divers.

This paper describes the design and integration of the deep water ROV (Remotely Operated Vehicle) capable of employing visual inspection in deep water structures, other additional capability is to take samples with an underwater arm. Visual inspection is the essential application for a ROV, and can also be used for; underwater structure inspection, underwater oil production system inspection and underwater pipeline inspection. The proposed underwater robot system in this paper has the following components:

1) Surface Control Unit (SCU)
2) Launch and Recovery System (LARS)
3) Tether Management System (TMS)
4) Remotely operated Vehicle (ROV)

It is important to mention that the LARS and TMS are commercially available components and they will be integrated to the system.

Note: Most vendors and commercial products are not mentioned within this paper due to the project's intellectual property.

The ROV's design phase is complete and it was financed by PEMEX (Federal Mexican Oil Company). The project has stalled, since we are waiting for the financial support from PEMEX for the system construction. A future objective is the design and construction of Work-Class ROVs, which can be used to perform PEMEX specific tasks.

Advantages of the project

The advantages of the project are:

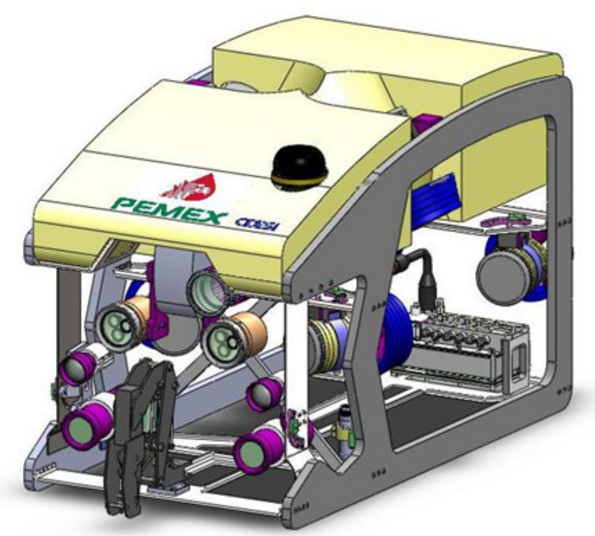
- Local technological development.
- Local technical support.
- Creation of a Mexican underwater technology research group, for future deep water projects development.

The paper is divided into the following sections: I. Introduction, II. General system characteristics and components. III. ROV design, IV. Surface Control Unit (SCU), V. TMS and LARS, VI. Power system and VII. Conclusions.

II. General system characteristics and components

A. Main system components

The main components for the system proposed here are: the ROV, the TMS, the LARS and the SCU, (see Figure 1). Note: The components that are show in Fig. 1 are not to scale.



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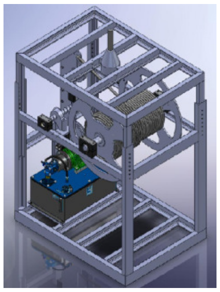

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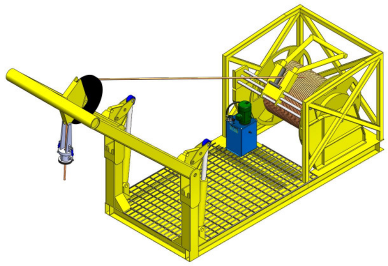

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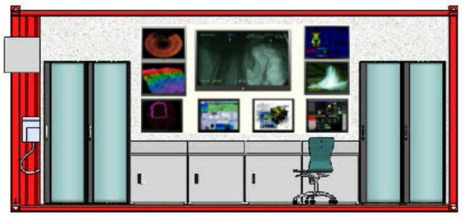


(1.d)

Figure 1. Main system components: (1.a) Remotely Operated Vehicle (ROV), (1.b) Tether Management System (TMS), (1.c) Launch and Recovery System (LARS) and (1.d) Surface Control Unit (SCU) located inside the cabin.

The components are described below:

1.-Remotely operated Vehicle (ROV): The underwater robot consists of a submersible platform and thrusters that allow the immersion and traveling in water. The robot has an on-board computer for the robot control and the management of the communication with the SCU. The data transfer is made by fiber optics located in the cable that physically connects the ROV to the SCU.

2.-Tether Management System (TMS): Cage to protect the ROV, and isolate the system from wave and current effects. Another aim of the TMS is to provide ballast to the system. The TMS is capable of containing the ROV and 200 meters of tethering cable. This cable has a smaller diameter and is more flexible than the LARS's cable.

3.-Launch and Recovery System (LARS): Crane system to immerse and recover the ROV from the water. The LARS has 1,800 meters of Umbilical Cable; this cable has a steel armor.

4.-Surface Control Unit (SCU): Where the system power transformers, control joysticks and system monitors are contained. The SCU is the device used by the ROV operator to controls the robot. The control unit is contained in a cabin which protects the user from the environment.

B. *Working principle of the system*

A diagram of the working system is shown in Fig. 2. It is possible to see the four elements which comprised the full system. From top to bottom it can be seen the SCU where the user visualizes and controls the system. The LARS is shown next to the SCU. The ROV is inside the TMS. Because of the LARS the TMS could be able to descent down 1,800 meters. Once the TMS is near the working place, the user stops the dive process, and then the ROV leaves the TMS and performs the desired tasks by the user, in a remotely operated way. Note: The components that are show in Fig. 2 are not to scale.

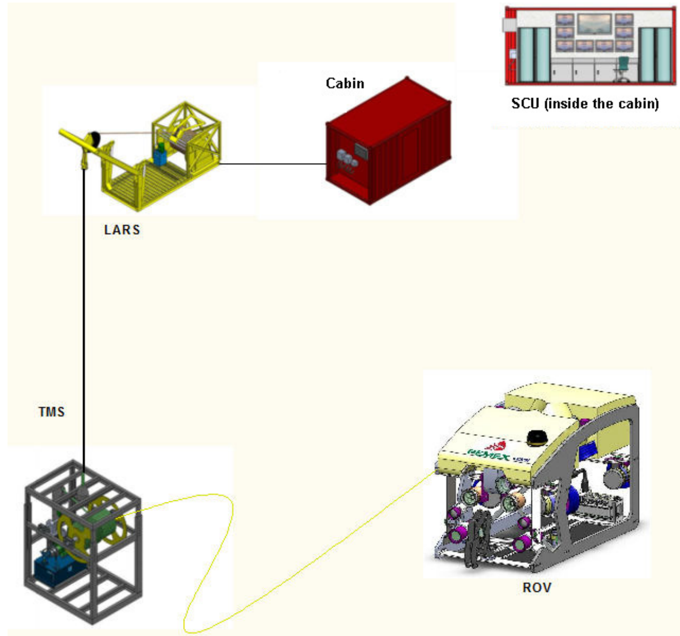


Figure 2. Working principle of the system.

III. ROV DESING

Deep water ROV main features are:

- Weight: 350 kg (Approximately).
- Dimensions: length 1.4 m x height 1.2 m x width 0.9 m (Approximately).
- Maximum Operation Depth: 2,000 meters.
- Maximums velocity: forward 1.25 m/s, reverse 1 m/s and vertical 0.55 m/s.
- Sensors: Depth sensor, Compass Altimeter, Rate Gyros and Sonar.
- 6 thrusters (see "*Propulsion system*" section).
- 3 cameras and 4 underwater lamps (see "*Video and illumination system*" section).
- 1 Pan & Tilt system.
- Auto pilot capabilities: Depth and Heading control.
- Hydraulic manipulator: 5 manipulator functions, for sample collection. Maximum sample weight: 18 kg.
- Power supply 440 Vac, 3ϕ, 60 Hz.

C. *Component selection for the ROV*

The ROV component selection was based on technical research. The main characteristics of the elements are; support for more than 2,000 depth meters, as well as the capability of supporting low temperatures. Fig. 3 illustrates the ROV's electronic architecture. The ROV is divided into the follow subsystems:

ROV Navigation system: The navigation system consists of; a sonar, an altimeter, a depth sensor, three gyros and a compass (see Table I).

TABLE I
NAVIGATION SYSTEM ELEMENTS

Elements	Qty	Data output
Sonar	1	RS-232 protocol
Depth sensor	1	RS-485 or RS-232 protocol
Gyros	3	Voltage or RS-232 protocol
Compass	1	Voltage or RS-232 protocol
Altimeter	1	RS-485 or RS-232 protocol

Secondary sensors: The ROV has complementary sensors that monitoring the ROV's internal variables, such as:

- Internal temperatures.
- Internal humidity levels.
- General voltage.
- General current.
- etc.

Propulsion system: The propulsion system is made of six thrusters: two of which are for the up and down movement and four are in a vertical configuration for the forward, reverse and turning movements. The thrusters are manufactured by Sub-Atlantic. Ltd.

Video and illumination system: The video and illumination system comprises 3 cameras, 4 underwater lamps and a Pan & Tilt system (see Table II).

- Cameras; one is located in the Pan & Tilt for navigation, another one with zooming for underwater manipulation assistance. The remaining camera is monochromatic with low light sensitivity function.
- Underwater lamps; 2 fixed lamps on the front and 2 lamps in the Pan & Tilt system.
-

TABLE II
VIDEO AND ILLUMINATION SYSTEM

Elements	Qty	Vendor
High resolution color camera for navigation purposes.	1	ROS. Inc.
Color camera with zooming for underwater manipulation assistance	1	ROS. Inc.
Monochromatic camera with low light sensitivity	1	ROS. Inc.
Fixed underwater lamp	2	Bowtech. Inc.
Pan & Tilt underwater lamp	2	Sidus Solutions. Inc.
Pan & Tilt system	1	Seaeye. Inc.

Manipulator system: The ROV has one 5 functions manipulator, from ISE. Inc. The manipulator will be operated from the surface using a joystick. The manipulator control is performed by proportional hydraulic valves. From Sub-Atlantic. Ltd. The manipulator is powered by a hydraulic unit (HU).

ROV control: The ROV has two control options; these options can be selected from the SCU by the user. The control options are: Depth control and Heading control.

Fiber optic multiplexers: The robot performs bidirectional communication with the SCU by using single mode fiber optics; however the system cable has only two fibers. In order to transmit all the information generated by the ROV an SCU it is necessary to use a fiber optics multiplexer. The ROV's multiplexer cards were selected considering small size occupancy, low power consumption and harsh environmental condition such as: low temperatures and high humidity levels. The selected multiplexer is designed by Moog. Inc. and has electronic board array with the following capabilities:

- Ethernet to fiber optic converter module: data transition 1,000 Mb/s.
- CAN to fiber optic converter module: data transition range from 62.5 kb/s to 1 Mbps.
- RS-232 to fiber optic converter module: 8 bidirectional channels, data transition 120 kb/s.
- RS-485 to fiber optic converter module: 8 bidirectional channels, data transition 625 kb/s.
- Video to fiber optic converter module: specified for high definition data transmission.
- Others modules such as: power, fiber optics connections, etc.

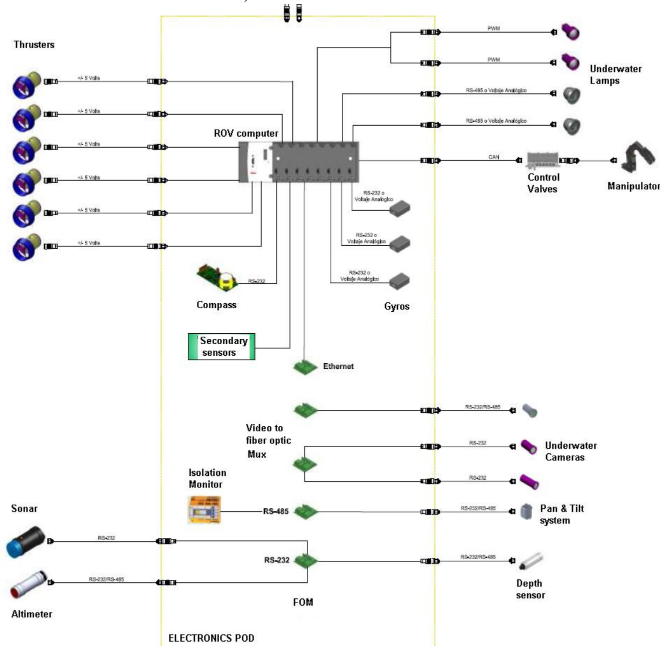


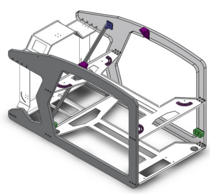
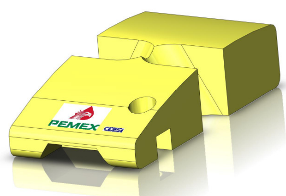
Figure 3. ROV's electronic architecture.

D. ROV Mechanical design

The mechanical design was conceived considering the tasks that the ROV could perform the underwater environment and the ROV elements. These elements are described in section "*C. Component selection for the ROV*".

The ROV chassis is made of Aluminum 3003-H18, due to its adequate corrosion resistance properties. The ROV's buoyancy foam has a low density that can support more that 4,000 meter in depth. Table III provides some characteristics of these two mechanical components.

TABLE III
MAIN MECHANICAL COMPONENTS CHARACTERICSTICS

Element	Physical Characteristics
	**ROV's chassis**: Weight in air 80.57 kg. Weight in water 72.42 kg. Volume 71.27 cm^3. Center of mass: x=-278.81, y=361.64, z=83.66.
	**Buoyancy foam**: Weight in air 139.82 kg. Weight in water 33.34 kg. Volume 239.84 cm^3. Density 583 kg/m^3.

Electronic pod: The ROV contains one pod for electronics and two oil-filled connection boxes.

The connection boxes perform the connection from; the external sensor, the general power supply cable and the external cables.

The electronics pod contains the ROV's computer, the electronic boards, etc. It is capable of supporting 2,000 meter in depth. Envisaging the aforementioned restrictions a finite elements analysis was carried out, considering the characteristic listed in Table IV and a pressure of 304 kg/cm^2 (pressure at 3,000 meter of depth). Fig. 4 shows the electronics pod deformation under the specified pressure. The maximum deformation is 0.00011 mm.

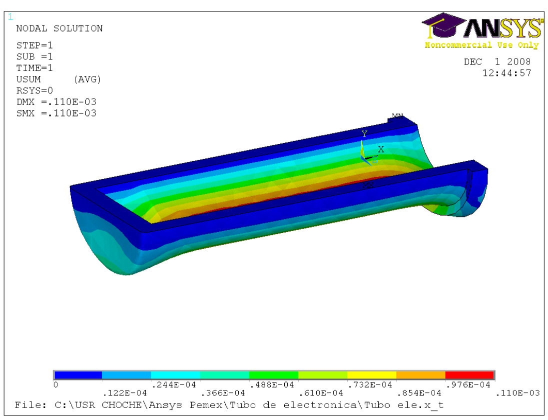


Figure 4. Electronics pod deformation under deep water pressure.

TABLE IV
ELECTRONIC POD MAIN CHARACTERICSTICS

Concept	Description
Dimensions	180 mm diameter x 650 mm longitude.
Material	316 inox steel
Volume	4.3047 cm^3
Weight in air	11.82 kg
Weight in water	7.40 kg
Electrónics pod thickness	30 mm

IV. SURFACE CONTROL UNIT (SCU)

The Surface control Unit (SCU) purpose is to control and monitor the ROV and the TMS. The remote system control uses; Ethernet, RS-485 and RS-232 protocols transmitted by the fibers optics located in the system cables (see section "*V. TMS and LARS*").

The SCU has the follow elements:

- 1 general ROV control Joystick.
- 2 Joysticks; one for the manipulator and one for the Pan & Tilt system.
- 5 Monitors;
  - One 42" monitor for the high resolution color camera.
  - Two 20" monitor for the color zoom camera and the monochrome camera. The video input are: NTSC, PAL Y/C (S-Video).
  - two 17" monitor for the sonar visualization.
- 4, 26" touch screens monitors for general system configuration and alarm deployment. The systems to be controlled and monitored from the GUI (Graphics User Interface) are:
  - TMS status.
  - ROV
    - General configuration.
    - ROV's secondary sensor monitoring.
    - Power and protections status.
  - System general power unit.
  - SCU status.
- 2 DVD recorders.
- SCU computer; industrial computer for real time application from National Instruments (NI). The computer has 14 slots for several applications such as: data acquisition and protocols; CAN, RS-485, RS-232, Ethernet, etc.
- Surface fiber optic multiplexer; it is a modular multiplexor from Moog.
- General system control software; developed in LabVIEW by NI^{TM}.
- General system power unit.

Fig. 5 shows a SCU distribution diagram where it can be seen three blocks according to their use:

1. Video deployment block: It is composed by the 5 visualization monitors and the two DVD recorders.
2. Monitoring and control block: Formed by the joysticks and four touch screens monitors.
3. Power supply block: Integrated by one transformer and extra power supply unit.
4. The Fiber Optic Multiplexer (FOM).

The system has two cabins; the first cabin contains tools and spares for eventual repairs. The second cabin contains the SCU with all its elements; one additional benefit of this cabin is the ROV operator protection from the offshore environment conditions.

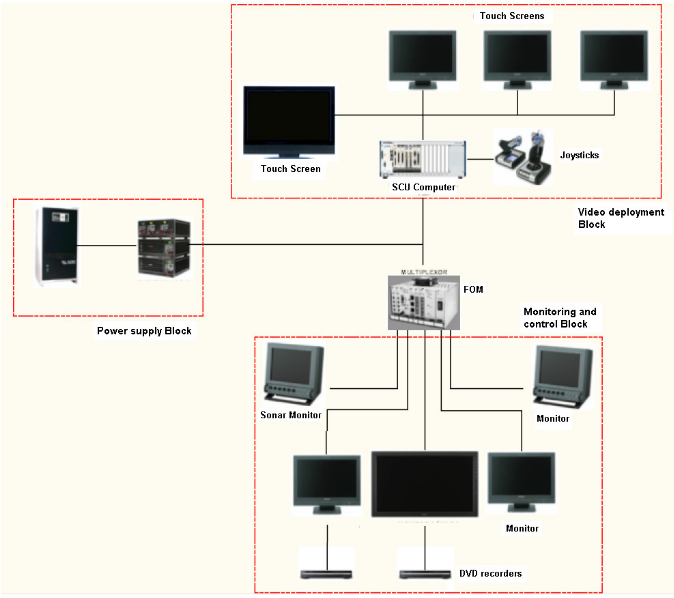


Figure 5. SCU distribution diagram.

The main cabins characteristics are (Fig. 2 shows one cabin in the general system working diagram):

- Dimensions 2.56 m width x 2.89 m height x 6.24 m length.
- Weight 2,500 kg.
- Material: steel.
- Air conditioner.
- Meets offshore safety requirements.

V. TMS AND LARS

As it was mentioned before the LARS and TMS are commercially available components that will be integrated to the system.

E. *LARS (Launch and Recovery System)*

The LARS main characteristics are (Fig. 1.c shows a LARS picture):

- 1,800 meters of Umbilical Cable (see "*System cables*" section).
- Weight: 13 tons (ROV, umbilical and tether cables weight not included.
- Dimensions: length 5.8 m x width 2.5 m x height pliable to 2.8m for transportation and 6.5 m when being used.
- Maximum load capacity: 3.5 tons.
- Power supply: 400 V_{ac}, 3ϕ.
- Easily installable in different ships.

F. *TMS (Tether Management System)*

The TMS main characteristics are (Fig. 1.b shows a picture of the TMS):

- 200 meters of Tether Cable (see "*System cables*" section).
- Maximum working depth 3,000 meters.
- Weight: 665 kg, plus up to 1,000 kg of additional ballast.
- Dimensions: length 1.95 m x width 1.2 m x height expandable from 1.92 m to 2.4 m.
- Monitored and controlled by fiber optic using the RS-285 protocol.
- 2 lights 250 W each.
- 1 monochromatic camera.
- Materials: stainless steel 316L and plastic.
- Power supply 3 kV_{ac}.

VI. POWER SYSTEM

The power system is responsible for the supply of the voltage and current of the complete system according to the specific system/element requirements. The system components (LARS, SCU and TMS+ROV) electrical characteristics are listed in the Table V.

Fig. 6 shows a complete system power diagram. This diagram has three blocks:

1. Ship's block: Where it is possible to see the ship's bus (440 Vac, 60 Hz). Connected to this bus are; the LARS (22 kVA), the SCU reduction transformer (440 Vac to 220/127 Vac, 6 kVA). Finally the elevation transformer (208 Vac to 3,000 Vac).
2. TMS's block: This block connects the TMS (3,000 Vac, 9 kVA) and the Tether Cable.
3. ROV's block: Here we have the HPU (Hydraulic Power Unit) (3,000 Vac, 60Hz). The ROV's reduction transformer (3,000 Vac to 300Vac-120Vac, 16 kVA). The reduction transformer has an AC-DC converter, which supply power to the ROV's electronics devices.

TABLE V
GENERAL SYSTEM POWER MAIN CHARACTERICSTICS

Element	Power (kVA)	Tension (V)	Current (A)
LARS	22	440	28.6
SCU	6	440	7.88
ROV + TMS	60	440	72.25

G. *Electrical protections of the system*

Additionally to the standard fuses and thermo-magnetic switches, the system will have two isolation monitors from Bender; one in the surface and the other in the ROV, these devices employs RS-485 as a monitoring protocol.

H. *System cables*

Umbilical Cable: The SCU is connected to the TMS by an Umbilical Cable, this cable is located at the LARS, measures 1,800 and its main characteristics are listed in Table VI.

Tether Cable: This Cable physically plugs the TMS to the ROV, it is located at the TMS. Its main characteristics are given in the Table VII, it is important to notice that the cable buoyancy is almost neutral.

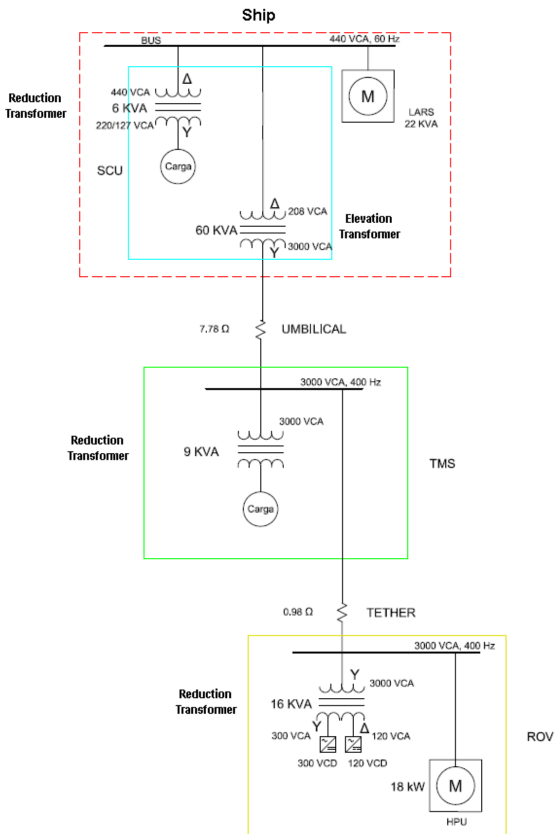


Figure 6. Completed system power diagram.

TABLE VI
UMBILICAL CABLE MAIN CHARACTERICSTICS

Concept	Description
External diameter	17.3 mm
Fiber optics	3, single mode
Power conductors	3, 11 AWG
Weight in air	1,112 kg/km
Weight in water	905 kg/km
Maximum bed radio	350 mm
Break tension	205 kN

TABLE VII
TETHER CABLE MAIN CHARACTERICSTICS

Concept	Description
External diameter	21.3 mm
Fiber optics	3, single mode
Power conductors	3, 14 AWG
Weight in air	399 kg/km
Weight in water	32 kg/km
Maximum bed radio	430 mm
Break tension	182 kN

Other cables: The system will have additional power cables in the surface to connect; the LARS and the main system power cable (connected to the SCU):

- Main system power cable: 20 m length. Cable with four 8 AWG conductors.
- LARS power cable: 50 m length. Cable with four 1 AWG conductors.

VII. Conclusions

The design considerations and element selection of the ROV that are able to employ visual inspection in deep water were reported in this paper.

It is important to mention that the design phase was financed by PEMEX and it is complete. The project current status is on standby, since we are waiting for the financial support from PEMEX for the system construction.

In order to minimize error, previous to the construction it is imperative to get more reviews done and reconsiderations in the ROV design, mainly in element selection and technical calculations. For this vital tack CIDESI has the assistance of experts in ROVs design, in this specific case from Mr. Jim Newman, manager of Woods Hole Marine systems, Inc, by an agreement of technical consultancy. Additionally CIDESI is looking for a technology transfer agreement from the "Institute For Exploration", specifically to acquire ROV's Hercules technical design memories and technical assistance.

Acknowledgment

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