DESIGN OF A LIFTING SKID FOR UNDERWATER ROBOT

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Abstract. *This work presents the design aspects of an innovative electro-hydraulic skid used to positioning a landed Remote Operated Underwater Vehicle (ROV) arm system, in a vertical motion range from the marine soil up to 3m. This equipment increases the capability of maneuver, manipulation skills and payload capacity of an ROV nearby its subsea working site. The configuration studied is a three degrees-of-freedom open kinematics chain type mechanical arm formed by rigid-body links and revolute joints, actuated by hydraulic linear actuators. The design process was strictly based on ISO and Petrobras standards for ROV interfaces. A finite element method (FEM) modeling, including a complete structural analysis with dynamic conditions such as buoyancy and fluid drag forces related to marine currents, was used to calculate the components mechanical strengths. The skid was conceived to operate in a teleoperated mode.*

Keywords*: underwater robotics, ROV skid, lifting mechanism, mechatronical design.*

1. INTRODUCTION

1.1. Operational scenario

The biggest oil & gas reserves in the Brazilian Continental Platform are located at Campus Basin, which represents nearly 84% of Brazil's oil production. Most of these reserves are below 400 m sea level and new very promising reserves were discovered in ultra-deep waters (Petrobras, 2008).

For approximately 30 years Underwater Production Systems – UPS - have been in use at Campus Basin and are proved to be very reliable solutions for subsea exploration. These UPS are mainly composed by subsea trees, manifolds, drilling systems, chokes, flowline mandrills, production adapter base, pipelines and risers (Fig. 1).

Figure 1. Deepwater facilities (FMC, 2006).

Remotely Operated Underwater Vehicles (ROVs) are widely used to perform inspection and intervention activities in UPS, such as equipment installation, maintenance, valve operations, cleaning and payload manipulation. In order to undertake intervention activities, appropriate tooling packages are installed onboard the ROV. They are designed to use the available resources of the ROV, which are essentially communication, electrical and hydraulic power supply units.

1.2. ROV intervention tasks configuration

ROVs are classified according to carrying out intervention tasks configuration in five ways (ISO, 2002) (Fig. 2):
(a) tooling with manipulators.
(b) tooling with a manipulator-held tool.
(c) tooling with TDUs (Tool Deployment Unit).
(d) dual down line method (with Remotely Operated Tool).
(e) tooling with skids or frames (fixed underneath the ROV).

1.3. ROV-tooling system with manipulators

A ROV-manipulator system can be relatively positioned to the intervened facility in the following ways:
(a) free-flying mode.
(b) attached mode.
(c) landed mode.

The position and attitude control in free-flying mode is highly depended on the human operator skill, due to marine current perturbation, ROV-tooling/water hydrodynamic interaction and forces and moments reactions at the task contact point. This mode is characterized by intense use of the vehicle thrusters and presents high consumption of energy.

In the attached mode the ROV-tooling system is firmly connected to the equipment under intervention in order to obtain precise and stable motions during execution of tasks. Usually the connections are made by a grabber manipulator or docking devices. A grabber manipulator is used whenever a manipulator is necessary to perform the tasks, so that the grabber holds a grasping handle placed nearby the region under intervention while the main manipulator executes the planned activity. Docking is to be used where the loading of the subsea equipment interface is not desirable, as in the case of the operation of needle valves or hot stabs, where heavier loads are being handled, as in the case of a jumper stab plate connection, or where many interfaces are close together, as in a panel (ISO, 2002).

The attached mode has some inconveniences like a limited operational working area, transference of forces and moments from the ROV to the equipment under intervention and the need of complex maneuvering commands from the operator during ROV approach phase to avoid impact and structural damages. This mode is time demanding.

Landed mode is best suited for tasks where the utilization of two manipulator arms and a large working area is imperative. This solution is not as precise as the attached mode for interventions in equipment interfaces, nevertheless is the best regarding subsea parts manipulation and installation, and can increase payload capacity.

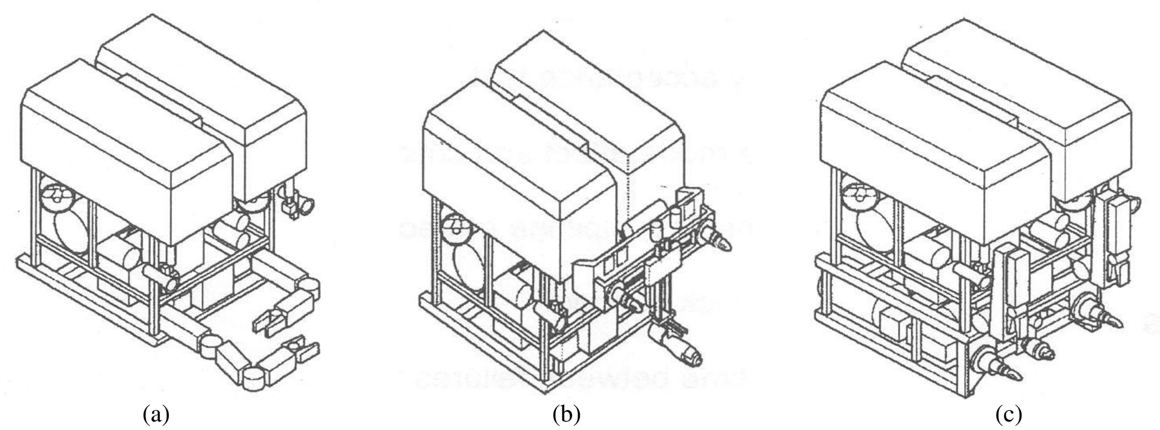


Figure 2. ROV intervention tasks configurations: (a) with manipulators. (b) with twin-point docking tool (TDU). (c) with underslung tool skid. (ISO, 2002).

2. BUPPA CONCEPTUAL DESIGN

2.1. Basic definition

The Lifting Skid for Underwater Robot – BUPPA - (Fig. 3) is a landed mode ROV-tooling system for medium duty work class ROVs, formed by an articulated planar mechanism able to perform lifting and angular motions from the sea soil. BUPPA was designed to do tasks at 2000 m below the sea level and operate in teleoperated mode. BUPPA can also operate in robotic mode by adding an autonomous control unit and appropriate transducers at mechanism joints.

The ROV is rigidly fixed at BUPPA platform and the mechanism is actuated by hydraulic cylinders, while its base touches the soil. BUPPA fulfills three essential functions:

a) ROV stability: downward motion is constrained due to soil contact, increasing the operator capability to maneuver the manipulators at a defined height. ROV vertical thrusters are activated to keep the base and soil contact.
b) ROV lifting: the vertical position varies from 800 mm to 3000 mm relative to soil.
c) ROV horizontal leveling: angular adjustments can be executed by operator commands.

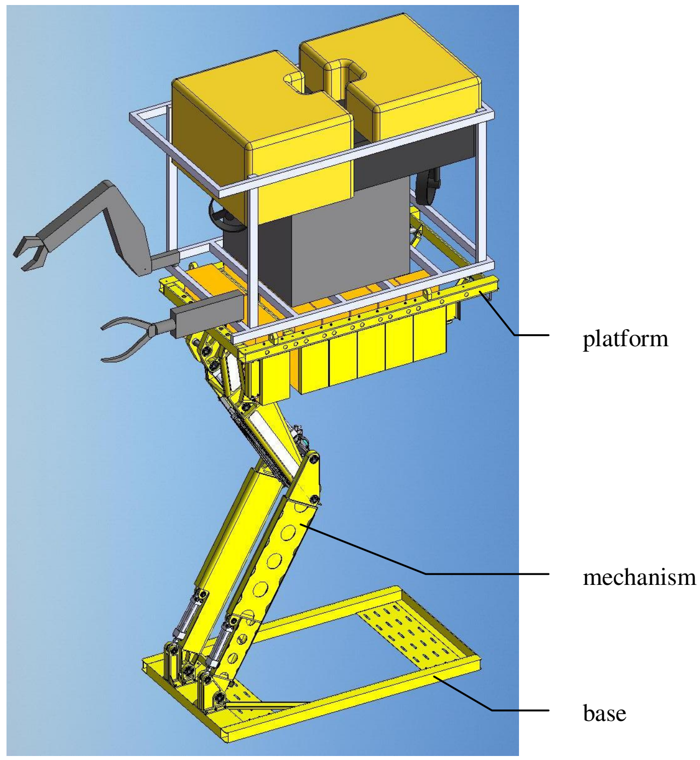


Figure 3: BUPPA-ROV system.

2.2. General characteristics

The main operational parameters of BUPPA are indicated in table 1.

Table 1. BUPPA operational parameters.

Maximum achievable depth:	2000 m LDA.
Volume:	2600 x 1500 x 767 mm (closed configuration).
Working height:	800 mm to 3000 mm.
Ground max. inclination:	-10^o to 10^o.
Estimated weight (submerged):	-10 kgf.
Estimated weight (air):	1070 kgf.
Vertical payload (submerged):	150 kgf @ 1,5 m from the platform.
Payload (closed configuration):	3300 kgf (submerged / on the RSV).
Minimum time (upward):	4 minutes.
Minimum time (downward):	4 minutes.
Power supply:	110 V @ 5A (given by ROV).
Hydraulic power supply:	138 bar @ 20 gpm (given by ROV).
Motion control:	Teleoperated mode.
Internal communication protocol:	RS 485.

2.3. Kinematics configurations

BUPPA can achieve safely ±10 degrees in angular displacement and 3000 mm height. Its limit configurations are presented in Fig. 4.

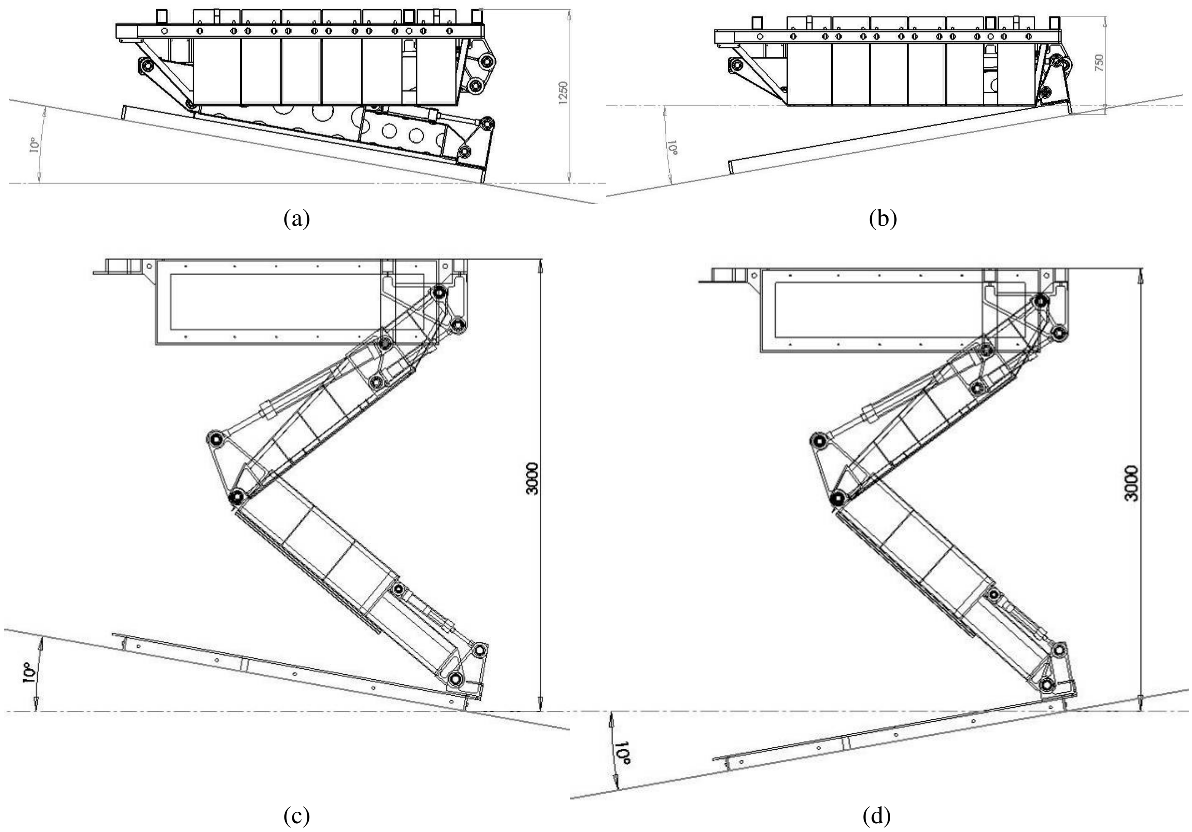


Figure 4: BUPPA limit configurations. (a) and (b) lower positions. (c) and (d) upper positions.

2.4. Accessory devices

There are some devices onboard to improve the human operator telepresence capability, especially during vertical motion where the linear actuators most be manually controlled to result in a simultaneous movement (table 2).

Table 2. Accessory devices for BUPPA motion control.

Device
pan-tilt head and video camera
spot light
laser projector
inclinometer transducer

For instance, the operator can avoid forward and backward displacements of the platform during a lifting motion with the help of some accessory devices. A laser beam defines a point at the base, which is observed by the camera and used as guiding reference (Fig. 5).

Another useful application occurs when the spot light illuminates a wide region in the range of the pan-tilt head and video camera, so that images of the neighborhoods can be generated.

2.5. Working cycle

The operational working cycle initiates at the RSV deck with the ROV mounting and fixation at BUPPA platform, with BUPPA in the closed configuration. Then, BUPPA-ROV system is connected to crane cables, lifted and moved from RSV into the sea water.

After the crane cable disconnection, the BUPPA-ROV system can move in a free-flying mode toward the target. When the system is nearby the sea soil, the human operator carefully maneuvers the ROV thrusters in order to land the system within a controlled approaching velocity, according to international standards (ISO, 2002) (Petrobras, 2007).

Once the BUPPA base has touched the soil, the mechanism can be opened gradually to position and orientate the ROV manipulators relatively to the working area.

When the desired positioning is obtained, the hydraulic actuators are settled to stop and consequently BUPPA becomes a rigid structure. The system is ready to perform the planned tasks.

During the mechanism opening and task execution phases the ROV vertical thrusters are activated to keep the base in a fixed and stable location.

After the task is completed, the mechanism is closed and the BUPPA-ROV system can move to another location or to the sea surface, where the crane cables will be fixed to retrieve the system back to RSV.

This cycle can be repeated indefinitely.

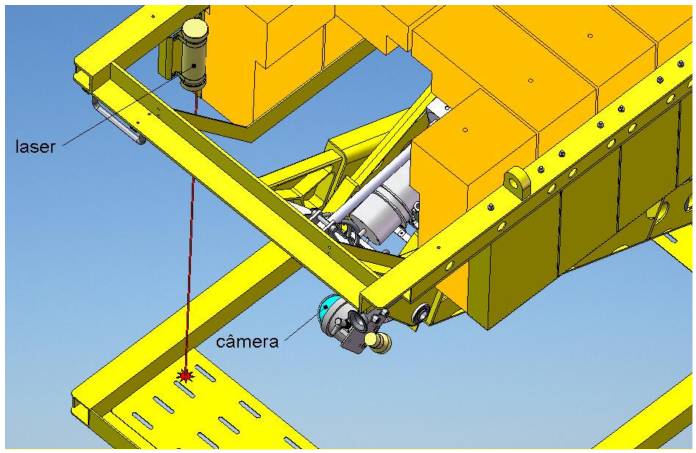


Figure 5: Monitored action for lifting motion.

3. HYDRAULIC CIRCUIT

The BUPPA hydraulic circuit was designed to be independent from the ROV hydraulic circuit, in order to avoid the ROV contamination through components in direct contact with water, such as hydraulic cylinders. A water presence transducer is used for monitoring oil contamination.

The hydraulic circuit is formed by a main circuit, an emergency circuit and actuators.

The main circuit is associated to the lifting and orientation motions. It contains the power unit, the valves and control unit.

In case of hydraulic and electrical power supply fail, there is an emergency hydraulic circuit to provide the mechanism retraction.

A Petrobras dual hot-stab connector located at the platform allows the connection of external hydraulic power supply (Fig 6).

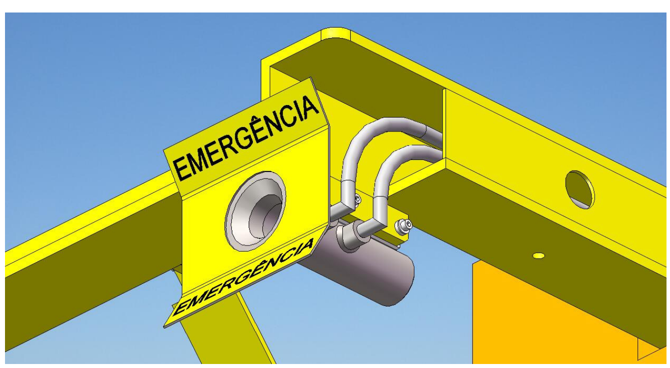


Figure 6. Petrobras dual hot-stab connector.

4. ELECTRO-ELECTRONIC COMPONENTS

The electro-electronic circuit is formed by five sub-systems: command box, onboard control, monitoring unit, instrumentation unit and junction box.

The command box, located at the ROV Support Vessel (RSV), has joysticks and dedicated electronic components so that the operator can send command signals to BUPPA onboard control via umbilical cable.

Onboard control is basically a commercial valve pack solution.

The monitoring unit is related to all internal transducers located at hydraulic circuit, such as:

- temperature transducers.
- pressure transducers.
- water presence transducers.

The instrumentation unit is responsible for the visualization of the working area. Its main components are:

- pan-tilt remote head and camera device.
- spot light.
- laser projector.
- inclinometer.

A junction box is a designed component where the electrical connectors are fixed and isolated from sea water.

5. STRUCTURAL ANALYSIS

To evaluate BUPPA-ROV system behavior for the most critical operational conditions, some models were developed and simulated based on established parameters and empirical data from ISO, Petrobras and API standards (ISO, 2002) (Petrobras, 2007), (API, 1998).

The scenarios considered in this analysis are the following:

a) BUPPA-ROV and environmental interactions.

- Related to working cycle operational conditions. Includes reaction loads and hydrodynamic forces due to marine currents.

b) BUPPA internal operational limits.

- Limit situations where the hydraulic cylinders are applying forces at the mechanism joints with the maximum nominal pressure. BUPPA is considered to be at 3000 mm height.

c) BUPPA critical parts.

- Dual Hot-stab integrity.
- Inclinometer container integrity.

5.1. BUPPA-ROV and environmental interactions

Here are described only the simulations due to environmental interactions. Some design parameters and values were not allowed to be presented in this paper.

5.1.1. ROV mounting at BUPPA platform

The ROV weight (in the air) exerts loads at transversal BUPPA platform structures. This is modeled by static distributed loads. BUPPA remains in closed configuration (Fig. 7).

5.1.2. BUPPA-ROV launching

Crane cables will be connected at ROV superior part during BUPPA-ROV system motion from RSV into the sea. The limiting factor here is the ROV nominal skid payload, since BUPPA is fixed underneath the ROV.

This limit was not achieved.

5.1.3. Soil landing

The BUPPA-ROV system landing is characterized by dynamic effects. Soil composition, system inertia, velocity and deceleration were considered in the analysis for the most disadvantaged situation.

The stresses and deformations were negligible.

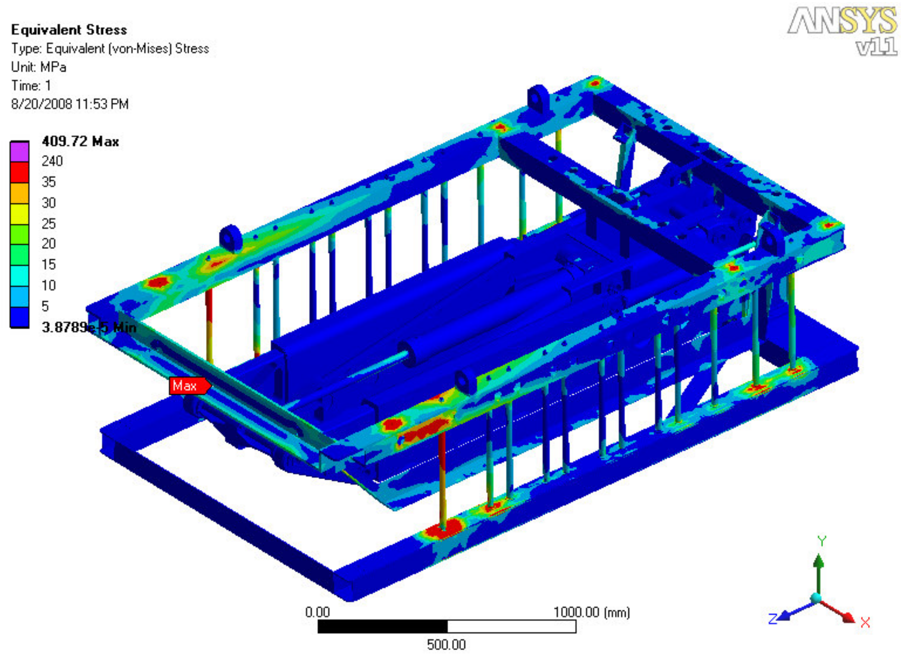


Figure 7. BUPPA stresses due to ROV installation.

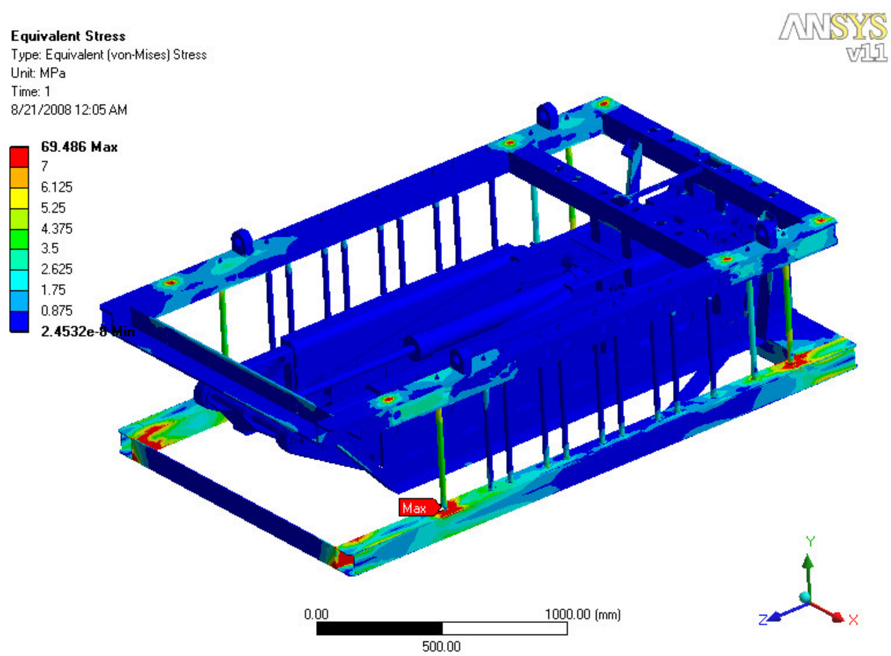
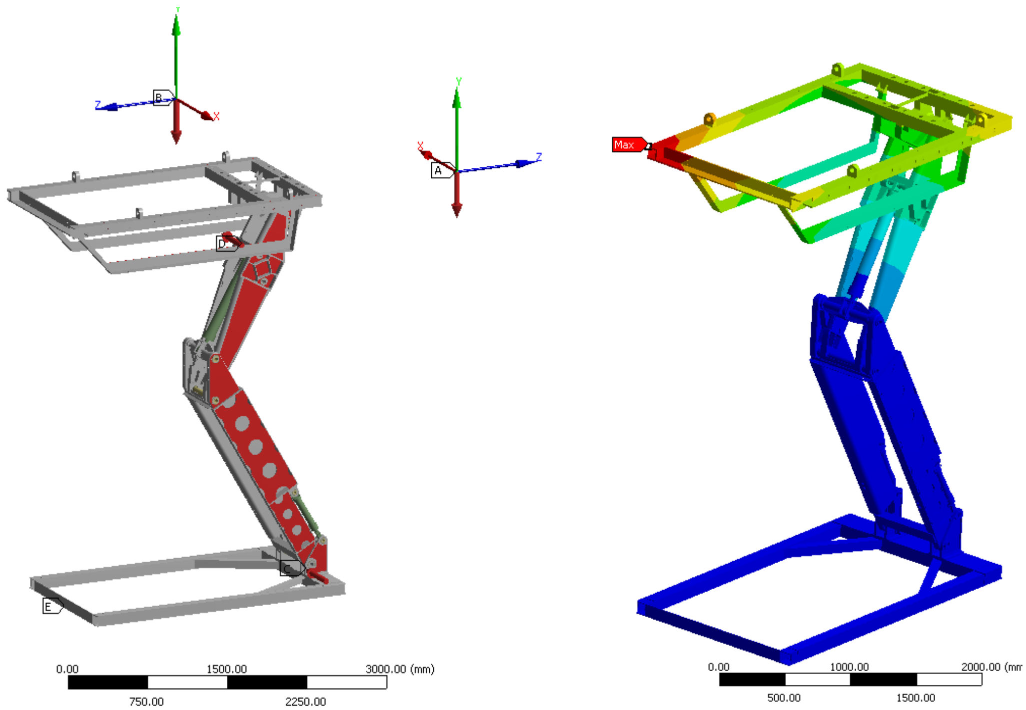


Figure 8. Von-Mises stresses due to landing.

5.1.4. Limit task configuration

This model considers the BUPPA-ROV system in full extension, the manipulator at maximum lift through envelope (210 kgf @ 2.0 m from the platform), hydrodynamic forces due to marine currents and forces generated by thrusters (Fig. 9).



(a) (b)

Figure 9. Limit configuration at working configuration. (a) Load conditions. (b) Deformations.

5.1.5. Accidental collision

In this simulation the external load is associated to manipulator end-effector collision with a rigid structure. The collision magnitude was estimated according to ISO standards for docking operation (Fig. 10).

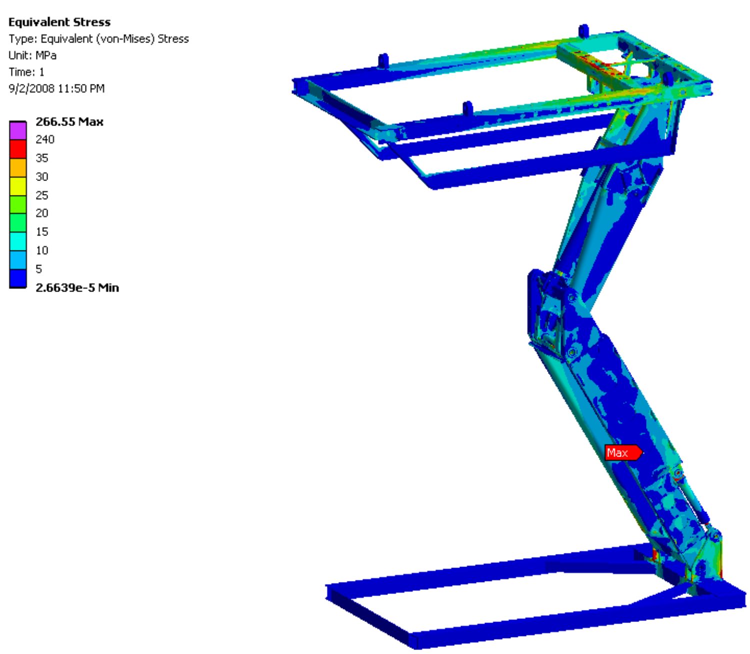
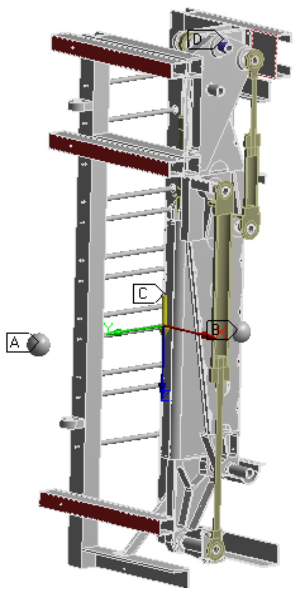


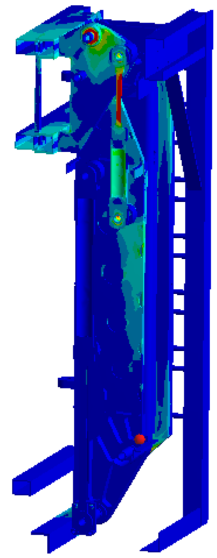
Figure 10. Von-Mises Stresses for collision simulation.

5.1.6. Emergency rescue

In case BUPPA is not connected to ROV, an operation is necessary to retrieve BUPPA from the sea to RSV deck. This is done by connecting the crane cable to a special part of BUPPA structure denominated rescue support (Fig. 11). The only load acting at the structure is related to BUPPA weight and is concentrated at the rescue support.



(a)



(b)

Figure 11. Emergency rescue simulation. (a) Load conditions. (b) Stresses.

6. CONCLUSIONS

The design aspects of the electro-hydraulic skid BUPPA used to lift a landed Remote Operated Underwater Vehicle (ROV) arm system were presented in this paper. The development process was strictly based on ISO, Petrobras and API standards for ROV interfaces, as well as some technical specifications from Petrobras Operational Center from Macaé, RJ.

BUPPA concept is an innovative solution that increases the ROV operator capabilities to perform activities in UPS with more stability if compared to free-flying mode.

The lifting and fine positioning adjustment of a ROV nearby an intervention site depends only on BUPPA mechanism configurations.

Structural optimization criteria were mainly related to internal space maximization to permit the inclusion of the fluctuators and obtain the best weight/rigidity ratio.

CAD simulation, numerical simulation and Finite Element Method program were intensely used along the design phases.

All mechanical, hydraulic and electrical components and materials defined in this project are commercially available.

The construction of a prototype is under consideration.

7. ACKNOLEDGEMENTS

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