Water depth offers the opportunity to enhance BOP control systems.

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With the development and possible deployment of the new Seawater Pressure Reduction Assembly (SPRA) on a deepwater vessel, Shell, Noble and Cameron have taken another innovative step to further enhance subsea BOP control systems and their shearing and sealing capability.

The increased hydrostatic pressure of the seawater plus the surface charge pressure in combination with the non-ideal gas behavior of the pre-charge gases (Nitrogen or Helium) in deepwater pose significant challenges to subsea accumulator systems, which do provide the emergency hydraulic shear and seal force to the BOP.

New deepwater well designs require the use of strong drill pipe and casing strings, which must be capable of being sheared against Maximum Anticipated Wellhead Pressure (MAWHP). To meet the increased demand for BOP shear/seal capability most of the existing systems may need to be upgraded. With conventional equipment (increased number of accumulator bottles) those upgrades would significantly increase the BOP weight and size. Such would require very expensive and time consuming upgrades to rig hoisting systems, rig structure and control systems.

To meet the increased operation capability for subsea control systems, and prevent costly rig upgrades, a solution to the engineering challenge had to be provided.

When studying the problem it became apparent that the hydraulic pressure used for closing the preventer was also used for opening. As the BOP rams open with only a fraction of the closing pressure it was evident that valuable energy was not being optimally used.

The challenge was to improve the BOP control system in such a way where both subsea and surface accumulators efficiency would be improved to generate enough power to activate shear rams on deepwater BOPs.

The SPRA is designed to reduce the seawater hydrostatic pressure on the open port of a subsea actuator. While it increases the open pressure from 200 psi to 1500 – 2500 psi, it significantly increases the ram closing/shear force from the casing shear rams (CSR) and blind shear rams (BSR) aided by the help of the seawater pressure (see Figure 1).

Figure 1: Drillship with SPRA system.

It sounds like a paradox, but “in a way” the challenge was turned into an important part of the solution, because increasing water depth will make it easier to shear as the closing force increases with water depth. It resolves the pressure and volume problem in deep water as result of non-ideal gas behavior of Nitrogen. This would allow deepwater rigs to use Nitrogen...
instead of Helium. It also may help to minimize the logistics of the supply and demand of both Helium and Nitrogen, currently being used.

The device is designed to maximize the efficiency of surface and subsea accumulators in volume and pressure delivery to the function. This is achieved by, allowing the SPRA to initially close the shear rams on open hole or against the pipe first, without using any surface or subsea accumulator volume or pressure, followed by the application of the shear / close pressure to the function thereafter. This is called the SPRA-Pilot Close Mode (PCM).

Prototype testing has shown that the amount of power unlocked by the SPRA system can be very substantial as the differential pressure across the piston increases with water depth. With the SPRA system on a deepwater BOP stack, shear seal performance in 10000 ft water depth against 10000 psi MAWHP is expected to increase more then 150% on the Dead-Man (DM) and Auto-Shear (AS) system compared to the use of standard configuration 8 x 160 gal piston accumulators (see Figure 2).

The optimum SPRA de-intensifier ratio or de-boosted opening pressure is dependent on:

a. The opening pressure supplied by the control system (1500-2500 psi),
b. The strength of the BOP operators,
c. The strength of the connection rod / ram interface,
d. The strength of the connection from the operator to the BOP,
e. The maximum allowable differential across the operator piston seal(s),
f. The strength of the shear ram(s).

For the Cameron EVO BOP the above performance improvement is based on a SPRA ratio of 1.54. The number of 25 US gal de-boosters fitted to the selected control system function depends on the operator open volume (see Figure 3, two deboosters).

In order to integrate the SPRA in existing BOP controls and to provide adequate redundancy, the hydraulic system is fitted with bypass valves for the de-boosters, a transfer barrier and the pilot valves in the operator close circuit. When the bypass for the pilot operated valves is closed, the BOP operator will remain in the open position when the block function of the ram operating system is selected. The two in series mounted pilot operated valves in the close circuit will provide a double isolation to the seawater hydrostatic head. By installing two dual valve assemblies in parallel, the system
would offer the same redundancy level as provided by the yellow and blue Point Of Distribution (PODs).

A transfer barrier is fitted in the close circuit to prevent seawater ingress into the operator when the SPRA is closing the ram preventer.

The SPRA control system offers the following modes to be selected (see Figure 4):

1. **Auto Close Mode (ACM):**
   - SPM bypass valve is Open
   - Transfer barrier bypass valve is closed.
   - SPRA bypass valve Closed.

   With the BOP control function in Block position, the SPRA will close the ram preventer using seawater.

2. **Pilot Close Mode (PCM):**
   - SPM bypass valve is closed.
   - Transfer barrier bypass valve is closed.
   - SPRA bypass valve closed.

   With the BOP control function in Block position, the SPRA will **not** close the ram preventer until the SPM valve is opened.

3. **Normal Close Mode (NCM):**
   - SPM bypass valve is open.
   - Transfer barrier bypass valve is closed.
   - SPRA bypass valve open.

   All SPRA controls bypassed.

   With the BOP control function in Block position, the ram preventer remains in the last position (standard control system).

Further control system integration is required in the computer logic to support the PCM. On conventional MUX control systems shear rams have four push buttons on the panel: open, block, close and high pressure close. For SPRA controls in PCM, two other push buttons must be added namely SPRA manifold open and block (see Figure 5). These two manifold functions must be interlinked with the open, block, close and high pressure close push buttons on the panel to assure that function operation is simple and performance controlled.

![Figure 5: Shear ram control panel push buttons.](image)

To maximize the shear seal power on the DM/AS system as shown in Figure 2, integration of the PCM will require the use of a timing circuit that separates the SPRA manifold open function and the close function.

When the control system does not offer the ability to separate the SPRA manifold open and the close function, then activation of both functions at the same time can be considered. This configuration would deliver a closing force equal to the conventional system, increased with the additional force generated by the SPRA as illustrated in Figure 2.

The additional power of a deepwater BOP CSR + BSR does come with a weight increase of +/- 45000 lbs consisting of:

- Controls (ROV Panels, etc) = 2432 lbs,
• 75gal Transfer Barrier (CSR) = 4793 lbs,
• 50gal Transfer Barrier (BSR) = 3592 lbs,
• De-booster (5 total) = 29,500 lbs,
• Miscellaneous Brackets = 4600 lbs.

To accommodate the additional weight, the BOP crane may have to be upgraded.

Modeling of blowout loads for high pressure subsea wells requires selection of heavy strings like a 14”, 109 lb/ft, Q125. Testing with the Super Shear casing ram showed that this pipe sheared with 3100 psi under surface conditions. To shear the pipe at 10000 ft water depth and against 10000 psi MAWHP the DM/AS system must deliver 7950 psia discharge pressure.

If a rig DM/AS system uses Nitrogen and 8 x 160 Gal, 7500 psi SWP accumulators at 10000 ft water depth, the system delivers 2251 psi shear pressure under the above conditions with a Super Shear Ram (see Figure 6, red lined boxes). A BOP shear / seal upgrade which includes installation of more 160 gal, 7500 psi SWP accumulators, from surface charged to 5000 psi, would not be practical from a weight and stack size point of view as the accumulator count increases to 15, see Figure 6.

<table>
<thead>
<tr>
<th>Accu surface charge (psia)</th>
<th>Accu Subsea discharge (psia)</th>
<th>Shear MAWHP (psia)</th>
<th>DM/AS Accu No.</th>
<th>DM/AS Volume US gal</th>
<th>Remarks</th>
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<tr>
<td>5000</td>
<td>7050</td>
<td>2251</td>
<td>8</td>
<td>1280</td>
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<td>7950</td>
<td>3151</td>
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<tr>
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<td>4175</td>
<td>8</td>
<td>1280</td>
<td>SPRA with 1.54 ratio</td>
</tr>
</tbody>
</table>

Figure 6: DM/AS accumulator count

Only when increasing the BOP accumulator charge pressure from 5000 psi to 7500 psi, the system is able to shear the 14” casing with the available 8 x 160 gal accumulators on the stack as the system in this configuration delivers 3601 psi shear pressure. An upgrade to 7500 psi charge pressure does, however, require the installation of HP piping and a 7500-5000 psi regulator. Further upgrades must be considered which may include a surface 7500 psi pump and a 7500 psi hot line reel.

The SPRA system upgrade shows that it might be able to outperform a system that uses 7500 psi accumulator charge pressure. After upgrading a BOP, the available shear pressure at 10000 ft water depth and 10000 psi MAWHP is 4175 psi (see Figure 6).

The SPRA system operated in a PCM can offer a deepwater rig to meet and exceed the API STD 53 requirement of shearing and sealing against a MAWHP on the control system and emergency control system at any water depth. “Sequencing of the CSR and BSR and any other function on the DM/AS is possible. Performance generated by the SPRA will be an important contribution to developing stronger BOPs.

In principle, pipe ram mechanical locks can also be made superficial at water depths exceeding 5000 ft, as the SPRA would generate the required ram closing force (by reduction of the seawater hydrostatic head on the open side) to maintain the ram closed position in the event BOP control system closing pressure is lost or removed.

Retrofitting the system would be possible on any existing BOP.