Design of Hydraulic Systems for Subsea Applications

By Royce Gerngross, Engineer Marine and Offshore & Dr. Alexandre Orthm, Project Risk Manager

Global Growth Drives Subsea Expansion

More than two-thirds of the earth's surface is covered by water, and there are many potential resources there that await exploration and development. Industries involved in this new frontier include mining, oil and gas, infrastructure, energy generation and natural science.

These activities all involve complex and highly technical systems. Many of them, particularly those performed beneath the sea's surface, utilize a broad array of electro-hydraulic systems to carry out their work-lower and lift equipment to the seabed, remote operation of subsea systems, and permanent monitoring of emplaced systems such as petroleum wellheads or communications cabling.

It is frequently assumed that such hydraulic equipment needs to be specifically designed and engineered using special materials to enable operation under the pressures and corrosive conditions of different sea depths. However, many standard hydraulic systems engineered for surface use can be, with sufficient customization, utilized effectively in this demanding environment.

Ultimately, the operation of hydraulic systems-whether on land at sea level atmospheres, or deep under the sea-requires isolating the hydraulic circuit from external environments and controlling the fluid to actuate work; the principles are the same, and thus the design principles for subsea simply call for considering additional conditions.

Comparison of Subsea Requirements

In order to select the best solution for a given application, it is necessary to understand how the different subsea water depths impact the hydraulic system. The analysis used in oil and gas exploration supply an effective set of guidelines.

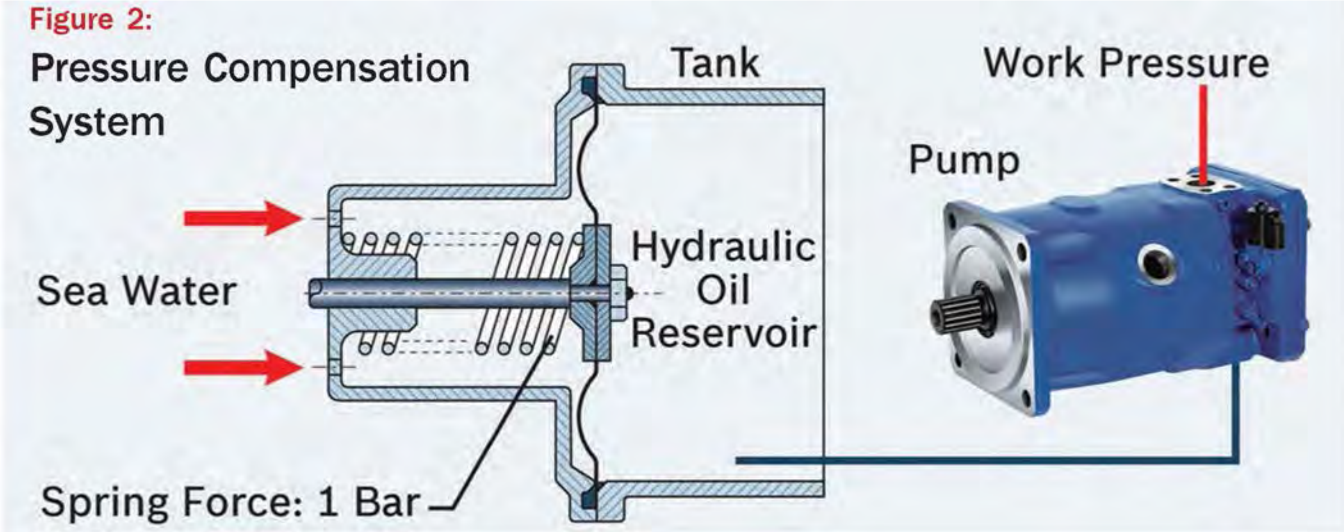
Shallow water: Up to 1,000 ft (305 meter)

At this depth, components must operate in saltwater, but not in significantly high water pressures. At this depth, (which includes the technical safe limit for divers not pressure suits, at 100 meters), the equipment is relatively easy to operate, put in place and retrieve. However, the surface light may penetrate up to 200 meters, thus promoting the growth of sea life over the equipment surface; this must be factored into designs of equipment such as hydraulic cylinder rods.

Table 1

Summary of the Main Subsea Requirements per type of Application

Req.	Applications	Ocean Energy	Oil & Gas	Mining	ROVs/ AUVs	Infra-structure	Natural Science
Water Depth	Shallow Water: <= 1,000 ft. (corrosion, sea life)	X	X	X	X	X	X
	Deep Water: >1,000 ft. (water pressure, distance to shore, full remote operation, sea currents)		X	X	X	X	X
	Ultra-Deep Water: > 6,000 ft (very high water pressure, extreme sea conditions, distances, large equipment)		X	X	X	X	X
Safety	Significant risk of injury to people or environment	Low	Very high	High	Low	High	Low
Reliability/ Availability	Cost of downtime due to unexpected field failures	High	Very high	High	Medium	High	Low
Maintainability	Ability to repair system on location or on sea surface (scheduled downtime)	Varying production	Continuous production	Varying production	Intermittent production	Continuous usage	Intermittent usage



,, **Deep water: from 1,000 ft. (305 m.) to 6,000 ft (to 1,830 m.)**

Every 10 meters, the water column increases the environmental pressure by 1 bar; thus, at a depth of 5,000 meters the ambient pressure is 500 bar. At these depths, all work is done with remote control systems and subsea robots such as ROVs (Remote Operated Vehicles) or AUVs (Autonomous Underwater Vehicles). Here, components become exposed to high external water pressures, which may require special design features like pressure compensation or structural modifications to accommodate the increased pressures.

These depths are typically found significantly far from shore, requiring floating operational facilities such as ships and platforms, creating further challenges.

,, **Ultra -deep water: From 6,000 ft (1,830 m) to 35,800 ft (10,911m)**

Beyond 6,000 ft, there is much less experience of subsea equipment (outside of military applications and research vessels). As depths increase, even the engineering of hoisting and tether equipment construction must change, to accommodate the dimensions and weight of the systems as they increase with the water depth. Furthermore, the ocean conditions become harsher, such as the size of waves or the forces caused by maritime currents.

The Subsea Enabler: Robotics

Since divers can't operate below 100 meters, the bulk of subsea activities must be performed by ROV s and AUV s, complex systems which utilize extensive electromechanical and electrohydraulic subsystems to accomplish tasks. Their operational depths can be in any range. Typically, robots are not submerged for long periods of time. However, it is critical they are ready when needed, and if they malfunction the downtime must be kept to a minimum.

Hydraulic drives can prove their full strength in these machines: they are powerful, compact, precise, intelligent and rugged, providing excellent power density and adroit flexibility for a wide range of tasks. ROV/ AUV developers continue to seek more sophisticated performance and reliability from the electrohydraulics systems integrated into their machines.

Subsea Design Requirements

Successful growth of many subsea applications depends upon equipment that can be reliably and safely deployed and operated over extensive periods of time, without requiring overly-expensive engineering, operating and repair costs. There are built-in costs for subsea work that are unavoidable: operating equipment at a distance with remote devices, and dealing with external water pressure and corrosion conditions. Careful planning and a willingness to integrate smart design principles into subsea hydraulic systems make it possible to accomplish these goals cost-effectively.

Pressure Compensation

Pressure compensation is useful in any system which operates below water. It is used to keep the pressure between external environment (seawater) and reservoir constant, as seals are typically designed for the pressure drop in one particular direction and limited to a specified amount.

Most components readily available on the market were designed for operation in normal surface environments. Almost all machines have sealing surfaces or parts which cannot withstand high subsea external pressures or high pressure drops. One option-more difficult and expensive-is to seal pressure-sensitive components inside a protective chamber. This is usually a container with rigid construction and heavy duty seals to withstand the high external pressures.

A more effective solution is called pressure compensation. Using this system a pressure is applied inside the component equal and opposite to the ambient pressure outside. In a typical hydraulic system, the standard reservoir is replaced with a sealed reservoir containing a flexible medium separator.

In this way the external environment pressure is transferred to the reservoir, just as a normal surface system has the external air pressure on top of the oil in the reservoir. The difference is the seawater is prevented from mixing with the oil. Through this clever system any component used on the surface can be used subsea as long as all volumes that normally contain air can be vacated of air filled with fluid and connected to the reservoir to maintain the pressure balance.

Subsea Industry Challenges

Several key industries already undertake significant subsea activities—here are some hydraulics-related challenges they face:

Oil and gas production

- The move to deep and ultra-deep water drilling is forcing more process equipment from surface to subsea
- Key requirements are ultra-high reliability, ability to install and maintain utilizing ROVs/AUVs technology
- Expected operating lifetimes are for the life of the field, typically covering 25 to 30 years
- New techniques to accurately simulate the performance of a hydraulic system across this timeframe becomes a key success factor

Subsea mining

- Most mining occurs in shallow water using current dredging technology
- As mining moves to deep and ultra-deep water in near future, ruggedness and long term durability will be crucial
- Several companies currently developing large remotely operated mining vehicles.
- Transport of bulk materials over long distances while overcoming additional water weight is key challenge

Communication & Power Transmission

- Infrastructure facilities, such as communication cable crossing the Atlantic Ocean, are subject to different underwater geography conditions, including different water depths and complex deep ocean currents
- Regular inspection and repair of power and communications cables in deep sea regions most significant
- Heavy dependence on ROV's or AUV's using hydraulics

Natural science

- Special observations ROV's and AUV's are under development
- Key capabilities include reliable operation of both moveable observation equipment—cameras and other sensors—and mobile sample-gathering tools
- Research locations are widely varied in terms of depths, salinity, currents and other conditions
- Reliability is ultra-crucial: failure of a ROV for even a day can drastically impact researchers with limited time and funding to complete projects

Corrosion Protection and Sealing

On offshore machines, it is common to have a seal, sealing surface, seawater, and some other medium in contact and interacting with each other. On large hydraulic cylinders, for example, maintaining the integrity of the cylinder rod, which is routinely exposed to environmental conditions in operation, is essential for maintaining the long-term operating life of the system.

The rod surface needs an appropriate coating to provide a good and durable base for the cylinder's tribological system between the cylinder head and the piston rod. There have been major advances in cylinder coating technologies, including metallic/metal mix systems applied with high velocity oxygen flame (HVOF) or cobalt alloy coatings applied via plasma arc welding.

In hydraulic actuator design there is always an interaction between seals, fluid, and material surface. The study of these three items is known as tribology. Knowledge of this is critical for system designers, to both keep seawater out of a system and keep the hydraulic fluid in.

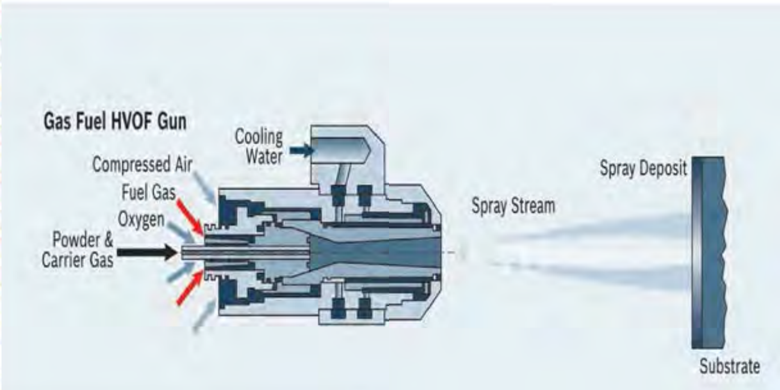
Human Safety and Environmental Protection

Equipment engineered for subsea applications must protect both people and the ocean environment from any damage. For deep water and ultra-deep water operations, surface operators need protection from equipment failures during the whole life cycle of the subsea system.

Subsea operations are carried out in environmentally sensitive areas. Hydraulic systems that follow safety principles, such as fail-safe systems that use a de-energization principle,

Figure 3:

HVOF Coating Technology for Large Hydraulic Cylinders



where the system automatically moves to a safe position if the power supply is cut off, are examples of systems with safety engineered-in.

These principles of risk assessment and functional safety have been established through international standards such as ISO 12100, ISO 13849 and ISO 4413.

Reliability and Availability

The reliability of subsea equipment with a projected long lifetime of 30 years in such a harsh environment is one of the largest challenges for the industry today. Reliable hydraulic system design for subsea application can apply different approaches at the same time:

- *Usage of components with a high degree of reliability: if available, a reliability indicator shall be used for comparison such as MTTF, B10 or Weibull distributions.*
- *Redundancy~ when possible and more cost-effective redundant architecture can be installed for higher system reliability: in some case, more than two components may be needed to support each other.*
- *Integration of failure diagnostic features, such as suitable sensors as well as the correct algorithm for processing the information to detect a failure and decide the correct reaction.*

In oil and gas applications, field operators expect to use subsea equipment during a well location's entire service life (30 years or more) with minimal maintenance. Suitable sensors have to be designed, integrated and pressure-proven to detect failures and, if possible, anticipate future failures by including condition monitoring functions.

Designing for Safe and Reliable Subsea Ops

At multiple frontiers and across multiple industries, subsea applications continue to grow. The safe, reliable and effective development of such opportunities has already been proven. However, as industries move deeper under the ocean, certain fundamental technical challenges increase, particularly for hydraulically-driven systems.

These challenges can be met through a combination of standard, "off-the-shelf' systems proven to operate in rugged conditions on the land, with suitable adaptations (such as pressure compensation) and smart, cost-effective application of more advanced materials where needed. This approach can ultimately enable a more cost-effective approach to subsea development and wider access to the potential resources this emerging "frontier" offers.

Source: Marine Technology April 2015

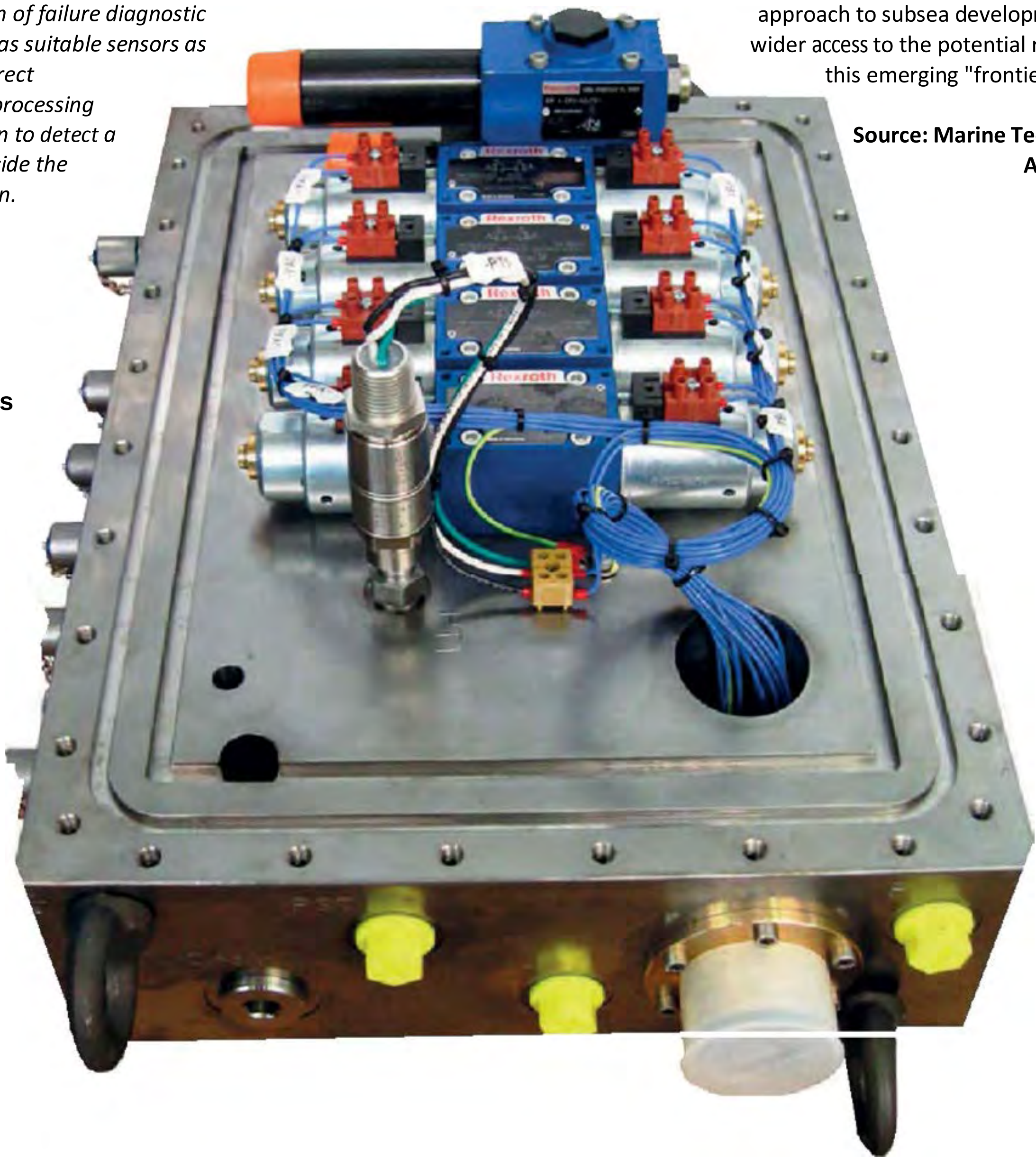


Figure 4: Example of industrial electrohydraulic valves adapted for subsea application.