White Paper

Best of Both World's - Subsea Safety Valve Motion Control

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Key Messages

- SubSea Electrohydrostatic Actuation System enables our customers to deploy electric actuation in all their SubSea Safety Valve Equipment such as Xtree, Well Intervention, BOP, HIPPS, etc.
- Insights into the primary features of this novel solution include Comparison of Technical Features to Existing Technology; Functional Safety Concept – SIL2; Design for Reliability; Performance Data; xTree Case Study

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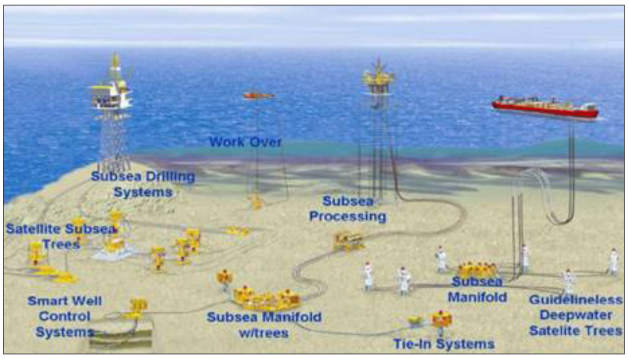
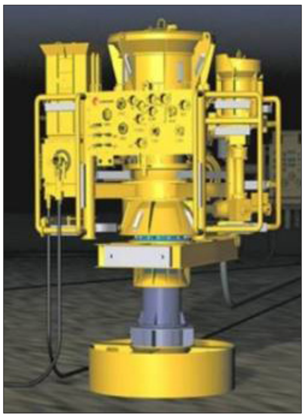
Summary

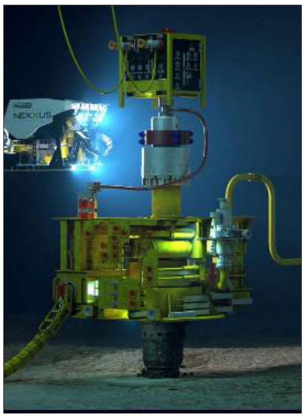
Electrification has been and continues to be a trend across multiple industrial markets. For SubSea process valve actuation electrification, electromechanical approach's has two major challenges. The actuator cost is very high and there is a significant risk of jamming. How do we combine the best features of Electric Actuation with Hydraulics Actuation and significantly reduce overall cost while increasing reliability and connectivity?

Moog is working with a major SubSea OEM on Moog's Patented (US9,631,455B2) subsea Electro Hydrostatic Actuation (EHA) solution that combines the best features. The modular solution allows the OEM to keep their existing hydraulic cylinders and failsafe springs and compensator. Moog provides an EHA connected to the ports of the OEM hydraulic cylinder and a Power Management Canister with a SIL2 Safety Architecture. The power management module interfaces via digital communication and a low DC voltage trickle charger to charge the onboard electric energy storage. This system allows the customer to have closed loop control of the hydraulic cylinder and connected process control valve. This distributed control system offers remote operation and enables IOT data management. Force, speed, system efficiency and health of vital components are monitored, evaluated and communicated to the OEM's system.

Moog's EHA technology is a well-proven technology first deployed in the Defense Industry in 2002 and now used on Commercial and Military Aircraft as well as many Industrial Markets. The Aircraft EHA design requires a high level of safety and reliability. This knowledge has been incorporated into Moog's SubSea design.







1 Introduction

In motion control, there are three main actuation technologies. Electro-Hydraulic actuation (EH) where a central hydraulic power unit provides hydraulic power to valves, which control hydraulic cylinders, has been the most widely used technology. Electric Mechanical Actuation (EMA) technology has been effectively used when a distributed power source was needed. Electric Hydrostatic Actuation (EHA) has recently been utilized to also allow for a distributed power source and can be used in a distributed manner to supply power to several actuators sequentially. Fig. 1 is a diagram, which outlines the technology and shows the advantages and disadvantages of each technology.

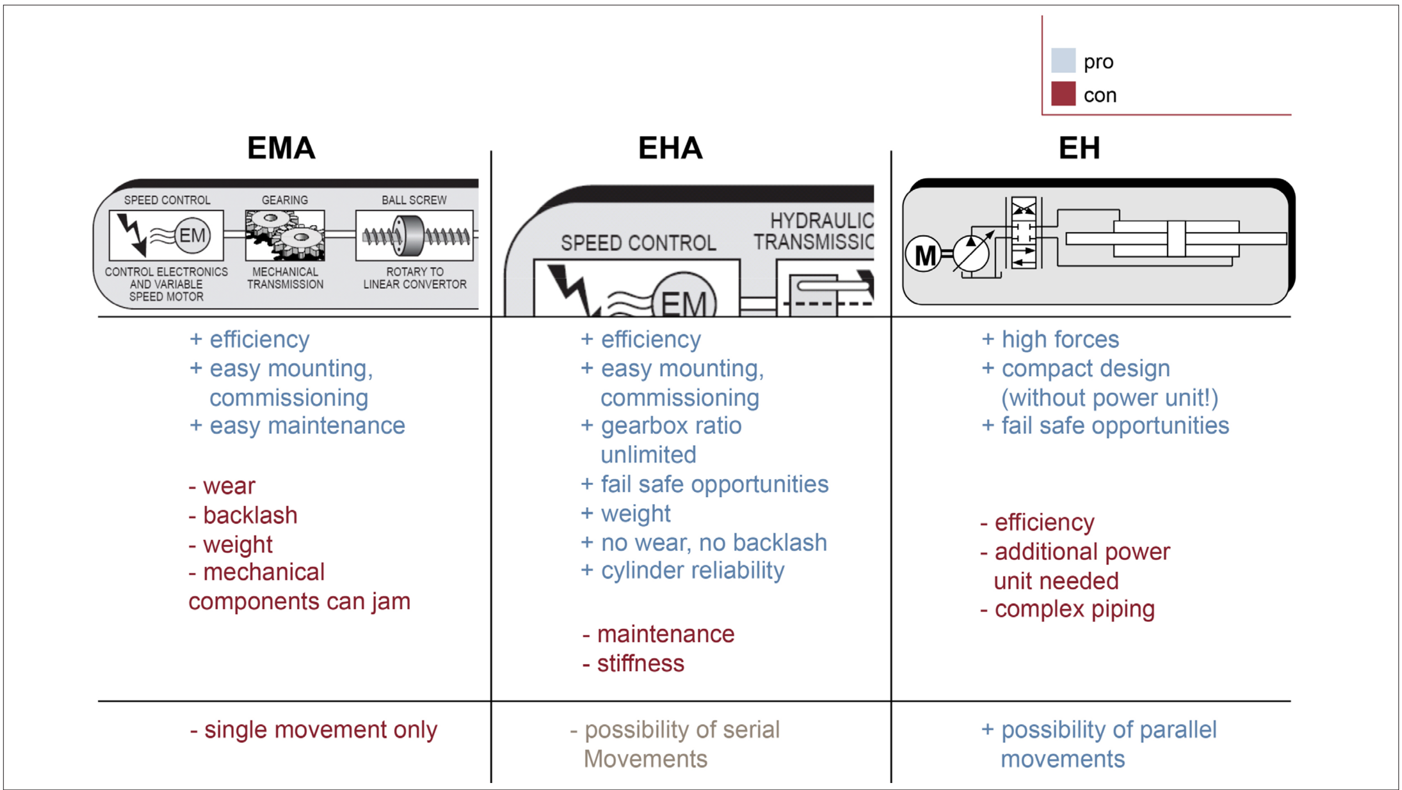


Figure 1 – Technology comparison

As oil production goes to deeper water the greater the need for removing the hydraulic power umbilical. This has led to replacing the umbilical with a hydraulic power unit skid and accumulator skid placed on the SubSea floor. There are economic benefits to this solution, however it lacks performance features that a distributed electric actuation control system offers such as health monitoring and data logging critical for the IOT. [1]

Existing requirements of controls in Xmas trees and subsea production systems are often based on established hydraulic solutions rather than functions. This becomes an understandable challenge to implement new technology. Moving away from a hydraulic system that people have confidence is a challenge, Winter-Larssen says. But, he adds: “We have come to a point where we believe we can make competitive electric system compared to hydraulic.” [2]

EHA offers the best of the current EH and the EMA. It utilizes the current reliable proven hydraulic cylinder and spring failsafe found on current SubSea equipment and offers the removal of the hydraulic umbilical and high-risk inefficient subsea accumulators. [3] It also offers all the performance features of the EMA. In addition, a single Electro Hydrostatic Power Unit can drive a single axis or can operate many separate sequentially operated axis.

2 Design Concept

The Electro Hydrostatic Actuations System (EAS) leverages the EHA technology and adds other features such as hydraulic safety valves to create added features required in a system.

There are two fundamental ways of running a subsea valve into its failsafe position. One is using a failsafe spring (Fig.2) , which is the most common method, and the second is utilizing the actuators motion control system to drive the valve into the failsafe position. (Fig.3). The proposed EAS utilizes a common mechanical unit that can be configured for both fundamental modes of safe operation.

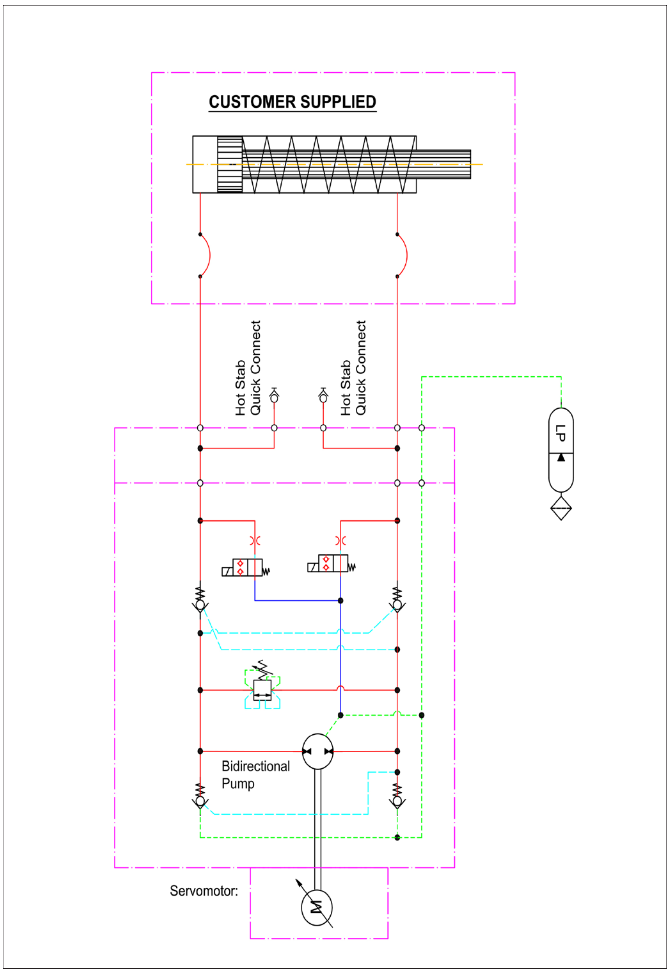


Figure 2 – EAS with Spring Failsafe Cylinder

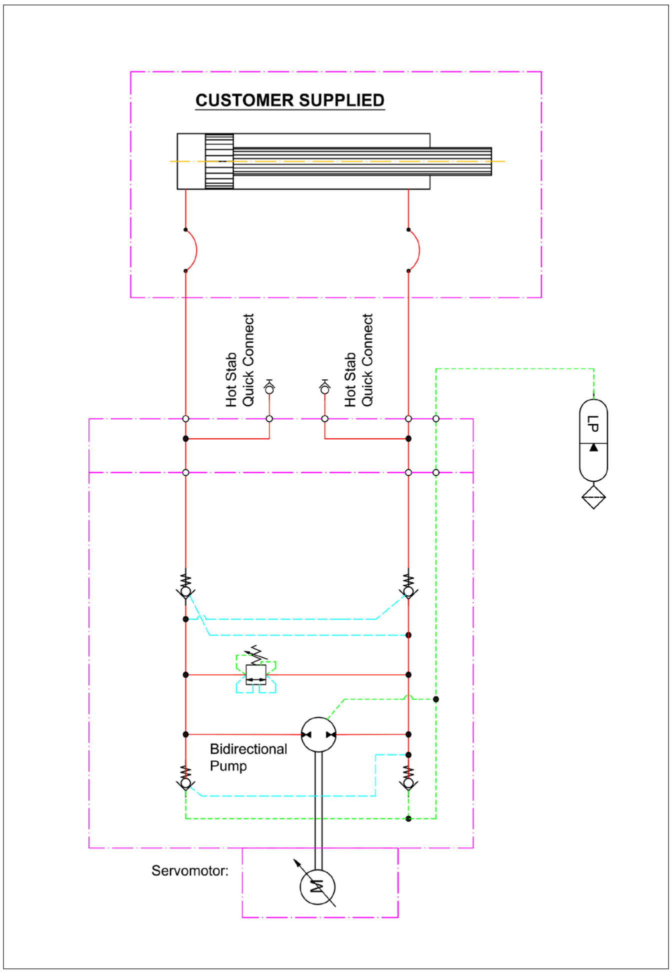


Figure 3 – EAS drive to failsafe position

For larger safety valves, 5 inch and larger, an EAS unit would be dedicated to each cylinder. For smaller valves, under 5 inches, an EAS unit could operate several cylinders sequentially through a valve distribution manifold.

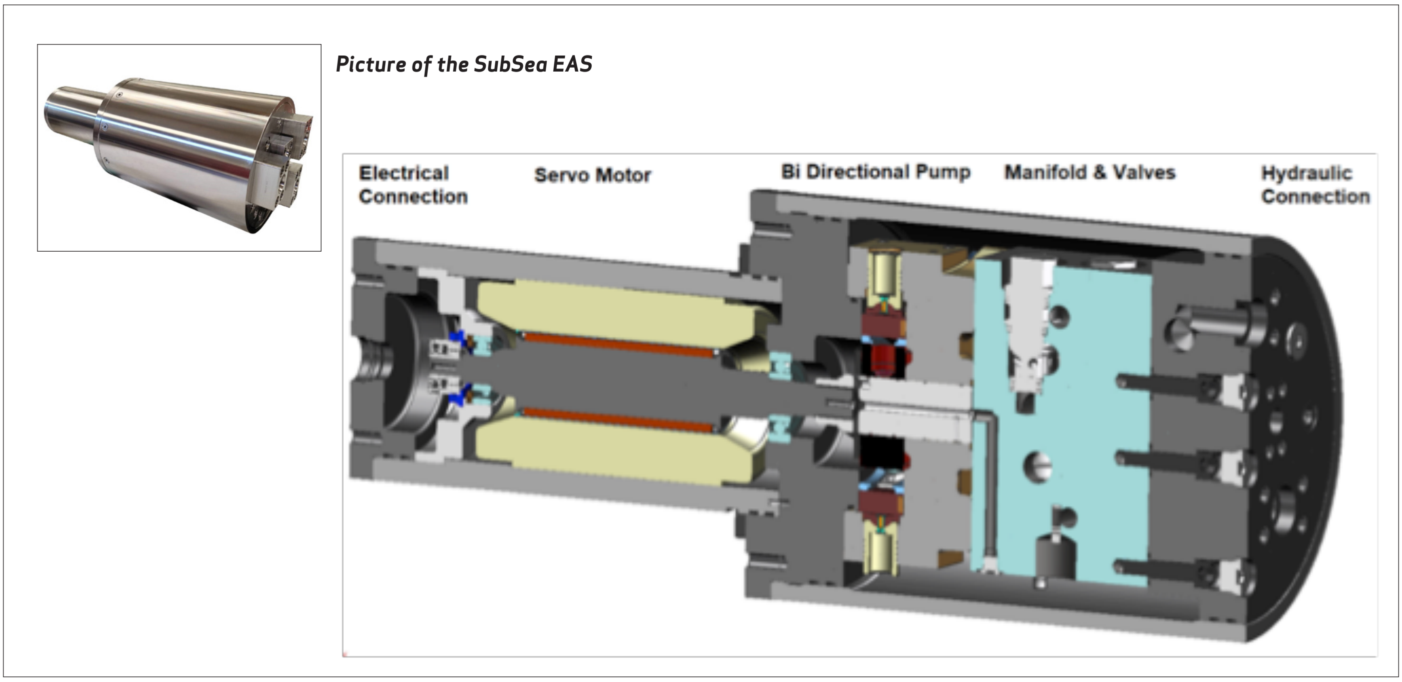


Figure 4 – EAS Cross Section View

3 Functional Safety Concept

Norwegian Oil and Gas Association recommends process valves for Isolation of production bore upon high pressure be SIL2. Typically, on subsea equipment a production wing valve (PWV) and production master valve (PMV) are redundant valves and are in series. [6]

4 Failsafe Spring Architecture

SIL2 is relatively easy to reach with a spring failsafe process valve [4, 5]. It requires that two redundant process valves in series, each actuation system having a SIL1 rating. SIL1 can be achieved by ensuring that the failsafe hydraulic valves do not have 24VDC to energize its solenoids and the internal hydraulic valve spring connects both side of the hydraulic cylinder to the hydraulic reservoir reference figure 2. This will freely allow the process valve spring to drive the cylinder into its failsafe position regardless if the servomotor is running or not since any pump flow will just circulate in and out of the hydraulic reservoir due to the failsafe position of the failsafe hydraulic valves. The valve failsafe position limit switch (SLP,SLS) is monitored and the switch will need to be made within a time tolerance. If this switch is not made within the time tolerance or there is a loss of the safe command from the customer controller, the Safety PLC will close both of the process valves to their safe position. A block diagram of the control system is found in Figure 5.

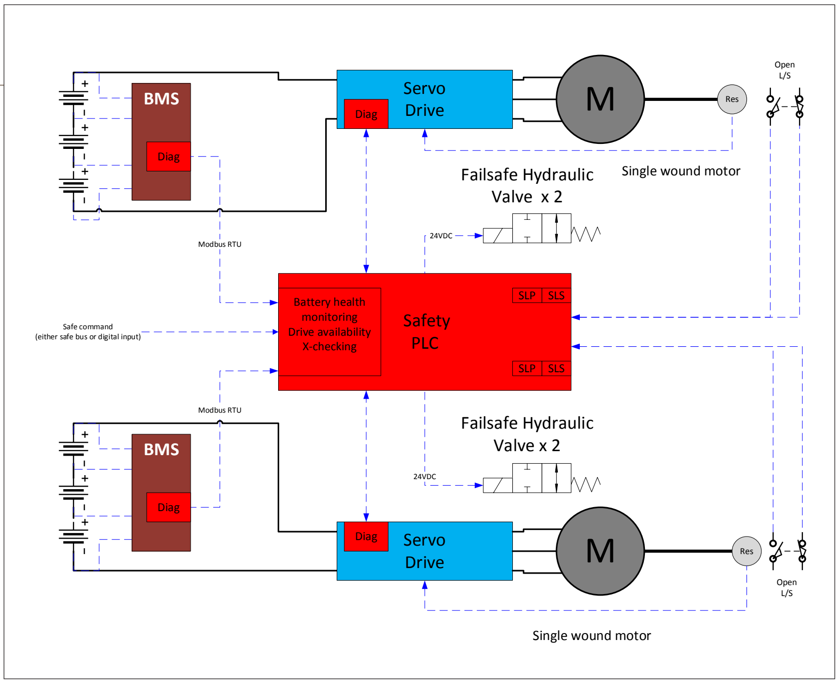


Figure 5 – EAS Cross Section View

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SIL2 is relatively difficult to reach when the process valve requires the electric drive system to move the valve into the failsafe position [4, 5]. It requires that two redundant process valves motion control systems in series each having a SIL1 rating. The first hurdle is that each single drive is only SIL 0 rated. Therefore, a redundant drive for each dual wound motor with dual resolvers is required. A safety PLC rated at above SIL2 will monitor the battery monitoring system (BMS, Diag) to ensure the servo drives will be supplied with sufficient current and voltage and that there is no degradation in the battery cells. The PLC will also monitor (Diag) if the motor rotation is within a tolerance. The PLC will monitor that the valve has reached its safe position within a given time. The PLC will also ensure that the safe torque off (STO) is enabled on the servo drives once the failsafe limit switch position (SLP,SLS) is reached. This ensures that the motor will not drive the valve out of the failsafe-closed position. If there is a failure in any of these monitoring systems or a loss of the safe command from the external customer controller, the Safety PLC will close both of the process valves to their failsafe position. A block diagram of the control system is found in Figure 6.

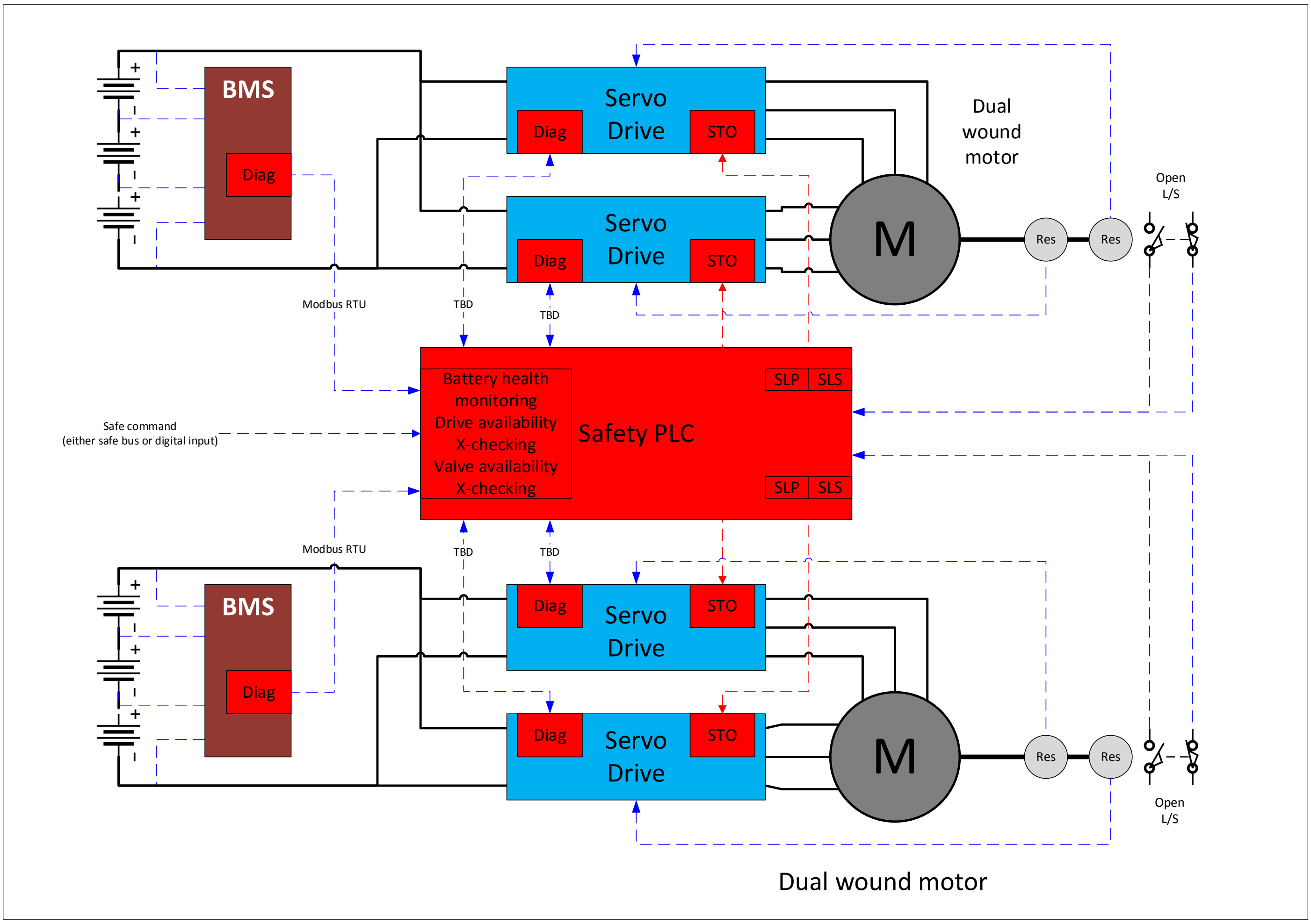

Figure 6 – Electrical Block Diagram of Drive to Failsafe Position SIL2

6 Design for Reliability of System

Failure rate (λ) is defined as the number of failures divided by the total operating time. It is commonly used to express reliability of a particular function, such as a safety function [7].
Failure rate data sources in preferential order are:

- Moog field data with similar or extreme environment

- Manufacturer field data

- Moog calculated data based on:

Oreda 2002 database	Field offshore data for hydraulics
SN 29500-15	Electrical components
IEC 62380	Electrical components

- Target SIL2, probability of dangerous failure (PFH) $>10^{-7}$ to $<10^{-6}$

7 Failsafe Spring

With a spring failsafe. The hydraulic circuit, which connects both sides of the cylinder to the compensator, becomes the only safety critical components required to reach SIL2. As shown below in (Table 1) the resulting PFH is 3.03E-07.

	X	Qty	X
Control Valve	9.30E-08	2	1.86E-07
Pipes	5.80E-08	2	1.16E-07
Cylinder	1.25E-09	1	1.25E-09
Result PFH			3.03E-07

Table 1 – PFH for EAS with Failsafe Spring Cylinder

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8 Drive to Failsafe Position

Without the failsafe spring. The electric actuator is required to powers the cylinder into the safe position. This requires a redundant electronics to reach SIL2. As shown in (Table 2) below the entire actuation system has a PFH of 9.62 E-07.

Component in series / parallel configuration Using summed λ_d and 1oo2 formula from IEC 61508-6 Annex B	**β Factor Used**	**DC Value Used**	**λ_d**	**#**	**λ_d**	Notes
Drive (Hardware Failure Tolerance of 1) (MTTFd based on similar drives) (Checked continuously during normal operation)	5%	90%	3.37E-05	1	3.37E-05	
Fuses for Energy Storage output & Power Supply output (using MIL-HDBK 217 for calculation)	5%	90%	5.00E-09	2	1.00E-08	
Capacitor to Drive cabling (using IEC 62380 for calculation)	5%	90%	1.83E-08	1	1.83E-08	
Drive to Motor cabling (using IEC 62380 for calculation)	5%	90%	1.32E-08	1	1.32E-08	
Energy Storage (Capacitor PFHd developed from supplier field data) (Checked on every deployment. Voltage checked continuously during normal operation)	5%	99%	3.56E-09	180	6.40E-07	
Capacitor to Drive cabling (using IEC 62380 for calculation)	5%	99%	1.83E-08	1	1.83E-08	
Sum of devices in series / parallel			SP Summed		**3.44E-05**	
			1oo2 Probability		**1.96E-07**	
Component non-redundant Using 1oo1 formula from IEC 61508-6 Annex B	**β Factor Used**	**DC Value Used**	**λ_d**	**#**	**Total λ_d**	
Motor (Hardware Failure Tolerance of 1) (from G series field data 2007 to 2013) (Checked continuously during normal operation)	Not required	Not required	9.97E-08	1	9.97E-08	
Pump (MTTFd taken from industrial piston pump)			3.81E-07	1	3.81E-07	
Check valve			3.05E-08	6	1.83E-07	
Fittings			2.54E-08	4	1.01E-07	
Cylinder and actuator (MTTFd developed from Moog gas valve history)			1.25E-09	1	1.25E-09	
Sum of non-redundant devices					**7.66E-07**	
Result	**PFH**					
(Sum of groups above)	**9.62E-07**					

Table 2 – PFH for EAS Driving to Failsafe Position

The actuation requirements for step response and frequency response are very low for simple open to closed safety process fluid valves. They typically have a lot of time to complete the entire stroke of the valve. There may be some production systems such as an anti surge valve which requires control of the compressor pressure for subsea gas compression. The EAS system has very good performance characteristics especially for process valves which have large force requirements. Typically this dynamic performance application is done by with EMA. Because of the large output force requirements, large rotating mass gear and screw arrangements are needed. This inertia is much higher in the EMA than the EAS because the gear and screw arrangement rotating mass is much higher than the rotating mass of the pump. The EAS system step response is 40 msec and the frequency response at +/- 10% signal is 80 Hz. This is very close to the performance of a good proportional hydraulic valve which typically has a step response of 30 msec and a frequency response of 90 Hz.

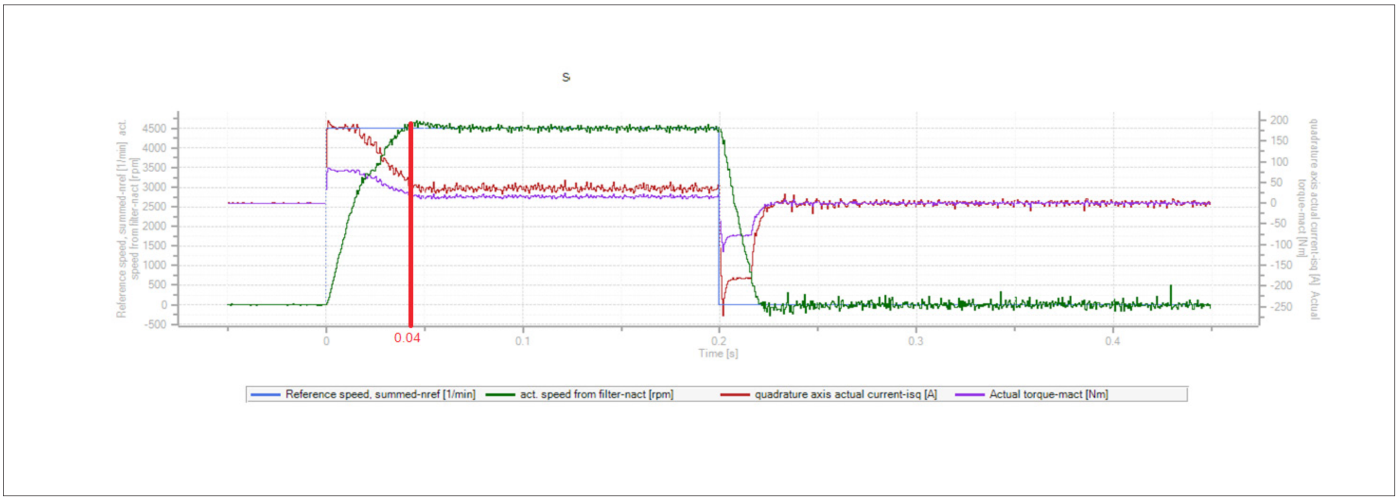

Figure 7 – EAS Step Response

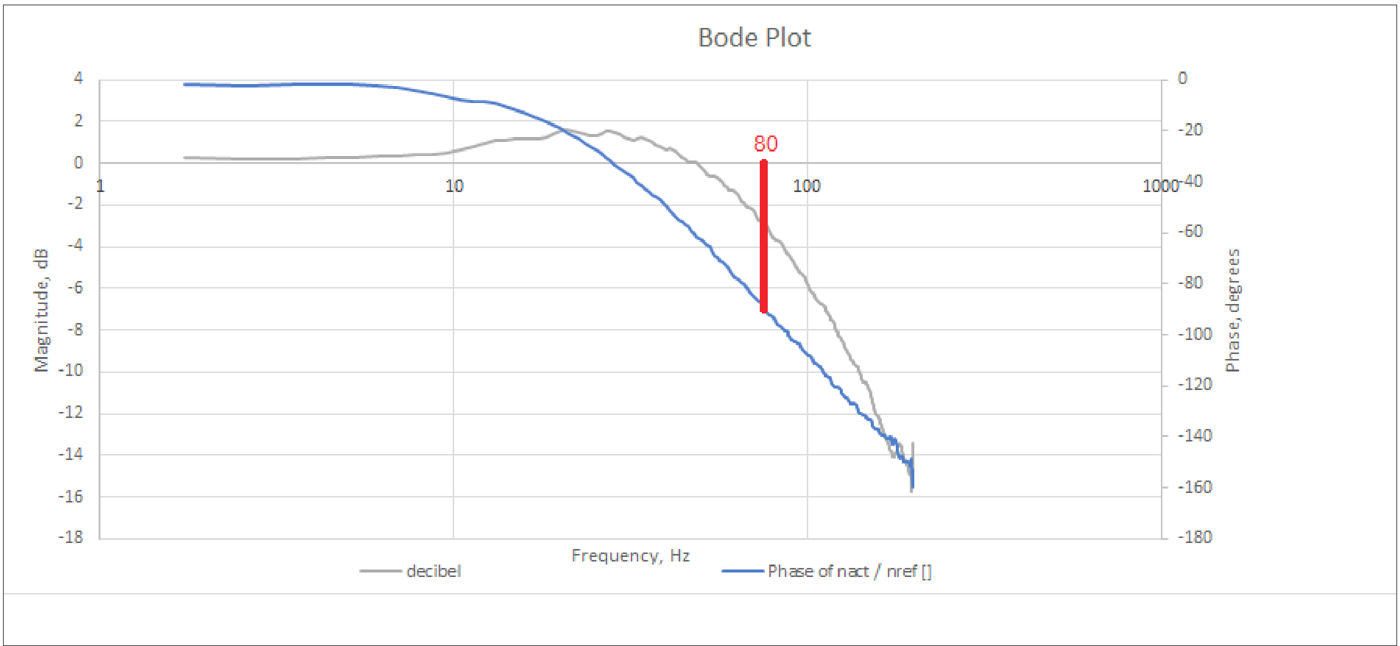

Figure 8 – EAS Frequency Response

For the safety critical xtree process valves there is always two valves with spring failsafe in series to ensure a SIL2 rating. The key is to ensure that the hydraulic circuit from both sides of the cylinder are connected to the pressure compensator. As described previously the safety PLC must monitor and ensure that when an unsafe condition exists that it removes power to the solenoids of the hydraulic valves. The spring in the hydraulic valve drives the valve to the failsafe position connecting the cylinder with the pressure compensator. (Fig. 9)

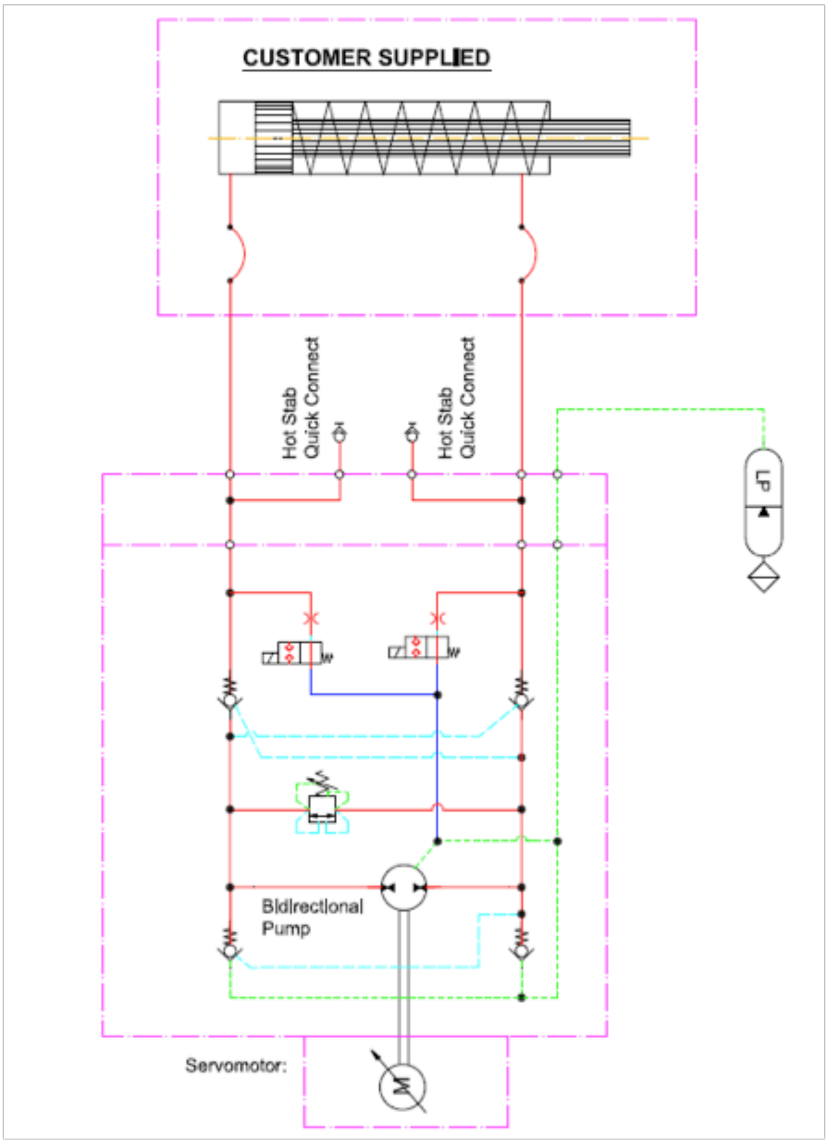

Figure 9 - EAS with Spring Failsafe Cylinder

To ensure redundancy in the entire system a two electronic canister approach is used. Redundant process valve drive systems are split so they reside in separate electronic canisters. The drive canisters store electric energy and are charged from a low voltage/current source. This allows for long tie backs as it does not require a high voltage and high current power supply from the customer. A total of six Moog EAS and two Moog Electronic canisters can operate all the process valves on the xtree. (Fig. 9) Each Moog EAS is 280 mm diameter by 700 mm long.

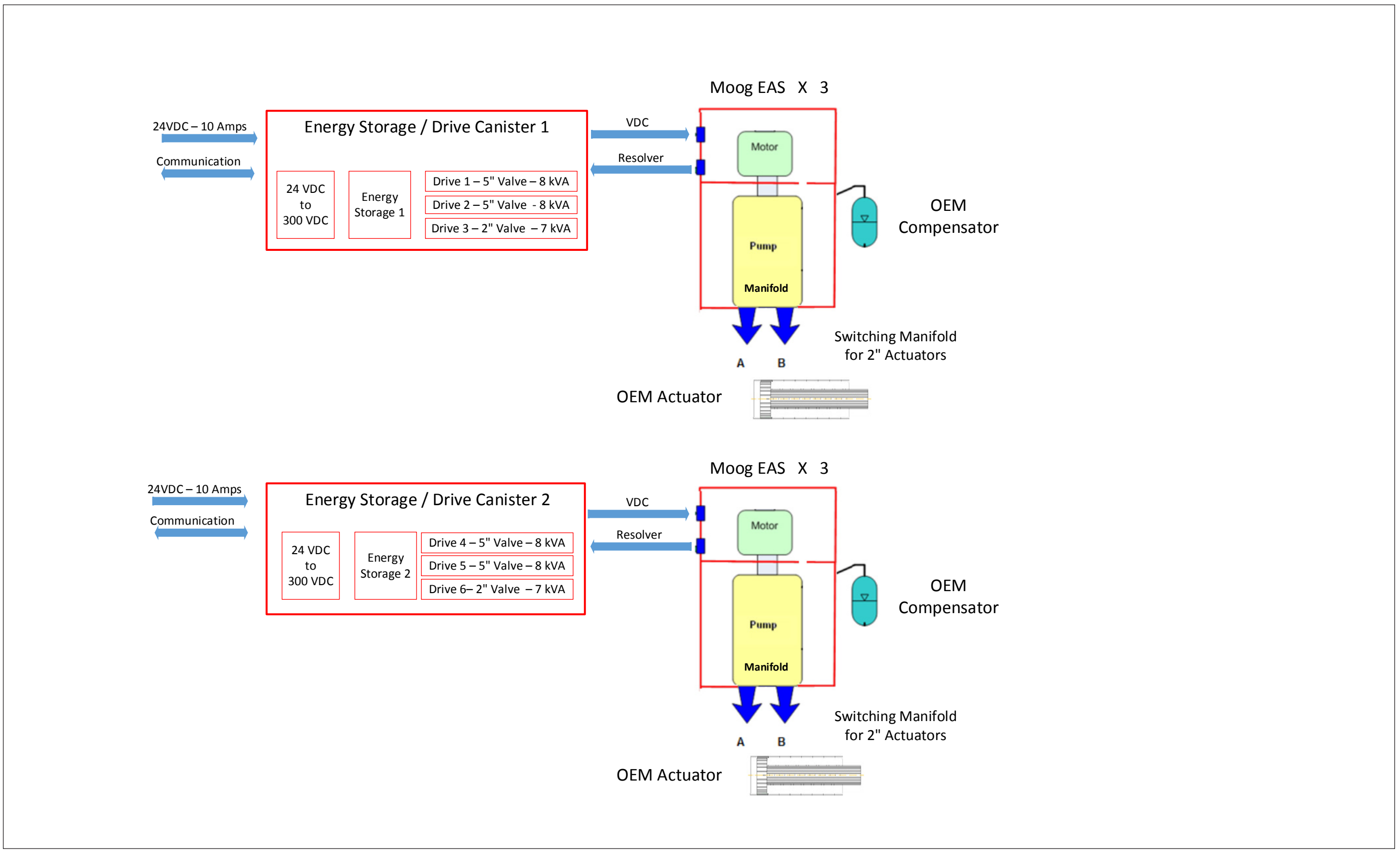

Figure 10 – Block Diagram for xTree EAS / Electrical Canister system

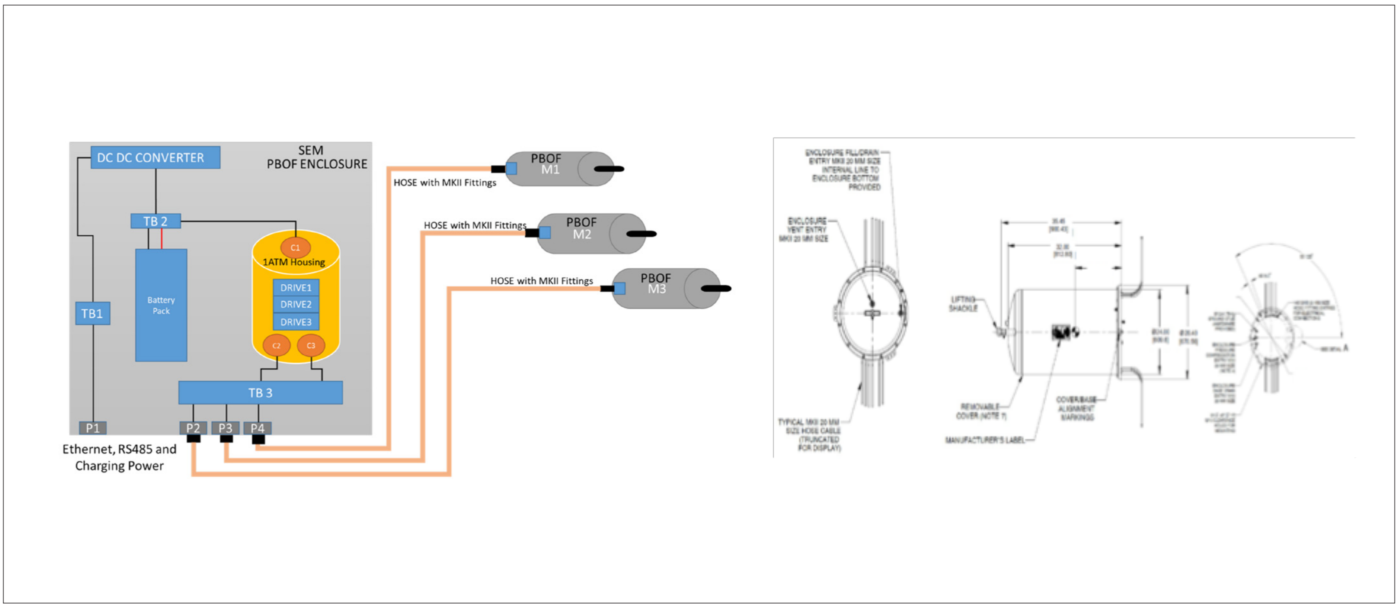

Figure 11 – Diagram for Electrical Canister system

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11 Conclusions

The subsea action solutions available today are based on hydraulic solutions with long umbilical's to the surface, subsea hydraulic power units, accumulator skids and distributed electromechanical actuation solutions. In this paper, we showed a novel solution, which gives you the best features of the current hydraulic solutions and the distributed electromechanical solutions. Since it allows the OEM to utilize their existing hydraulic cylinders, failsafe springs and mechanisms, the time to develop this new solution is minimized and the risk to the end user is low. The system is scalable and can operate the largest of cylinders, such as a shearing ram of a blowout preventer, down to small cylinders, which can be sequentially run off a single EAS system. The EAS system is the best of both hydraulic and electric technology and is a path for the OEM's and end users to realize large savings.

12 References

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12 Information

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