IEEE - Best of Both Worlds

SubSea Valve Motion Control

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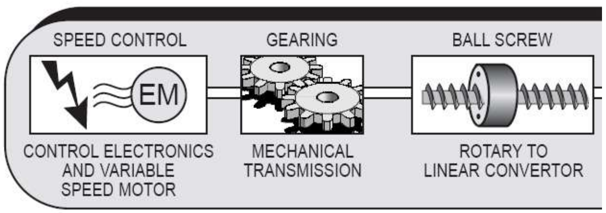
Motion Control Technology Comparison

MOOG

General Technology Comparison

pro
contra

EMA

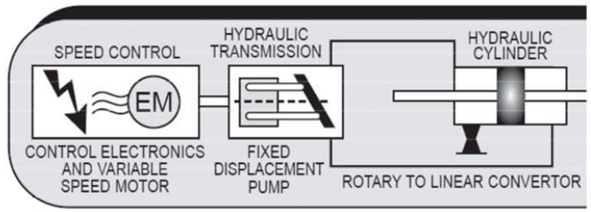


+ efficiency
+ easy mounting, commissioning
+ easy maintenance

- wear
- backlash
- weight
- mechanical gearbox can block

- single movement only

EHA

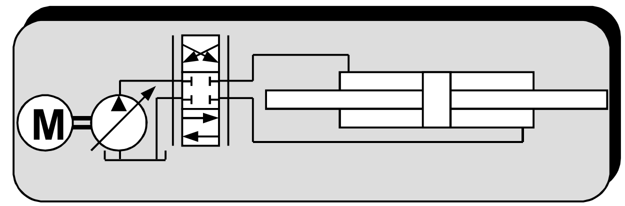


+ efficiency
+ easy mounting, commissioning
+ gearbox ratio unlimited
+ fail safe opportunities
+ weight
+ no wear, no backlash
+ cylinder reliability

- maintenance
- stiffness

- possibility of serial movements

EH

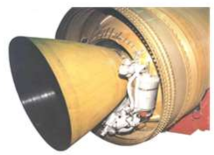


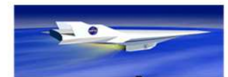
+ high forces
+ compact design (without power unit!)
+ fail safe opportunities

- efficiency
- additional power unit needed
- complex piping

+ possibility of parallel movements

Moog EHA: Company Background – Actuation Heritage





1951 Moog Founded
Hydraulic Servovalve

1982 Entered Electro-mechanical Actuation Market

1999 – Developed Two-Fault Tolerant Electro-mechanical Actuation.

2000 – Developed Electro-hydrostatic Actuation

2002 – Develop Two-Fault Tolerant Electro-hydrostatic Actuation

1950's
- Titan
- Jupiter
- Atlas

1960's
- Minuteman
- Polaris
- Atlas
- Saturn
- Terrier Tartar
- Pershing
- Titan II, III

1970's
- Space Shuttle SRB & Orbiter
- Trident C4
- Peacekeeper

1980's
- Ariane 4
- Ariane 5 (EM)
- Trident D5
- SM2 (EM)
- SRAM II (EM)

1990's
- Titan IV
- Atlas III/V (EM)
- Delta 4 (EM)
- Delta IV SRB
- Pegasus (EM)
- Kistler K-1 (EM)
- GMD (EM)
- X-38 CRV (2FT EM)

2000's
- NGLT
- 2GRLV (2FT EHA)
- X-43A (EM)
- Next Gen ICBM

Why did Aircraft Industry Go with EHA Technology Instead of EMA Technology

Aircraft Industry Primary Flight Control Requirements:

- No single failure should prevent the aircraft from flying.
  - Systems Require Redundancy
  - Output mechanism of actuator can not have a risk of Jamming
    - Electromechanical Screws have a potential failure mode of Screw Jamming
    - Hydraulic Cylinders potential failure mode is not Jamming instead it is Leakage

By Wire Solution for the Aircraft is EHA

- Electric Drive
- Hydrostatic Transmission (instead of electromechanical transmission)

Latest Generation of Military and Commercial Aircraft use EHA for Primary Flight Control

- F35
- A350
- 787

SubSea Movement to Electrification

SubSea Electrification

- SubSea Equipment is moving towards Electrification:
  - -Lower overall costs since large hydraulic power lines are not required to run from ocean surface to subsea
  - -Less components which results in higher reliability
  - -Easier to implement Prognostics, Automation, Autonomous Operation and the Internet of Things (IoT)

- SubSea Today:
  - -Has moved the Hydraulic Power Unit and Accumulators to Ocean Floor. Still use original hydraulic actuation circuits

- Would like to move to full Electrification, however several challenges remain:
  - -Cost to change technology is high
  - -End user struggle with the Risk associated with the new technology
  - -Screw Jamming Risk

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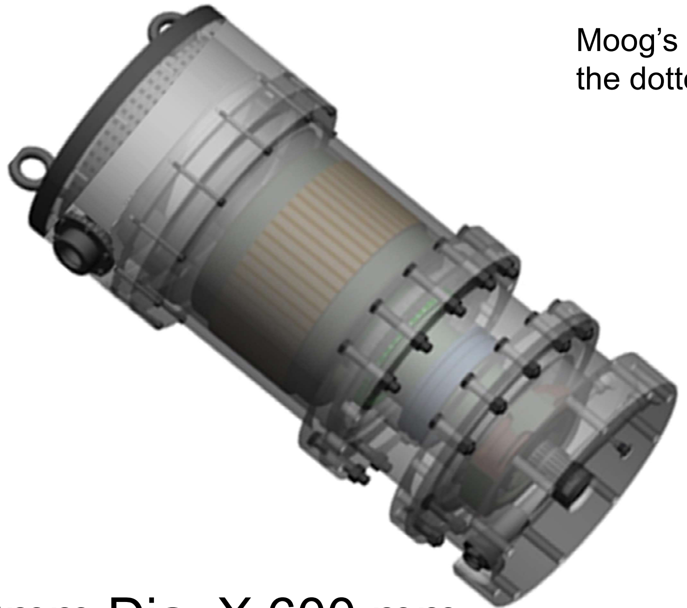
EHA - Best of Both Worlds

- Utilize the key Hydraulic Elements:
  - -Keep the Robustness and Power Density of current Hydraulic System
  - -OEM can use existing hydraulic cylinder and spring failsafe
  - -OEM do not need to make major mechanical changes to the existing equipment

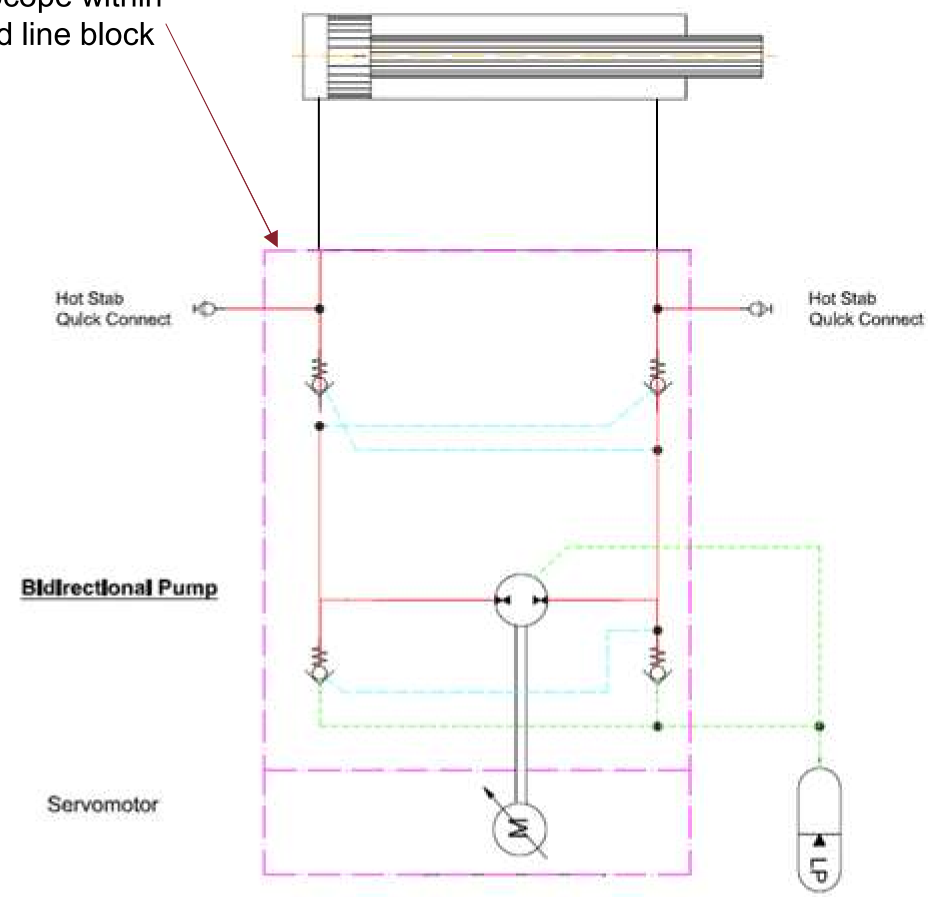
- Distributed Electric Power Unit & Controls:
  - -Many small compact electro hydrostatic power units can be integrated along side existing hydraulic cylinders.
  - -Enables a high connected system for the next generation of SubSea Controls
    - -Advanced Prognostics
    - -Automation
    - -IoT

Electro Hydrostatic Power Unit - EPU



250mm Dia. X 600 mm

Moog's Scope within the dotted line block



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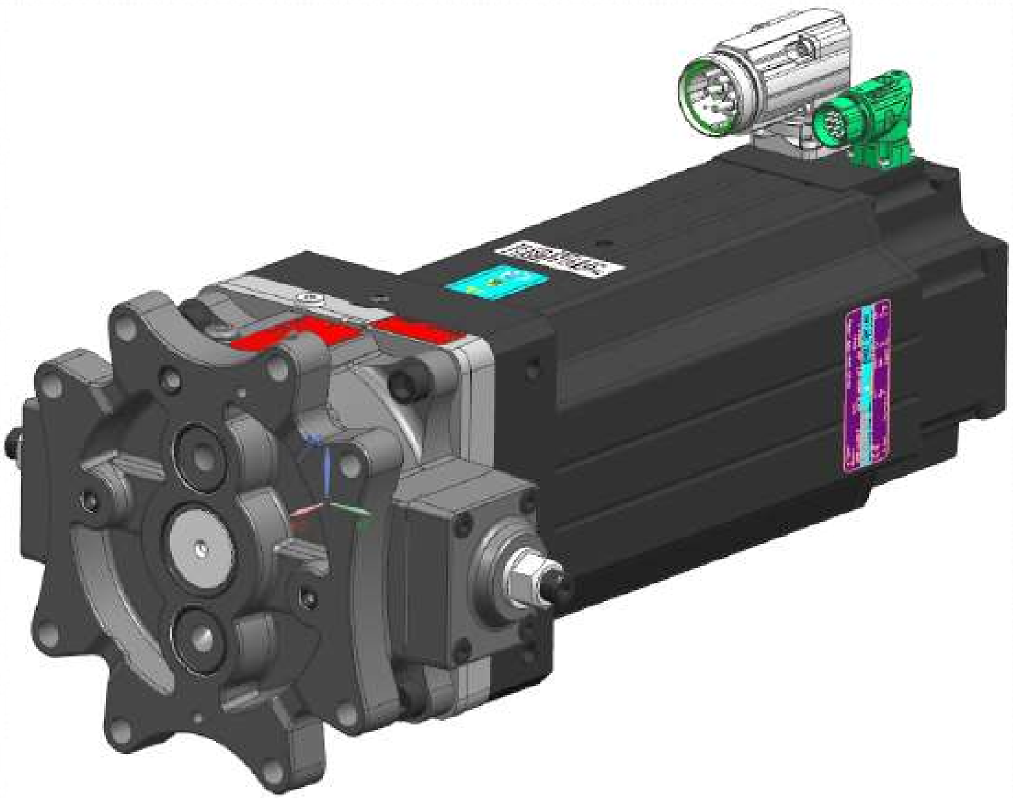
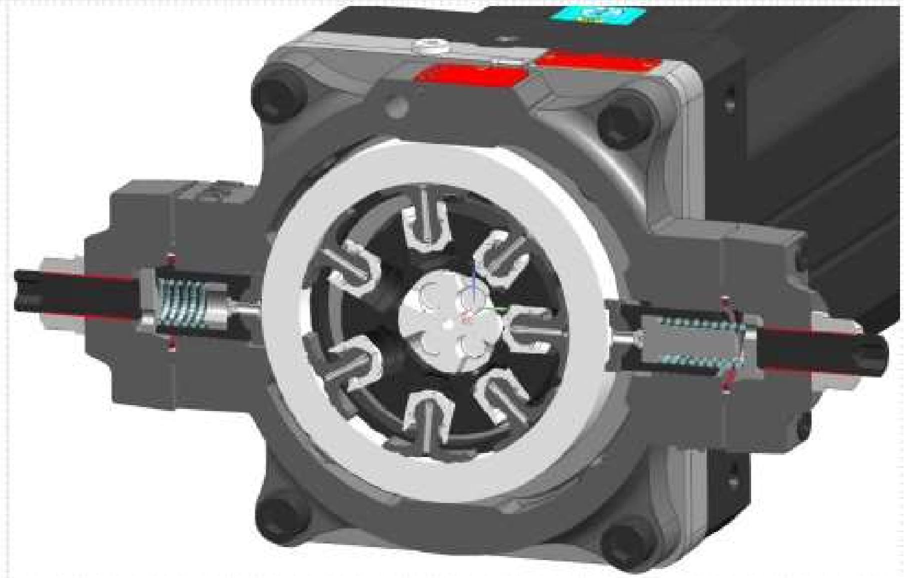
Moog’s Industrial Electro Hydrostatic Power Unit - EPU

Electro Hydrostatic Power Unit - EPU



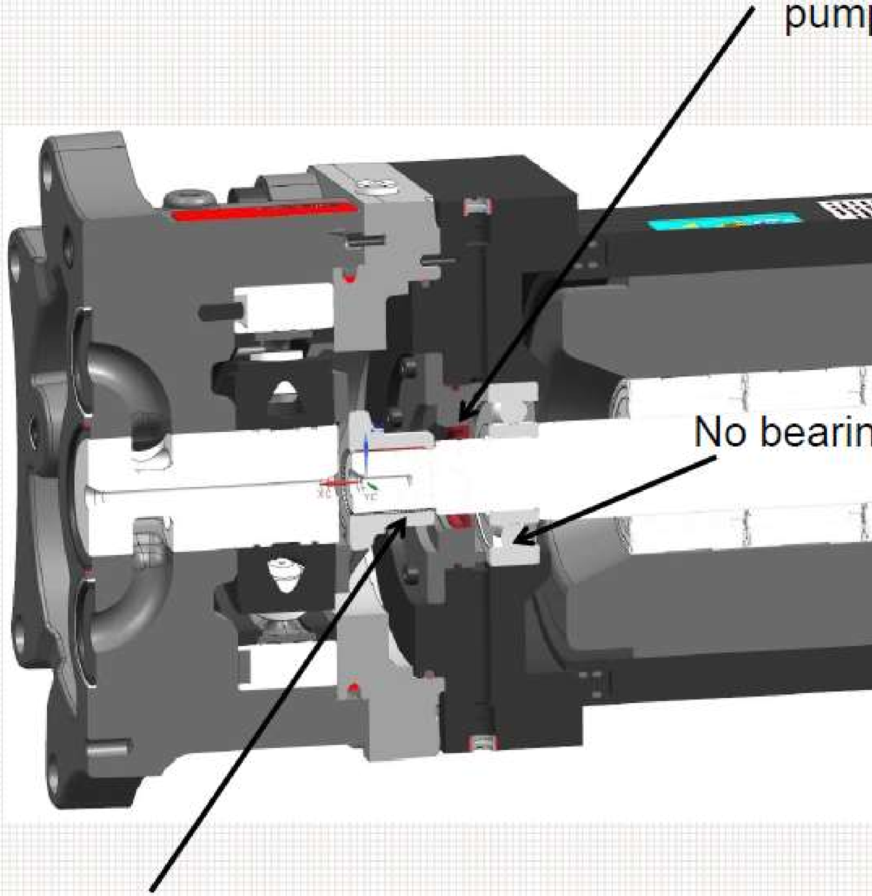


rotary group optimized for speed variable and 4Q operation

interface for manifold assembly

Electro Hydrostatic Power Unit - EPU

EPU Design



Moog Features:
Manifold interface
4Q operation
Motor/Pump direct connection
Permanent Load holding capability
Dual Displacement
External leakage line
Pump flushing line

Servo Motor Capability

Features

- Light weight, high power density motors
- Custom voltages, speed and torque
- Proven Laminations
- SmCo Magnets
- Specific stack & windings
- Screw integrated into the Motor

Permanent Magnet Brushless Motor Capability

High Torque Density

Qualified magnetic circuits

- Variant designs

Full Custom Designs

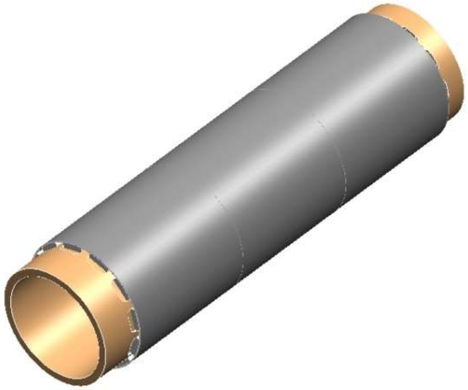
- FEA based

Environmental Conditions

- 1300 – 2000 Bar
- Ambient 200°C

Robust Hardened design

- Sleeved encapsulated rotors
- High temperature insulation systems
- Chemical compatibility
- Shock: 500G 11ms, Sine Pulse
- Vibe: 10-2000 Hz, 0.06 double Amplitude



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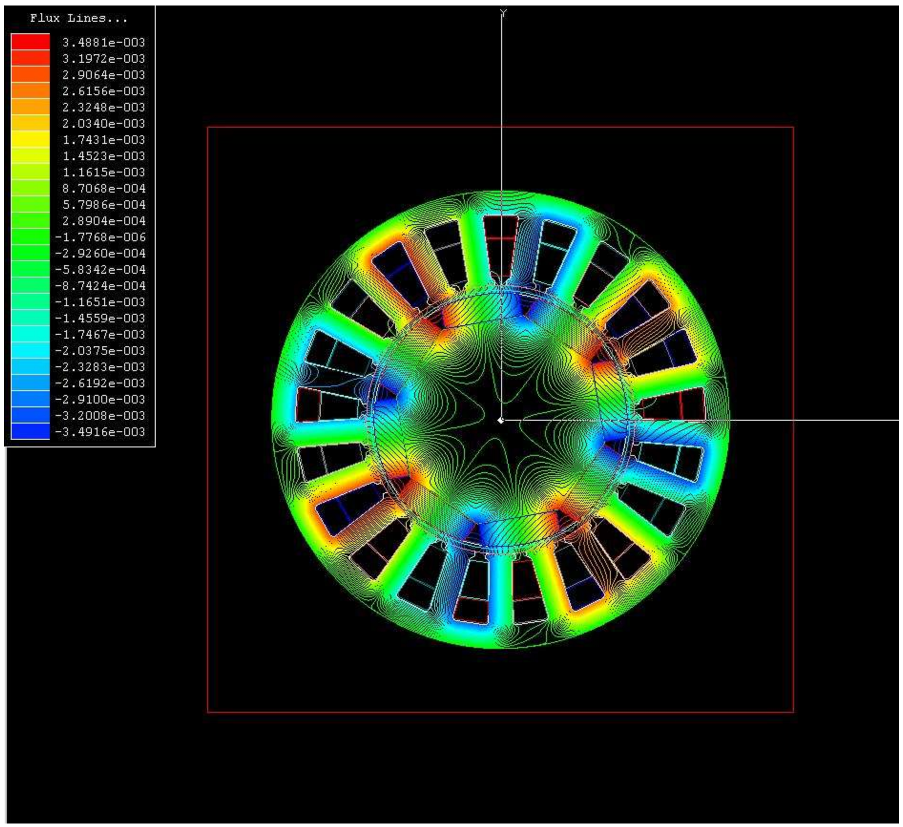
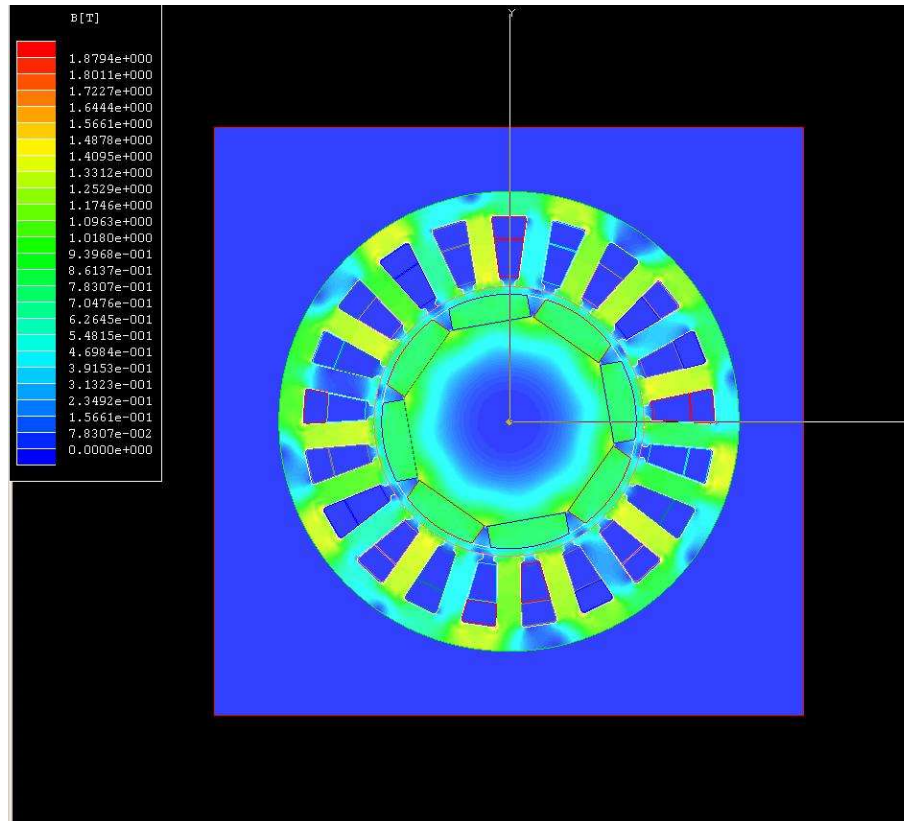
Motors - EM Design

FEA Electro-Magnetic design

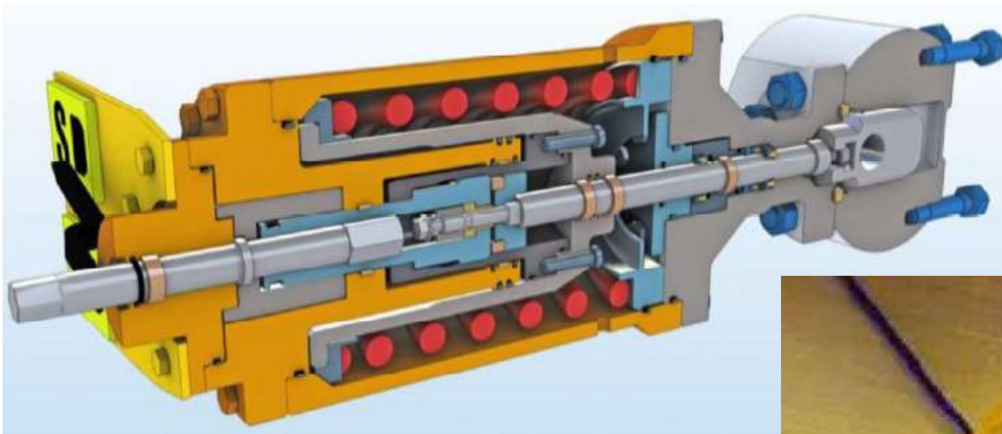
Dynamometer performance validation





Case Study - Xtree

Current Hydraulic Powered X-Tree Gate Valves



Reliable Cost Effective Electro Hydrostatic System

•Electro Hydrostatic Power Unit is a common size

•Use two Electric Drive Canisters and strategically select valves for electric system redundancy

•Reducing mechanical component increases reliability from SIL 1 to SIL 2

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X-Tree Valves

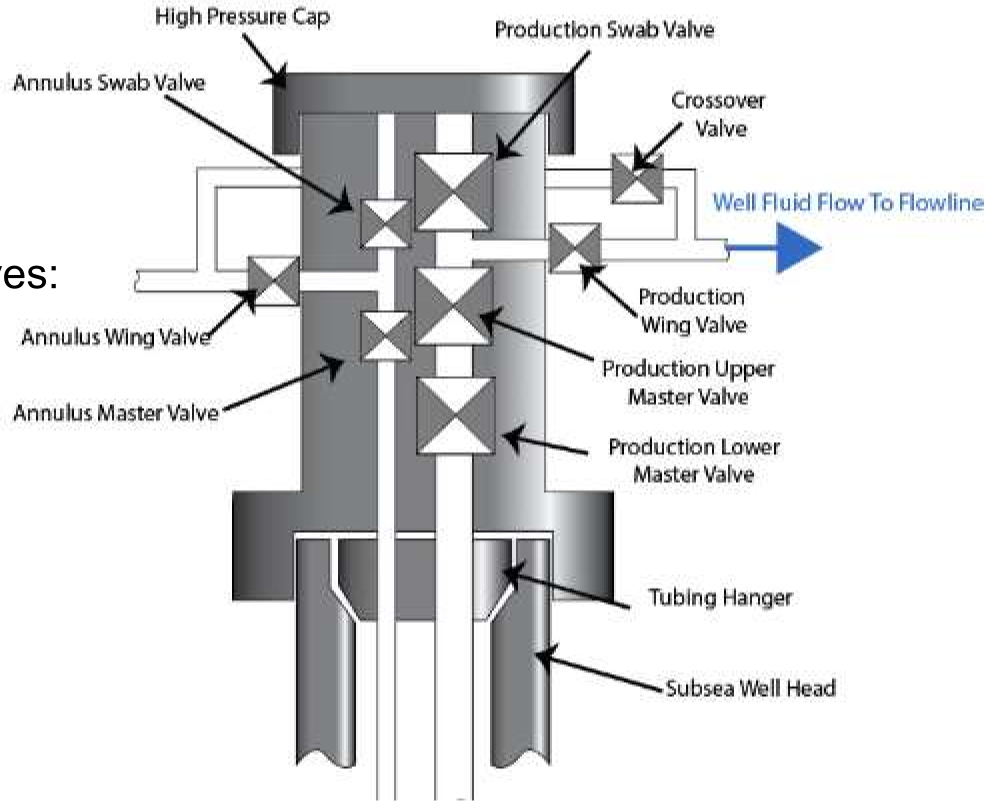
X-Tree Valves:

Well Fluid Flow and Chemical Injection Gate Valves:

Linear Failsafe Actuator Required:

- 40,000 lbf (4 Valves)
  Annulus Wing 2” Valve
  Annulus Master 2” Valve
  Annulus Swab 2” Valve
  Cross over 2” Valve

-(7”) 230,000 lbf (4 Valves)
or
-(5”) 130,000 lbf (4 Valves)
Production Swab 5” or 7” Valve
Production Upper Master 5” or 7” Valve
Production Lower Master 5” or 7” Valve
Production Wing 5” or 7” Valve



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One EPU Size for all Applications

		SubSea EPU - Xtree		
		40000lbf - 2" Valve	130000lbf - 5" Valve	230000lbf -7" Valve
Motor Voltage (G6-V-4)	VDC	315	359	469
Motor Current	Arms	19	19	35
Motor/Pump Speed	RPM	2800	3000	3700
Pump set displacement	cu.cc/rev	10	10	19
Drive Power Requirment	kVA	6	7	17
Time for Stroke	seconds	3	21	21

Xtree - Scope of Supply

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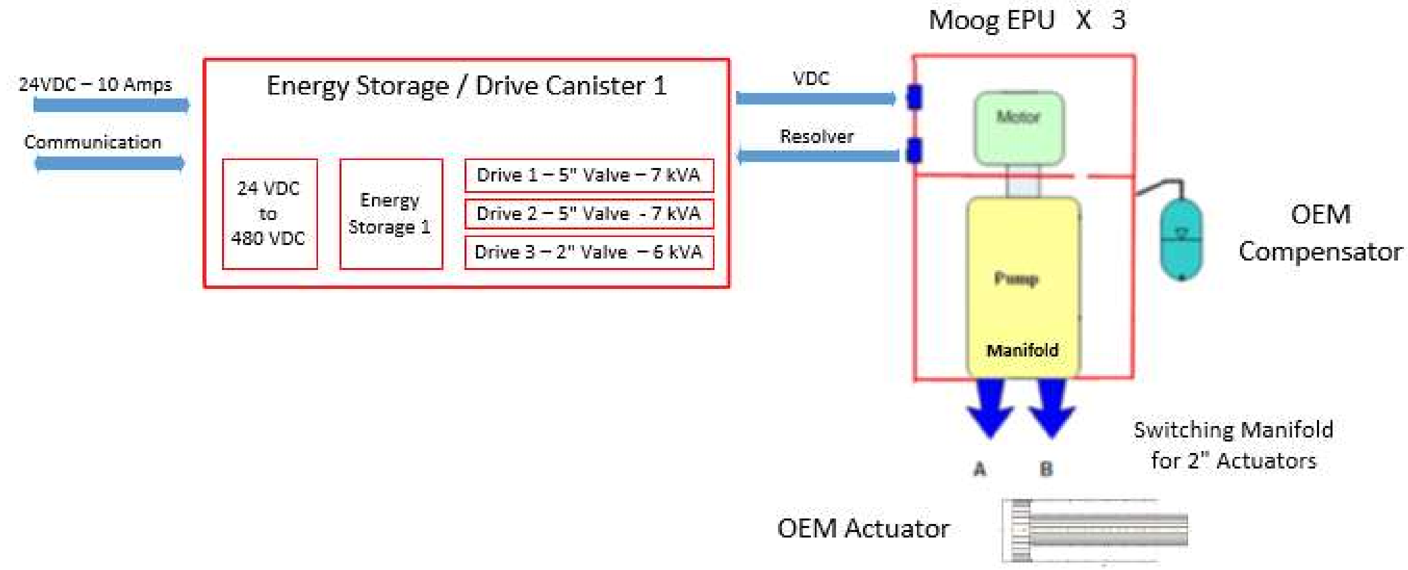
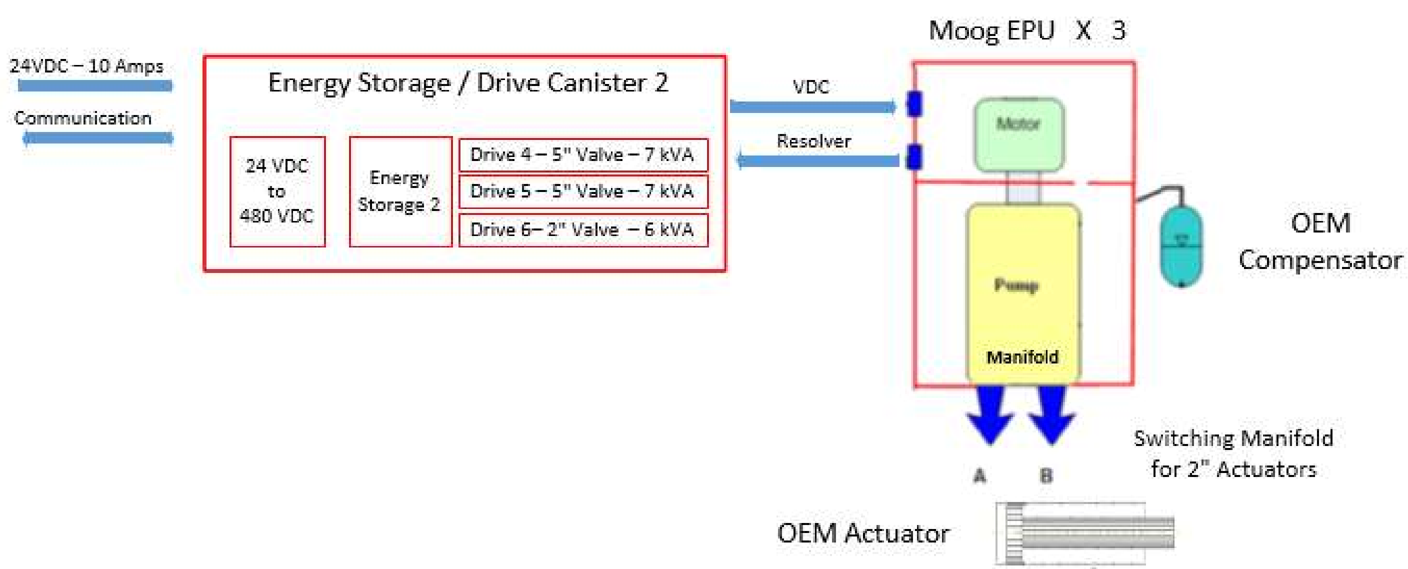
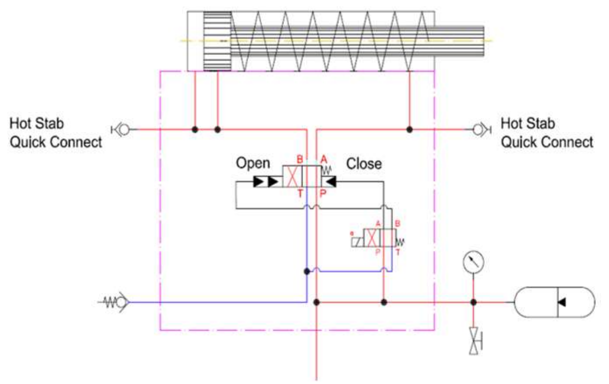




Current Mechanical System Design Analysis – SIL 1

Component non-redundant Using 1oo1 formula from IEC 61508-6 Annex B	**β Factor Used**	**DC Value Used**	**λ_d**	**#**	**Total λ_d**	
Manual valve - accumulator			2.90E-07	1	2.90E-07	
Solenoid Valve - N/O			9.30E-08	1	9.30E-08	
Spring return two way valve			1.67E-08	1	1.67E-08	
Check valve			3.05E-08	2	6.10E-08	
Fittings			2.54E-08	12	3.04E-07	
Pipe rupture			5.87E-08	8	4.70E-07	
Pressure Gauge			1.77E-07	1	1.77E-07	
Accumulator			8.28E-07	1	8.28E-07	
Cylinder and actuator (MTTFd developed from Moog gas valve history)			1.25E-09	1	1.25E-09	
Sum of non-redundant devices					**2.24E-06**	
Result	**PFH**					
(Sum of groups above)	**2.25E-06**					



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Moog Mechanical EPU Design Analysis – SIL 2

- Used ISO 13849-1 and IEC 61508-6 analysis methods to determine failure rates

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					**7.66E -07**	

Thank you

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