Hydraulics/Fluid Power

Best Practices And Common Pitfalls With Hydraulic Drive Systems

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BEST PRACTICES AND COMMON PITFALLS WITH HYDRAULIC DRIVE SYSTEMS[1]

As compared to electro-mechanical drives, a hydraulic drive system offers increased reliability, lower maintenance, increased power density, flexibility in layout, and a lower cost of construction. However, without a proper design, many of the benefits will not be realized. This paper is the result of an informal survey of best practices and common pitfalls in the design and implementation of hydraulic drives for movable bridge applications.

1. Cylinder Location and Mounting Considerations

To achieve the maximum benefit of choosing a hydraulic drive for movable bridge, it is critical to properly locate hydraulic cylinders. The buckling strength of the cylinder is a critical parameter in sizing. If the stroke of the cylinder is long, both the rod and bore diameters will also be large. Consequently, a large flow rate will be required to move the bridge in the given time periods. As a result, the power unit must produce more flow and horsepower. Everything is magnified; not only is the reservoir and motor pump groups larger, but the piping valves, filters, manifolds, and required floor space are also increased. And, the larger the size, the greater the material cost and the more difficult the installation.

The optimum location includes two considerations:

A. Cylinder Near Point of Rotation

- Minimize Buckling Length
- Minimize Stroke
- Minimize Cylinder (and Overall Hydraulic System) Size
- Reduce “Swing” (The angle of rotation of the cylinder that necessitates clearance on the pier)

B. Cylinder in the Maximum Vertical Position

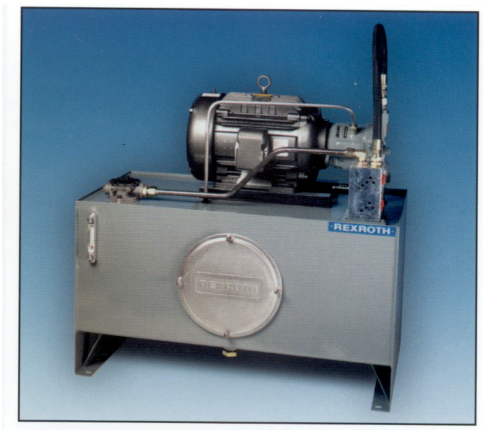
- Minimize Side Loads
- Improves Performance of the Seals

The mounting location of the cylinder should be considered in the very early stages in the design of the bridge. Although the specifics are beyond the scope of this paper, substantial cost savings can be achieved by minimizing the size of the piers and required excavation. With a hydraulic drive, the layout is flexible, less floor spare is required, and alignment issues are practically eliminated.

2. Power Unit Layout

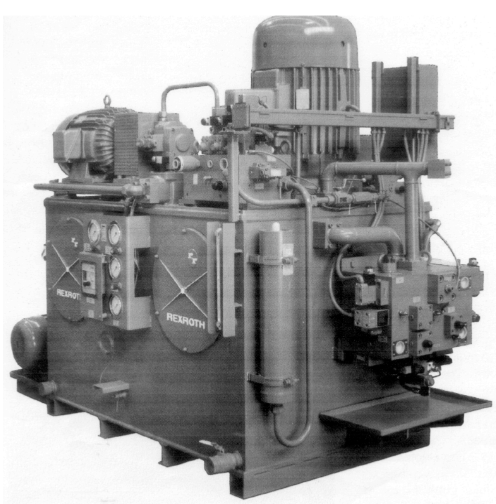
The degree of flexibility in the layout of a hydraulic system enables the designer to best adapt the unit to the machinery room. However, accessibility for maintenance should be optimized with both the overall shape of the unit and the placement of the individual components. Most power units can be classified into one of the below styles:

A. Horizontal Pump Motor Group on Top of Tank
If the unit is small (less than 100 gallons) a space saving design may be the motor pump group horizontally mounting across the tank top. This allows easy access to the main components and minimizes the overall footprint. However, **care should be taken so that the suction requirements of the pump are met**. For example, if a large flow rate is required, the pump may cavitate.



Low Noise	Fair
Accessibility	Good
Overall Size	Excellent
Suction Characteristics	Fair

B. Vertical Mounted Motor Pump Group on Top of Tank
This configuration offers reduced noise, good suction characteristics, and a minimized footprint. However, the pump will not be readily accessible. Therefore, **all needed adjustments for the pump controls must be tubed to the top of the power unit**. For example, a Bosch Rexroth A10VSODR is a pressure compensated axial piston pump. If it were to be used for an in-tank configuration, an A10VSODRG control should be substituted so that a pressure relief valve mounted on the tank will be the method to adjust the pump's compensator setting. In addition, a "**D flange" electric motor is highly recommended**. If a "C flange" motor is used, the entire motor pump group assembly must be removed in order to change the electric motor. Whereas, with a "D-Flange", the bolts are configured such that the motor can be removed without distributing the pump.

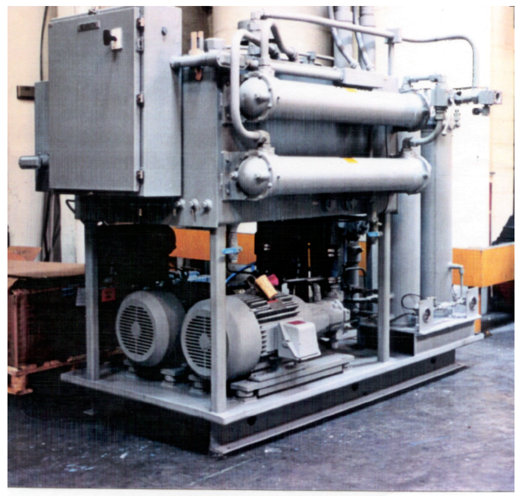


Low Noise	Excellent
Accessibility	Fair
Overall Size	Excellent
Suction Characteristics	Excellent

C. Pump Motor Group Below the Tank (Overhead Design)

An overhead design minimizes the required footprint, but will require additional vertical clearance. The compromise of this configuration may be some difficulty in accessing the motor pump groups.

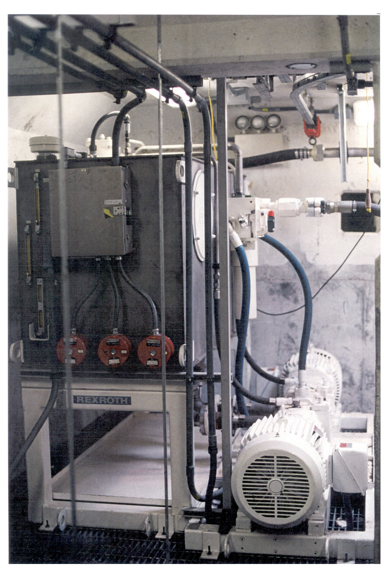
Low Noise	Good
Accessibility	Good
Overall Size	Excellent
Suction Characteristics	Excellent



D. Motor Pump Group on Side of Tank (L-Shape)

This configuration requires the maximum floor space. **This design offers the most convenient plumbing and accessibility to all components, and is the recommended design wherever feasible.**

Low Noise	Good
Accessibility	Excellent
Overall Size	Fair
Suction Characteristics	Excellent



3. <u>Reservoir Assembly</u>

A. Size

In addition to simply storing oil, the reservoir assists in conditioning the fluid. For example, the reservoir should be adequately sized so that the fluid has sufficient detention time for cooling, aeration and settling of particles. A widely practiced “rule-of-thumb” is to size the reservoir volume to be three times (3X) the total flow rate per minute. In addition, the displacement volume of the actuator should be considered.

At the minimum oil level (i.e., when the cylinders are extended), the pump suction should be a sufficient height above the bottom of the tank so that any settled debris on the bottom is not disturbed and pulled through the system. For example, Bosch Rexroth’s standard is to locate the bottom of the chamfer of the suction line two times (2x) the length of the pipe diameter for lines 1 _” and smaller. For suction lines greater than 2”, one and a half times (1 _ x) the pipe diameter is sufficient.

B. Material

For outdoor applications with extended design lives, stainless steel is recommended. The material cost for a stainless steel reservoir is approx. 31/2 times that of carbon steel; however this is small in comparison to the possible costs associated with corrosion. Rust is not only a concern with the tank itself, but can eventually contaminate the fluid and thus the entire system.

If stainless steel is used for the reservoir, painting the interior of the tank is not recommended. Experience suggests that even the best fabricators struggle to achieve the proper surface for painting. Furthermore, the exact quality is extremely difficult to check prior to installation. Therefore, a risk of contamination can result from paint flaking.

C. Construction

A well-designed reservoir should include:

- Baffles to assist with cooling and aeration
- Down pipes for all return and drain lines to prevent the introduction of air
- Clean-out covers
- Separate drain valves and sampling valves. (Samples taken from the bottom of the tank are not representative of the overall system cleanliness level.)
- Provision for temperature switch, thermometer, level switch, and site level/ temperature gauge
- Guards to protect all devices from mechanical damage
- Drip pans underneath the entire assembly, and perhaps underneath each filter and fill connection
- For ease of maintenance, a low watt density heater can be mounted in a bulbwell. (However, the heater must not have an integral thermostat.)

On new construction, it is recommended to incorporate a detention basin into the concrete for the full oil volume of the reservoir.

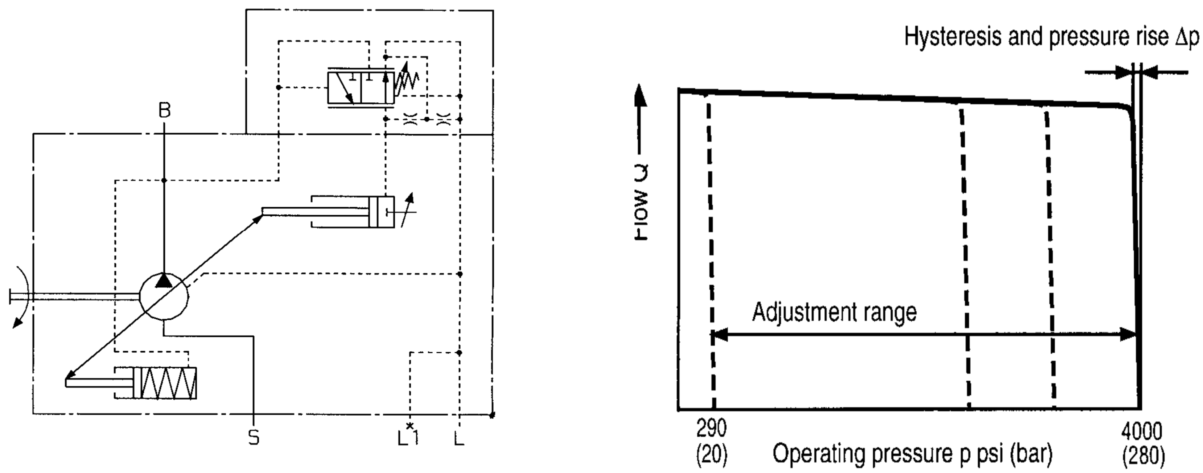
Machinery room in which cut-out in the floor provides storage for 100% of the hydraulic reservoir. (Storage area under grating)

4. Pump Controls

Bosch Rexroth, as well as most manufactures of axial piston equipment, have a seemingly infinite number of available pump controls. However, movable bridge applications are typically suited to one of the three types described below:

A. Pressure Control (DR)

The use of a single pressure compensator is the most basic control available for a variable piston pump. No electronic controls are needed, and the setting can easily be adjusted in the field with a set screw. Applications such as larger span locks and vertical lift bridges are very well suited for this control. In addition, the control has also been used with some bascule bridges. Bosch Rexroth designates this control as a “DR”, however the identical configuration is available from other manufactures.



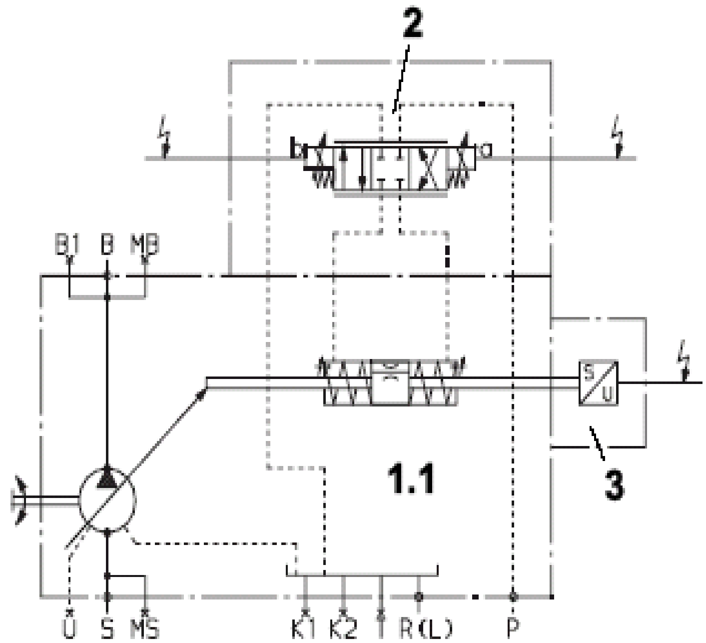
BoschRexroth DR Control

As with all pump controls, the load (force required to move the bridge) will determine the actual system pressure. With a DR control, the pump will deliver the amount of fluid required by the actuators. As illustrated in the above graph, the pump will deliver full flow (full speed) until the pressure increases to the compensation setting. With this control, valving elsewhere in the hydraulic circuit must control the bridge speed.

The compensator setting should be slightly above the normal maximum pressure experienced by the system at the pump. This is a function of the load pressure under maximum dynamic conditions (not the static maximum holding load of the cylinders dictated by AASHTO), and the sum of all pressure drops in the system. The system relief valve, located near the pump, should be at least 200 psi above the compensator setting.

B. Proportional Flow Control (EO)
This control option has been successfully used on a few larger bridges such as SW 2nd Ave and AIW Bridge Replacement. A proportional valve is mounted on the pump, and its pilot signal regulates the pump's output flow. Therefore, the command signal to the valve is proportional to the flow output of the pump. Many variations of this control exist, but all include a separate pressure compensator, similar to the DR discussed above, that acts as a safety to limit the maximum pressure. If the valve is not equipped with integrated electronics, driver cards must be supplied separately. To alleviate miscommunication, it is suggested that these cards are supplied by the pump manufacturer. Finally, a small fixed displacement pump is usually "piggy backed" on the main pump to provide a pilot signal to the proportional valve.

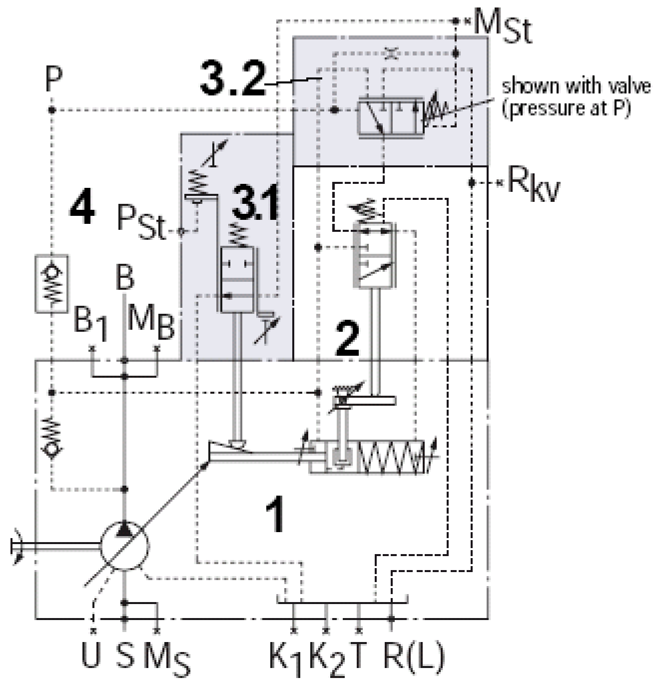
In conjunction with a PLC – based control system, this type of control offers the maximum flexibility in regards to field adjustment and design capabilities. Often, the software is configured to ensure that a maximum horsepower in the system is not exceeded.



BoschRexroth EO Control

C. Constant Power with Proportional Flow Control (LR2DN)

This pump control governs both the speed of the bridge, and protects the electric motors. It was used on projects such as Hampton roads Bridge, Mantoloking , and Popps Ferry. The output of the pump is regulated by a pilot signal from a pressure reducing valve that is mounted elsewhere in the system. As pilot pressure increases, the output flow of the pump also increases. Therefore, the flow rate is dictated by a command signal to the proportional valve. Similar to the EO control, a pilot pump and driver cards are required. This pump control automatically limits the output horsepower from the pump



BoschRexroth LR2DN

5. Circuit Tips

A. "Leak – Free" Valves

Pilot check valves, counter balance valves, or even poppet directional valves are often used to hold a load (bridge) in a given position. If the position must be maintained for a matter hours, no special provision is needed to avoid drift. However, for extended duration, care must be taken to avoid unrealistic assumptions. "Leak –free" does not necessarily imply absolute "zero leakage":

Valve Design	Typical Leakage Rates	Considerations
Spool Type	> 10 drops per minute, even with blocked center	Not recommended for positive load holding
Poppet-Style	Typical maximum value of 1 drop / minute	1. The higher the pressure, the lower the leakage rate. (The poppet seats better at increased pressure.) 2. Leakage rate is a function of the pressure drop across the valve. 3. Pressure decay is a function of volume: the larger the trapped volume (line size / actuator volume) the more profound the pressure decay.
Soft Seat Poppet	= 0 under favorable conditions	1. Very sensitive to contamination. 2. Leakage rate may increase over time. 3. Rated for only low to medium pressure 4. Not available in large sizes.

The convention of one (1) drop denotes 0.004 cubic inches, and for most hydraulic fluids a volumetric change of approximately _% occurs per 1000 psi. Consequently, even with apparently low leakage rates aggressive pressure decay can be realized. If conventional valves are not sufficient to prevent drift, alternate solutions should be investigated. For example, the hydraulic system can intermittently cycle.

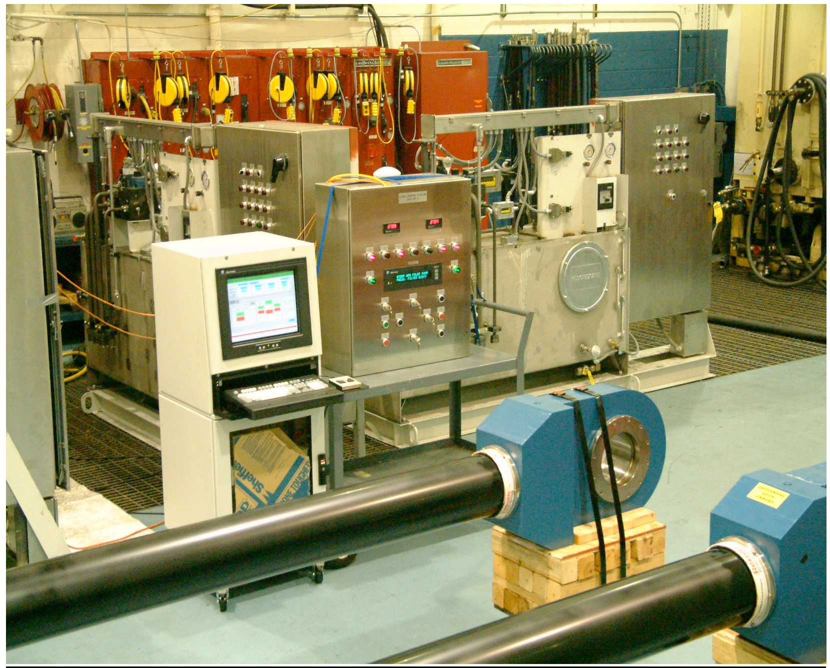
B. Speed Control

Controlling the bridge speed can be accomplished with the three general methods summarized in the following table.

Solution	Advantages	Considerations
Variable Volume Pump	1. Most efficient 2. Variable speeds	1. Layout may require long line lengths 2. Multiple Actuators
Manual Flow Control Valves	1. Simplicity	1. Effects of temperature and load pressure 2. Constant speed only 3. Lower accur acy
Proportional Flow Control Valves	1. High accuracy 2. Variable speeds 3. Synchronization 4. Repeatability	1. Must integrate properly with control system

C. Synchronization of Cylinders

For applications requiring higher accuracy in speed or position control, the electronic controls must be integrated with the hydraulic system. For example, it may be prudent to synchronize the cylinders for a rolling lift bridge. This is best accomplished when the hydraulic system and electronic controls are provided by a single vendor, and a shop test can be performed to demonstrate the synchronization algorithms.



Integrated shop testing with hydraulic power units, electronic controls and cylinders with position feedback.

D. Safety

Safety can be optimized through redundancy and the use of appropriate faults in a hydraulic drive system. Some methods include:

- **Redundancy** - Multiple motor pump groups and cylinders can be used to accomplish the speeds required in normal operation. Then, in the event that a component fails, the system can operate at a lower speed without any mechanical modifications other than opening / closing ball valves.
- **Operation in Loss of Power** – Provisions can be made to the hydraulic system to enable limited operation in the absence of power such as hand pumps, accumulators, manual valves, and gravity close.
- **Pilot Operated Check Valves** - These valves prevent runaway of the bridge in the event of a hose break or other failure. With the absence of pump pressure, the leaf will lock in place until someone manually actuates a valve or starts the pumps.
- **Electronic Monitoring of System Status** – Parameters such as high pressure, ball valve position, oil level, and temperature can be monitored to ensure safe operation. If appropriate, the system can be set to automatically shut down in the presence of a fault.

6. Hydraulic Fluid

For movable bridge applications, the selection and maintenance of fluid is a function of temperature, cleanliness level, and environmental concerns. In other applications, considerations such as extreme high pressures or resistance to fire may also be relevant.

A. Temperature

The ambient temperature and duty cycle determine the needed viscosity range of the fluid. Axial piston equipment (pumps) are the most sensitive component in the hydraulic system in regards to viscosity. The pump data sheet indicates the allowable limits as well as the suggested viscosity range. If needed, a reservoir heater and / or heat exchanger can be incorporated in the hydraulic system.

B. Cleanliness

Similar to viscosity, the pumps are usually the most sensitive component in the hydraulic system for movable bridges. (In very high performance test systems, servo valves may have more stringent requirements.) And again, the pump data sheet indicates the allowable cleanliness level. **Clean oil is the key to extending the system's life and minimizing the operating costs**. Some provisions to ensure optimum performance include:

- **Stainless steel reservoir / piping** – corrosion can contaminate the fluid
- **Sample fluid approx. every 6 months** – send fluid to an independent laboratory for analysis and implement any recommendations for improvement.
- **Fill connection above return filter and use a filter cart to add oil** – experience suggests that 55 gallon drums of oil are not always at an optimum cleanliness level. The return filter will help prevent most contaminants from entering the tank.
- **Auxiliary filtration loop**- For infrequently operated bridges, consider a small auxiliary filtration loop on the reservoir that operates on a timer.
- **Sealed reservoir** – A "lung type" breather that prevents the entrance of outside air and moisture in the system gives a remarkable return on investment. These assemblies are relatively inexpensive and substantially extend the life of the system. With conventional breathers, a volume of air, the size of the total rod volume is pulled into the tank each time the bridge cycles. A lung type breather prevents this.

C. Environmental Concerns

In recent years, some government agencies have adopted a policy of using environmentally friendly fluids. All environmentally friendly fluids degrade and thus have a limited life. Whereas, a well maintained mineral fluid can be expected to last the useable life of the hydraulic system itself. However, the latest generation of environmentally friendly fluids do seem to be performing better than their predecessors.

Relative Biodegradability of Lubricant Base Oils

st Degradable		eVegetableOilsSyntheticEstersPetroleumMine	

As discussed in regards to the power unit layout for new construction, an integral detention basin in the pier may be an alternative to the use of special fluids.

7. Tubing and Piping

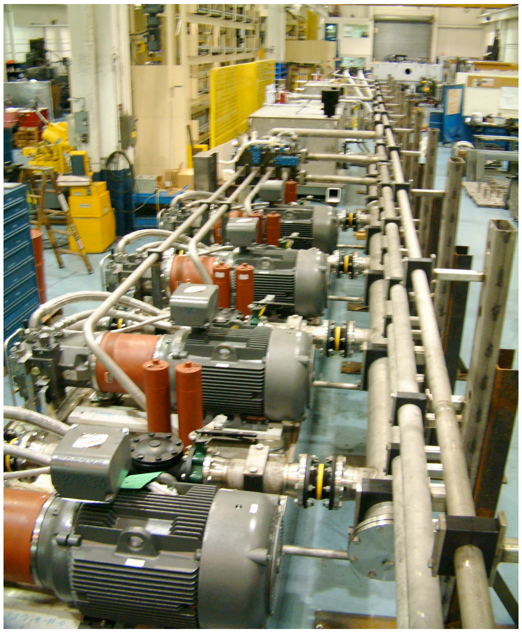
For outdoor applications, the use of stainless steel tubing or piping is recommended. Stainless steel flanges and hose ends in larger sizes (greater the 2”) are not usually stock items. However, they are commercially available and have been used on many bridges.

The appropriateness of tubing as opposed to piping is summarized in the below table.

	Advantages	Cautions
Tubing	1. Welding not required 2. Smaller bend radius / efficient runs 3. Cost 4. Easy to use	1. Vulnerable to Mechanical Damage 2. NPT fittings 3. Proper fittings for stainless steel : no 37?JIC flare 4. Not recommended for sizes greater than 1 1⁄2”
Piping	1. Robust 2. High pressures 3. Leak free – “O- ring seal”	1. Quality dependent on skill of the welder 2. Higher cost

In addition, a designer may consider the use of socket weld as opposed to butt weld. In general, socket welding is recommended for field piping and butt welding is appropriate for qualified in-house welders.

Socket Weld	Butt Weld
1. All excess weld on outside of pipe 2. Two welds per connection Pickling and passivating may not be required for stainless steel field piping. 3. Proper flushing is required 4. Visual inspections and pressure testing may eliminate radiographic testing	1. Quality dependent on skill of welder 2. One weld per connection 3. Potentially higher quality 4. Pickling and passivating typically required 5. Visual inspections and pressure testing may eliminate radiographic testing



All piping for the AIW Bridge was manufactured at BoschRexroth

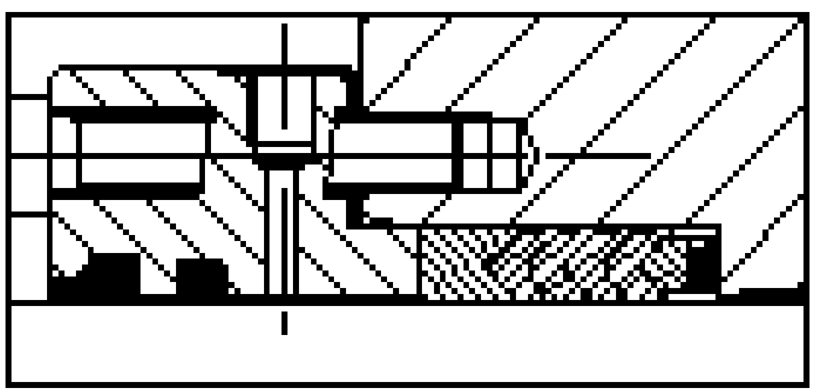
Extensive field welding can increase cost, create contamination, and if not performed by qualified individuals, the overall quality of the system may be encumbered. Therefore, a designer may consider a layout that lends itself to pre- fabrication in the shop with the use of straight runs and strategically placed manifolds.

8. Hydraulic Cylinders

The cylinders are the single most expensive components in the hydraulic system, and the victim of many pitfalls. Unfortunately, a poorly designed or manufactured cylinder is easily detected. Considerations most common for movable bridge applications are summarized below.

A. Seals and Bearings

1. Avoid slip-stick
2. Monitor wear with port
3. Extend life of seals with use of shims to adjust compression
4. Proper fluid; compatibility and cleanliness level
5. Sufficient bearing area for applications



Detail of Seal Assembly

B. Corrosion Resistance
A variety of rod protection is available. Unless the hydraulic system is for a temporary installation, either a stainless steel rod with chromium plating or a carbon steel rod with a quality ceramic coating should be selected. The below table is organized according to increasing performance.

Rod Materials and Coatings		
Rod Material and Coating	**Characteristics**	**Suggested Applications**
Carbon Steel with Chromium Plating	Limited corrosion resistance / lowest cost	Temporary systems only
Carbon Steel with Nickel / Chromium Plating	Limited corrosion resistance / low cost	Temporary systems or indoor / controlled environments
Stainless Steel with Chromium Plating	Very good corrosion resistance, susceptible to mechanical damage / may flake Cost effective in smaller size rods as compared to carbon steel with ceramic coating	Outdoor applications / applications which require and exposed thread on the rod
Carbon Steel with Ceramax 1000	Excellent corrosion resistance, resistant to mechanical damage. Cost effective in larger sized rods as compared to stainless steel with ceramic coating	Outdoor or even submerged applications
Carbon Steel with Ceramax Engineered Coatings	Maximum resistance to corrosion and mechanical damage / higher cost	Most aggressive applications such as offshore platforms

Several cylinder manufacturers offer proven ceramic coatings. However, some shops may attempt supply an inferior ceramic coating that has not been tested. To ensure a level of high quality, the ceramic coating should, as a minimum, meet the following characteristics:

1. Designed for application: Properties to match characteristics of base material.
2. Process of Shot blasting, bond coat spraying and top coat application is executed in one continuous sequence.
3. No manual control for:
   - Gas flow
   - Electro plasma power

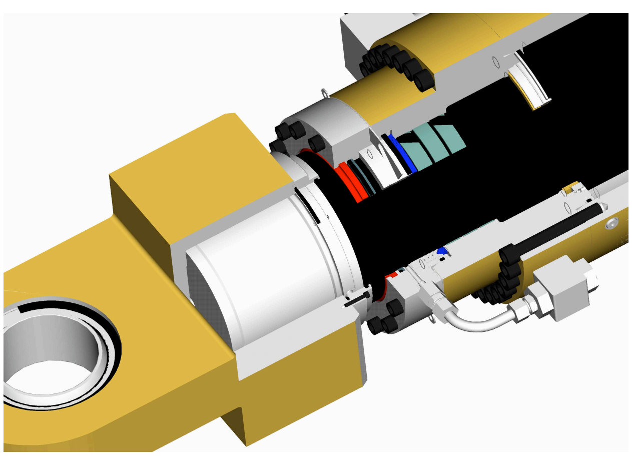
- Power feed
- Carrier gas of power feed
- RPM of the rod in relation to the longitudinal feed of gun

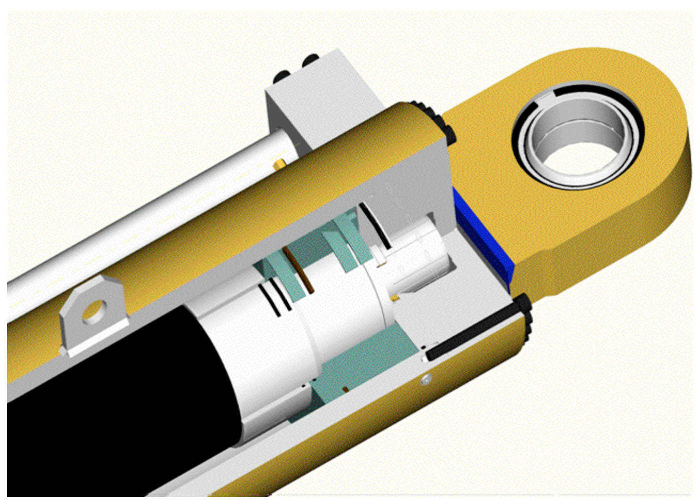
4. Coating applied in a conditioned area.
5. Homogenous, uninterrupted, non-conductive and impermeable.
6. Layer is corrosion resistant to DIN 50021 ESS for a minimum of 1000 hrs (Salt Spray Test).
7. Surface roughness RA. 0.1 to 0.3 um.
8. Minimum thickness of 150 micron.
9. Use of sealant not permitted.

C. Cylinder Construction

Manufacturer's standard practices may not be optimum for cylinders for movable bridges. Therefore, it is recommended that the following construction features are considered in developing specifications to ensure a proper level of quality and to facilitate ease of maintenance for the life of the cylinder.

- **Bolted head/bolted bottom-** Bolted Connections have super strength and facilitate maintenance and even eventual refurbishment (the bore is accessible for honing without cutting the ends off).
- **Wiper -** Cleans debris from rod prior to the seals & bearings.
- **Spherical Bearing – or cardanic ring** Allows freedom of movement to prevent side loads.
- **Provisions for lifting –** Lifting lugs should be located for easy access and should not interfere with piping.
- **Manifold with piping integral to the cylinder-** The manifold & piping should be installed and tested at cylinder manufacture's shop. This ensures that the manifolds are considered early in the design of the cylinder.





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