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3.7 HYDRAULIC SYSTEMS

3.7.1 Introduction

There are two general types of hydraulic systems used in movable machinery applications. These are the "Open" and "Closed" loop hydraulic circuits, which are described subsequently. More detailed descriptions may be found in "Using Industrial Hydraulics" by T. C. Freudenthal (1984).

3.7.1.1 Open Loop Circuit

In open loop circuit applications, the pump draws fluid from a reservoir and pushes this fluid into the hydraulic system. After passing through the control valve circuitry and the actuator, the fluid returns to the storage reservoir. Typically, the reservoir is sized so that it will hold a minimum of three times the volume that can be displaced by the pump in one minute. For example, a 30-gallon per minute pump would be mated with a 90-gallon reservoir.

An open loop pump only pumps fluid in one direction. For this reason, an open loop pump is normally supplied with a large diameter low pressure inlet port and a smaller high pressure outlet port. In open loop circuit design, the direction of the actuator's motion must therefore be accomplished by the use of directional control valves.

Open loop hydraulic circuits are the most common in movable bridge applications. This is because most hydraulic movable bridges are actuated by hydraulic cylinders, which require large volumes of fluid as well as differential flow rates in and out of the hydraulic cylinders. Another advantage of the open loop circuit is that several different actuator functions can be performed simultaneously from a single pump. A disadvantage of the open loop circuit design is its relatively large size and weight due to the large volume of oil required.

3.7.1.2 Closed Loop Circuit

In a closed loop circuit design a single hydraulic pump is used to drive one or more hydraulic motors. The closed loop circuit is not viable for hydraulic cylinder applications because of the different fluid volume displacements during extension and retraction. The fluid that passes through the actuator is returned directly to the low pressure side of the pump. For proper operation, the pump must receive the same quantity of oil at its inlet as it is pumping from its outlet.

A charge pump is always used in a closed loop hydraulic circuit. The charge pump is usually a small fixed displacement pump (usually about 15% of the displacement of the main pump). The charge pump always works on the low pressure leg of the main loop pumping filtered fluid into the loop. The pressure in the low pressure leg is maintained at a value of usually between 100 to 300 psi by a relief valve.

During operation, the main pump control can cause the pump's displacement to "go over center," which means that the main pump can pump high pressure oil from either of its two main ports. In other, words, it can cause a clockwise or counterclockwise flow of fluid through the main loop plumbing. This will allow the actuator to operate in either direction of rotation.

In closed loop systems, pressure, flow, and directional control are all achieved by the controlling elements of the pump. Cross port relief valves are incorporated to protect the actuators from load induced pressure peaks.

The advantages of the closed loop system are that high horsepower systems are compact, they operate with a minimum amount of excess fluid storage, and they are highly efficient. The pump controls direction, acceleration, deceleration, speed, and torque of the motor actuator, and hence pressure and flow control components are not needed. These systems also provide excellent dynamic braking control, which is highly desirable in most movable bridge applications.

3.7.2 Hydraulic Control Systems

There are many types of hydraulic system controls. Hydraulic system control refers to the way in which flow and pressure is regulated from the system's pumps. In general, the three types of hydraulic system controls used in movable bridge applications are "constant horsepower control", "electronic proportional control", and "hydraulic cylinder control". Each is described below.

3.7.2.1 Constant Horsepower Control

Constant horsepower control (also known as horsepower limiting) uses a prime mover (electric motor) which drives the pump at a constant speed. The intent is to keep the motor working at a constant horsepower level. To maintain constant horsepower, the mathematical product of flow and pressure must be a constant value. Therefore, if the flow is high, the operating pressure must be low. Since the operating pressure level of a system is dictated by the load conditions, the flow must vary with changes in load induced pressure to maintain the product of flow and pressure at a constant value.

Constant horsepower controls sense the load induced pressure in the systems and regulate pump flow accordingly. The pump control holds the pump at its maximum displacement until the pressure reaches the point at which regulation or "compensation" begins. This type of system always uses a system pressure relief valve. Once the end of regulation is achieved, the slightest increase in system pressure will open the relief valve and bypass the minimum pump flow back to the tank.

3.7.2.2 Electronic Proportional Control

Electronic proportional control utilizes a proportional solenoid to vary the pump displacement. The pump varies from minimum to maximum displacement proportionally to the current of a 24 volt DC command signal. As DC current is applied to the proportional solenoid, the solenoid pushes the pilot spool with a specific force. When the current, and therefore the force, is high enough the pump begins stroking and producing flow. Further increases in signal current will increase the pump's output flow proportionally.

3.7.2.3 Hydraulic Cylinder Control

Hydraulic cylinder control utilizes a hydraulic adjusting cylinder and pilot system to control pump flow. The pilot circuit is designed to meet the requirements at hand. This type of control can be used in both open and closed loop hydraulic circuits.

3.7.3 Interlocking

Control systems on movable bridges are provided with interlocking controls that cause the bridge to be operated in a manner that provides safety to the traveling public while protecting the equipment. The requirements for interlocking controls between the hydraulic span drive and other equipment such as; span locks and traffic gates and signals are discussed in Section 3.6.9.2.

3.7.4 Inspection of Hydraulic Components

3.7.4.1 Accumulators

The purpose of an accumulator is to store energy in the form of pressurized hydraulic fluid. Although there are several different types of accumulators, gas charged accumulators are the most common.

A gas charged accumulator stores hydraulic fluid under pressure by compressing an inert gas (usually nitrogen). A rubber bladder separates the gas chamber and the oil chamber. Initially, the oil chamber is vented to atmospheric pressure and the gas chamber is pre-charged with nitrogen to a known setting through a gas valve.

Generally, accumulators are maintenance free. The nitrogen pre-charge should be checked at least every 6 months as follows:

> Close the isolation valve between the system and the accumulator. Slowly vent the accumulator using the venting needle valve. By carefully watching the pressure gauge, a gradual decay in pressure will be seen as the fluid empties. However, the moment the accumulator rids itself of all the oil, the needle on the pressure gauge will immediately drop to zero. The pressure from which the needle drops is the pre-charge pressure.

If the nitrogen pre-charge is below that value required by the system design, then the accumulator should be recharged. Recharging an accumulator can be highly dangerous and should only be performed by a qualified technician who is fully trained to properly and safely perform this procedure!

3.7.4.2 Valves

Modern hydraulic system valves are very reliable. Considering the relatively low usage of movable bridge hydraulic systems, problems with system valves should be minimal. However, dirty system fluid or unintentional maladjustment could lead to problems with hydraulic valves. The inspector and/or maintenance staff should periodically perform the following for the system valves:

Pressure Relief Valves

1. Verify that pressure settings on all relief valves are correct. Adjust as necessary.

2. Check for leaks with manifold interface. Replace seals/O-rings as necessary. Re-torque valve body mounting bolts or valve cartridge.

Directional Control Valves

1. Verify that the spool moves freely. Verify that manual override pushbuttons are functional.

2. If spools are sticking, disassemble valve and inspect internal components for wear, scoring, and fluid debris.

3. Check for leaks with manifold interface. Replace seals/O-rings as necessary. Re-torque valve body mounting bolts.

4. Check condition of pilot lines, if applicable.

Shut Off Valves

1. Inspect all shut off valves and their connections to the system piping for leaks.

2. Verify that these valves are fully open or fully closed as required by the system.

3.7.4.3 Hydraulic Cylinders

Hydraulic cylinders are used for span motion or actuation of locking devices. Cylinders should be periodically inspected to ensure proper, safe and long term operation. The inspector and/or maintenance staff should:

1. Observe extension and retraction of hydraulic cylinder rods. Span or locking device movement should be smooth.

2. Inspect condition of cylinder rod coating. Look for scoring, nicks, or other surface imperfections that could damage the rod seals.

3. Inspect area around rod seals for fluid leakage. A small amount of fluid is not cause for alarm. If leakage is excessive, the rod seals should be replaced.

4. Inspect cylinder valve manifold blocks and piping attachments for leaks. Correct as necessary. Verify that flexible hoses do not scrape anything due to cylinder movement.

5. Inspect all connections of the cylinders to the structure or locking device. Verify that all bolted connections are tight. Verify that cylinder end pin connections have freedom of movement.

6. Verify that cylinder attachments have freedom of movement throughout the entire operating range.

7. Lubricate cylinder end bearing/pin connections monthly. Wipe off excess lubrication.

3.7.4.4 Pumps

Periodically inspect system pumps and observe/listen during operation. Operation should be smooth. If equipped with a flow meter, verify that the pumps provide the flow as required by the design. The inspector and/or maintenance staff should:

1. Inspect pump suction, high pressure lines, and case drain lines for leaks. Tighten as necessary. Verify that suction shut off valves are fully open, if equipped.

2. Check tightness of bell housing to pump and motor to bell housing connections. Check tightness of shaft coupling assemblies. Check tightness of other pump/motor mountings.

3.7.4.5 Rotary Motors

Periodically inspect the system's hydraulic motors and observe/listen during operation. Operation should be smooth. The inspector and/or maintenance staff should:

1. Inspect pressure line and case drain line connections for leaks. If found to be loose, the inspector should note the condition and recommend that they be tightened. Check all housing joints for leaks. Verify that suction shut off valves are fully open, if equipped.

2. Check tightness of hydraulic motor to its support and mating equipment. Check tightness of shaft coupling assemblies, if applicable.

3.7.4.6 Filters

Adequate and proper system filtration is the most important aspect of maintaining any hydraulic system. The environment that movable bridge hydraulic systems must operate in makes proper system filtering even more critical. Without proper system filtration, degradation as well as catastrophic failure could result.

Degradation failure of system components results from the abrasiveness of tiny particles wearing the close tolerance surfaces of internal components. Degradation failure spreads throughout the system, and is usually not detected until the damage is irreversible. Indication that degradation failure has occurred include sluggish system response, loss of speed adjustment accuracy, inability of the system to produce full load, and/or overheating.

Catastrophic failure is the immediate failure of a system component and is usually related to large particles causing moving parts to jam or stick. In pumps, dirt can block lubrication passages and cause pump failure. Large debris can collect in orifices which supply oil to the pilot circuit of pilot operated relief valve, pressure compensated flow controls, etc.

Considering the fact that contaminants cause failure, positive steps must be taken to ensure proper system filtration.

Suction Filter

Suction filtration is achieved by locating a filtering element between the reservoir and the pump. Generally, the strainer is well below the minimum oil level within the reservoir. This however, makes servicing suction filters very inconvenient. Consequently, it is not unusual for these filters to go unserviced until they starve the pumps and cause cavitation damage.

Hopefully, a system is equipped with suction filtration access holes that are present in the reservoir to allow servicing of the suction filters without having to drain the reservoirs. Biannual cleaning/replacement of these elements is recommended.

Pressure Filter

A pressure filter is an element contained in a housing that is subjected to the full system pressure and flow. Pressure filters are commonly used to protect high pressure components such as directional spool valves and piston type hydraulic motors.

Proper inspection/maintenance/replacement of pressure filters is critical because if a clogged filter element was to rupture in service, a large concentration of contamination would dump directly into the components it was supposed to protect.

The following should be regularly performed on system pressure filters:

1. Visual clogging indicators should not be relied upon. Pressure filter elements should be removed monthly and inspected. Filter elements should be replaced as necessary.

2. If equipped with electronic clogging warnings, filter element should be replaced immediately upon receiving a system warning of a clogged filter.

3. As a minimum, all system pressure filters should be replaced annually.

Return Line Filters

Return line filtration is based on the assumption that a clean hydraulic system will remain clean if the contamination is filtered out of the fluid soon after it is ingested or created by the system.

The following procedures should be performed regularly on system return line filters:

1. Visual clogging indicators should not be relied upon. Remove and visually inspect return line filter elements monthly. Filter elements should be replaced as necessary.

2. If equipped with electronic clogging warnings, filter element should be replaced immediately upon receiving a system warning of a clogged filter.

3. As a minimum, all system return line filters should be replaced annually.

3.7.4.7 Piping, Tubing, and Hoses

Plumbing systems for hydraulic movable bridge machinery often consist of complex arrangements of high pressure piping, stainless steel tubing, and hoses. Piping runs usually contain many bends, elbows, fittings, and mountings due to the complex nature of the bridge structure. Vibration from operation of the equipment, vibrations from vehicular traffic, as well as movement of the equipment itself has the tendency to loosen piping fittings and piping supports. This in turn can cause system leaks as well as damage to the plumbing from not being adequately supported.

The following should be regularly performed on hydraulic system plumbing:

1. Visually inspect the condition of all flexible hoses. Any damaged, nicked, or worn hoses should be replaced immediately.

2. Visually inspect all plumbing fittings for signs of leakage. Any loose fittings should be tightened as required. O-ring or other seals should be replaced as required.

3. Inspect piping support systems. Check tightness of hangers and mounting hardware.

4. Visually inspect all pump and control valve pilot lines for leakage. Loose pilot lines should be tightened.

5. Visually inspect inlet and outlet plumbing to main pumps. Loose connections should be tightened as necessary.

3.7.4.8 Hydraulic Fluids

Water has been used as the working fluid in some hydraulic systems, including the original operating system of the Tower Bridge in London. However, most modern movable bridge hydraulic systems utilize either standard mineral oil or synthetic environmentally friendly vegetable oil as their working fluid. The useful life of these fluids is not infinite. Several factors influence the life expectance of hydraulic fluid including system usage, operating temperature, system cleanliness, water intrusion, etc. Synthetic vegetable oils tend to oxidize after several years and require replacement.

Laboratory analysis on system fluid should be performed at least on an annual basis. Samples should be analyzed for viscosity, contamination levels, wear elements, and water content. Annual fluid sample analysis will greatly assist in determining when system fluid requires replacement.