Heavy Movable Structures, Inc.

SIXTH BIENNIAL SYMPOSIUM

October 30 - November 1, 1996

Doubletree Resort Surfside
Clearwater Beach, Florida

Hydraulic Lifting System for SR 520 Bridge, Seattle, Washington

by

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HYDRAULIC LIFTING SYSTEM

FOR SR 520 BRIDGE

Seattle, Washington

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1.0 INTRODUCTION

Washington State Route 520 forms a major east - west link between the business and financial center of Seattle and the rapidly growing Eastside communities of Kirkland, Bellevue and Redmond. Central to this highway link is the Evergreen Point Floating Bridge which spans Lake Washington and was first opened in 1961. Because of the extreme depth of Lake Washington, a floating bridge design was chosen. At the center of the bridge, a floating draw span was constructed to accommodate vessels which would not pass beneath the east and west high rise portions and also to allow opening for relief of wind and wave forces during extreme storm conditions.

The main movable portions of this bridge are two lift decks and two draw spans, See Figure 1. In an opening operation, the east and west lift spans raise and the respective floating draw spans are drawn beneath them. Because of the extremely high traffic volume that uses this bridge (there is only one practical alternate route) and because of the absolute requirement to protect the bridge during extreme storm conditions, reliability of the draw span operation is essential. In over 31 years of use, maintenance and dependability of the original bridge equipment had become problematic, and in 1993, the Washington State Department of Transportation (WSDOT) commissioned a study to develop an action plan for renovation or replacement of the bridge operating machinery. This study was part of a larger study intended to upgrade the entire bridge and which included the following two goals:

1) to replace the grated roadway on the lift decks with a concrete surface incorporating a barrier median, and
2) to correct potentially dangerous problems inherent in the original control system.

It soon became clear that these two goals would not be achievable by equipment renovation and it was decided to replace the existing equipment with entirely new machinery and control systems.

2.0 BACKGROUND

The original design of the lift deck system utilized an electro-mechanical drive. This was accomplished by lifting eight guide columns on each side of each lift span with a system of long link chains and counterweights. The sixteen lift chains, and therefore the guide column lift, were synchronized through a long single shaft to which were connected five motor reducer sets.

There were multiple problems with the existing drive. First, the chains frequently broke due to uneven load conditions caused by jamming and chain-to-sprocket pitch incompatibility. Secondly, the large counterweights themselves posed a serious potential safety threat since a catastrophic failure of multiple chains could either drop a counterweight or cause it to jam on its guide column, either one of which could penetrate the bottom of the flanking pontoon. To eliminate these problems and to achieve the previously stated goals, it was decided that the new machinery should have the following capabilities and characteristics:

1) it must be able to lift the increased weight of the new lift spans (approximately 800,000 lbs. each);
2) if at all possible, it should eliminate the need for counterweights;
3) redundancy of the machinery and backup control systems must be such that no failure of any element would prevent a bridge opening or closing operation; and
4) controls must be properly interlocked in such a way as to effectively eliminate the possibility of inadvertent lift deck operation

After a thorough evaluation of all options in light of these requirements, it was decided that a hydraulic lift system was most appropriate for the bridge renovation, because of its high power density and simplicity of operation.

3.0 THE LIFT SPAN HYDRAULIC SYSTEM

The main movable portions of the bridge are two lift spans (decks) and two draw pontoons. In an opening operation, the east and west lift spans are raised and the respective floating draw pontoons are "drawn" beneath them.

Each lift span is now lifted by two hydraulic subsystems (see Figures 2 and 3). These subsystems are not hydraulically interconnected, but are controlled by a common deck level controller (DLC) system.

The main components of each hydraulic subsystem (see Figure 4) are a reservoir, two pump/motor units (Item 1, Figure 4), four proportional directional valves (Item 2, Figure 4), and four cylinders (Item 3, Figure 4). There are two hydraulic cylinders at each corner of each lift span, with the four north side cylinders being driven by the north side subsystem and the four south side cylinders driven by the south side subsystem. The cylinders are mounted vertically (rod end up) and act directly on the lift span (see Figure 3). There is one proportional directional valve for each cylinder. The proportional directional control valves provide smooth acceleration and deceleration of the span lift.

Critical components in the system are redundant to allow operation in the event that one or more of these components become inoperable. The redundant components are the pumps, motors, cylinders, and directional control valves. The system is normally in an automatic mode, controlled totally by the main PLC and the DLC. Manual control of the hydraulic system is also possible, where the proportional valves are operated directly from the push-button station (see description below). There is also a manual mode in which four manually operated globe valves (Item 4, Figure 4) allow the bridge to be lowered in the event of a total control failure with the bridge up.

Other features of the hydraulic system include flow fuses on each of the three main lines that run to each cylinder. Each fuse valve stays open and allows flow at normal flow rates. If the flow increases to an abnormally high level, then the valve will close, shutting off all flow through the valve. This will prevent excessive loss of fluid if a hydraulic line breaks. In the event that a hydraulic line breaks, the oil supply to the cylinder will stop. Because of redundant cylinders, the motion of the bridge will continue, but at a slower rate.

The heaters in the reservoir keep the fluid warm for proper operation in cold weather. There are three heaters to allow for adequate heating capacity and redundancy.

A monorail with a manual chain hoist is provided for major maintenance of the hydraulic power units. The monorails are mounted to the ceiling of the pontoon cells above each hydraulic power unit.

4.0 DECK LEVEL CONTROLLER (DLC)

To keep the lift spans in a level position during the raising and lowering operations, two deck level control systems are used, with one system controlling each span.

Each cylinder has a linear transducer that monitors its position continuously and sends a signal to an 8-axis Deck Level Controller (DLC), consisting of 8 microprocessor-based, closed loop valve drivers, interconnected through the parallel I/O interface. The controller continuously compares the position of each cylinder relative to the pre-set speed and sends a corrective action signal to the corresponding proportional directional control valve. The valve in turn sends a main-stage feedback signal to the controller.

The DLC is programmed to control the lifting and lowering of the deck at pre-set speeds. The DLC takes into account that during lifting the full flow of the pumps can be used on the blind end area of the cylinder, while the flow must be limited during lowering as a result of the smaller rod end area of the cylinder.

During normal operation the Auto-Manual selector is in Auto mode and the Programmable Logic Controller (PLC) is in charge of the operation, assuring that all bridge operations occur in the correct sequence. When the operator pushes the "Deck Lift" button, the PLC sends a signal to the DLC to start the lift operation. The end of the lifting stroke is detected by the DLC from the cylinder position transducer (without the need of a limit switch) and a signal is sent to the PLC. Lowering is done in a similar way. The DLC continuously sends a 4-20 mA signal (proportional to the extension of the cylinders) to the PLC to show the height of the deck on the operator's console.

Some of the most common problems related to hydraulic cylinders (such as a broken hose or a rapidly leaking cylinder seal) will be detected by the pressure switches located at each cylinder. These signals are sent to the PLC, which turns on a lamp at the Hydraulic Cylinder Status/Control Panel to warn the operator of some malfunction at a specific cylinder. At this time the operator can either:

A. Disable that cylinder and continue with the operation.

B. Stop, determine the problem and decide how to resume operation (Auto or Manual).

The Enable/Disable function selected from the Hydraulic Cylinder Status/Control panel is operated through the PLC on the cylinder Enable/Disable control. This allows the system to be operated in an Auto mode even if one cylinder is damaged and has been disabled. The DLC keeps the Deck level in this mode, even if there is only one cylinder bearing the load at one corner and the pressure at this cylinder has to be higher than at the other cylinders. (The pump pressure compensator is set at 2,200 psi instead of 1,250 psi as needed for two-cylinder operation.)

In the "Manual" mode, all control functions by-pass the PLC and DLC, and are transferred to the Manual Control Box located on the bridge deck. In this mode, care must be taken to avoid any manual operation of a disabled cylinder.

In "Manual" mode, the "Lift" or "Lower" orders are given to the amplifier card of each cylinder directly, allowing control of the individual Proportional Directional Valves regardless of the leading or lagging response of the cylinders. During lifting, full voltage can be applied to the amplifier card, because the required flow is the maximum available from the pumps. During lowering, as a result of the reduced area of the cylinders, the proportional control valves must reduce the oil flow to keep the deck speeds within the rated speed.

5.0 THE HYDRAULIC LIFTING CYLINDER

The hydraulic lifting cylinders (12" bore, 8" rod) provide a very simple and reliable means of moving the two lift decks. The cylinders have several important features:

- High strength rod (AISI 4340), with spherical end (6" radius).
- Integral Temposonic Position Transducer.
- Counterbalance valve in the piston retract port which hydraulically locks the cylinder and will prevent descent if a hydraulic line breaks.
- Design safety factor of over 3.5 :1 based on maximum load induced pressure.
- Ceramic protective coating on cylinder rods for the marine environment.

6.0 MANUAL OPERATION

In the "Manual" mode, all control functions by-pass the PLC and DLC, and are transferred to the Manual Control Box located on the bridge deck. In this mode, care must be taken to avoid any manual operation of a disabled cylinder.

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7.0 FIELD TESTING

The field testing of the bridge (including the lift span) was somewhat drawn out, because testing could only be done during the weekends (often only during weekend nights) due to traffic requirements. There were few hydraulic problems, except that the flow fuse valves often shut-off the cylinder line without apparent cause. It was determined that the control system occasionally caused the proportional valves to go to the full open position (nearly closing the other valves), and the resulting surge of flow exceeded the 150% design allowance. The problem was solved by modifying the flow fuses for higher capacity.

The control system was extensively field tested. During this testing, the initial ¼ inch allowable vertical misalignment of the corners of the lift deck was changed to 1 inch to increase the stability of the system. This was well within the 3" corner to corner warpage allowance of the lift deck.

8.0 SUMMARY

Use of a hydraulic lift system at the SR 520 Evergreen Point Floating Bridge met all of the project goals:

1. Ability to lift the new heavier lift decks without the use of counterweights because of the high "power density" of hydraulics.
2. Simplicity of operation.
3. Reliability to assure operation at critical times.
4. "Fail safe" control logic to prevent an inadvertent deck lift.

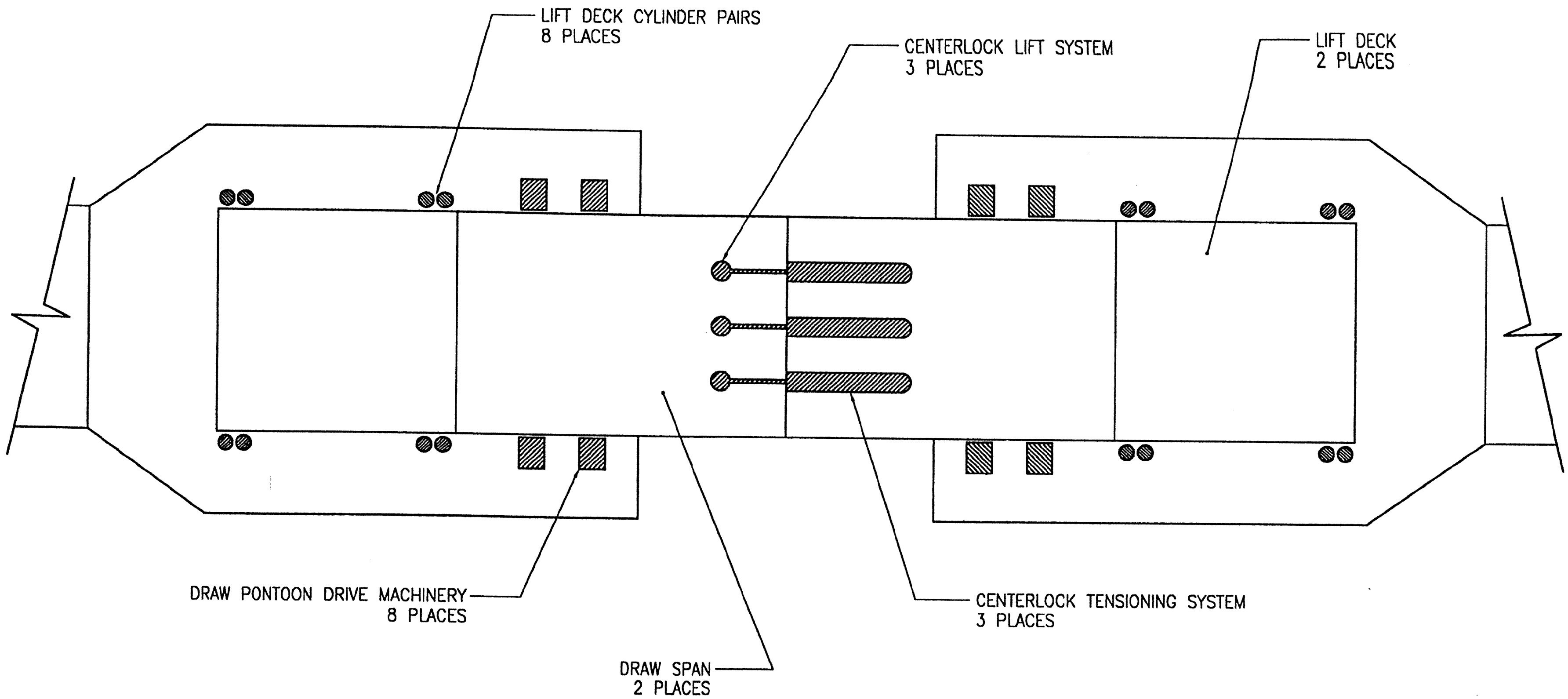

FIGURE 1
520 BRIDGE MECHANICAL EQUIPMENT

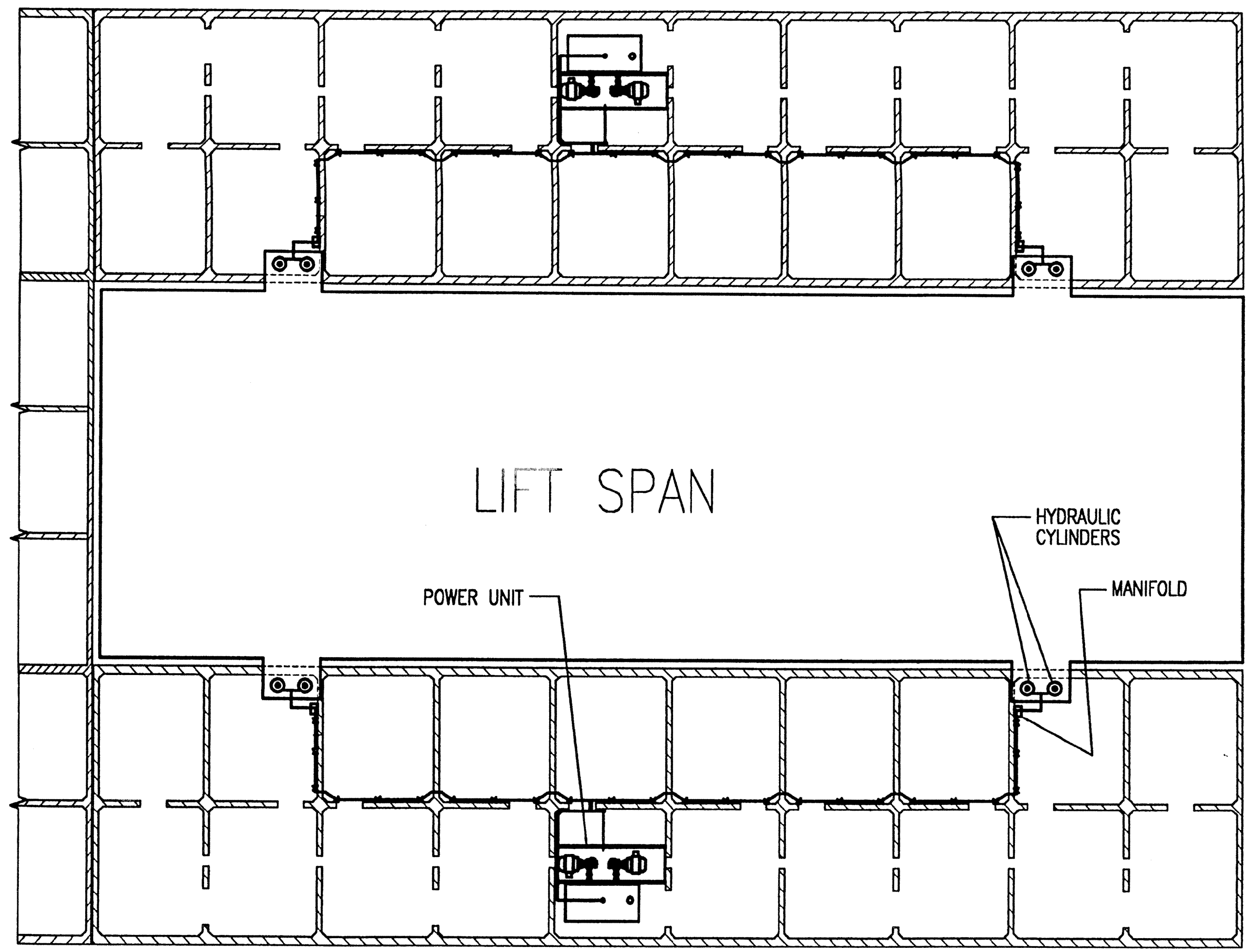

FIGURE 2
HYDRAULIC LIFT COMPONENTS

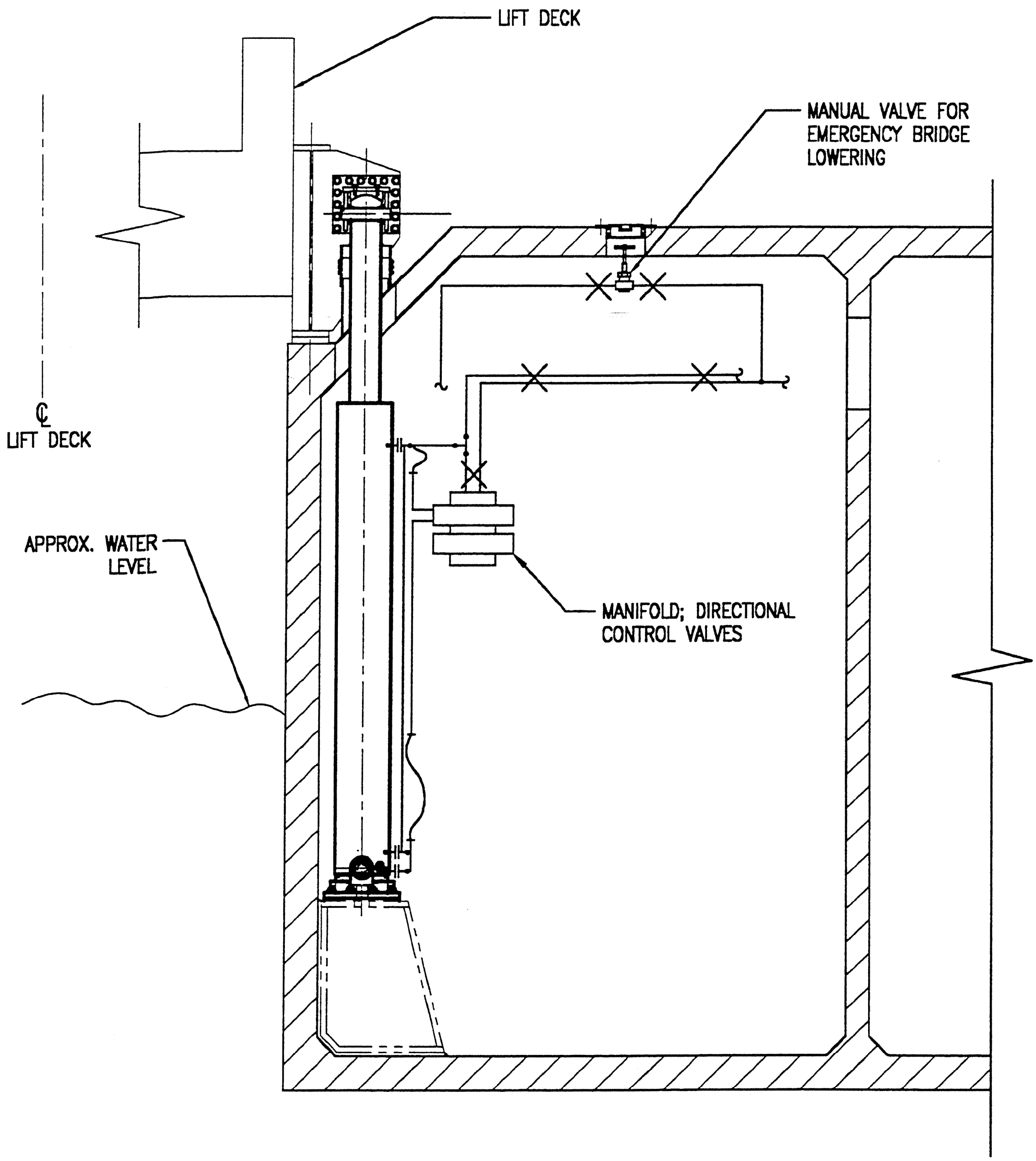

FIGURE 3
LIFT CYLINDER

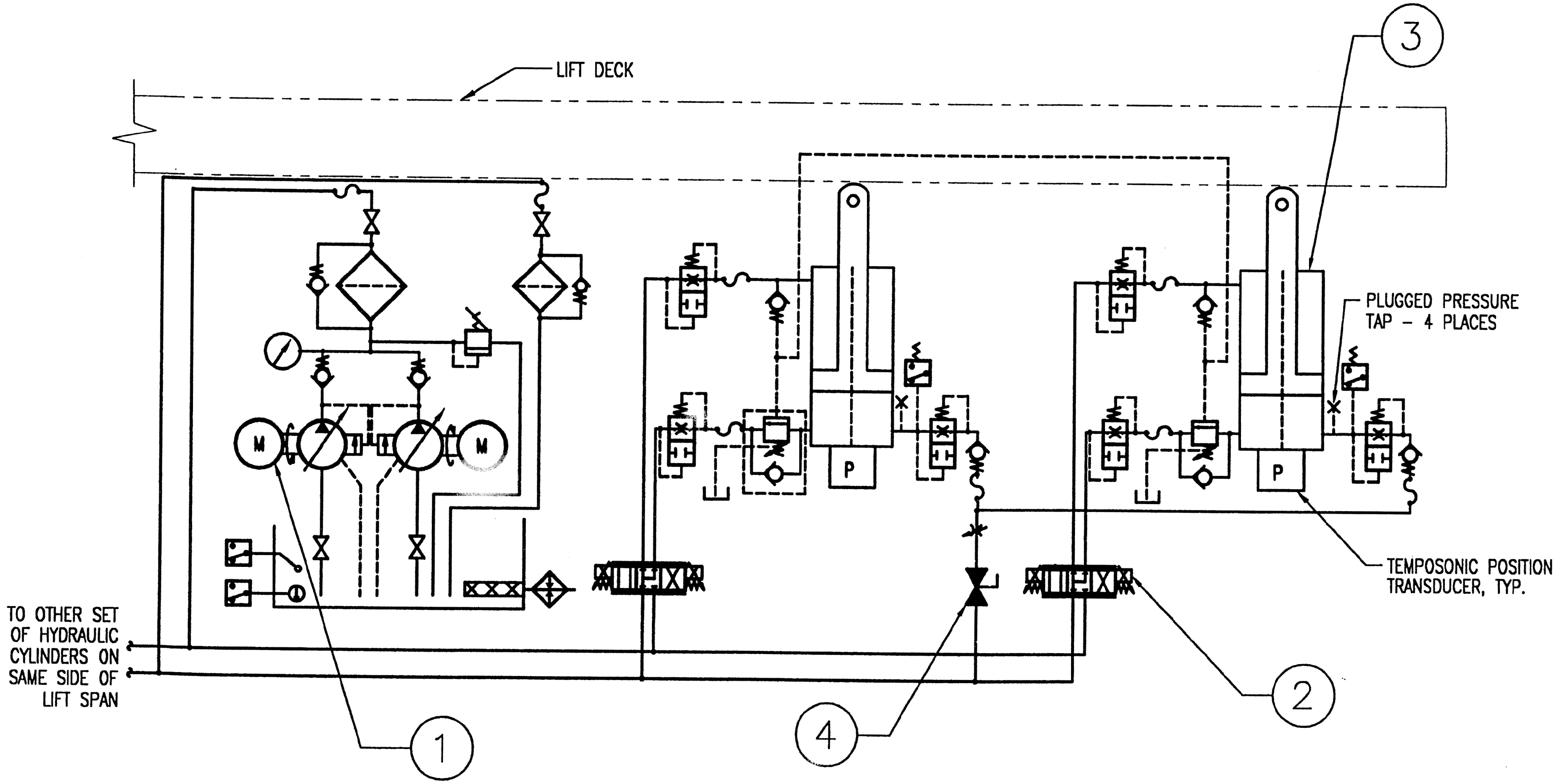

FIGURE 4 - HYDRAULIC SCHEMATIC