THE SECOND BIENNIAL
SYMPOSIUM AND EXHIBITION
ON
MOVABLE BRIDGE
DESIGN AND TECHNOLOGY

# LOW SPEED - HIGH TORQUE FLUID MOTOR DRIVE FOR MOVABLE BRIDGES

BY
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## DEDICATION

This paper and the paper titled "Data Aquisition System for Movable Bridges" are dedicated to the following:

The Bridge Design Division of the Wisconsin Department of Transportation and the City Engineer of Manitowoc, Wisconsin for their confidence in Hazelet + Erdal to design a completely new "State-of-the-Art" hydraulically operated system for their new Chicago-type Rolling Lift Bridge to carry 10th Street over the Manitowoc River in Manitowoc, Wisc.

The Bridge Design Division of the Indiana Department of Highways for thier condifence in Hazelet + Erdal to also provide a similar design for their two new Chicago type Rolling Lift Bascule Bridges to carry Indianapolis Blvd. and Dickey Road over the Indiana Harbor canal in East Chicago, Indiana.

## SUMMARY OF HYDRAULIC SYSTEMS DESIGNED BY HAZELET + ERDAL

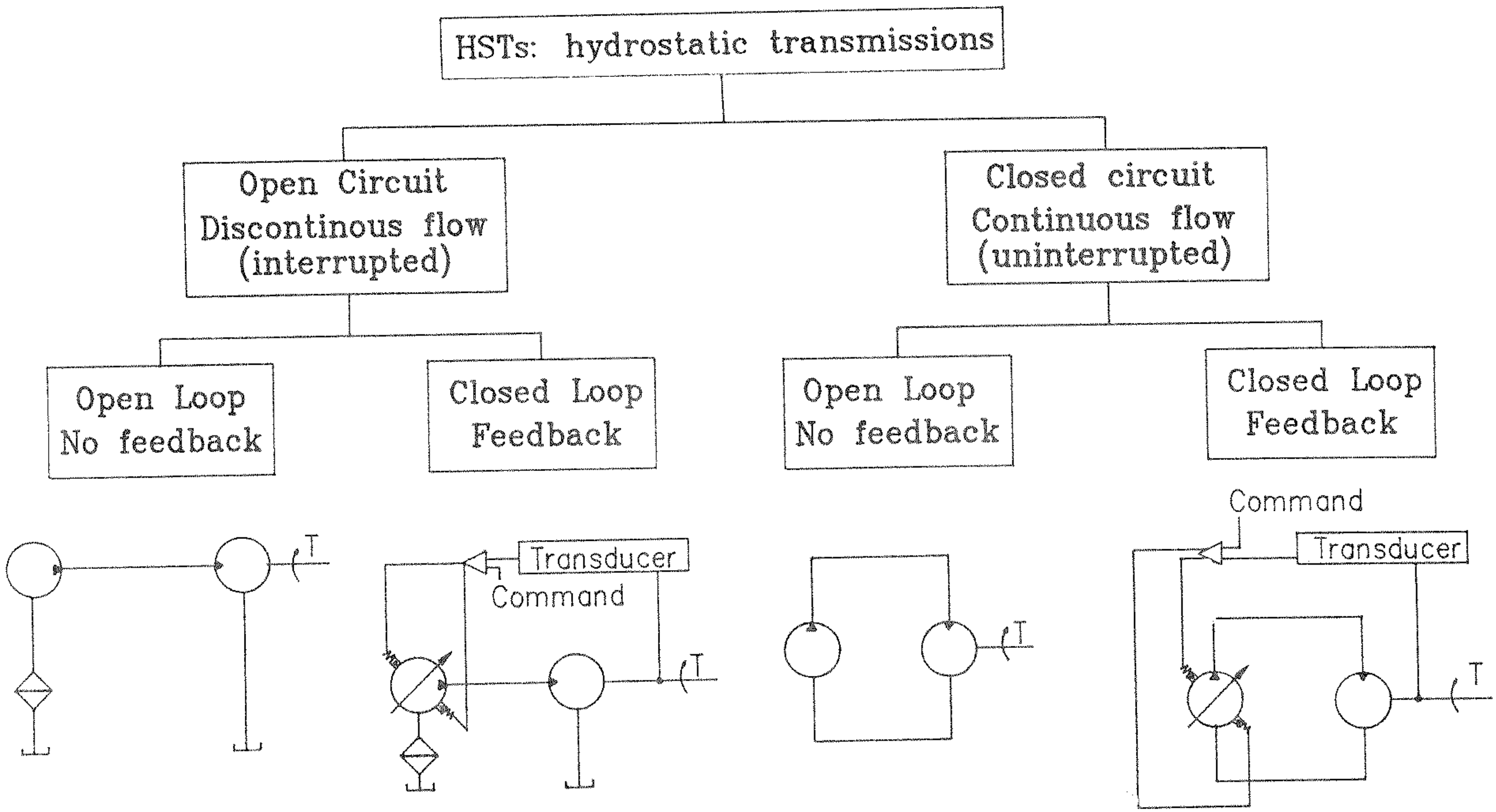
A paper titled, "The Development of the Hydraulic Systems Designed from 1965 to the State-of-the-Art Hydraulic Systems of Today" was presented at the First Biennial Movable Bridge Symposium. The four basic HST configurations for hydrostatic transmission are shown on the next page.

The first four were open-circuit open-loop hydraulic systems, which required the operator to manually monitor the speed of the moving leaves and to control the acceleration and deceleration.

The fifth and sixth bridges in St. Joseph and St. Clair, Michigan were closed-circuit open-loop hydraulic systems, which also required the operator to manually monitor the speed of the moving leaves and to control the acceleration and deceleration.

The three hydraulically operated bridges that have been designed two of which have now been constructed. They are closed circuit, closed-loop hydraulic systems. After the operator has manually lowered the traffic gates and cleared the bridge of pedestrians, they have pushbutton automatic operation. Pushbutton operation has been made practical by the application of state of the art equipment.

The shear locks used at the center of the span on the rolling lift bridges have no moving parts: Therefore, they must be engaged before the moving leaves are fully closed and slide into place as both leaves simultaneously reach the fully closed position. Automatic operation requires that continuous precise indication of the location of each leaf must be input to the Programmable Logic Control (PLC). The PLC is programmed to make all necessary adjustment in its' output to the moving leaves to bring them together at the fully closed position. The rear locks are then driven, the brakes are set and the traffic gates raised automatically. The operator must turn the control switch to OFF.




Four Basic HST Configurations

## DEVELOPMENT OF THE HYDRAULIC SYSTEMS AND DESIGN SPECIFICATIONS

The first two bridges were designed with no mention of hydraulic operation of movable bridges in either AASHTO Movable Bridge Specifications or in AREA Manual, Chapter 15, Part 6 Movable Bridges. The Joint Industrial Conference (JIC) Specifications were used as a guide along with much research and meetings with manufacturers.

The 1970 Edition of AASHTO Movable Bridge Specifications included a paragraph on hydraulic pressure limits and rating of equipment; this Paragraph 2.5.18 Power Hydraulic Systems is copied hereinafter for your reference.

The next four bridges were designed after continued research and with the helpful manufacturers' representatives. The problems that came up becuase of the Contractor's lack of understanding of the application of the systems to movable bridges indicated that a Comprehensive Specification for the design, fabrication and construction was needed.

As a member of AREA Committee 15, the author, stated at a meeting that we had four highway bridges and two railroad bridges in operation, but the word hydraulic was not even mentioned in Chapter 15 Specifications. You know the response, the author was asked to take on the task of writing the specifications needed with the Movable Bridges subcommittee reviewing and developing the final draft for vote of approval of the full committee. After three years of continued research and the help of my associates, the specifications were approved and included in the 1984 Edition. A copy of Articles 6.4.8.1 "Allowable System Pressures" and 6.4.8.2 "Pressure Ratings for Hydraulic Components" are copied hereinafter for your reference. This is only a very small portion of the total specifications covering Hydraulic Systems.

During the development of the AREA specifications an in-house study was made to see how large a rolling lift bridge could be economically operated by hydraulic cylinders. The longest single leaf rolling lift railroad bridge in the U.S. would have taken tremendous cylinders that would make it completely out of the question. Therefore, the problem of developing a system that could economically be used on any size bridge needed to be solved.

As the results of Hazelet + Erdal's extensive research, a system was developed which would utilize the latest state of the art equipment used in industry but not yet applied to movable bridges. A layout of one-half of the hydraulic drive for one leaf is shown on Page . The system was presented to the Wisconsin Department of Transportation, their Green Bay District and the City Engineer of Manitowoc, Wisconsin, who all gave their approval to use this new untested system to operate the new 10th Street Bridge carrying US 10 (Southbound) over the Manitowoc River in Manitowoc, Wisconsin.

Construction of the new bridge is nearing completion and testing of the new system is scheduled to start October 5, 1987. The presentation of this paper at the Symposium will report on the operation of the bridge that is scheduled to be opened to traffic this fall.

The use of Programmable Logic Controllers (PLC) for the automatic control of the moving leaves also provided the capability for so much more at very little additional cost. A complete monitoring, self-diagnostic, and data acquisition system had also been included in the package that had been approved for the proposed bridge in Manitowoc. The hydraulic system parameters, that are monitored with diagnostic messages displayed and printed, are discussed in another paper titled "Data Acquisition System for Movable Bridges". A Basic Closed-Circuit Closed-Loop Hydrostatic Drive is shown on Page .

Plans for two Chicago type rolling lift bascule bridges in the City of East Chicago, Indiana, for the Indiana State Highway Commission had been completed several years earlier. A proposal was made to update the operation of these two bridges to the State of the Art Hydraulic Systems of Today, and was accepted. The Indianapolis Blvd. bridge carrying US 12 and US 20 over the Indiana Harbor Canal in East Chicago, Indiana is scheduled to be opened to traffic October 6, 1987. The presentation of the paper at the Symposium will report on the operation of the bridge and the opening ceremony. The Dickey Raod bridge carrying SR 912 over the Indiana Harbor Canal will be advertised after the Indianapolis Blvd. bridge is opened.

## AASHTO STANDARD SPECIFICATION FOR MOVABLE HIGHWAY BRIDGES - 1978

2.5.18. - Power Hydraulic Systems.

The working pressure of hydraulic system shall preferable be limited to 1,000 psi (6,895MPa), with relief valves set at 100 psi (.690MPa) above the working pressure. All piping, valves, cylinders, and other equipment shall be designed for 2,000 psi (13,790MPa) service at 100+/-F (37.8+/-C). The pump shall have a continuous pressure rating of 120 percent of the specified working pressure with sufficient volume to open the span in the required time, including acceleration and deceleration.

## AREA MANUAL FOR RAILWAY ENGINEERING STEEL STRUCTURES - 1984 EDITION

6.4.8 - Hydraulic Systems and Components

6.4.8.1 Allowable System Pressures

(a) The hydraulic system shall be designed and hydraulic components proportioned such that the maximum allowable system pressures shall not exceed the following, except as otherwise permitted by prior written approval of the Company.

| | |
|---|---|
| Normal Operational. | 1000 psi |
| Operational against maximum specified loads. | 2000 psi |
| Holding against maximum specified wind loads. | 3000 psi |

(b) Normal operation shall be defined as operation against Condition A loads specified in Art. 6.3.6. Operation against maximum specified loads shall be defined as operation against Condition B & C loads specified in Art. 6.3.6. Holding against maximum specified wind loads shall be defined as holding the movable span in the fully open position, static condition, against the loads specified in Art. 6.3.6 (e).

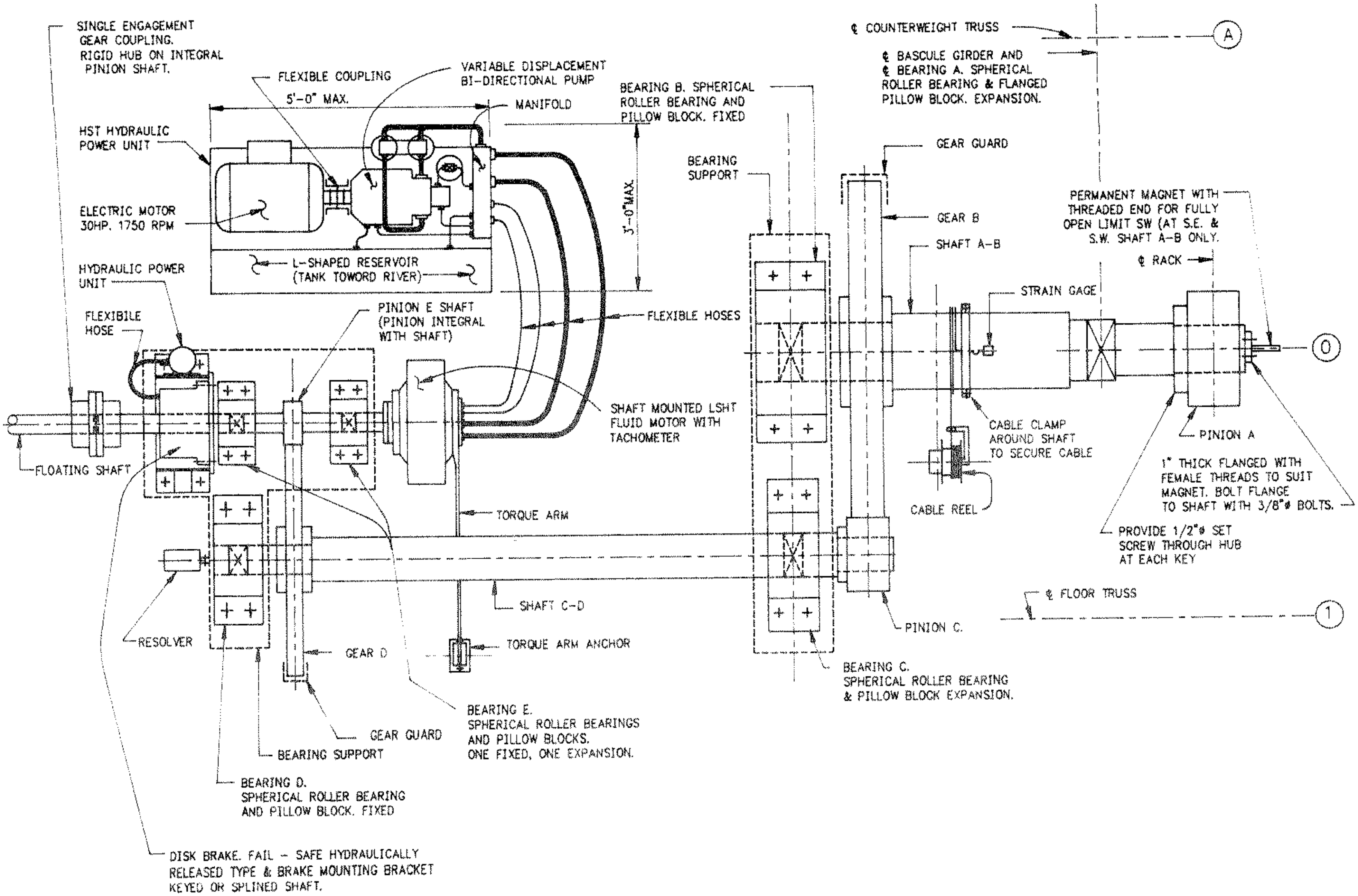
6.4.8.2 Pressure Rating for Hydraulic Components

(a) Minimum working pressure ratings for hydraulic components shall be as follows, except as otherwise permitted by prior written approval of the Company.

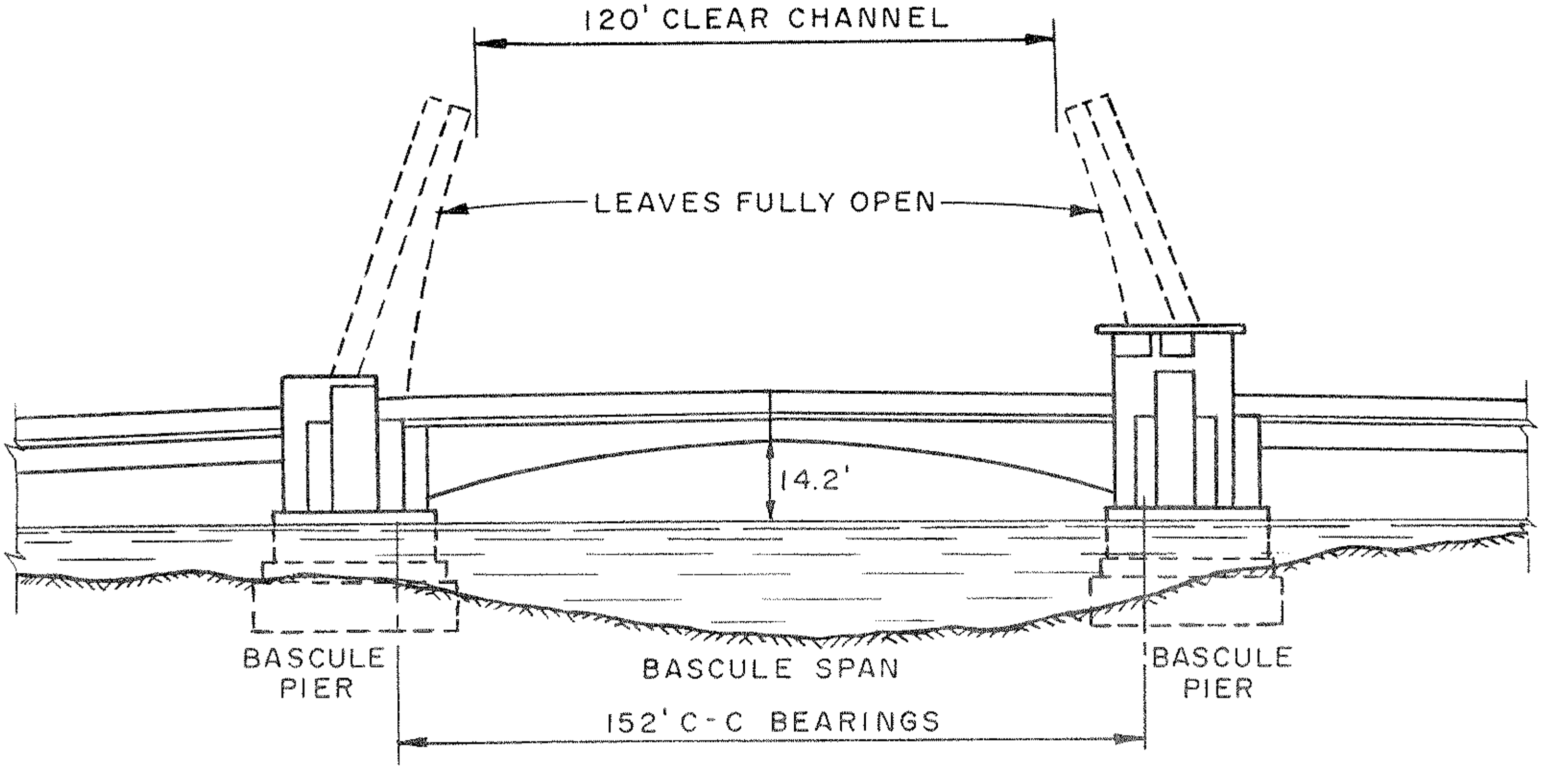
| | |
|---|---|
| Pipe, tubing and their fittings: | 3000 psi |
| Flexible hose and hose fittings: | |
| For pressure lines | 5000 psi |
| For drain lines | 2000 psi |
| Cylinder, pumps, valves and all other components: | 3000 psi |

(b) Working pressure rating shall be defined as the maximum continuous operating pressure for the component. For pipe, tubing, flexible hose and fitting the working pressure ratings are equal to the burst pressure rating divided by a minimum factor of safety of 4. For cylinders the working pressure rating shall be equal to the NFPA theoretical static failure pressure rating as required by Art. 6.5.37.11 divided by a minimum factor of safety of 3.33. For pumps, valves and other components the working pressure rating is equal to the maximum allowable peak (intermittent) pressure rating divided by a minimum factor of safety of 1.5.

(c) The minimum factors of safety designated in paragraph (b) apply to system having light to moderate operating shock loads during operation resulting in short duration peak system pressures no greater than two times the allowable maximum operating pressure against Conditions B or C loads, whichever is greater. For systems having higher shock loads pressures, the factors of safety shall be increased proportionally.




PLAN OF OPERATING MACHINERY FOR 1/2 LEAF




44' ROADWAY AND TWO 9' SIDEWALKS

**U.S. 10 OVER MANITOWOC RIVER**

**IN MANITOWOC, WISCONSIN**

DESIGNED 1985

**DEVELOPMENT OF THE HYDRAULIC SYSTEMS AND DESIGN SPECIFICATIONS** (Cont.)

U.S. 10 (EASTBOUND) OVER THE MANITOWOC RIVER
IN THE
CITY OF MANITOWOC, WISCONSIN
(SHOWN IN ELEVATION ON PREVIOUS PAGE.)

Double Leaf Rolling Lift Bascule Bridge Providing 120 Ft. Clear Channel at 0+/- Skew.

The design is a closed-circuit closed-loop hydraulic system.

Each leaf is operated by two independent hydraulic power units each driving a low speed high torque (LSHT) fluid motor coupled to a drive pinion and a hydraulically operated disc brake. This pinion is part of two sets of open gear train and delivers the power to the rack pinion. All of the above equipment is on the moving leaf. The two systems are coupled together and are symmetrical about the centerline of the leaf. If a problem developes in one of the systems it automatically shuts itself down and the leaf is operated by the functioning system. The LSHT motor of the disabled system is placed in a freewheeling mode and turns with the shaft.

Each Hydaulic Power Unit consists of an L shaped reservoir on a base that supports a 30 HP Squirrel cage induction motor driving a variable displacement, overcenter for reversing flow, piston type pump with an integral charge pump and an electrically actuated pump servo controller mounted on the pump. The power unit also includes the flexible coupling with guard, manifold(s), valves, piping between power unit components, filters and all other required accessories.

Double Leaf Rolling Lift Bascule Bridge Providing 68 Ft. Clear Channel at 0° Skew.

The design of the hydraulic system is bascially the same as the U.S. 10 Bridge over the Manitowoc River except for the size and capacity of the equipment.

STATE ROUTE 912 OVER THE INDIANA HARBOR CANAL
IN THE
CITY OF EAST CHICAGO, INDIANA

Double Leaf Rolling Lift Bascule Bridge Providing 118.5' Clear Channel at 3+/- -30' Skew.

The design of the hydraulic system is basically the same as the U.S. 10 Bridge over the Manitowoc River except for the size and capacity of the equipment.

## DEVELOPMENT OF THE HYDRAULIC CIRCUIT

1. Basic Hydraulic Closed Circuit (Closed Loop Feedback is added on Plate 9.) with a variable volume piston pump driven by a 1800 RPM synchronous electric motor is shown on Plate 1. The swash plate can be varied in both direction to reverse the flow in the closed circuit. The hydraulic motor which drives the moving leaf will turn in either direction at the speed determined by the volume of flow of hydraulic fluid from the pump. When a moving leaf has an overhauling force (due to a wind load and/or out of balance load) that tries to drive the moving leaf faster will cause the hydraulic motor to act a hydraulic pump. The oil will be forced through the piston pump which in turn will act as a hydraulic motor and drive the electric motor faster than sychronous speed. At speeds greater than synchronous speed, the motor will act as a generator which will supply power back into the electrical power source. The restraining force of the electric motor will vary with the magnitude of the speed above synchronous speed. This is called regenerative braking.

2. While the hydraulic fluid is being pumped around through the loop, a small amount of fluid seeps out thru the seals into the outer casing of the hydraulic pump and hydraulic motor. A drain is provided from each housing back to a reservoir. To make up for this lost hydraulic fluid a constant volume charge pump is provided that will provide hydraulic fluid which will maintain a minimum pressure in the loop as shown on plate 2. This pressure is equal to the pressure relief valve setting in the charge pump circuit. All excess fluid pumped by the charge pump will flow back into the reservoir over the pressure relief valve. The pistons in the pump also need this back pressure during the time the piston is returning from the pressure stroke.

   The charge pump is on a common shaft with the electric motor and variable piston pump. Therefore the electric motor must also have the capacity to not only drive the variable piston pump, but also the constant volume charge pump.

3. In order to protect the variable piston pump from contamination picked up in the loop, motor, or from the reservoir, filters have been added on each side of the loop and in the intake line to the charge pump as shown on plate 3. The hydraulic fluid in the loop will only pass through the filter on the return side going to the pump. On the pressure side leaving the pump, the hydraulic fluid will flow through the by pass check valve and bypass the filter. The check valve in line with the filter will allow flow in only one direction through the filters.

   The fluid from the resevoir is filtered before it is pumped into the circuit. If the differential pressure (pressure drop) across the filter exceeds the spring value in the by-pass check valve the portion of fluid flow not needed to maintain this differential pressure will flow thru the check valve.

## DEVELOPMENT OF THE HYDRAULIC CIRCUIT

4. The AASHTO design specifications requires that the moving leaf should be capable of operating against a horizontal wind load of 10 pounds per square feet. The pressure required by the hydraulic power unit to drive the moving leaf against this load must be below the maximum pressure that is allowed to be developed in the circuit. Crossover relief valves are placed across the hydraulic motor as shown by heavier lines on the plate 4. They should be set to provide the pressure required for the moving leaf to operate against the design load.

5. Remote Control of the Swash Plates must be provided in order for one operator to be able to control the four hydraulic power units in the two machinery rooms, one on each side of the channel. Only five input signals will be sent to each of the four servo control units. They are

    1. Raise Full Speed
    2. Raise Creep Speed
    3. Stop
    4. Lower Creep Speed
    5. Lower Full Speed

    When a change in signal is sent to the servo, it will accelerate or decelerate to the new command speed. A change from raise to lower or vise versa cannot be made without first going thru stop. Each of the acceleration and deceleration ramps should be separately adjustable. The servo controls are sent directly to the servo control units adjacent to the variable piston pumps. A speed feedback is sent back from a tachometer for the servo to compare with the command. Automatic adjustment of the controls will synchronize the input speed to the output feedback speed. If an erotic feedback or no feedback is received the servo immediately sends out a "servo malfunction" signal. This signal will drop out that power unit on the leaf and place the hydraulic loop in a free wheeling mode. See next item for description of free wheeling. This will enable the LSHT hydraulic motor to rotate with the hydraulic fluid flowing around the loop formed by the free wheeling valve and the LSHT motor.

6. There are times when the LSHT hydraulic motor should be able to rotate without hydraulic pressure being applied to motor. This is accomplished by placing a two position flow control valve across the LSHT hydraulic motor. The valve is controlled by a solenoid which must be activated to close the valve and make it non-effective in the circuit. When the solenoid is not activated, the spring will return the valve to the open position. This arrangement is fail safe with the hydraulically released mechanical brake, where the unloading valve solenoid must be activated to allow the hydraulic pump to develope the pressure need to release the brake. When power is last the unloading valve will automatically open and set the brake.

## DEVELOPMENT OF THE HYDRAULIC CIRCUIT

7. In the event of a servo malufunction on both power units on a leaf, the bridge speed and direction would have to manually operated at the power units. To avoid the necessity of any manual controls in the machinery room, the swash plate must be mechanically held at a creep speed setting in the Raise Direction. The speed of the bridge will be constant at a creep speed when the electric motor is started from the control console. A low voltage starter is being used to reduce the in-rush of current to the motor since it is being started under load. The change in direction is accomplished with the use of a three-way valve shown on plate 7. Applying power to the Raise or Lower solenoid, the spool will shift and determine the direction. When no power is applied, the springs will center the spoon and "Block" the flow of oil to the hydraulic motor. The spoon completes the loop on the pump side so that the fluid can continue to circulate through the pump. The hydraulic motor side is blocked to apply the "hydraulic brakes" at the value of the crossover pressure relief valves. When we do not want the hydraulic brakes applied we deactivate the freewheel valve and the moving leaf can "freewheel" or drift subject only to exterior forces.

8. Some hydraulic motors need cooling by means of circulating oil through the outer casing. This also provides a means of getting any fluid that has leaked pass the seals from the interior pressure chambers of the motor back to the reservoir. This is accomplished with a small three position valve across the pump portion of the loop and a pressure relief valve that will maintain the low pressure side of the loop at its setting. These valves are shown on Plate 8. The high pressure side of the loop applies the higher pressure through the internal pilot line to shift the spool. The return line from the LSHT motor to the reservoir has a 30 psi check valve to maintain 30 psi minimum pressure in the casing. A 65 psi check valve across the casing will bypass the fluid if the pressure drop exceeds 35 psi. A branch circuit off the motor cooling and/or flushing line provides make-up fluid to the low pressure side of the motor loop when the blocking valve is centered. The two position valve, as shown on Plate 8, is controlled by a pilot line from the high pressure side of the motor loop.

9. The equipment added to Plate 9 is described in the paper titled "Data Acquisition System for Movable Bridges" being presented by the same author.

10. The hydraulic power unit shown on Plate 10 is provided for each of the four brakes. There are two main portions of the circuit. The electric motor driven pump developes pressure up to the setting of the pressure relief valve which must be high enough to release the brake. That loop is shown blocked by the two-way valve. When the solenoid is activated to shift the spool, the 1,000 psi pressure is applied to the brake to release it. The pressure switch only indicates that a minimum pressure of 750 psi is available to release the brake. When the solenoid is deactivated, the "Unloading Valve" blocks the pressure

from the motor and unloads the pressure on the brake back to the reservoir allowing the brake to set. This is fail safe because the brake will set if power is lost. In the event of some other malfunction in the circuit the brake can be manually released.

11. The completed hydraulic circuit for one power unit including the low speed-high-torque-hydraulic motor and the mechanically applied-hydraulically released brake is shown on Plate 11. There are a total of four of these complete units required for the bridge, two on each moving leaf. In the event of a malfunciton in any portion of one power unit on a leaf the blocking valve and the free wheeling valve are deactivated allowing the hydraulic motor to rotate with the gear train while the other power unit drives the moving leaf.

12. A "Key to Hydraulic Equipment" with the quantity of each item required for one double leaf bascule bridge is given on Plate 12.

13. A "Description of Hydraulic Operation" of the two moving leaves is given on Plate 13. There are two programmable logic controllers (PLC) used, one to control the operation of the bridge and the other as a standby. The word logic has been added to the name because the designation of PC is now used for personal computers.

## HYDRAULIC SYSTEM RETROFIT OF EXISTING BRIDGES

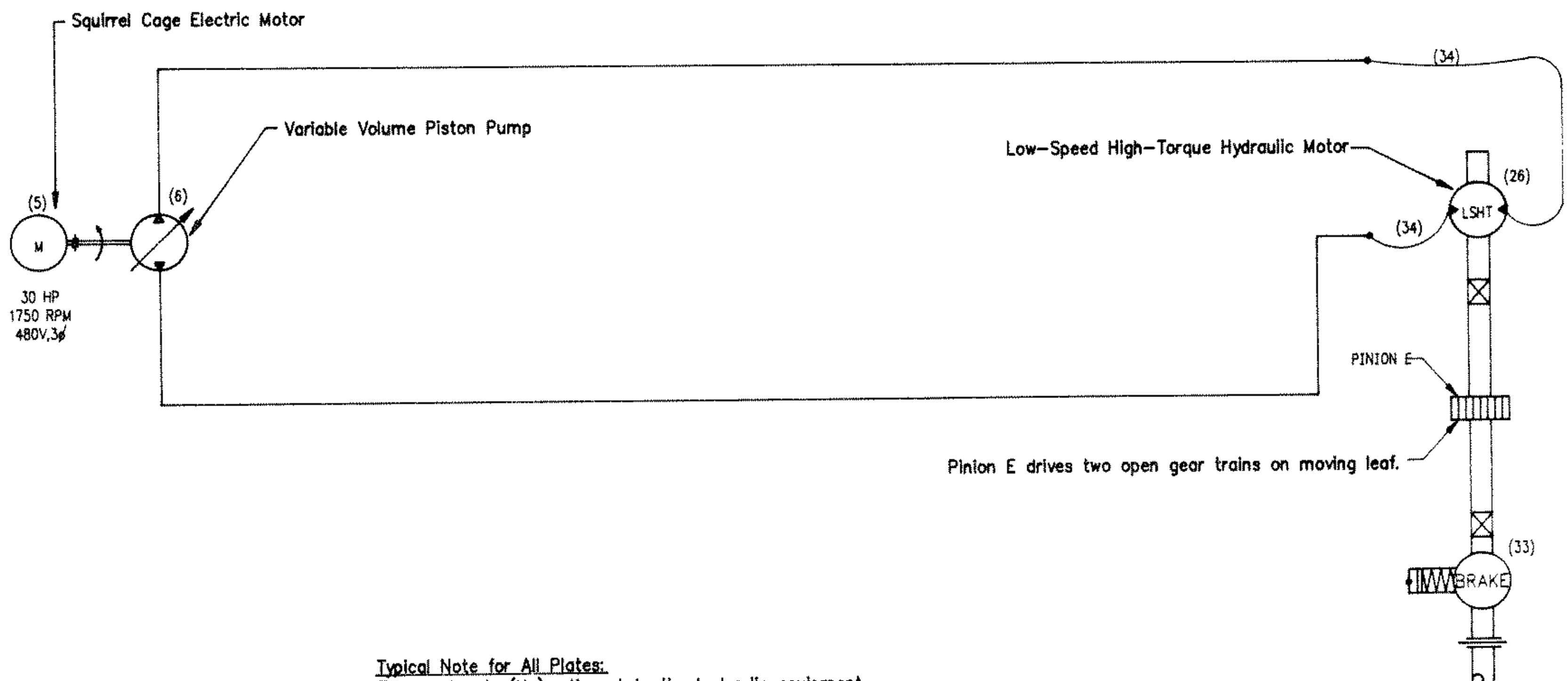
Each bridge to be reconditioned could be retrofitted with four hydraulic drives - one drive to operate each rack pinion. Each hydraulic drive would be a combination hydraulic-mechanical system consisting of a hydraulic power unit, low speed high torque (LSHT) fluid motor and a hydraulically operated brake. The LSHT motor would be coupled to one of the pinions of the existing open gear train, providing that the existing gearing is in good enough condition to justify reuse. Otherwise, suitable new gearing would have to be provided. At some bridges a speed reducer may have to also be provided if the existing open gearing does not have the required amount of gear reduction. If speed reducers are required either LSHT motors or conventional fluid motors could be used.

Two LSHT motors would normally drive each bridge leaf but one LSHT motor could drive each leaf if necessary. Two hydraulically operated brakes would be provided as parking (machinery) brakes for each leaf. Motor brakes would not be needed because each hydraulic drive would provide dynamic-regenerative braking action during leaf deceleration. The parking brakes would be set after the bridge comes to rest to assist in holding against maximum wind loads or can be used as emergency stopping brakes, if necessary, to bring the bridge to a stop faster than dynamic-regenerative braking action can provide. The result would be much lower shock loads on the machinery and structure during normal operation and the problem of adjusting brake time delays for sequenced brake setting would be eliminated.

Controls for the hydraulic system would be solid-state proportional electro-hydraulic servo valve type control. The controls would provide pre-set acceleration and deceleration of the bridge leaves. The rate of acceleration and/or deceleration can be adjusted to suit bridge conditions. Either automatic pushbuttons and/or manual joysticks could be provided at the operator's console. The existing operator's console at each bridge would require minor modifications, which could most likely be done in place at the bridge, to accommodate the hydraulic control systems. Motor controls would have to be modified or replaced, depending on their type and condition, to operate the electric motors which drive the pumps of the hydraulic power units. The new or revised motor controls would be simpler than the existing arrangements because the electric motors would be NEMA B Squirrel Cage type AC motors requiring only one direction of rotation. The hydraulic circuitry would provide the necessary fluid flow direction to open or close the bridge leaves.

The cost to retrofit a bridge with hydraulic drive would be approximately $500,000 per bridge. This cost is an average amount which would vary depending on the amount of work which may be required at the bridge.

## Index to Plates

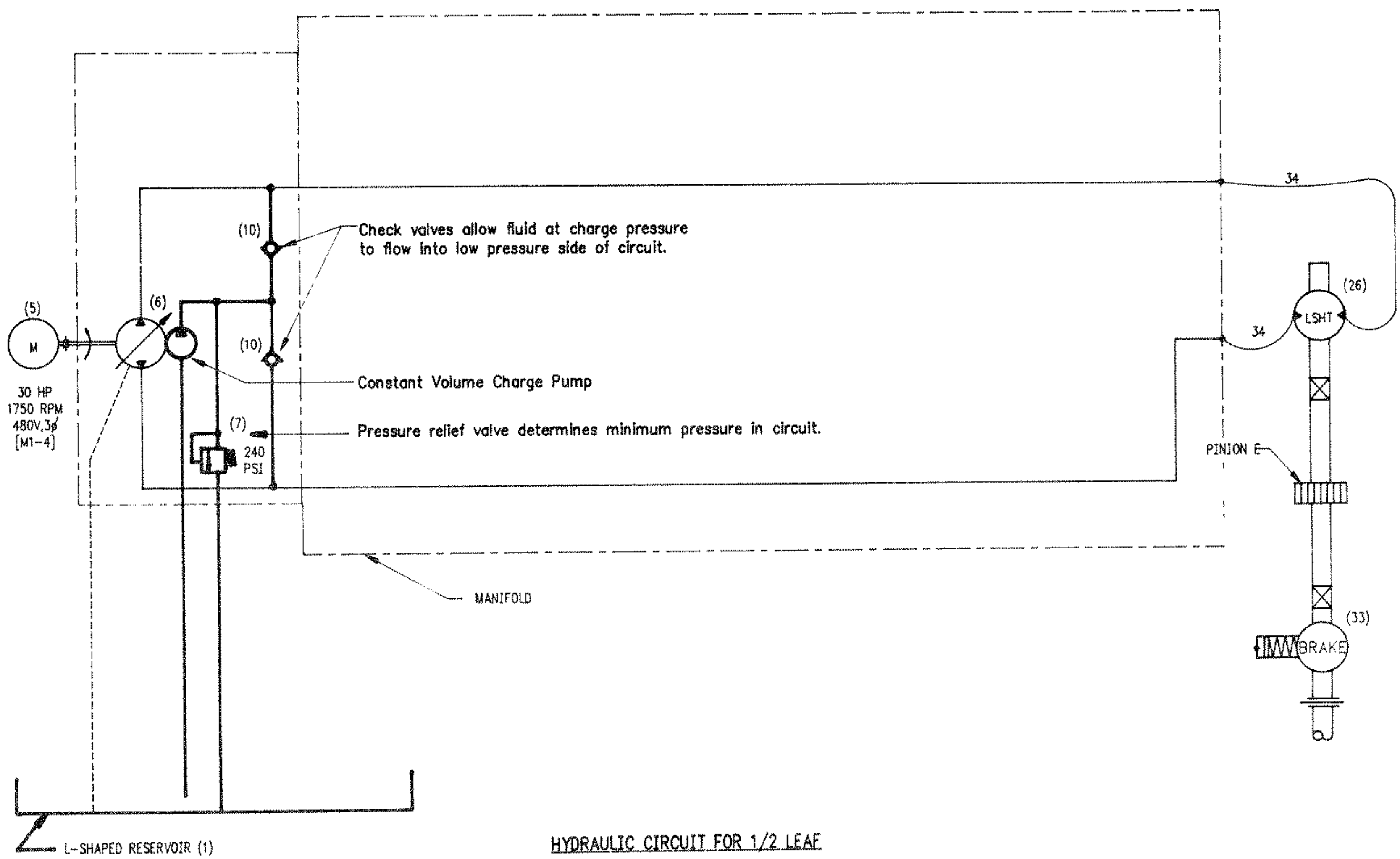



<u>Typical Note for All Plates:</u>
The number in (No) adjacent to the hydraulic equipment
refers to the number in the "Key to Hydraulic Equipment" given on Plate 12.

<u>HYDRAULIC CIRCUIT FOR 1/2 LEAF</u>

<u>BASIC CLOSED CIRCUIT</u>

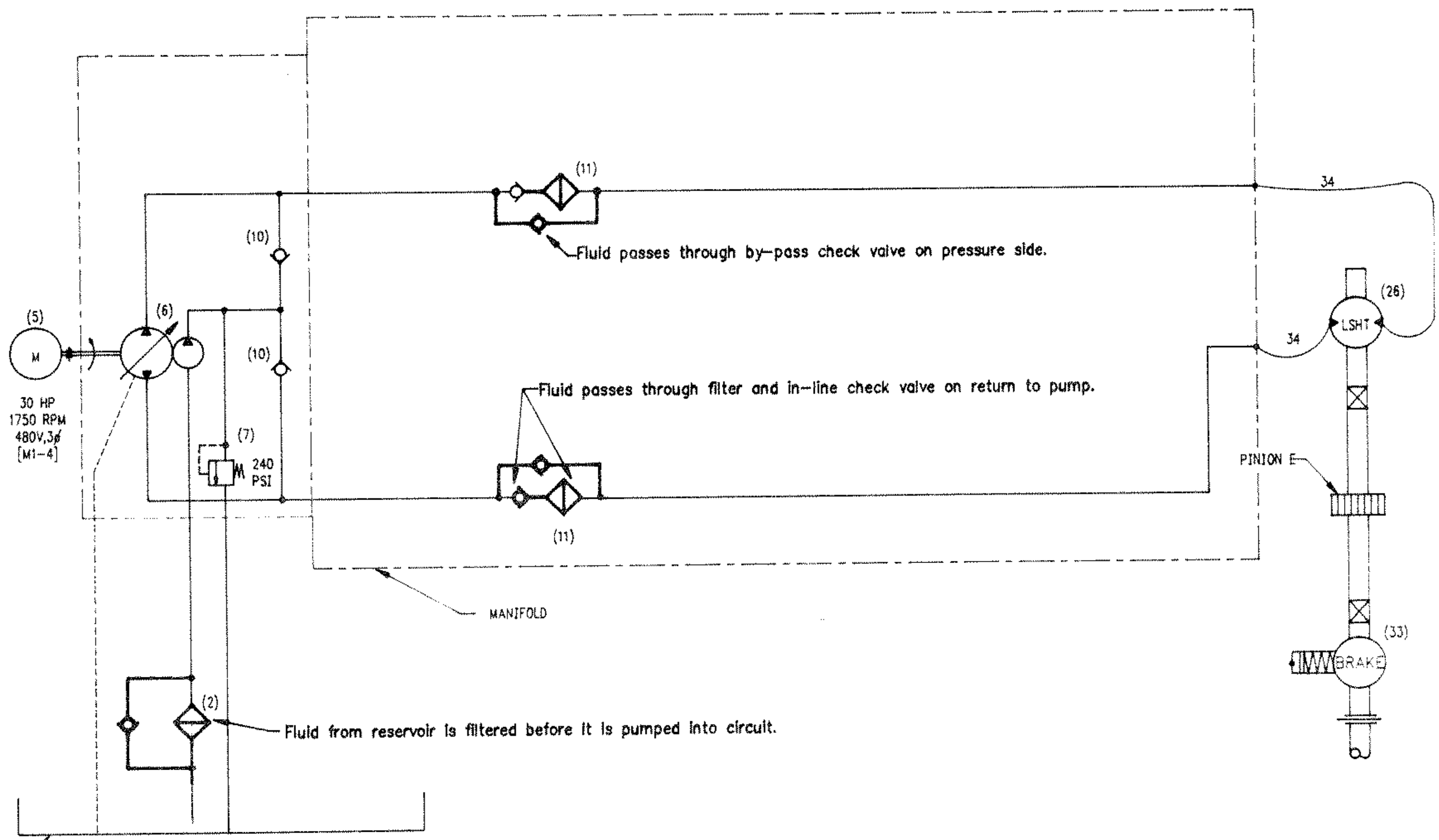
PLATE 1




HYDRAULIC CIRCUIT FOR 1/2 LEAF

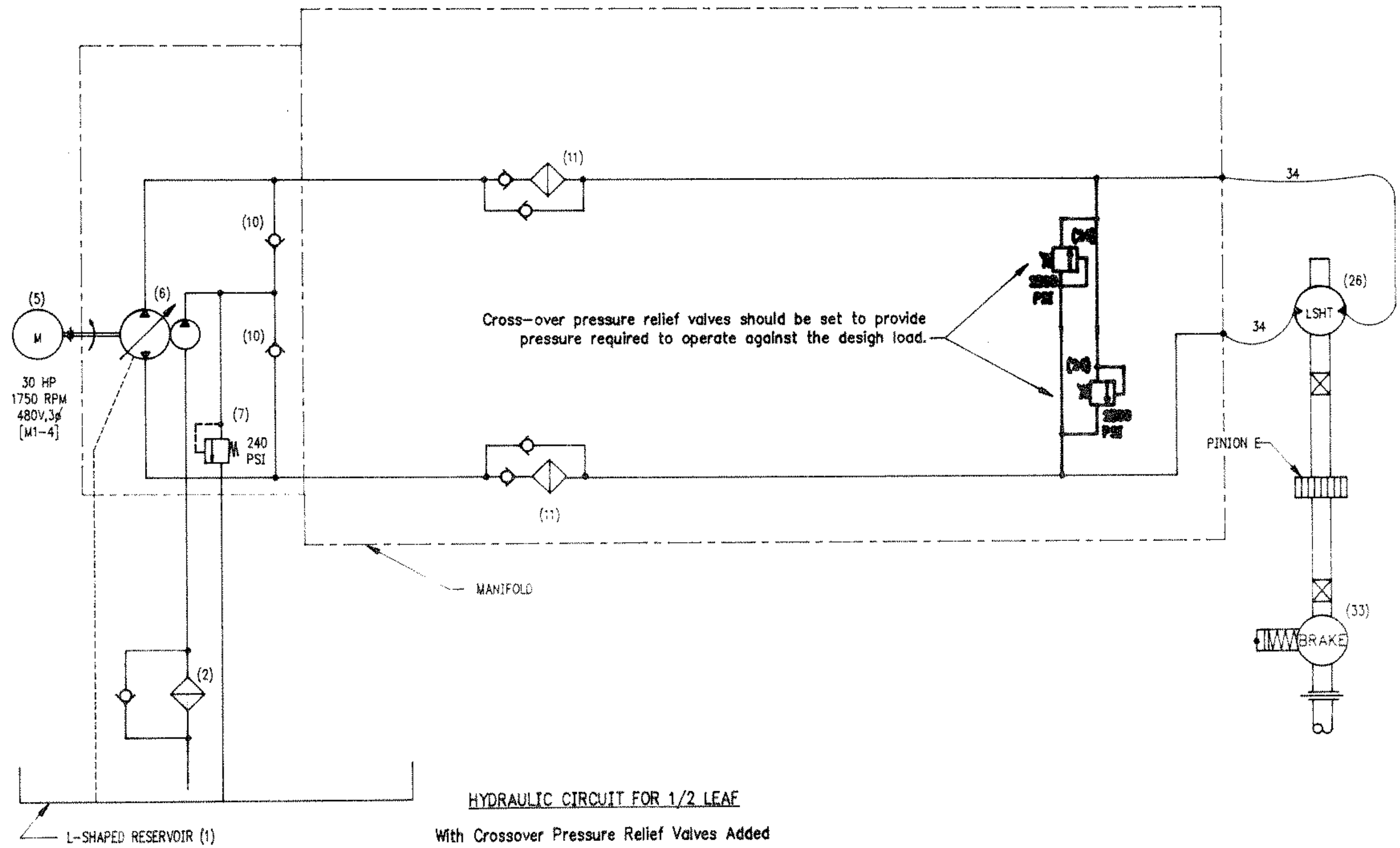
With Charge Pump and Reservoir Added

PLATE 2



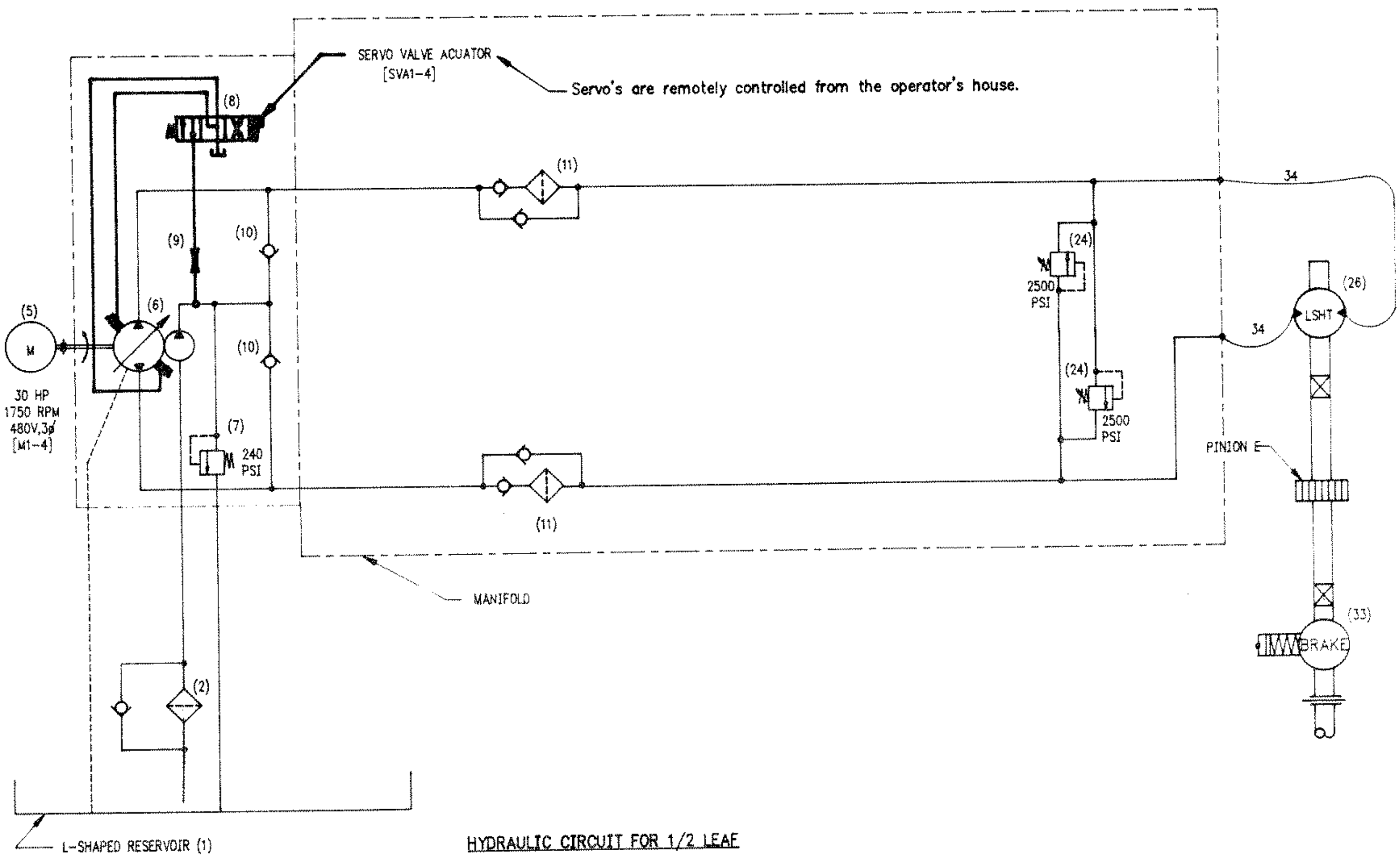

## HYDRAULIC CIRCUIT FOR 1/2 LEAF

With Filters Added



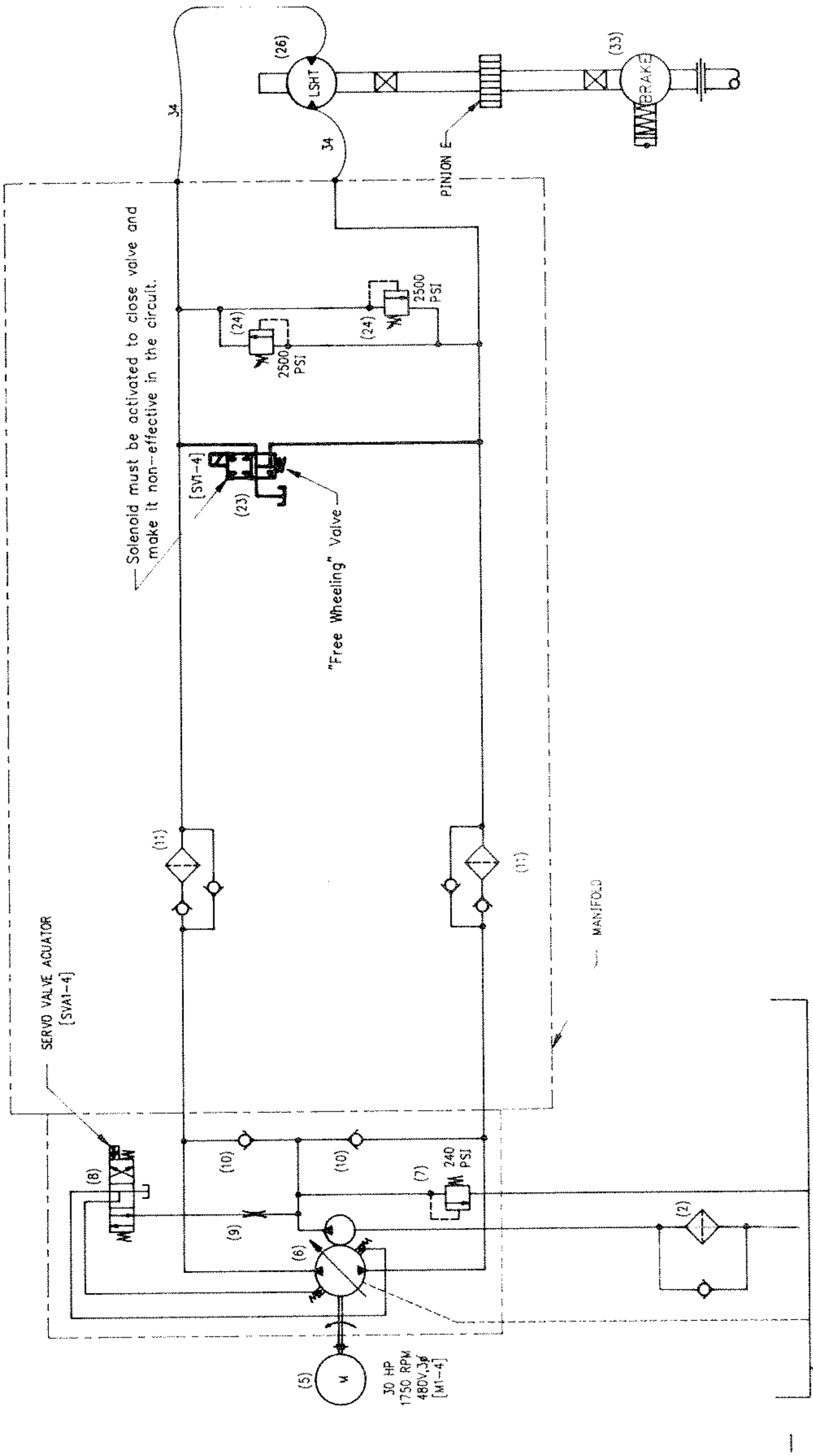

HYDRAULIC CIRCUIT FOR 1/2 LEAF

With Crossover Pressure Relief Valves Added




HYDRAULIC CIRCUIT FOR 1/2 LEAF

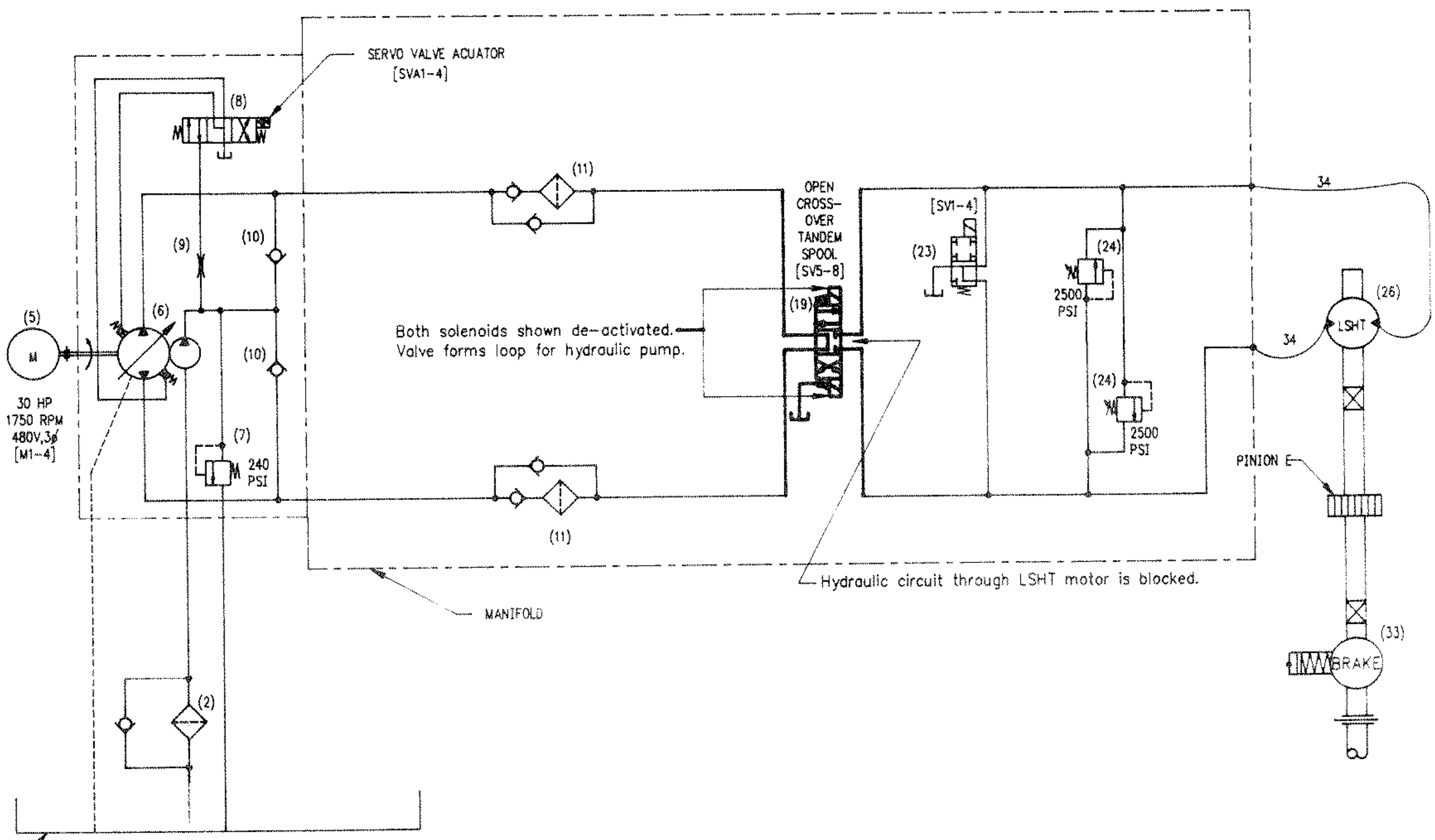
With Servo Controls of Pumps Added




**HYDRAULIC CIRCUIT FOR 1/2 LEAF**

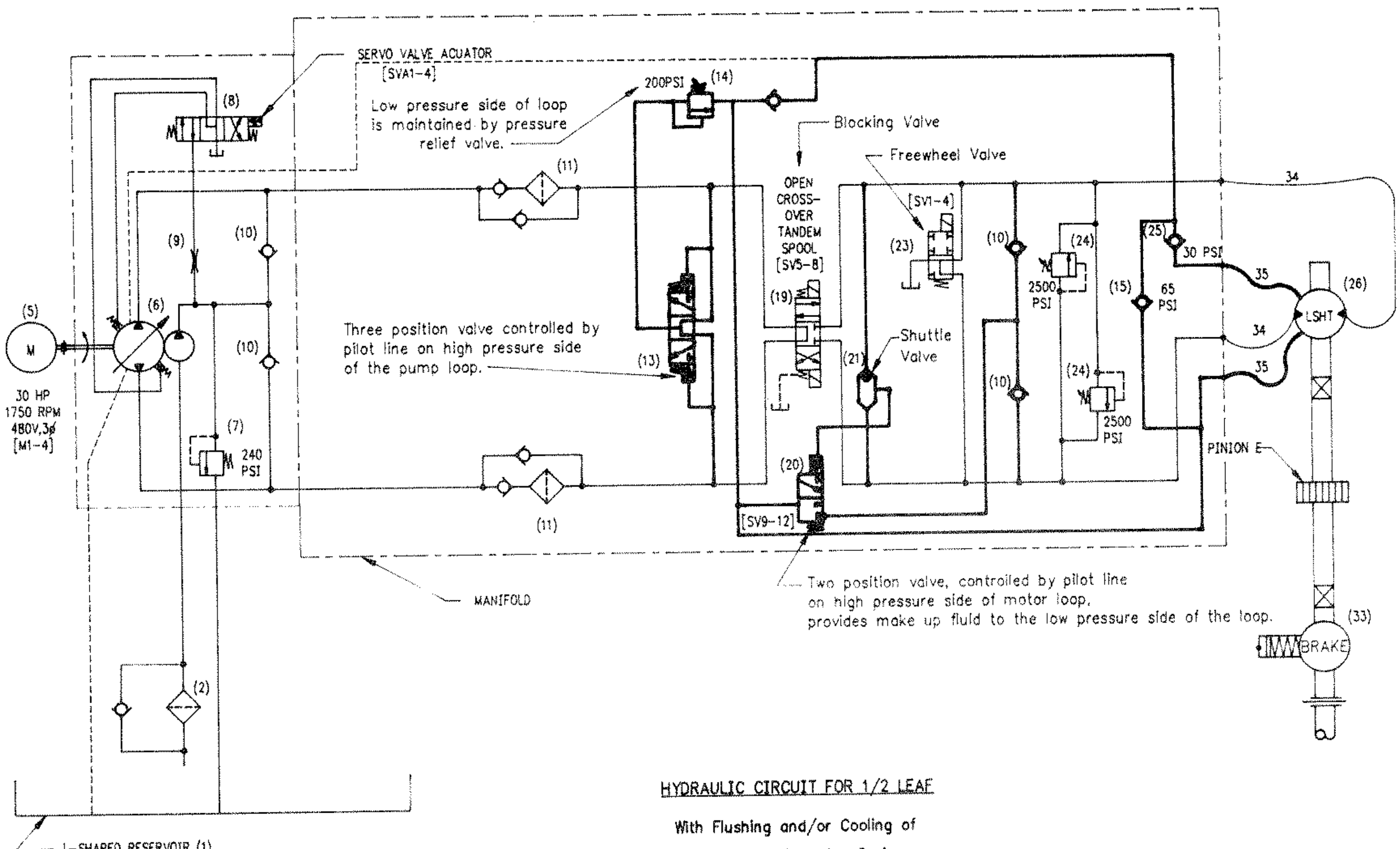
With Freewheeling Valve Added

PLATE 6




HYDRAULIC CIRCUIT FOR 1/2 LEAF

With 3 Position Blocking Valve Providing Crossover Flow




HYDRAULIC CIRCUIT FOR 1/2 LEAF

With Flushing and/or Cooling of
LSHT Hydraulic Motor Casing

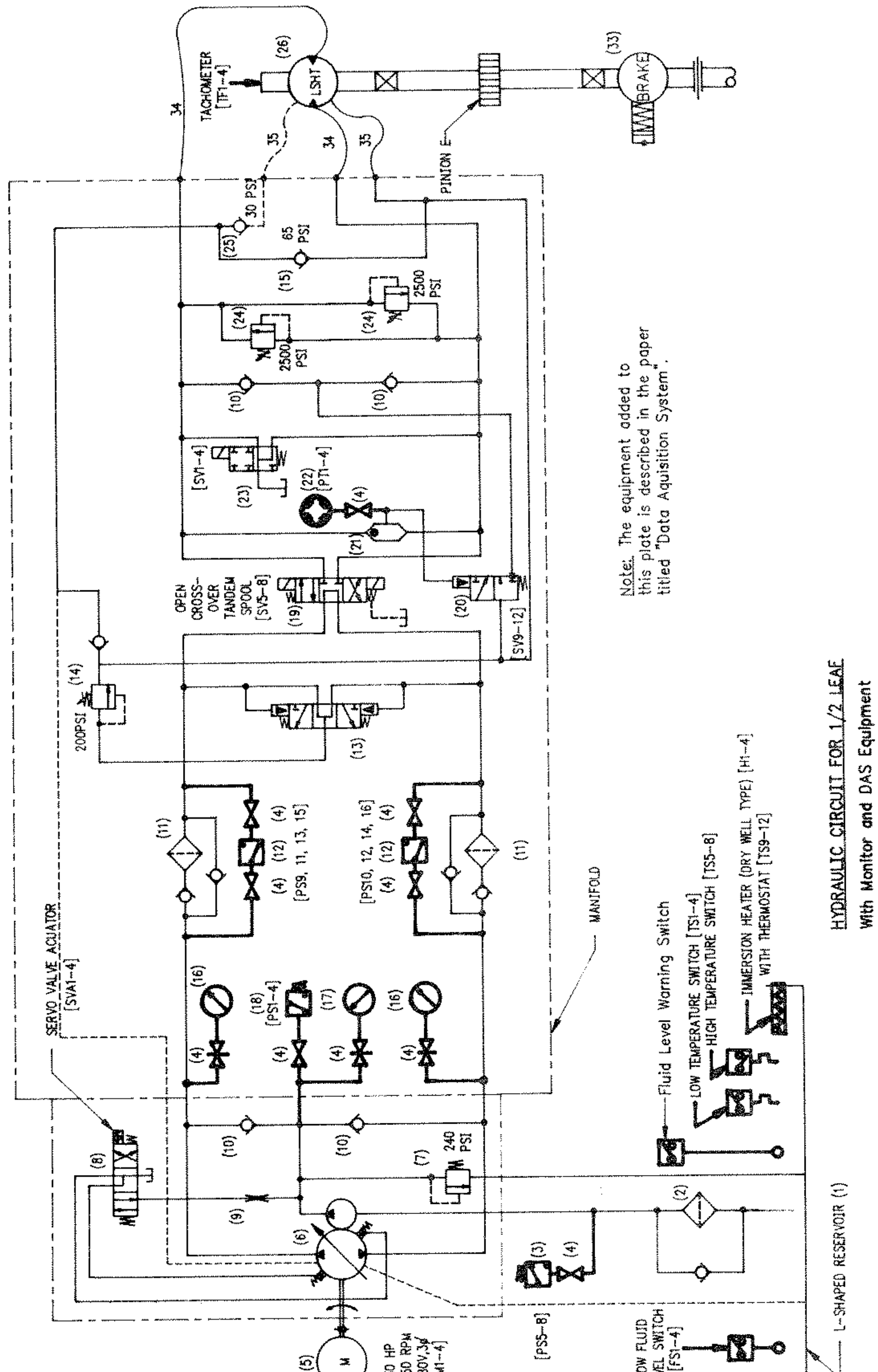
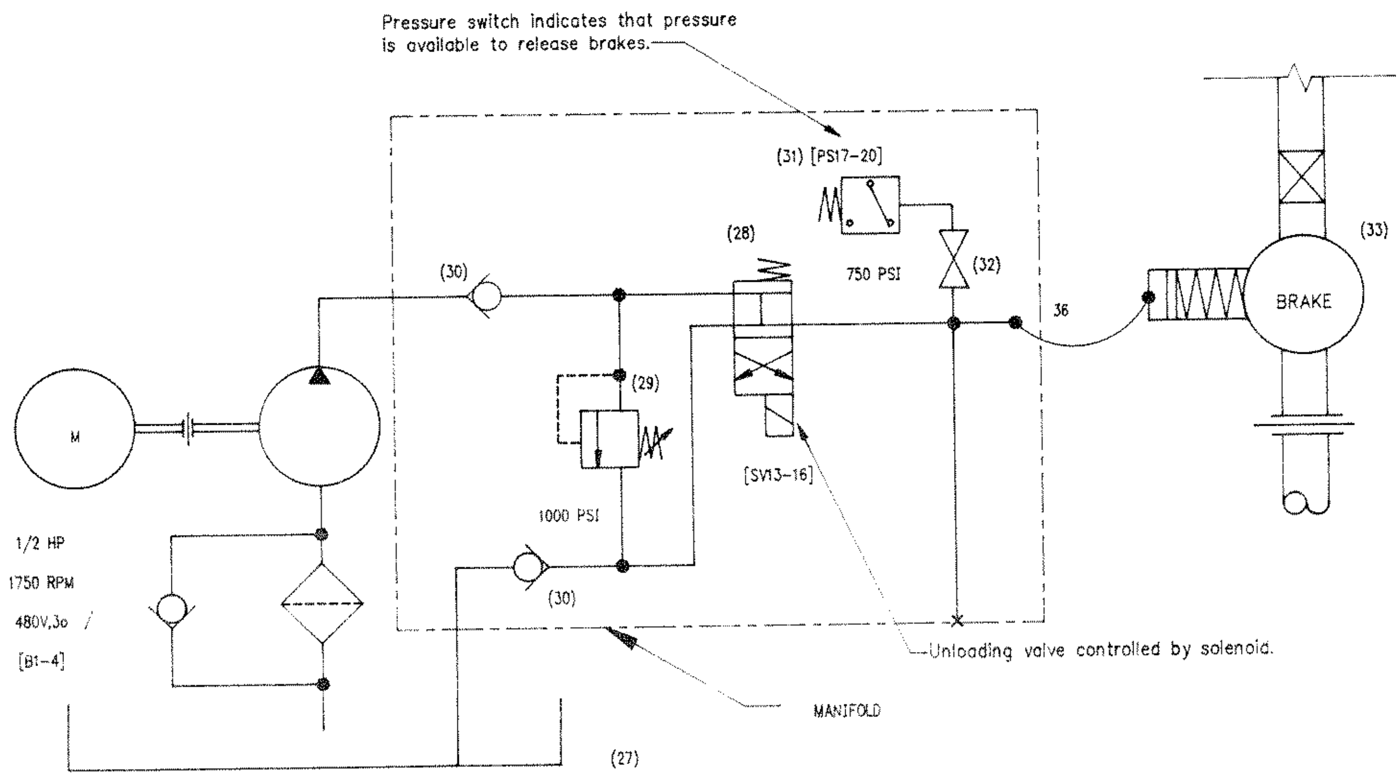
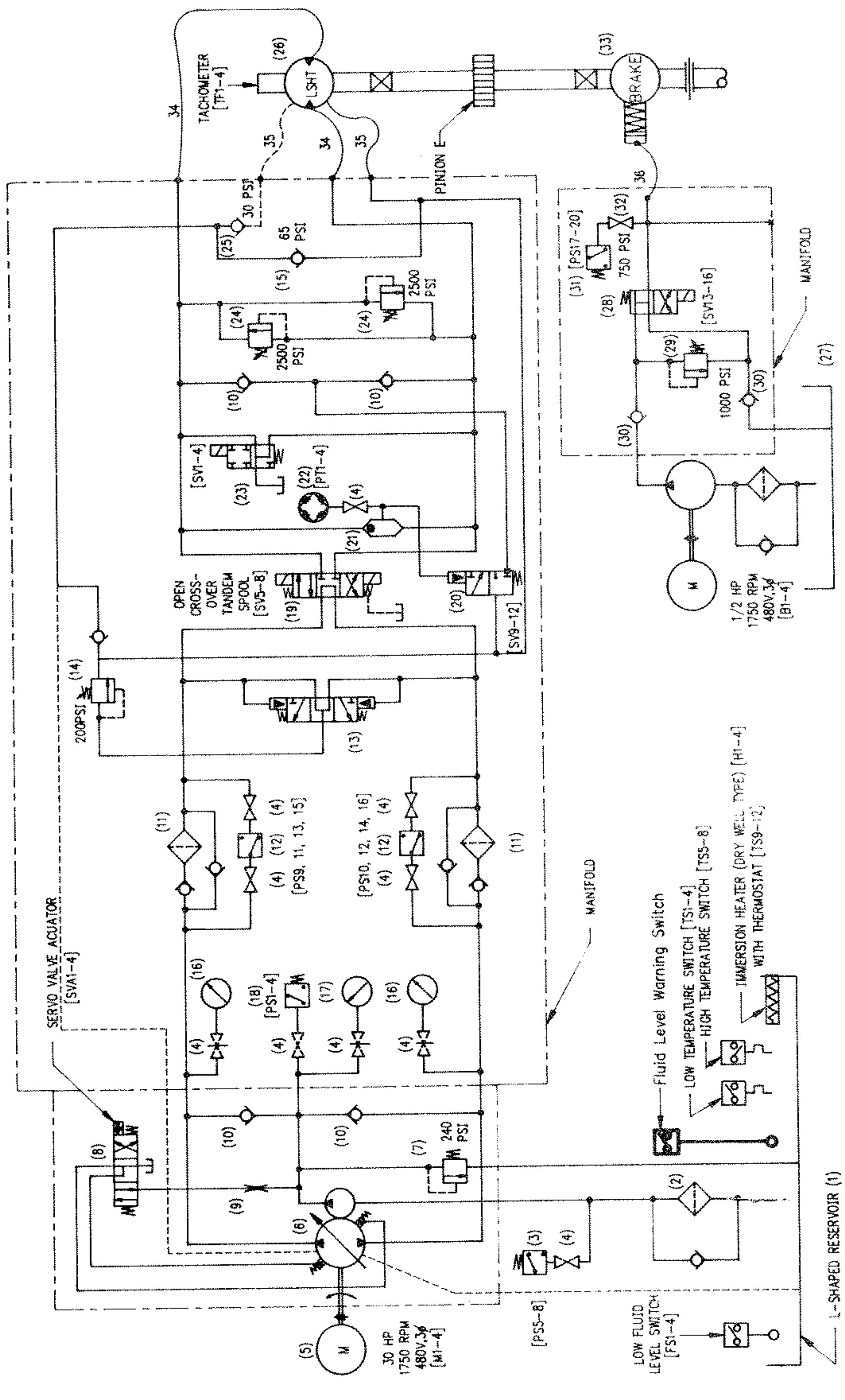

HYDRAULIC CIRCUIT FOR 1/2 LEAF
With Monitor and DAS Equipment
Note: The equipment added to this plate is described in the paper titled "Data Aquisition System".
TACHOMETER [TF1-4]
LSHT
(26)
BRAKE
(33)
PINION E
34
35
30 PSI
65 PSI
2500 PSI
OPEN CROSS-OVER TANDEM SPOOL [SV5-8]
[SV1-4]
[PT1-4]
[SV9-12]
200PSI
SERVO VALVE ACUATOR [SVA1-4]
[PS9, 11, 13, 15]
[PS10, 12, 14, 16]
[PS1-4]
MANIFOLD
240 PSI
Fluid Level Warning Switch
LOW TEMPERATURE SWITCH [TS1-4]
HIGH TEMPERATURE SWITCH [TS5-8]
IMMERSION HEATER (DRY WELL TYPE) [H1-4]
WITH THERMOSTAT [TS9-12]
30 HP
1750 RPM
480V,3φ
[M1-4]
[PS5-8]
LOW FLUID LEVEL SWITCH [FS1-4]
L-SHAPED RESERVOIR (1)

PLATE 9




HYDRAULIC POWER UNIT FOR A BRAKE




COMPLETED HYDRAULIC CIRCUIT FOR 1/2 LEAF

PLATE 12

## KEY TO HYDRAULIC EQUIPMENT
(Key numbers are shown on Plates 1 through 11)

| HYD. KEY | QUANTITY | DESCRIPTION |
|---|---|---|
| (1) | 4 | RESERVOIR WITH ACCESSORIES |
| (2) | 4 | SUCTION LINE FILTER WITH BYPASS |
| (3) | 4 | VACUUM SWITCH |
| (4) | 48 | SHUT-OFF VALVE |
| (5) | 4 | ELECTRIC MOTOR |
| (6) | 4 | VARIABLE PUMP WITH INTERNAL CHARGE |
| (7) | 4 | CHARGE PRESSURE RELIEF VALVE |
| (8) | 4 | ELECTRICALLY OPERATED SERVO VALVE |
| (9) | 4 | FLOW CONTROL VALVE |
| (10) | 24 | CHECK VALVE (5 PSI) |
| (11) | 8 | RETURN LINE FILTER W/PRESSURE FREE FLOW |
| (12) | 8 | DIFFERENTIAL PRESSURE SWITCH |
| (13) | 4 | DIRECTIONAL CONTROL VALVE (3-POS./3-WAY) |
| (14) | 4 | PRESSURE RELIEF VALVE |
| (15) | 4 | CHECK VALVE (65 PSI) |
| (16) | 8 | HIGH PRESSURE GAUGE |
| (17) | 4 | CHARGE PRESSURE GAUGE |
| (18) | 4 | CHARGE PRESSURE SWITCH |
| (19) | 4 | DIRECTIONAL CONTROL VALVE (3-POS./4-WAY) |

| HYD. KEY | QUANTITY | DESCRIPTION |
|---|---|---|
| (20) | 4 | DIRECTIONAL CONTROL VALVE (2-POS./3-WAY) |
| (21) | 4 | SHUTTLE VALVE |
| (22) | 4 | PRESS. TRANSDUCER (STAIN GAGE TYPE) |
| (23) | 4 | DIRECTIONAL CONTROL VALVE (2-POS./4-WAY) |
| (24) | 8 | HIGH PRESSURE RELIEF VALVE |
| (25) | 4 | CHECK VALVE (30 PSI) |
| (26) | 4 | LOW SPEED HIGH TORQUE (LSHT) MOTOR |
| (27) | 4 | HYDRAULIC POWER UNIT FOR BRAKE WITH THE FOLLOWING MANIFOLD MOUNTED COMPONENTS: |
| (28) | 4 | DIRECTIONAL CONTROL VALVE (2-POS./4-WAY) |
| (29) | 4 | PRESSURE RELIEF VALVE |
| (30) | 8 | CHECK VALVE (5 PSI) |
| (31) | 4 | PRESSURE SWITCH |
| (32) | 4 | SHUT - OFF VALVE |
| (33) | 4 | EMERGENCY BRAKE |
| | Flexible Hydraulic Hoses | |
| (34) | | 1.25" I.D. 5000 PSI W.P. FLEXIBLE HOSE |
| (35) | | .75" I.D. 2000 PSI W.P. FLEXIBLE HOSE |
| (36) | | .25" I.D. 2000 PSI W.P. FLEXIBLE HOSE |

# DESCRIPTION OF HYDRAULIC OPERATION

PLATE 13

NORMAL (AUTOMATIC) OPERATION
*WITH SERVOS AND PC1 OR PC2*

A. TO RAISE BRIDGE:

1. THE ELECTRIC MOTORS (5) ARE STARTED AND FLUID BEGINS TO CIRCULATE THROUGH LSHT MOTORS (26) TO PROVIDE CASE FLUSHING.
2. OPERATOR PRESSES "BRIDGE RAISE" PUSHBUTTON.
3. EMERGENCY BRAKE POWER UNITS (27) ARE STARTED & DIRECTIONAL CONTROL VALVES (28) SHIFT. PRESSURIZED FLUID RELEASES EMERGENCY BRAKES (33).
4. DIRECTIONAL CONTROL VALVES (19) AND (23) SHIFT TO PERMIT FLUID FLOW TO LSHT MOTORS (26).
5. SERVO VALVES (8) SHIFT TO PROVIDE CONTROL PRESSURE TO PUMP (6) SWASHPLATE POSITION ACTUATORS.
6. PUMP SWASHPLATES ARE POSITIONED TO PRODUCE THE CORRECT PUMP (6) OUTPUT VOLUME AND FLOW DIRECTION.
7. DIRECTIONAL CONTROL VALVES (13) AND (20) SHIFT DUE TO INCREASING PILOT (SYSTEM) PRESSURE. CASE FLUSHING THROUGH LSHT MOTORS (26) CEASES.
8. LSHT MOTORS (26) BEGIN TO ROTATE AND ACCELERATE BRIDGE LEAVES TO FULL SPEED.
9. RETURN FLUID FROM LSHT MOTORS (26) COMBINES WITH MAKE-UP FLUID FROM CHARGE PUMPS AND PASSES THROUGH DIRECTIONAL CONTROL VALVES (19), RETURN LINE FILTERS (11) AND BACK TO PUMPS (6).

B. TO LOWER BRIDGE:

SAME AS TO RAISE BRIDGE EXCEPT OPERATOR PRESSES "BRIDGE LOWER" PUSHBUTTON. PUMP (6) SWASHPLATES ARE POSITIONED TO PRODUCE REVERSE FLUID FLOW WHICH CAUSE LSHT MOTORS (26) TO ROTATE IN OPPOSITE DIRECTION.

C. NORMAL STOP:

THE MOVING BRIDGE LEAVES ARE STOPPED BY PRESSING "NORMAL STOP" PUSHBUTTON. ALL SERVO VALVE (8) *CONTROL COMMANDS WILL BE INTERRUPTED AND BRIDGE* LEAVES WILL DECELERATE TO STOP AT PRESET RATE.

D. EMERGENCY STOP

THE MOVING BRIDGE LEAVES ARE STOPPED BY PRESSING "EMERGENCY STOP" PUSHBUTTON.

1. THE BLOCKING VALVE (19) SOLENOIDS WILL DEENERGIZE AND THE VALVES WILL SHIFT, BLOCKING FLOW OF HYDRAULIC FLUID. DIRECTION CONTROL VALVE (23) SOLENOIDS WILL DEENERGIZE ALLOWING THE LSHT MOTORS (26) TO FREEWHEEL. THE EMERGENCY BRAKES (33) WILL SET BRINGING THE LEAVES TO A RAPID STOP.
2. POWER TO THE ELECTRIC MOTORS (5) WILL BE *INTERRUPTED AND THE ELECTRIC MOTORS AND* PUMPS (6) WILL DECELERATE TO A STOP.

EMERGENCY (NON-PC) OPERATION WITH SERVOS

OPERATOR RAISES AND LOWERS BRIDGES LEAVES AT *VARIABLE REDUCED SPEED USING POTENTIOMETERS, ONE* FOR EACH LEAF, TO CONTROL PUMP SERVO VALVES. HYDRAULIC CIRCUIT OPERATION IS SIMILAR TO NORMAL OPERATION. EMERGENCY BRAKES (33) AND REAR LOCKS (NOT SHOWN) MUST BE OPERATED WITH EMERGENCY *CONTROLS.*

EMERGENCY (NON-PC) OPERATION WITHOUT SERVOS

PUMP (6) SWASHPLATES ARE PHYSICALLY HELD. SEE SPECIAL PROVISIONS.

POWER FAILURE

ANY ELECTRICAL POWER LOSS WILL DE-ENERGIZE THE ELECTRICAL CONTROL CIRCUIT AND STOP THE MOVING LEAVES IN THE SAME MANNER AS EMERGENCY STOP.

## FUNCTIONAL DESCRIPTION OF MAJOR PRESSURE AND DIRECTIONAL CONTROL COMPONENTS

(7) CHARGE PRESSURE RELIEF VALVE: LIMITS MAXIMUM CHARGE PUMP OPERATING PRESSURE. PREVENTS DAMAGE TO PUMP SERVO CONTROL SYSTEM.

(8) SERVO VALVE: PROVIDES FLUID FLOW CONTROL FOR PUMP SWASHPLATE POSITIONING.

(13) DIRECTIONAL CONTROL VALVE: OFTEN REFERRED TO AS A "PURGE VALVE" OR "SHUTTLE VALVE". ALLOWS GREATER VOLUME OF FLUID TO RECIRCULATE THROUGH RESERVOIR FOR GREATER COOLING AND LONGER FLUID LIFE. ALSO PERMITS MAKE-UP FLUID TO JOIN LSHT *MOTOR RETURN FLOW TO PREVENT CAVITATION.*

(14) PRESSURE RELIEF VALVE: PROVIDES SUFFICIENT BACK PRESSURE FOR LSHT MOTOR MAKE-UP FLUID.

(19) DIRECTIONAL CONTROL VALVE: OFTEN REFERRED TO AS A "BLOCKING VALVE". ISOLATES PUMP FROM LSHT MOTOR TO PREVENT CREEP AND PERMITS REVERSAL OF FLUID FLOW TO LSHT MOTOR IN THE EVENT OF SERVO CONTROL FAILURE TO PERMIT EMERGENCY OPERATION WITHOUT SERVOS.

(20) DIRECTIONAL CONTROL VALVE: ALLOWS AUTOMATIC LSHT MOTOR CASE FLUSHING WHEN ELECTRIC MOTORS ARE STARTED. FLUSHING REMOVES DEBRIS FROM MOTOR CASES AND PROVIDES MOTOR WARM-UP AT VERY LOW AMBIENT TEMPERATURES.

(23) DIRECTIONAL CONTROL VALVE: *REMOVES PRESSURE FROM LSHT MOTOR* MAIN LINES TO PERMIT CASE FLUSHING AT START-UP AND PERMITS FREE-WHEELING OF LSHT MOTOR IF HYDRAULIC DRIVE IS INOPERATIVE.

(24) *PRESSURE RELIEF VALVE: LIMITS MAXIMUM SYSTEM PRESSURE AT* LSHT MOTORS. VALVES CAN BE ADJUSTED TO 3000 PSI MAXIMUM, IF NECESSARY, TO PERMIT BRIDGE OPERATION AGAINST HIGHER THAN NORMAL WIND LOADS IF ONE HYDRAULIC DRIVE IS INOPERABLE ON ONE OR BOTH LEAVES.