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SESSION WORKSHOP PRESENTATIONS

"HYDRAULICS FOR AN UNBALANCED BRIDGE"

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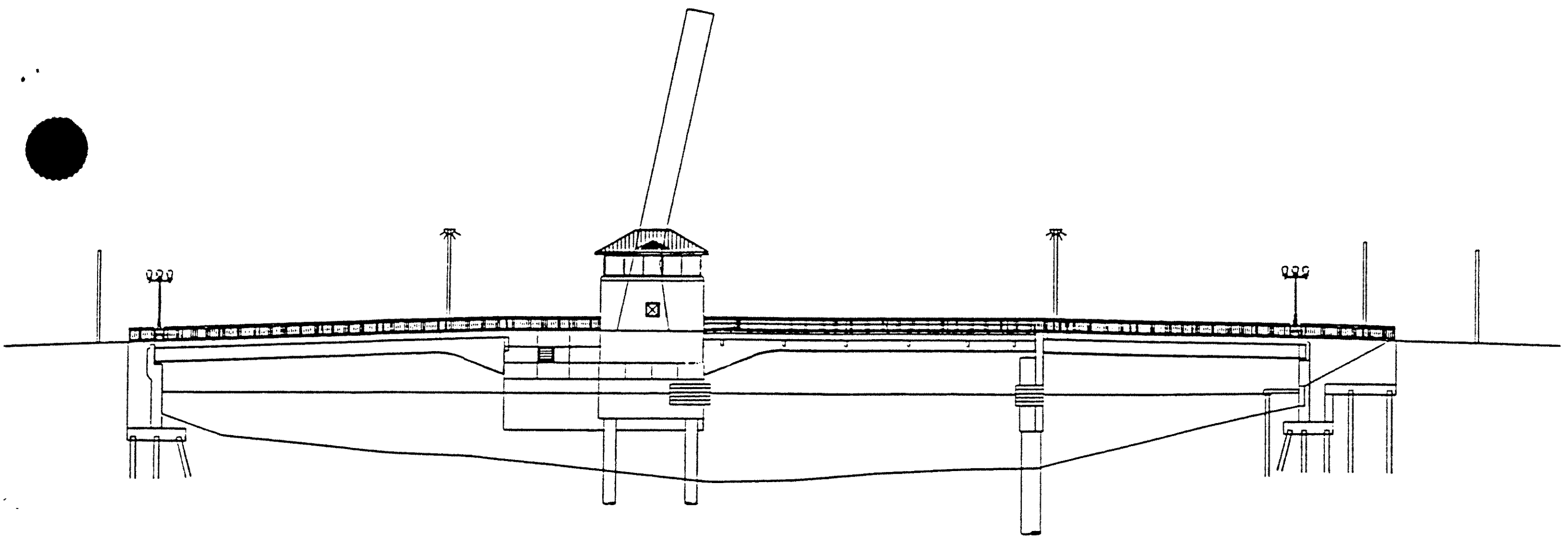
The Oilgear Company



SHEBOYGAN, WISCONSIN

HYDRAULICS FOR AN UNBALANCED BRIDGE

By Gary R. Krill

of

The Oilgear Company
Milwaukee, Wisconsin

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Introduction

Industry in all sectors has benefited by the advancements in technology. Not withstanding those advancements, bridge designs in terms of materials, improved fabricating methods and design analysis has allowed for the fabrication of lighter bridge structures, reduction of expensive necessary counter weights, and lower structural loads.

The Sheboygan bridge design, a non-counterbalanced trunnion type, developed by Teng & Associates, Chicago, Illinois, provided the least environmentally disruptive configuration for the South 8th street location. Key background factors about the bridge are:

- Crosses the Sheboygan river near its outlet to Lake Michigan.
- Is part of a master plan to extend an existing river walk on the east side north bank to the west and the south bank for further development.
- Is used mainly to allow the passage of pleasure craft with limited commercial use.
- We understand the unbalanced concept was selected as the lowest cost solution due to the narrow waterway and the desire to minimize disturbance of the river bed, a Superfund site.

The South 8th street movable bridge project is part of a three span, 273 foot bridge project, replacing a dual leaf, electro-mechanical design over the Sheboygan river built in 1922. The 78 foot long, non-counter weighted movable span is raised and lowered by four (4) hydraulic lift cylinders arranged in two (2) pairs and coupled on either side of the (2) main longitudinal girders of the main deck. Hydraulically, the cylinder's are connected on the left and right side of the girders in pairs. The dual cylinder arrangement is supplied by a multi-pump, dual hydraulic power unit system.

The hydraulic system incorporates proportional valve technology to control flow for both the raising and lowering process. Resolvers and pressure transducers are used to provide the control system with position and load signals for position reference, limit switching, and vernier control of the proportional flow controlling devices. True position and load, derived from these devices, is displayed for the operator.

Oilgear was commissioned to supply and coordinate the installation of the hydraulic system, the bridge controls, and emergency operational systems. All systems are controlled by the Oilgear *System 2003*, which includes a Triple Modular Redundant PLC system making the operation of the bridge essentially automatic. To that end Oilgear has acted as the System Integrator and provided the coordination for the fluid power and control system.

Features and General Arrangement

The bridge is for both vehicle and pedestrian use. The four (4) lift cylinders used are each 26" dia. bore x 9" dia. rod x 11' 0" stroke and horizontally mounted using 12" trunnions and compression struts. The designers were concerned about the use of traditional hydraulic counterbalance devices, especially when the bridge is at rest in the full open position or stopped at a partially elevated position for any reason. To address the static holding requirement and provide redundancy, collet type rod brakes are fitted to each hydraulic lift cylinder. Figures #1, #2, and #3 show cylinder installation and crank plate detail.

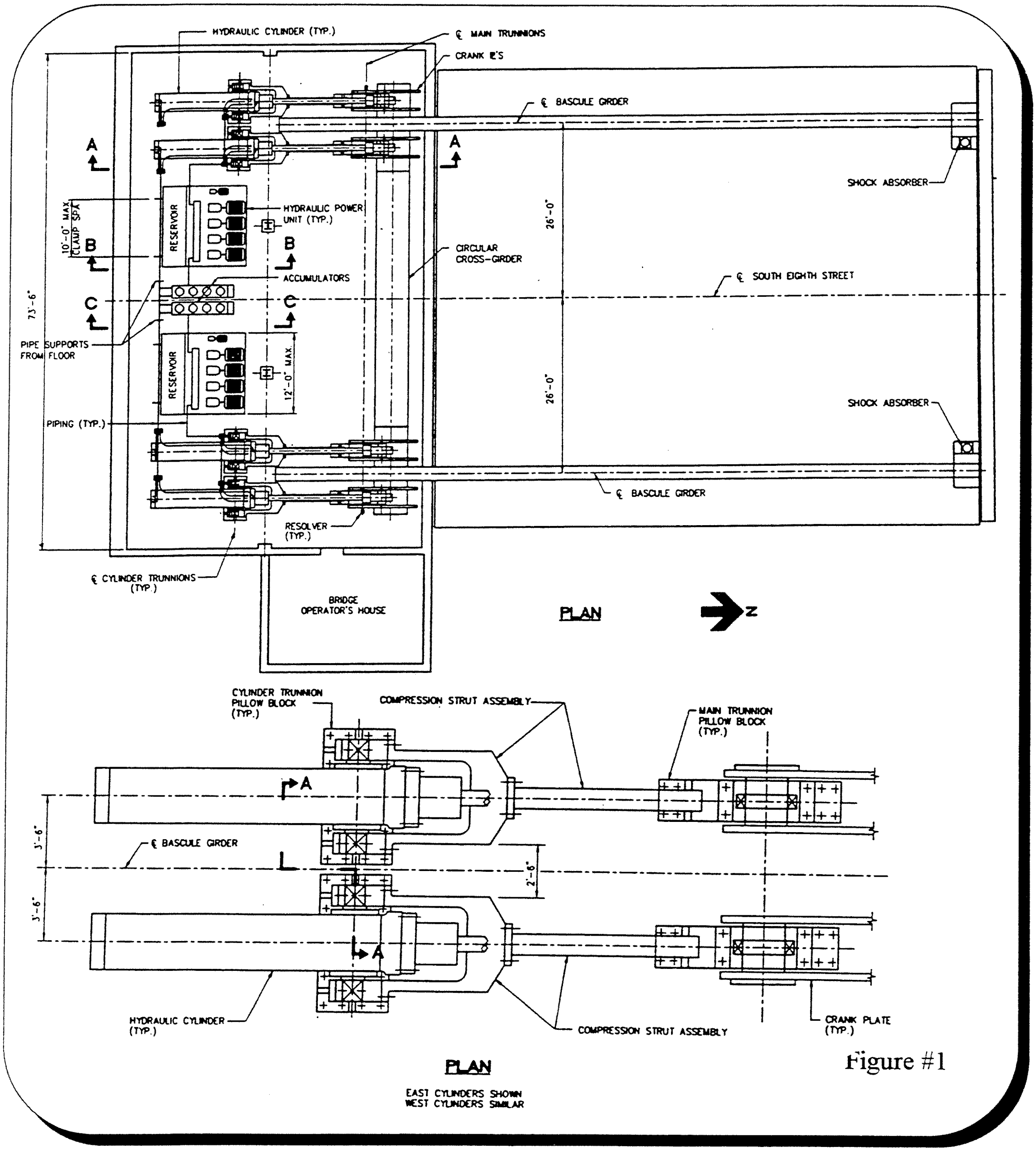


Figure #1

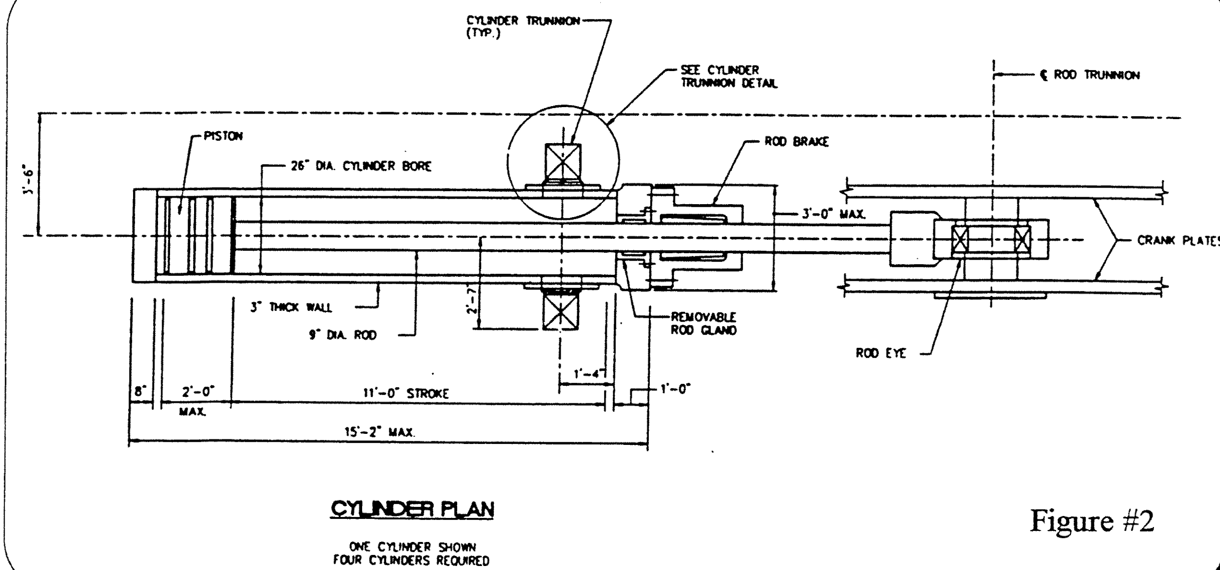


Figure #2

The basic bridge specifications are given below.

- Movable span length = 78 feet
- Movable span width = 76 feet
- Vehicular width = 48 feet
- Clearance opening = 75 feet
- Full cycle time = 90 seconds
- Bridge span weight (approximately) = 716,000 pounds

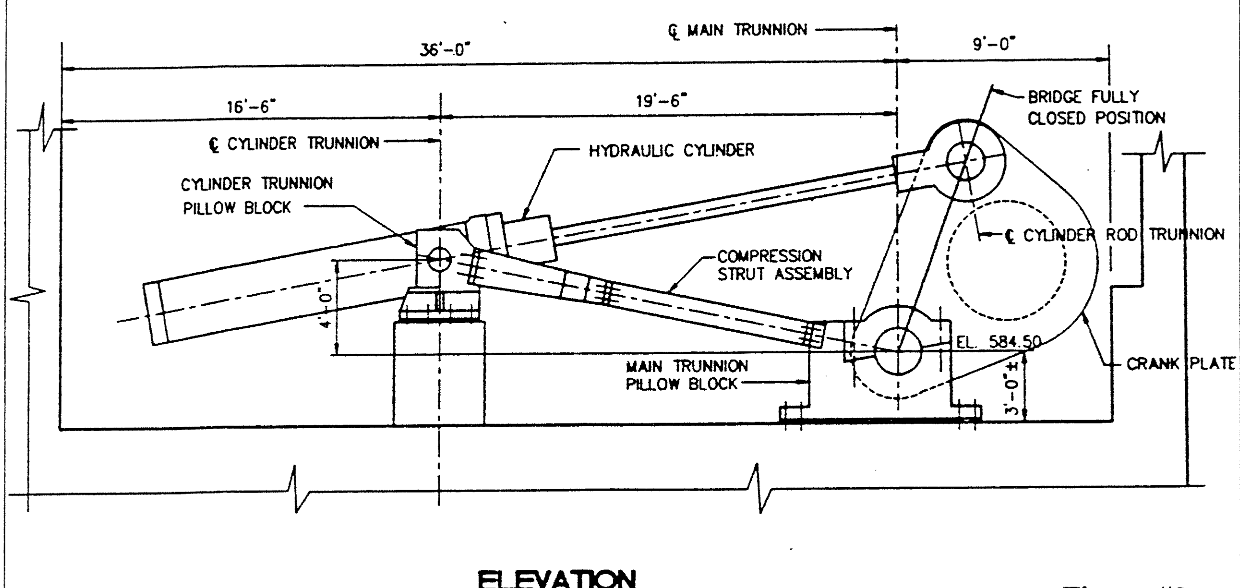


Figure #3

System Requirements

The system requirements as set for in the specification called for a basic circuit arrangement that would maintain a balanced load across all the lifting cylinders in accordance with AASHTO Standard Specifications for Movable Highway Bridges. The system was to provide enough flexibility to operate the bridge at reduced capacity from only one power unit and only one pump if necessary. Under extreme conditions, operation using just one pump and only one pair of operating cylinders at increased pressure was also to be possible. Under conditions of total power failure, provisions were to be made which would allow the bridge to be lowered from any open position. Conservation of energy, always a good practice, was to be implemented as practical.

Integrated Fluid Power System

The Oilgear Company is providing a fully integrated hydraulic power unit assembly. The equipment supplied includes two (2) stainless steel, 1200 gallon reservoirs assemblies, an auxiliary accumulator fluid supply for zero power let down operation and four (4) remotely mounted, cylinder manifolds. The power units are cross piped to provide transfer of hydraulic control between power units should one power unit or a main control manifold be out of service.

The fluid delivery lines going to the cylinder pairs include cross piping with isolation valves so that the cylinders can be cross fed for equal prêssure (load) distribution during normal operation and isolated by shutoff valves should a cylinder pair be out of service.

As stated previously, integral with each cylinder are hydraulic cylinder rod brakes. Because of the fully unbalanced nature of the structure, the designers conservatively integrated these devices into the system. The brakes are collet type locking brakes and are not to be used for dynamic braking under any conditions. They are to be used as parking (static) brakes when the leaf is fully raised or stopped at an intermediate position.

HPU Assembly Detail

The 1200 gallon stainless steel reservoir assemblies include (4) Oilgear PVK-370 (370 cc) axial piston pumps. Each pump is driven by a 1200 rpm, 150 horsepower electric motor. The pumps are equipped with pressure compensated, horsepower limiting controls in accordance with the design specification. The pump controls include four electrically commanded pressure compensated settings. Those commands include a minimum or soft start command, usually about 250 psi , a minimum set pressure of approximately 500 psi, used for cylinder filling during normal lower modes, a 2500 psi setting for normal lifting and holding, and an auxiliary setting of 4500 psi for (2) cylinder only operation.

Each reservoir assembly further includes auxiliary pumping equipment for control pressure purposes and the main system integrated control manifold. Return line filters filter all oil before it is returned to the reservoir. Figure # 4 shows the general reservoir assembly circuit.

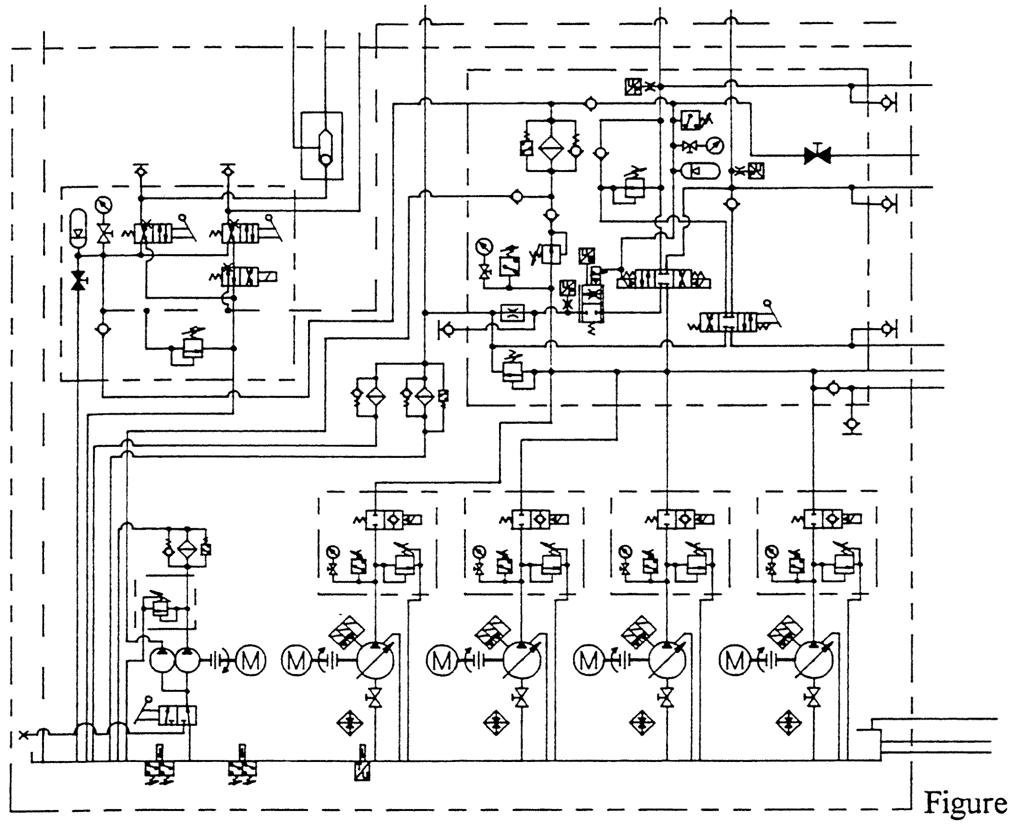


Figure #4

Auxiliary Fluid Power Supply

Located between the two power units and integrated with both main power unit assemblies is an accumulator assembly. This assembly indirectly provides fluid needed to release the lift cylinder rod brakes in a full power outage condition. The accumulator APU provides ample fluid to displace the operating cylinders the required .625 inches to release the collet brakes. In addition, sufficient volume is provided to push the bridge over center and initiate the emergency gravity close mode if necessary.

Every time the system is powered up, the control system checks the main accumulator system to insure a correct precharge is present in the accumulators. As part of the startup and shutdown sequence, the electrically operated accumulator bleed down valves are first opened to check precharge and then closed. One pump from each power unit is used to charge the accumulators to the required charge level.

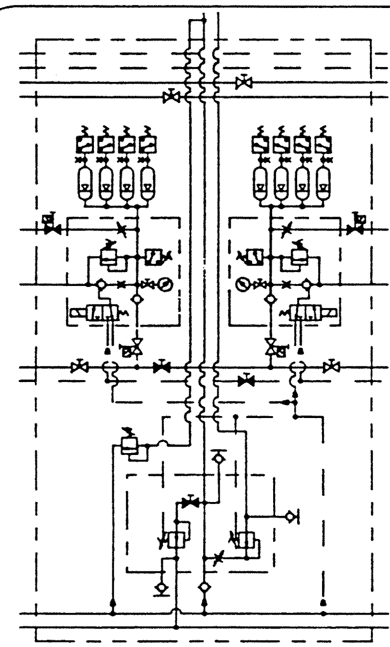


Figure #5

The proper charge pressure is sensed by the system. Note that if the auxiliary power unit is required, manual valves must be opened to allow fluid into the main operating system. The accumulator system can not be charged with this valve open.

Operational Philosophy

The Oilgear Company in evaluating the system requirements recognized that a traditional meter in, meter out circuit as provided by conventional four way proportional valves would not be the best way to maintain good system stiffness (hydraulic) and thus good control. The unbalanced design results in maximum lifting pressures initially as the bridge starts to open and can reduce to near zero or go over center as the bridge approaches its full open position. The net effect of this, is an automatic decompression or softening of the hydraulic system.

Oilgear analyzed several circuit options. Those options included circuits which were fully counterbalanced and circuits using variable back pressure devices both mechanical and electrical. The fully counterbalanced approach would have resulted in unexceptable high energy requirements when the bridge was initially lifted. The back pressure devices considered were active elements and would have been controlled electronically. Analysis of this solution indicated that control gains may ultimately have been to low for stability, and adequate control.

With the different approaches considered, the Oilgear Company chose an approach quite conventional in controlling loads which vary widely over their displacement range. The concept of using a meter out circuit automatically results in a system which is hydraulically stiff and less susceptible to instability. By using good control techniques, excellent velocity and position control can be achieved. The Oilgear meter out hydraulic circuit provides a maximum net lifting force advantage when maximum net force is required (initial opening). Maximum system stiffness occurs when the bridge reaches its full open position. The driving side of the cylinders is maintained compressed by the pumps operating under pressure compensated control. The exhausting side of the cylinders is maintained compressed by virtue of the restricting throttle valve. Compressed oil trapped on both sides of the cylinder keeps the system stiff during this no load condition, the one most susceptible to wind gust instability.

Bridge Operating Sequence

Referring to the simplified circuit in Figure #6, the operational philosophy that governs all operating modes is that if the bridge is fully lowered and in a zero energy state, the rest of the system must also be in a zero energy state including the emergency operating accumulator subsystem. If the bridge is fully down, no consideration is given to operation under any modes if all electric power is lost. From this it follows that any time the bridge can be raised, the control system must perform system checks of the hydraulic system as well as the accumulator subsystem for readiness. The control system further checks for the number of cylinders to be used (supervisory override). If only two cylinders are used, the control prompts for designation of the cylinder pair and adjusts the control parameters accordingly.

After the remaining system readiness checks have been completed (oil level, oil temperature, control pressure etc.), the pressure compensated, horsepower limited pumps are electrically commanded for soft start (minimum compensated) pressure condition and sequentially started. Following the accumulator charging sequence, the remaining pump blocking / loading valves are commanded open placing the pumps in a system ready state. One by one, cascaded commands to the other pumps are made. Each pump is commanded to full operational pressure. The solenoid operated cartridge check valves automatically block back flow from each pump and isolates it until it has achieved system commanded pressure. Pressure switch signals associated with each pump are checked by the integrated control system to determine if all pumps are on line for full bridge operation. If all pumps are not on line, the control system determines how many pumps are on line. Control commands to the proportional throttle valves will reflect the number of pumps on line.

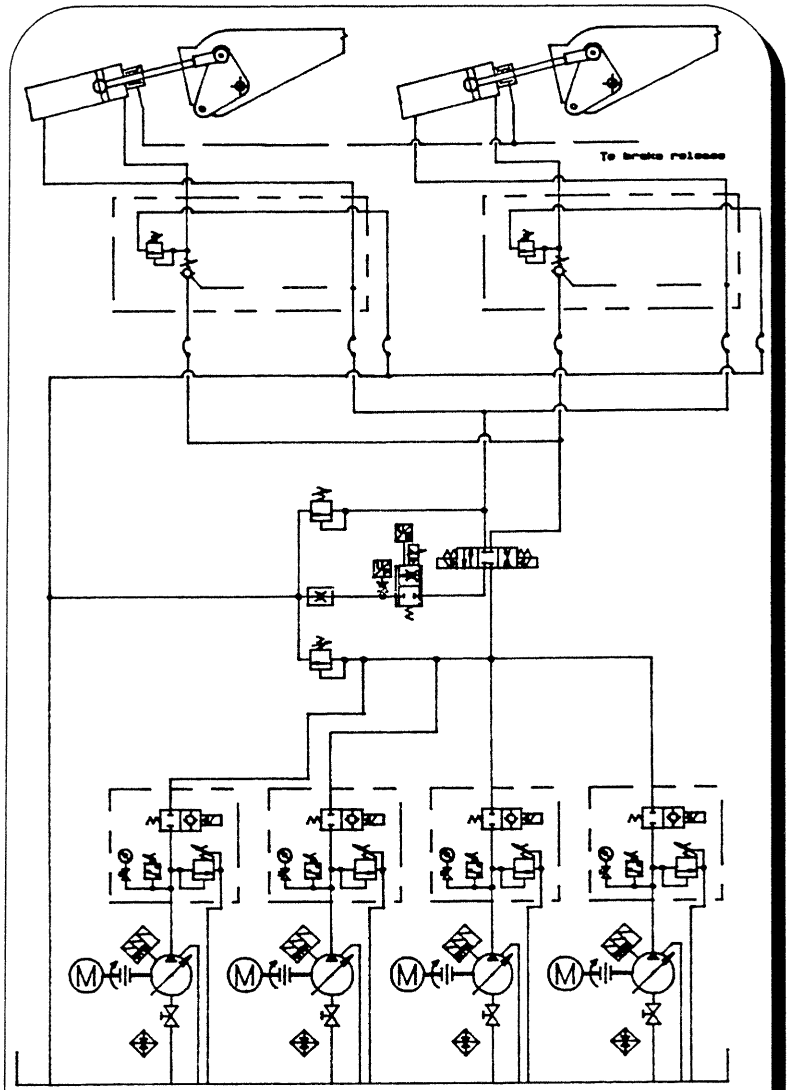


Figure #6

Once all pumps are on line and the main pressure header is pressurized, a command is given to release the rod brakes. The main power directional control valve is slowly opened allowing oil to pass through metering slots and compress the system. Oil compression takes place all the way to the throttle valve which is still in a ready state.

The control metering valve is now ramped open to provide a specified acceleration rate of eight (8) seconds. The TMR PLC control system constantly monitors leaf position and adjusts the opening of the throttle valve for an ever increasing pressure drop. With all pumps are on line, a system normal condition exists. A pressure signal is fed back to the control system which modifies the throttle valve opening with the goal of maintaining a constant pressure drop across a fixed orifice located in the throttle valve discharge line. A constant pressure drop across this orifice represents a constant flow and consequently a constant cylinder velocity. Conditions other than all pumps running represent a modified mode and only open loop commands are used. The commands are modified depending on the number of pumps used and bridge leaf position.

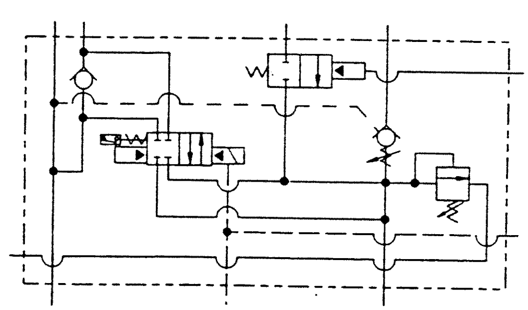
In anticipation of the final position the TMR PLC calculates the start position for the specified six (6) second deceleration command. A two (2) second command to stop follows the deceleration sequence. Working in harmony with the throttle valve, the power directional control valve is slowly shifted to neutral and the rod brakes set. The pumps are commanded to standby pressure.

The lowering sequence is similar to that explained above with the exception that the bridge, in all cases, must be raised approximately 0.5 degrees to release the collet type rod brakes. Once released, the power directional control valve is shifted to admit low pressure oil to the bore end of the cylinder. The lowering mode pressure command is kept low as very little force is required to start motion. The power directional control valve now diverts oil from the rod end of the cylinder to the throttle valve. Again the system, assuming all pumps are operational, corrects open loop commands to achieve a constant pressure drop across the meter out fixed flow orifice and thus constant cylinder velocity.

Integrated System Operational Features

Cylinder Mounted Manifolds

The circuit shown in figure #7 is for the cylinder mounted manifold assembly. A feature of the manifold assembly is the manifold mounted cylinder bypass valve. In compliance with the specification, either pair of operating cylinders may be bypassed and allowed to free wheel, mechanically following the operating pair of cylinders. Additional circuitry, not all of which is shown, provides for the exhaust of the differential oil when oil is displaced from the cylinder bore end. A replenishing check valve is included to make up the differential oil when the cylinder is moved forward.



Figure

The control system checks all the bypass valve position limit switches to insure the correct operational state for the commanded function. The control system also insures that the bypass valves on the non-bypassed pair of cylinders are closed before operation can commence.

The manifold provides over-pressure protection on the rod side of the cylinder, a cross piloted safety check valve on the rod side, and a remotely controlled emergency meter down logic valve.

Emergency Close Feature

Referring to the partial circuit in figure #8, the circuit shows the major components and the connection to the auxiliary accumulator subsystem. In the event all system power is lost to the system and both main power units are shut down, all valves will return to their normally closed position. The rod brakes will lock and the bridge will be stationary. Per the specification, regardless of the reason for power or control loss (all cylinders must be functional), an operating mode must be provided to lower the bridge.

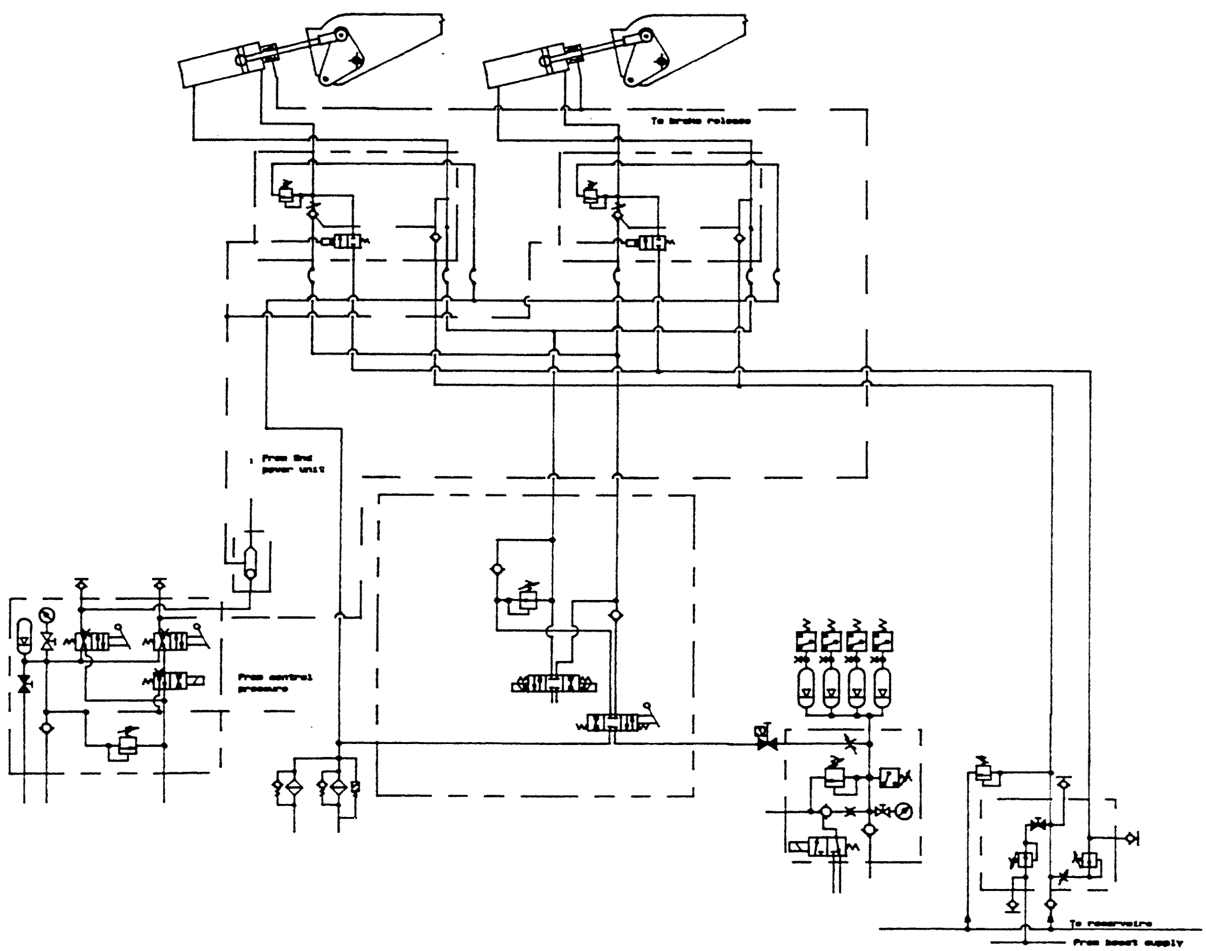


Figure #8

As described elsewhere, the accumulator subsystem has been checked and charged. A manually operated directional valve has been incorporated into both of the main operating manifolds, making manual lowering of the bridge a one man operation. This operation can be performed from either power unit.

To initiate operation, the accumulator operating valve must be opened. Fluid is now provided to the main manual operating let down valve. Because the main power four way valve is blocked port and centered, any oil introduced between the power 4-way and cylinder will pressurize the system. To lower the bridge, it must first be raised to release the brakes. A manually operated valve, with oil supplied by the control accumulator, is operated to pressurize the brake release system. A second manual valve is then actuated to allow fluid into the rod side of the cylinders. Oil flows from the bore side of the cylinders through the manual control directional valve and the bridge raises. The manual meter down control pilot valve may then be energized to open the pilot operated meter down cartridge valves.

In order to keep the meter down loading as balanced as possible, the flow from these valves is exhausted into a pressure compensated flow control network which limits the rate of decent. The oil is recirculated back to the cylinders with the differential oil be made up by the anticavitation check.

Summary

The Oilgear Company is proud to have been chosen to integrate and coordinate the hydraulic and electronic control system for this project. Working in harmony with the Project Consultants and Construction Company has proved most enjoyable. Oilgear believes we have addressed the operational aspects and requirements. We expect long life and excellent performance from the system supplied.

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