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SESSION WORKSHOP NOTES

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"Niantic Rv. & Stoneferry Bridges & PLC Controls"

BRIDGING
the NIANTIC

Presented by:

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The Rexroth Corporation

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Bridging the Niantic

The Niantic River Bridge project was bid on May 4, 1988, and opened to traffic three years later on May 4, 1991. Roughly 1.5 miles of Route 156 in East Lyme and Waterford, Connecticut were improved and the new bridge structure is 1,825 feet long, with a 34 foot wide roadway (see attached pictures of old and new bridge).

History

This project was to replace and old swing bridge with a new double leaf bascule bridge. The reason for this change was the condition of the old swing bridge, which due to age and corrosion, had to be derated for load carrying capacity.

Design Consideration

Per Connecticut Dept. of Transportation's (DOT) request the bridge had to be of movable type. Due to heavy currents in the Niantic River, bridge piers had to be kept as narrow as possible so as to minimize the restriction to the water flow. After investigating the electro-mechanical drive solution, the consulting engineer (Greiner) found that the pier widths would be too large. Further investigation showed that an electro-hydraulic drive system would allow for a narrower pier even after leaving enough room for maintenance of equipment. Thus, hydraulics was the chosen operating mechanism.

Bridge Design

The movable span across the Niantic River is a double leaf, fixed trunnion bascule bridge. The bascule span provides a minimum vertical clearance of 31 feet at mean high water with the leaves in the closed (or down) position and a horizontal clearance of 100 feet between the bascule pier fenders with the leaves in the open (or up) position.

Each bascule leaf is supported by two trunnion shafts that are affixed to a main plate girder and the secondary trunnion girder. Each trunnion shaft is mounted into a trunnion bearing about which the leaf rotates. The leaves normally open 79 degrees from horizontal and can open a maximum of 82 degrees before the counterweight will contact bumper blocks recessed into the pier's counterweight pocket.

When the bridge is closed, the main girders rest on live load shoes located approximately 10 feet to the channel side of the trunnions. Before traffic is allowed to cross the bascule span, the nose lock bars must be extended into the receiving sockets on vertical deflections at the center of the span.

Hydraulic Drive System

Each bascule leaf is driven by an identical, yet separate, hydraulic system that consists of two main pump/motors, one emergency pump/motor, a 500 gallon reservoir with an attached valve manifold, and a pair of double acting cylinders. The hydraulic fluid flow rate is regulated by a proportional valve which receives an electronic signal from a control amplifier card. Each control card interfaces with a position feedback potentiometer located at the northeast or southwest trunnion bearing. This device tracks the position and speed of a leaf to maintain the proper acceleration throughout an entire cycle.

Drive machinery is designed in accordance with AASHTO (American Association of State Highway Transportation Officials).

Normal opening time for the bridge per the AASHTO has to be typically 60 seconds and actually the bridge opens a little faster. Emergency closing time of bridge is also per AASHTO article 2-1-3, Conditions B & C.

Normal operation consists of using the service power, two main hydraulic pumps/motors for each leaf, two cylinders and all associated electronics and limit switches.

Emergency operation usually occurs when there is a power failure and the automatic transfer switch brings the emergency generator on line. The emergency pumps and motors are used to drive the bridge while the generator powers the bridge functions.

Other variations of emergency operation include the use of one main pump and motor with service power, the use of one cylinder with one main pump/motor group and service power, or in the event of major electronics failure the bridge can be operated manually with the hydraulics which request outside technical assistance.

The following are some key features of the electro-hydraulic system design (refer to hydraulic schematic HS 43-A9-A012-D).

- Stainless steel reservoir, minimum size 3X maximum combined pump output plus enough volume to empty one cylinder into the reservoir for servicing.

- Stainless steel piping for protection against corrosion due to environment.
- All fittings 3/4" and above to be stainless steel butt-weld type with O-ring sealing.
- All hoses 3/4" and above to be SAE split flange type with O-ring or JSO female swivel type with O-ring.
- Silica moisture absorber on tank breather side to prevent moisture from contaminating fluid in reservoir.
- Two motor pump groups for achieving 100% of maximum speed. If one set fails, bridge can still be run at 50% of maximum speed.
- Heavy duty hydraulic cylinders with bolted head and bottom, and manifolds bolted directly over port for protection against line rupture.
- Piston rods made of stainless steel with 30-35 micrometers of hard chrome plating for protection against corrosion due to the environment.
- Heavy duty chevron seals for positive sealing and long life.
- Bronze bearing liners for long life.
- Sharp edged bronze ice scraper ring for removing ice due to freezing rain.
- Mounting hydraulic cylinder via spherical bearing at each end to compensate for construction or alignment inaccuracies.
- The use of a premium grade anti-wear hydraulic oil with a high viscosity index to accommodate the wide temperature range of operation (Mobil DTE 11).
- Pressure switches to monitor line breaks and minimize potential oil spills.
- Flow level switch for low level warning and low level shut-down.
- Electrical and visual clogging indicators on all filters to give operator a warning at the control console.
- Bayonet manual overrides on directional valves for emergency operation in the event of control power loss.
- Proportional control of acceleration and deceleration.
- Special layout of power units for space and maintenance reasons.
- Use of manifolds to avoid pipe connections and hence leakage related problems.
- Each hydraulic cylinder has its own safety and control manifold. If there is a hose break, the cylinders will quickly stop in that position and also no further oil leakage will occur.

Controls

The bridge control system consists of two main components, the control console located in the control tower on the north end of the east bascule pier and the motor control center located on floor down from the roadway entrance. The control console and the motor control center are both computerized with a Square-D programmable controller system and are linked together for communication purposes with a twisted pair cable. The programmable controller system is made up of a processor to make decisions, input cards to read the status of the devices and output cards to tell the devices to operate.

The control console is where all operator functions to control the bridge take place. The control console contains all bridge status indicators and system push buttons and switches. Also, the Square-D processor which controls all bridge functions, is located inside the console.

The motor control center is where the incoming electrical service power is connected into the bridge system and distributed to all the bridge electrical devices. The motor control center is broken up into individual cubicles that contain protective breakers and control relays which tell the device when to operate. The bridge service power is 480 volt, 3 phase, 4 wire, 60 Hz and 400 amp.

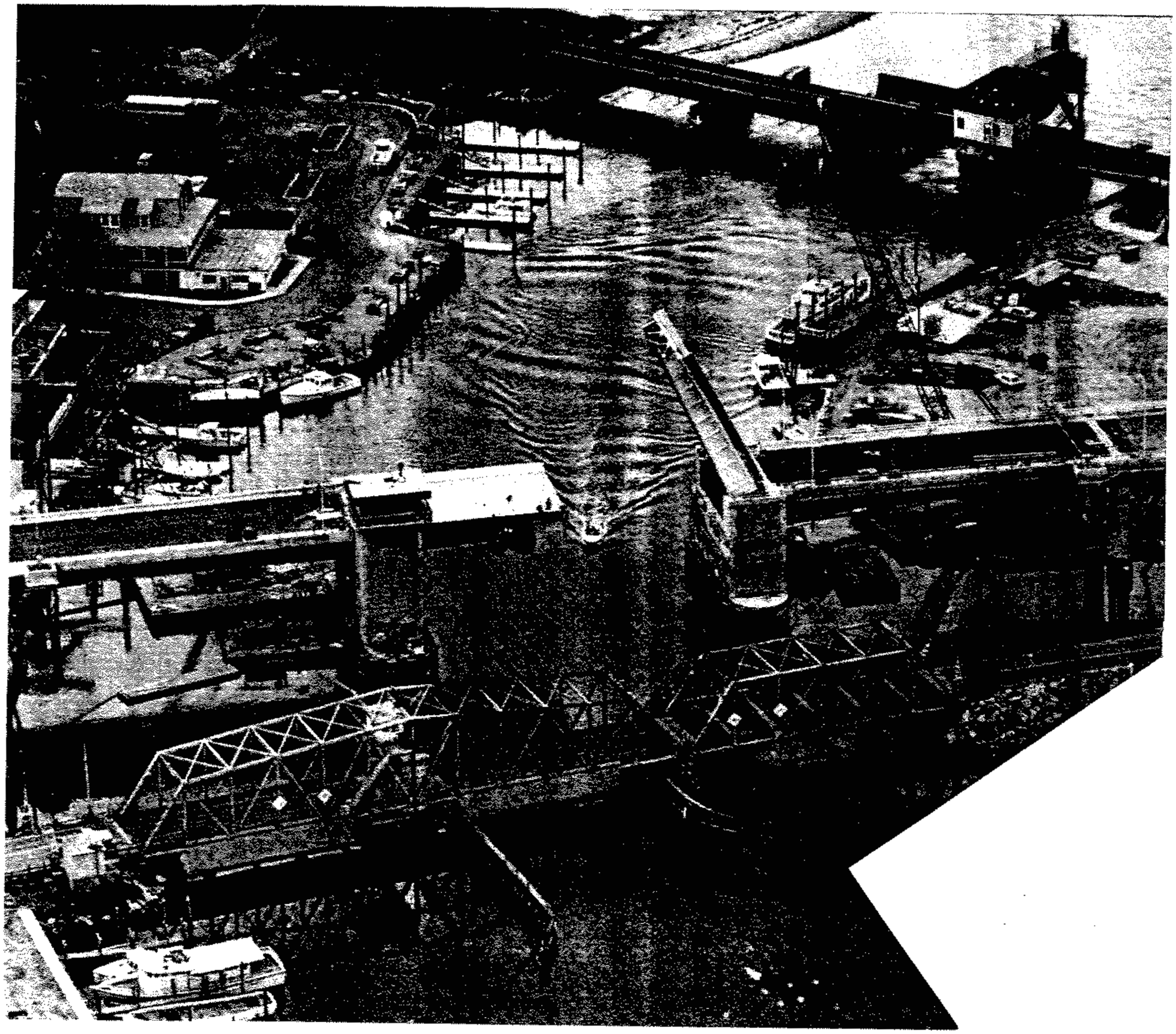
A 4 inch diameter submarine cable crosses under the Niantic River between both bascule piers. All of the far side (west side) power supply and control conductors are carried in this cable.

The Rexroth Corporation designed the hydraulic system in close cooperation with the consulting company (Greiner Engineering). Complete system was built and shipped to the project site in the middle of 1990. In the fall of 1990 Rexroth supplied and installed all interconnecting piping (stainless steel) between power units and the cylinders and started the system. Complete system was flushed and cleaned to SAE Class 5 before handing over to the general contractor (Cianbro) and finally the end customer, Connecticut DOT.

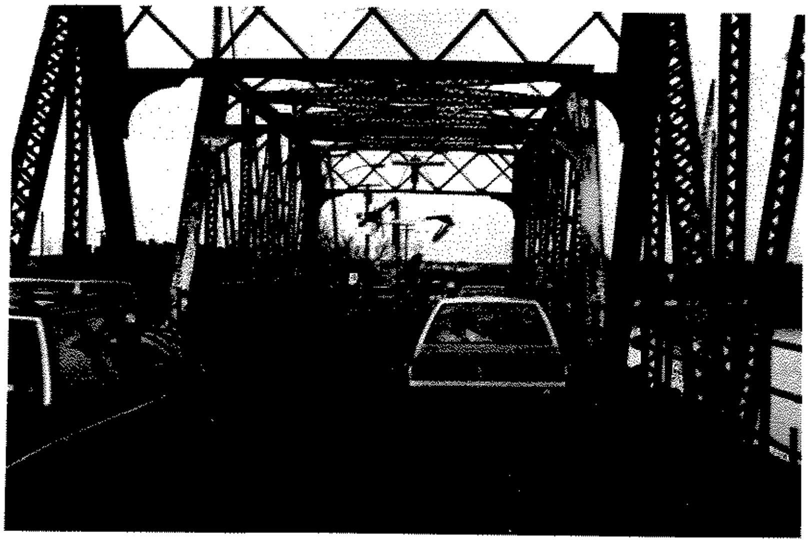
Complete system has been working very satisfactorily.

The Day

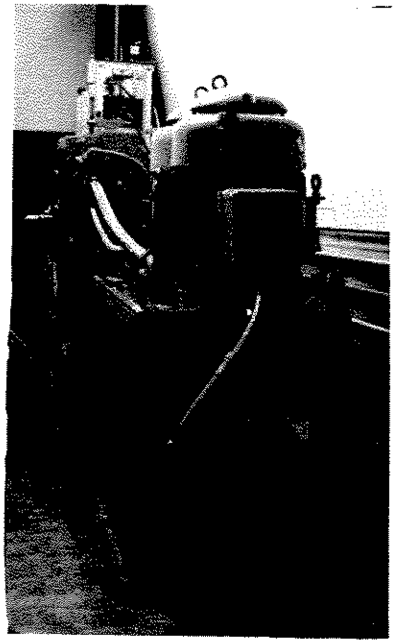
WEDNESDAY, MAY 1, 1991



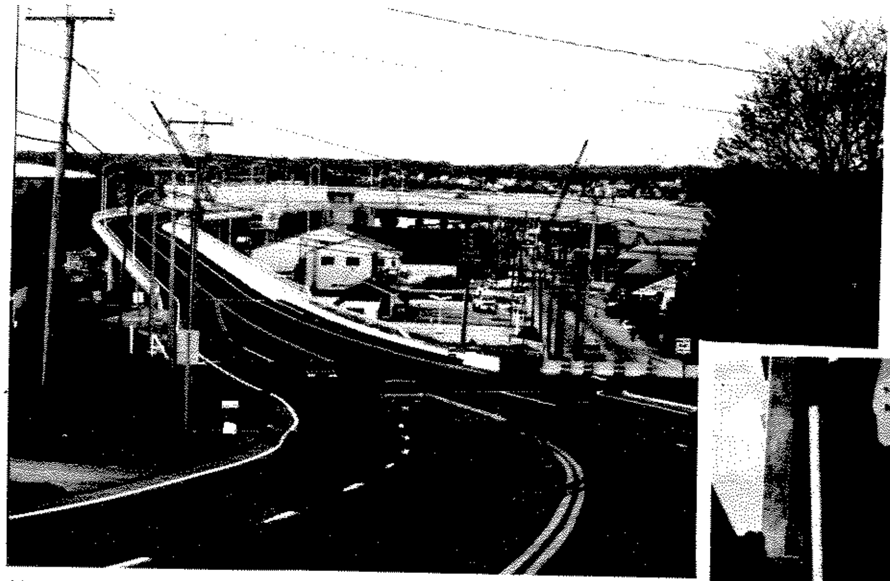
BRIDGING the NIANTIC



Original bridge

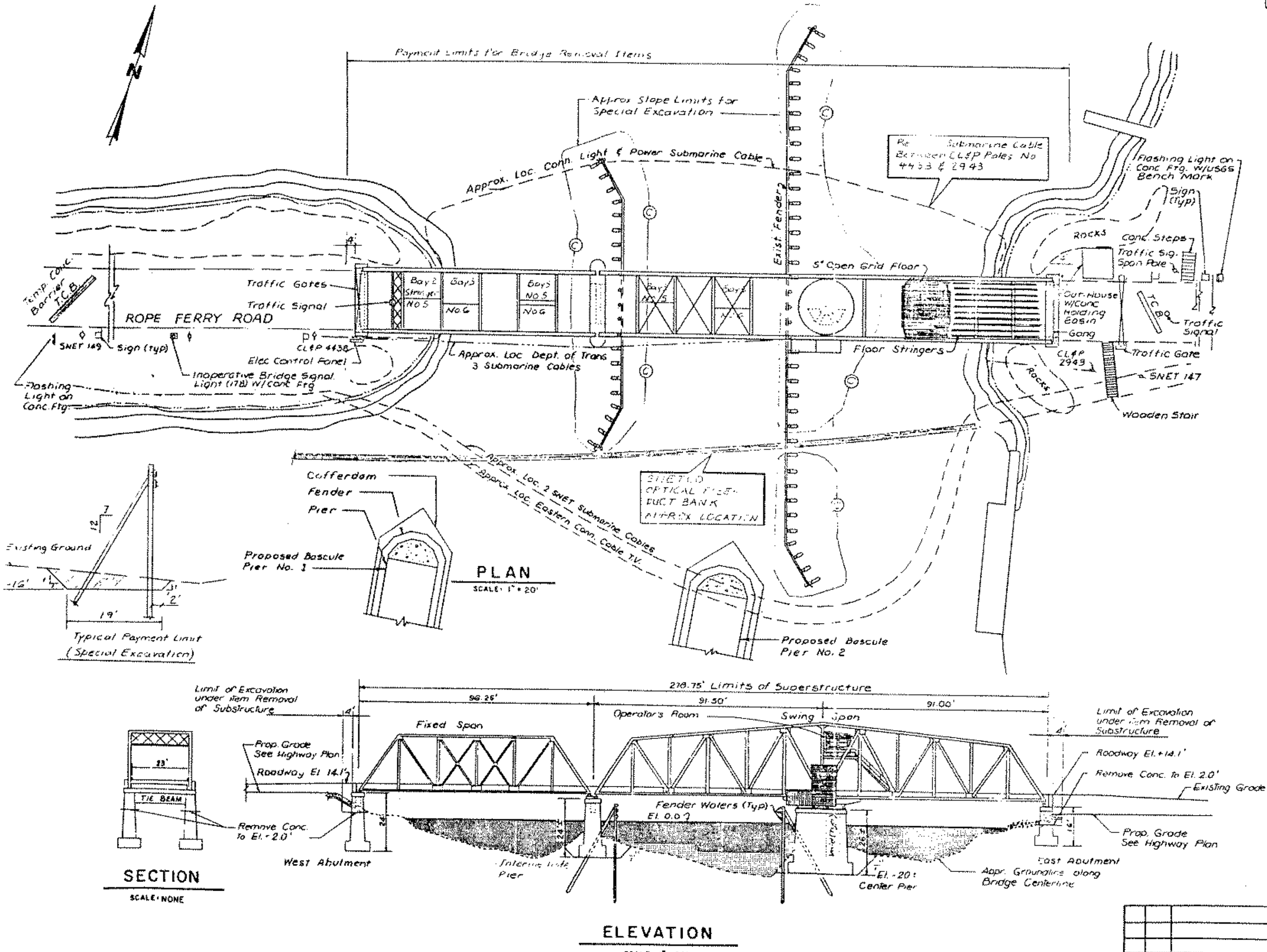


Modular Hydraulic Power Unit (special arrangement to suit space requirements & maintenance needs)



New, hydraulically operated movable bridge

Heavy duty hydraulic cylinder; bridge in partially open position (2 cylinder/side)



THE INFORMATION, INCLUDING ESTIMATED QUANTITIES OF WORK SHOWN ON THESE SHEETS IS BASED ON LIMITED INVESTIGATIONS BY THE STATE AND IS IN NO WAY WARRANTED TO

1	CONN	EAST LYME-WATERFORD	BRN - 1363(3)	44-102	1988	156	133	306

NOTES - BRIDGE REMOVAL

1. For General Notes see Str. Sht. 3.

2. Construction methods and time schedules for removal of bridge items shall be approved by the Engineer.

3. SUPERSTRUCTURE: Complete removal of the bridge superstructure and other appurtenances will be paid for at the Contract Lump Sum Price for "Removal of Superstructure". Six (6) stringers to be salvaged are shown on the bridge plan; stringer numbering is from north to south. - See Special Provisions.

4. SUBSTRUCTURE: Complete removal of piers and other appurtenances, partial removal of the abutments and the removal of the abandonend CL&P submarine cables will be paid for at the Contract Lump Sum Price for "Removal of Substructures". - See Special Provisions.

5. FENDER SYSTEM: Removal of the existing fender system as required for the installation of the temporary fenders, and the complete removal of the remaining fenders at a later date, including timber planks, walers, timber piles and related hardware, will be paid for at the Contract Lump Sum Price for "Removal of Fender System". See Special Provisions. Temporary fenders are not shown. For details see Str. Shts. 161 & 162.

6. EXCAVATION (EXCEPT PIERS AND ABUTMENTS): Excavation along the existing fender systen to Elev. - 16.0 (MSL), exclusive of pier removal, will be paid for at the Contract Unit Price per C.Y. for "Special Excavation". - See Special Provisions.

7. REGRADING: See Highway Plans for regrading of approaches and riprap installation at the abutments.

SEQUENCE OF BRIDGE REMOVAL OPERATIONS

A. Place and lock swingspan into open position, disconnect electric power supply.

B. Identify and protect operational submarine cables, remove abandoned submarine cables.

C. Remove fixed span superstructure.

D. Excavate around West Pier under item "Special Excavation", remove West Pier in its entirety.

E. Remove westerly fender system and complete "Special Excavation" items along this portion of the fender system, as shown on the plans or directed by the Engineer. PROTECT FIBER OPTIC & OTHER SUBMARINE CABLES.

F. Sweep entire Navigation Channel, 50 ft. from the north-westerly tip of the existing fender system to a minimum 50 ft. south of the new bascule piers; remove all construction debris. See Special Provisions.

G. Remove Swing Span.

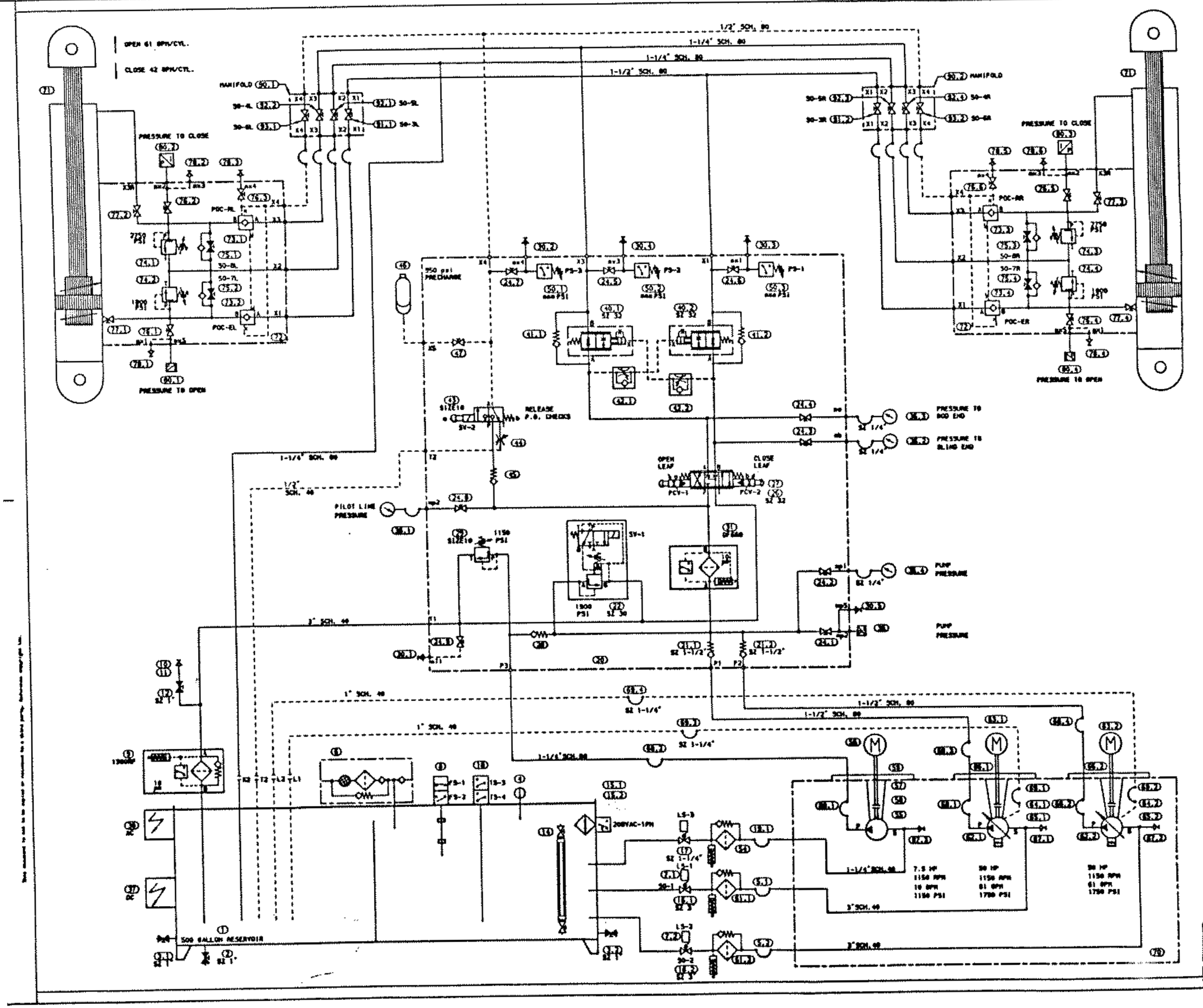
H. Excavate around the Turn-Pier under item "Special Excavation", and remove the Turn-Pier in its entirety.

I. Remove easterly fender system, complete "Special Excavation" items as shown or as directed by the Engineer. PROTECT FIBER OPTIC & OTHER SUBMARINE CABLES.

J. Sweep entire navigation channel, 50 ft. from the north-easterly tip of the existing fender to Bascule Pier 2., and remove all construction debris.

CONNECTICUT
DEPARTMENT OF TRANSPORTATION
EAST LYME – WATERFORD
REPLACEMENT OF
NIANTIC RIVER BRIDGE & APPROACHES
ON ROUTE 156
REMOVAL OF EXISTING RTE. 156 BRIDGE

ENGINEER MACCHI ENGINEERS BY: STRUCT. MECH. ASSOC.
DESIGNER IH DRAFTER BGM CHECKER JR



FIELD CONNECTION SIZES:

X1 = 1-1/2" SAE 6000 PSI 4-BOLT FLANGE (CODE 62)
X2, X3 = 1-1/4" SAE 6000 PSI 4-BOLT FLANGE (CODE 62)
X4 = SAE-12 STR. THRD. O-RING PORT (1-1/16-12UN-2B)
L1, L2 = SAE-20 STR. THRD. O-RING PORT (1-5/8-12UN-2B)

MANIFOLD CONNECTION SIZES:

P1, P2, XR3 = 1-1/2" SAE 6000 PSI 4-BOLT FLANGE (CODE 62)
P3 = 1-1/4" SAE 6000 PSI 4-BOLT FLANGE (CODE 62)
T1 = 3" SAE 3000 PSI 4-BOLT FLANGE (CODE 61)
ALL G's = SAE-4 STR. THRD. O-RING PORT (7/16-20UNF-2B)
X5 = SAE-12 STR. THRD. O-RING PORT (1-1/16-12UN-2B)
T2 = 1/2" SAE 3000 PSI 4-BOLT FLANGE (CODE 61)

LEFT & RIGHT CYLINDER:

BORE	= 320 mm	= 12.6 in
ROD	= 180 mm	= 7.09 in
TOTAL AVAILABLE STROKE	= 2640 mm	= 103.9 in
APPLIED STROKE	= 2540 mm	= 100 in
AREA-BORE ONE CYLINDER	= 124.7 in sq	
AREA-ROD ONE CYLINDER	= 39.4 in sq	
AREA-ANNULUS ONE CYLINDER	= 85.3 in sq	
TOTAL BORE AREA TWO CYLINDERS	= 249.4 in sq	
TOTAL ANNULAR AREA TWO CYLINDERS	= 170.6 in sq	
RATIO BORE AREA:ANNULAR AREA	= 1.46:1	
MAX. VELOCITY OPEN OR CLOSE	= 0.157 ft/sec	
MAX. FLOW TO OPEN BRIDGE IN 53 SEC.	= 122 gal/min	
MAX. FLOW TO CLOSE BRIDGE IN 53 SEC.	= 84 gal/min	

ISSU	DATE	NAME
DRWN	10/94	E. MARTO
CK'D		
APP'D		

HYDRAULIC SCHEMATIC
DESCRIPTION:
HYDRAULIC POWER UNIT
SCALE: NS
JOB NO.: 175527
CUST. P.O.: 44-102
CODE NAME: NIANTIC RIVER BRIDGE
FILE NO.:
HS43-A9-A012-D-
SHEET: 1 OF

Stoneferry Bridges - Hull, England.

The paper will describe the basic design of the bridges, the principal operating elements, the early design work and the novel features of the control system.

Basic Design

The two bridges are identical bascule bridges with an overhead counter weight- sometimes known as a *Dutch Style*. The bridges span the River Hull in the city of Kingston upon Hull, usually known by its shorter name of "Hull". Each bridge carries one lane of a dual carriageway - the Hull outer ring road. Traffic is very heavy and, to limit the length of traffic jams, the bridges are required to operate at high speed. A further requirement was a very high reliability and multiple redundant operating systems. There is also a need to operate very efficiently both in terms of electrical power absorbed, and operator expertise required.

Physically each bridge is identical apart from being 'handed'. The bridge leaf is 26 metres long and, together with the overhead counterweight, the moving mass is over 360 tonnes. The bridge leaf is lifted by four hydraulic cylinders mounted underneath the structure, the control manifolds are as close as possible to the set of cylinders also being underneath the bridge leaf and the pumps are in a machinery hall built between the heels of the two bridges. at full speed the bridge leaf moves at one degree/second. That doesn't sound very fast but the visual effect is startling. The operators need not open the bridge to the full angle of 90 degrees each time a vessel passes underneath, they only open as far as is necessary for each particular ship. In this way the disruption to the road traffic is kept to a minimum and the river users are grateful for a swift passage through this tidal section of the waterway.

Principal Operating Elements

The operating system for the bridges seems,at first sight, to be unduly complicated, but the client insisted on a very sophisticated PLC system (Progammable Logic Controller) with a level of instrumentation that far exceeded the normal requirements for a basic hydraulic circuit. Early on in the design stage we found that we could make good use of the wealth of information available to the PLC to design a control system where all the normal hydraulic functions were replaced by a sub-routine in the PLC programme itself. The reasons for this stem from the difficulty of controlling a mass with a very low natural frequency, the limited power available and the constraint of having all the pumps in a central location (hence distant from the cylinders) so that they each set of pumps could act as a standby for the other bridge. The details of the design process and the factors which lead to the current arrangement are more fully discussed in the following section.

Each hydraulic cylinder is fitted with a manifold incorporating pilot operated check valves (load locking), pressure relief valves (overload limitation), anti-cavitation check valves (allow the cylinder volume to remain full if the relief valves allow the bridge to move), motorised ball valves (freewheeling and panting) and a manual release ball valve.

The main control manifold underneath the bridge consists of a system of five logic elements arranged in the classic format. The elements controlling the flow to the cylinders (P-A and P-B) are proportional throttle valves with electronic feedback of the poppet position. The elements controlling the flow returning from the cylinders (A-T and B-T) are proportional pressure relief logic elements with stroke controlled solenoids giving electronic feedback of the solenoid position. The fifth logic (P-T) is a pressure relief element and cover arranged as a three way pressure compensator.

On the same stand as the main control manifold is an emergency bypass manifold. This consists of a slugged pilot operated directional control valve, meter out pressure compensated flow controls, pilot operated check valves and an anti-intensification relief valve. This manifold gives a very simple but inefficient control of the bridge and is brought into play if there is a problem with the more complicated main control manifold. This manifold can also be used along with a manual control facility built into the pump system to operate the bridge leaf with a complete failure of the computer systems.

The main control manifold can be isolated from the cylinder lines and the pressure lines by six motorised ball valves. These are under PLC control but they do have manual overrides. The main control manifold has to be isolated before the emergency bypass manifold can operate.

For PLC controlled operation of the bridge using this emergency bypass manifold, two pumps are started for each bridge and a set flow of 160 l/min is called up by the PLC. The bridge can then operate at quarter speed using half power. For powered but manual operation using this manifold, i.e., in the even of a total PLC failure, the pumps are started in local control and the flow called up using the built in relays on the VT card. The manual overrides on the valve solenoids serve to give this computer free operation.

The pumps are installed in a machinery room between the two bridges. Each pump delivers up to 360 L/min and can work at up to 200 Bar. However they are fitted with motors of only 55kW power and rely on the PLC to ensure that they are not overloaded. The strokes of the pumps are controlled by the PLC with an electronic feedback of stroke position. There is a manual stroking system built into the control circuit so the pumps can be called upon to deliver oil when the motors have been started in a local control configuration.

The PLC controls the flow from the pumps and the flow to the cylinders. The flow from the pumps is arranged to be a only a little more than the cylinders require and the excess spills over a pressure compensator. The PLC controls the number of pumps and cylinders in use and matches the flows and speeds to suit. (The heel of the bridge leaf incorporates a torsionally stiff structure that means that the hydraulic cylinders do not need to be synchronised and that operation with less than four cylinders is possible.) The load control is performed by the PLC controlling the back pressure on the cylinders. The control algorithm is based on information from pressure transducers on each cylinder volume. Finally the PLC controls the power demanded by each pump by monitoring the signal from motor current transducers and adjusting the bridge speed to limit the extent of any overload caused by gusts of wind.

In the event of total power failure, an emergency lowering system enables the bridge to be returned to the closed position. This system consists of the manual release ball valves on each cylinder manifold and a common lockable needle valve on the same valve stand as the control manifolds. The lowering procedure is to open all of the ball valves which connect the four full bore volumes to the needle valve and then to open the needle valve which connects these volumes to tank. The cylinder annuli are refilled via the anti-cavitation check valves built into each cylinder manifold. The safety of the system is maintained by having a speed limiting jet fitted beneath each manual release ball valve and a check valve fitted to the needle valve end of the hose leading off the cylinder manifold. The check valve prevents a burst hose from exhausting the oil out of all of the cylinders should one hose fail in the line between the cylinders and the needle valve. The central location of the single needle valve is particularly convenient for giving a sensitive speed control of the leaf - the adjustable opening of the valve, coupled with not too much skill demanded from the operators, can give a very gentle landing at the fully down position. A pair of hand pumps connected to the annulus lines permit the bridge to be tipped away from the 90 degree position, also allowing the leaf to lower against wind forces.

When the bridge is fully down, motorised valves connect both cylinder volumes to tank to allow the cylinder to 'pant' under the actions of bridge deflections caused by traffic. These ball valves are part of the cylinder free wheeling system that lets the PLC operate the bridge with less than the full compliment of four cylinders. Motorised ball valves were chosen not for their elegance - they have none - but for their safety. The operating actuator (the small electric motor and gearbox) is completely separate from the hydraulic function (the ball valve). When the valve is required to be closed (leak free when holding the weight of the bridge) it can be driven closed without the need of any form of pilot pressure. A manual override is built in and limit switches signal the exact position of the valve. A power failure does not cause the valve to open and its position does not depend on any form of spring detent. When the valve is required to be open it must have the same characteristics, i.e., no reliance on pilot pressure or the maintenance of power, no spring detents and permanent signalling of its position to the PLC.

Early Design Work

Before the main contract was let for the construction of the bridges, the employers (Humberside County Council) let a design contract to Mannesmann Rexroth to fully define the hydraulic, electronic and electrical systems. This was an unusual departure from the rigid protocol normally associated with the letting of civil engineering contracts in the UK. All of the major hydraulic equipment suppliers in the country were invited to tender for the manufacture, installation, commissioning etc. of the consultants reference design so that they could see the 'value for money' that each supplier represented. The successful bidder was then employed in a design capacity to turn the reference design into a fully working system and to guarantee the operation and success. By this route the end user kept a close relationship with the designers (something that would be very awkward in the normal arrangement), the designers were able to adjust the system to suit their own equipment and the responsibility for the success of the venture was taken away from the consultants (world famous Rendel, Palmer and Tritton).

We chose a full scale computer simulation of the hydraulic circuit to prove to the consultants that our system would perform correctly. The outcome of the simulation was basically favourable but we were able to use the model produced as a sophisticated design tool when the first results showed a small problem with the control of the load holding valves.

The simulation commenced by modelling every component in circuit for each mode of operation, i.e., raising and lowering. The models were created using information from the data sheets, intelligent guesswork and approximations. With the individual models completed, the system was then brought together using physical details of the installation as well as the information on the circuit diagram. Regarding the installation, we had to give details of the length and diameter of each pipe run, the position, length and type of each flexible hose, and the friction in the bearings in the rod end spherical eyes as well as all of the bearings carrying the bridge and counterweight mechanism. We knew that the simulation was particularly thorough when we were asked for the moment of inertia of the electric motor shaft and how much the speed pulls down when the pumps are under load. The bridge leaf was not simulated apart from its mass and inertia and the way in which wind forces effected the load (a function of wind speed, direction and bridge angle).

The early results of the simulation showed that we were correct in assuming that there would be problems with the stability of the load holding as the weight of the counterbalanced bridge leaf went overcentre because of the effect of gusts of wind. The natural frequency of the spring mass system was about 1 Hz and the hydraulically operated load holding valves closing time was estimated at 16 seconds to achieve stability. We had experience of slugging the operation of the Rexroth load holding valve (The Check-Q-Meter) by fitting tiny jets in the pilot lines. The effect of the jets can be enhanced by fitting accumulators in the pilot lines as well, but we were unsure about getting 16 seconds reliably and consistently.

Using the written simulation as a design tool we proceeded to try out various circuit modifications to satisfy our clients (and ourselves) that stability could be achieved by other means. The final system used logic elements in a classic configuration for directional control: one each for the flow directions P-A, P-B, A-T and B-T. A fifth element was added (P-T) to provide a 3-way meter-in pressure compensator. The inlet logic elements (P-A and P-B) were proportional throttle valves (Rexroth Type FE) made into pressure compensated meter-in flow controls by the action of the fifth logic. These valves control the speed and direction of the bridge. The flow returning from the cylinders is controlled by the remaining two logic elements (A-T and B-T) which are pressure relief valves. These were fitted with proportional relief valve pilot heads. Having used proportional valve technology for both the directional and load control elements, i.e., controlled by electronics, it followed that the task of load control of the bridge could be moved to the PLC (Programmable Logic Controller).

Each cylinder was already to be fitted with two pressure transducers because of the data logging facility required by the specification. We found that we could make good use of the information these transducers provided by making the load control valves (pressure relief valves) respond to PLC outputs and building the 16 second time constant into the PLC software.

For example: Suppose we were lifting the bridge, flow through the manifold would be P-A and B-T. The pressure in the cylinder full bores (our port A) would be monitored and could be seen to start to drop under the influence of a wind gust assisting the raising of the bridge. If the pressure fell below our set limit of 20 Bar the PLC would start to ramp up the setting of the relief valve logic through which the flow of oil from port B (the cylinder annuli) returns to tank. The increased back pressure would cause an increase in the full bore pressure and when the figure of 20 Bar is regained the ramping would cease and the relief valve setting remain at its new value. If the full bore pressure starts to exceed 50 bar, the back pressure is ramped down until the full bore pressure is below 50 Bar. The hysteresis is built in to stop the system from hunting, i.e. the pressure between 20 Bar and 50 Bar is stable and does not induce any change in the control parameters. The ramp rate is effectively the closing time of the load control valve and we increase the stability on deceleration by increasing the ramp rate by a factor of four. This enables the large inertial load, and consequent high angular momentum, to be restrained.

The new control system was subjected to a sensitivity analysis to see how much the simulated result varied with changes in the models of the components just in case some of our guesswork was shown to be critical to the operation of the system. The system model was then subjected to a frequency sweep of typical wind gusts based on wind gust velocity profile research from the consultant engineers.

Our client was satisfied that the problem had been solved and in practice the final PLC programme was very like the assumed PLC programme. (Here the simulation was being used to try out various PLC control algorithms as well as to refine the design of the hydraulic circuit.) The only difference between the real and modelled algorithm came from the discovery that the bridge, when built, had an even lower natural frequency because of the slenderness of the counterweight arms. These were bending and transmitting the motion to the stiffer bridge deck by effectively oscillating the counter-balancing force. We overcame this additional instability by simply typing in two different numbers in place of 50 and 20. You can imagine the problems this additional instability would have created had we been using hydraulically controlled load control valve, problems compounded by the discovery of this extra low natural frequency only ***after*** the hydraulic system had been installed.

Actually the simulation produced other useful results. We were able to reduce the size of the electric motors and demonstrate a confinable overload on acceleration. We evaluated a power controller whereby the motor current was measured (again using transducers that had been fitted primarily for the data logging) and the bridge speed was reduced by the flow controller (proportional throttle valve) if the power level was too high for too long. By this means speed control was retained by the proportional valve under the bridge leaf and not controlled by the flow of oil from the pumps far to far away for stability. The individual pump flows are controlled by the PLC via a proportional valve built onto each pump displacement circuit (The Rexroth E01 control on the A4VSO pump). The flow required from each pump was determined by dividing the flow required by the proportional valve (also under PLC control) by the number of pumps available and running. A reduction of bridge speed automatically reduces the flow from the pumps and the power drawn from the electric motor is therefore reduced. In fact the flow from each pump is arranged to be a little greater than the simple equation described above. The addition of a limited excess flow ensures that a small amount of oil spills over the pressure compensator and control always remains with the proportional valve. The following of pump stroke with the opening of the proportional throttle valve and the operation of the pumps at load induced pressure plus the setting of the compensator (the proportional valve pressure differential) is as close as we could get to load sensing on the pumps and is the key to assuring full speed operation of the bridge on the limited power available (220 kilowatt per leaf). True hydraulic load sensing would have been impossible because of the distance between the cylinders and the load, there would also have been problems in trying to arrange the pumps to share the load equally.

The simulation also showed us that we had to do something about the cylinder cushions. These were supposed to limit the damage caused to the structure in the event of a stop switch failure when the bridge position was controlled by the back up proximity detectors rather than the absolute angle encoder. The simulation demonstrated that when the cushions were entered, the increasing back pressure could not be distinguished from a gust of wind. The decelerating force was matched with an increase in pressure on the driving side of the cylinder piston and the bridge velocity curve had only a small, and temporary, depression. On the installation we overcame this effect by making a pressure tapping to the oil on the underside of the cushioning ring and fitting a differential pressure switch (actually a filter clogging indicator) to the cylinder port blocks. The PLC programme was written to perform an emergency stop if the bridge was ***not*** decelerating when the switch showed that the cushions had been brought into action.

Control System

As mentioned earlier, the PLC's have a critical role in operating the hydraulics but the extent of their control function is not limited to hydraulics alone.

1. Each bridge leaf is operated by two PLC processors working in a 'hot back up' mode. The two processors both run the programme, one having an active control and the other checking on the responses of the first. The standby PLC seizes control and locks out the other one if it detects any errors.

2. The software for the control of each bridge provides an automatic compensation for pump failure, cylinder failure and control valve failure. This is exercised as an automatic shut down and restart on redefined configurations. The detection of failure in this respect is done by comparing the valve actual position feedbacks (from the proportional valve stroke control LVDTs) with the PLC output signal of demanded position.

3. The hydraulic circuit is arranged with motorised ball valves to connect together the outputs of the pumps for one bridge with the outputs of the pumps for the other bridge. By selective operation of these valves, and the motorised ball valves on the pressure lines of the main manifolds, it is possible to use the pumps for one bridge to operate the other bridge, or to use a pair of pumps out of one set of four to operate each bridge. The software hurdles jumped in the development of this feature were enormous. The first requisite was that the operation of the flow control valves must be reduced to allow for a reduced number of pumps feeding the pressure line to each bridge. This was already in because the system can cope with the mathematics involved in allowing for individual component failures. The second, and much greater problem, is to do with the operation of the pump stroke controls. The flow demanded from the pump matches the flow requested by the flow control valve plus a little bit to keep the pressure compensator live. When operating with pumps belonging to the other bridge, the pump delivery is controlled by a different PLC to the one driving the flow control valve. High speed communication links are brought into circuit to enable the information to be sent backwards and forwards to keep the hydraulic control stable.

4. All four PLC's have their Input and Output image tables mirrored another computer via a dedicated data highway. This information is recorded and packed onto a pair of hard disks to provide data logging of every PLC input and output for every scan of the PLC. There is automatic archiving to a tape streamer of every single bridge lift. The data logging is performed by a very fast PC (33MHz was considered fast when the system was installed nearly three years ago). The use of a separate computer for data logging leaves the PLCs free to concentrate on the control of the bridge.

5. Another computer, the operator graphics computer, provides the operators with animated graphics displays and messages although the bridges are able to work without the graphics functioning. The Graphics programme uses the image of PLC input and output fields for information but the displays are generated locally. The datalogging computer serves only to retransmit the PLC information on a local area network.

6. Within the same operator graphics computer is a second graphics programme which provides a set of animated displays for engineering personnel. These are for engineering analysis and show strokes and feedbacks for all proportional control valves, graphical displays of all system pressures, motor currents and oil and motor temperatures and graphical indication of the state of all pressure switches and limit switches, .

7. A third computer, the auxiliary graphics computer, located in the electronics room with the datalogging computer, is also loaded with the same two graphics programmes and is connected to the network. The datalogging computer can rerun the PLC input/output image table from its memory or from the archives. The other two computers do not distinguish between real bridge operations and replays and so the graphics packages can be used on recorded data to evaluate past events. The replay can be at full or reduced speed.

8. The datalogging computer is capable of charting, plotting and numerical analysis of data logged information against any criteria, e.g. plotting cylinder pressure against angle, flow against motor current etc. Individual inputs can be compared on a scan by scan basis to identify causes and effects in the event of a breakdown.

9. The PLC software provides for logging-on of every operator. The operators can be given different levels of access,

i.e., basic operator control, bridge master control and several levels of engineering control. The bridge responds differently to the different levels of access and different graphics screens are available. For example, when the bridge maintenance latches are in place the bridge can rest against them which means that the load has to be lifted slightly to allow them to be removed. The Bridge operators are unable to move the bridge when the latches indicate 'in' because of a software interlock. The Bridge master is permitted to 'inch' the bridge when the latches are in because his level of access causes the software interlock to be disregarded.

10. LED matrix message display units give instructions directly to the operators independently of information given via the graphics packages. The display units are driven by each PLC, one display unit for each bridge. By this means it is possible to call the graphics display system one of the redundant modules.

11. There is access to operate and cycle every single item of plant via an overseer panel which communicates directly with each PLC processor. Software in the PLC prevents any damage being caused by this 'forcing' facility. It is not possible to operate the bridge from this panel even if the engineer knew all of the correct keystrokes to put every piece of plant into the correct configuration. This has been a deliberate feature of the software control. The panel is provided only as an aid to maintenance and is particularly useful in tracing electrical faults by eliminating PLC output card failures. Two levels of control are available to the engineers using this panel based on the access level described above. The lower level incorporates procedural interlocks as well as machinery interlocks, e.g. operation at the lower level would not allow an engineer to raise a traffic barrier if the bridge were not fully down even though no harm would come to the barrier. Operation at either level of access would not

allow the barrier raise contactor to be energised if the barrier limit switch already signalled that the barrier was fully raised. Maintenance personnel familiar with the use of 'forcing' functions on PLC programming panels would appreciate the advantages of such a system. Normally forcing of outputs is done with a good deal of trepidation and concentration and equipment still gets broken.

12. The same overseer panel gives operator access to a special menu designed to duplicate every single operator pushbutton or joystick. This is used to restore bridge operation in the event of a pushbutton failure.

13. Each of the graphics computers has a diagnostic programme which compares the sequence of inputs from the PLC image table with a predefined operating envelope. Alarms and faults are diagnosed and relayed to the operators. Since every input is logged, the operators response to the faults is also logged and, since the access is PLC controlled, the operators identity is recorded. On Stoneferry Bridge big brother **is** watching. The fault diagnosis system creates logs of faults for maintenance personnel. A memo facility built into the programme gives an ability to add notes to build up a historical data base of faults and repairs along with an informal 'this is what we did last time' record.

14. A fifth PLC runs an identical programme to the controlling PLCs but all the inputs come from the datalogging computer running a special simulation programme. The computer effectively pretends to be the bridge and it responds to the PLC outputs by providing PLC inputs. The computer communicates directly with the PLC processor thus avoiding the need for a duplication of the input and output cards. A duplicate operator control station is provided which, along with the Auxiliary graphics computer running the operators graphics and fault diagnosis programmes, enables a new operator to be trained just as if they were driving the real bridge. The training officer interfaces with the

simulation programme and can test the operator by creating various wind speed or traffic conditions as well as creating imaginary failures of any plant item. The ability to simulate the failure modes of items is useful in testing the operating system against 'What if..' scenarios. The system can also be used for testing changes to the operating software before it is downloaded to the real controllers connected to the real bridge.

15. The PLC's also have control over two high tension transformers in a local supply substation. The PLC monitors the incoming supplies (from two different parts of the grid) and selects which supply to use. A large UPS (uninteruptable power supply) enables all the computers to remain live while the changeover is made.

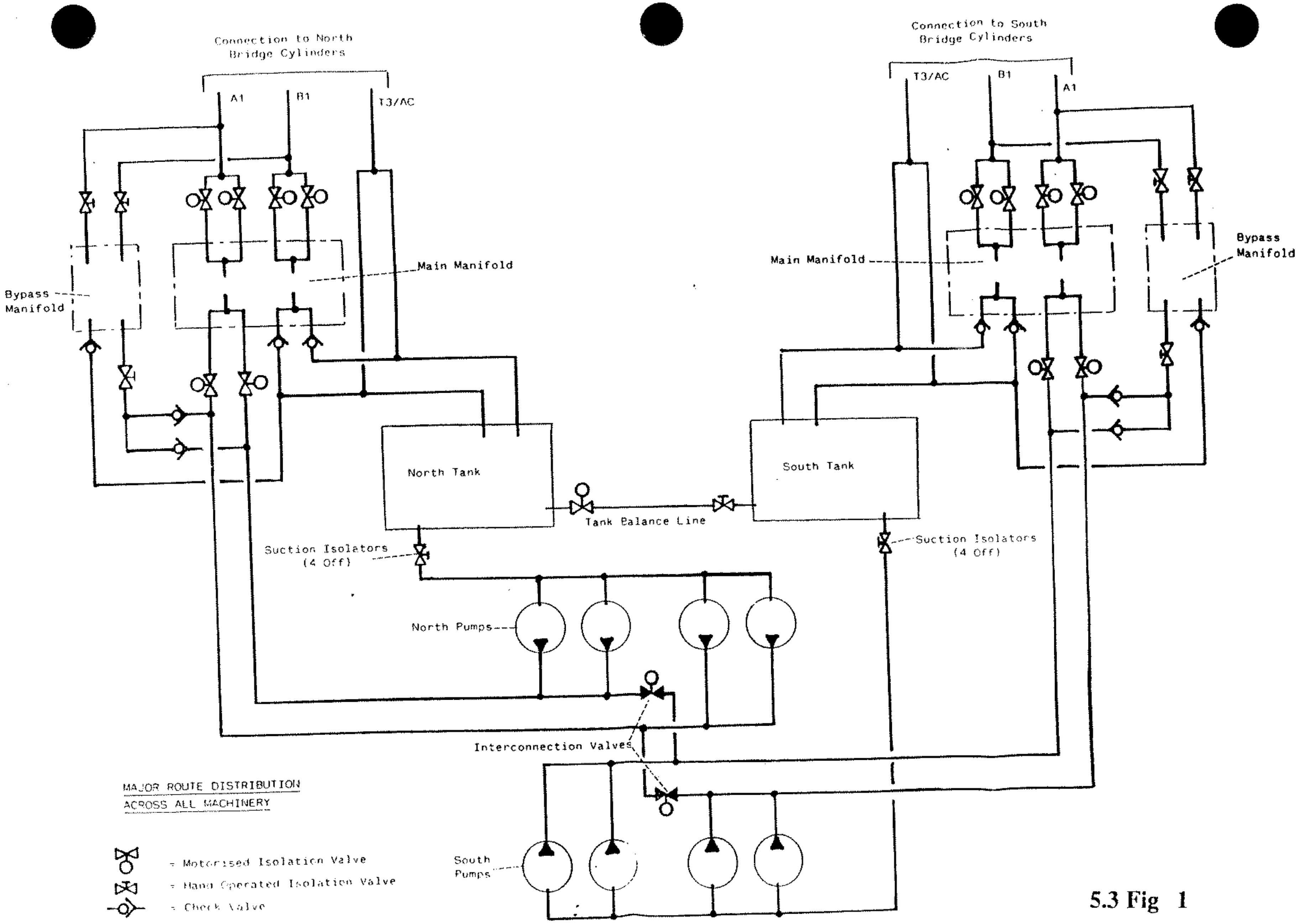
16. The PLC's interface with the fire detection system and provide the operators with warnings as to the state of the alarm and the discharge of the Halon gas. In the event of a fire the PLC automatically stops the bridge and shuts down all the equipment.

17. The PLC monitors the bridge angle whilst the system is dormant and guards against the bridge being lifted by a boat trapped underneath on a rising tide. When this happens the traffic lights are operated and an alarm signal is sent to a central security office. If the angle increases to create a stop of above 50mm the traffic barriers are automatically lowered.

18. The bridge operator access control equipment is also used to control access to the building and the electronics rooms (housing the data logging and simulation computers). Reports are generated, and records kept of every person who accesses every room or operates the bridge. The report includes illegal attempts to access prohibited areas.

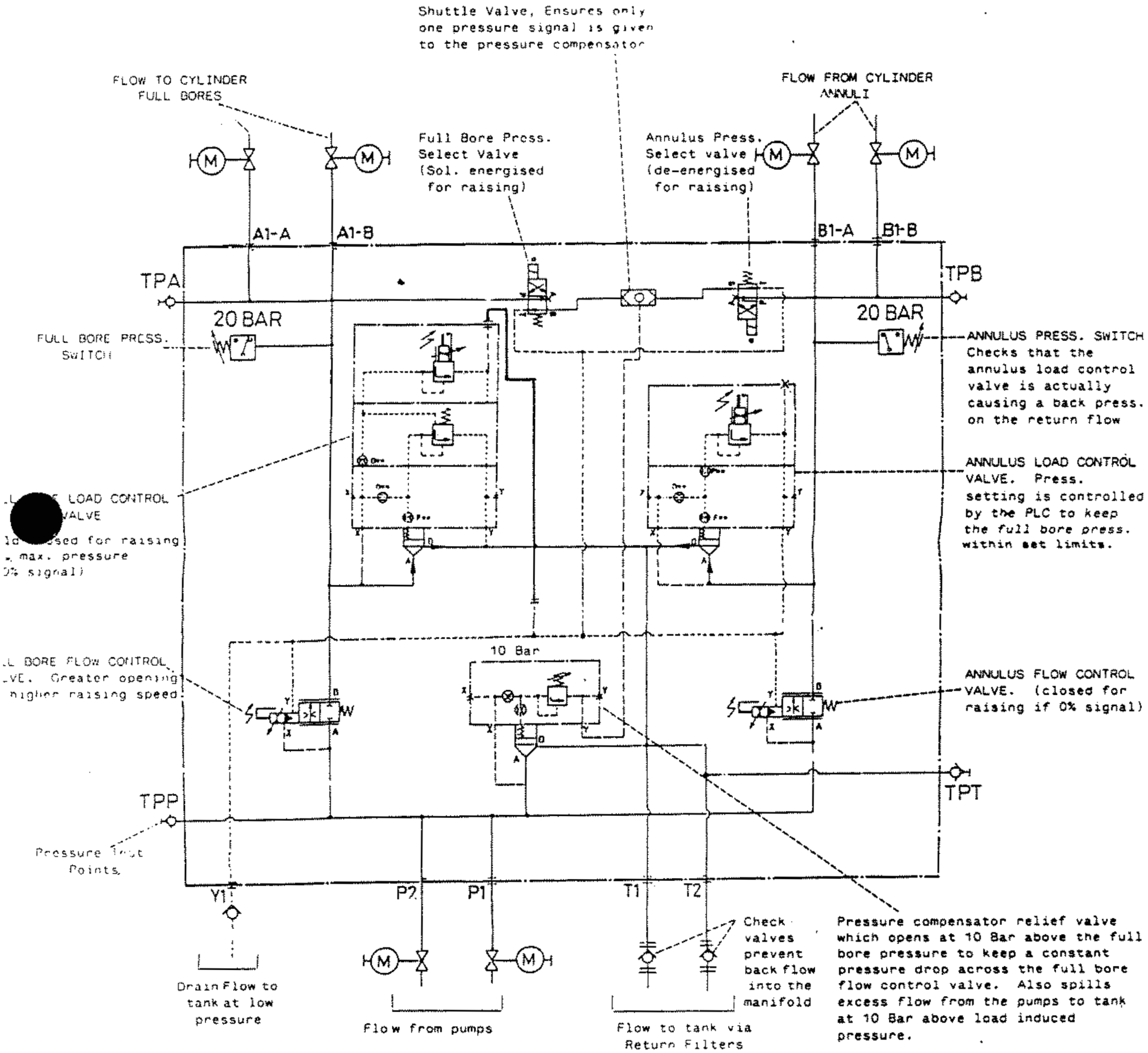
In Conclusion

The bridge has operated very successfully to date, there have been one or two breakdowns but the built in redundancy and intelligent control of the implementation of standby systems has not caused a failure to operate. Needless to say there has been a substantial investment in software as well as hardware and the client fully cooperated with the extended commissioning such a system requires. He could see the long term benefit to his staff and is now reaping the rewards. The sophistication of the hydraulic system relies on the abilities of the PLCs to provide control functions normally done hydraulically. Unless a customer is already contemplating the use of computer power and datalogging instrumentation the extra cost involved would probably make such a system uncompetitive. In this case the use of the computer power was fundamental to the operation of the system - the bridge could not be controlled by conventional means while still retaining all of the redundant facilities required by the customer. We should look to the future a little, computers are becoming faster and cheaper, they are more acceptable in safety critical situations and proprietary software packages for networking, diagnosis and graphical display are becoming more readily available. Perhaps Stoneferry Bridge is just a taste of things to come.


Connection to North Bridge Cylinders
A1
B1
T3/AC
Main Manifold
Bypass Manifold
North Tank
Tank Balance Line
South Tank
Suction Isolators (4 Off)
Suction Isolators (4 Off)
North Pumps
Interconnection Valves
South Pumps
Connection to South Bridge Cylinders
T3/AC
B1
A1
Main Manifold
Bypass Manifold
MAJOR ROUTE DISTRIBUTION ACROSS ALL MACHINERY
= Motorised Isolation Valve
= Hand Operated Isolation Valve
= Check Valve

5.3 Fig 1

(1) MAIN MANIFOLD - RAISING



Shuttle Valve, Ensures only one pressure signal is given to the pressure compensator

FLOW TO CYLINDER FULL BORES

FLOW FROM CYLINDER ANNULI

Full Bore Press. Select Valve (Sol. energised for raising)

Annulus Press. Select valve (de-energised for raising)

FULL BORE PRESS. SWITCH

ANNULUS PRESS. SWITCH Checks that the annulus load control valve is actually causing a back press. on the return flow

.L E LOAD CONTROL VALVE ld sed for raising . max. pressure 0% signal)

ANNULUS LOAD CONTROL VALVE. Press. setting is controlled by the PLC to keep the full bore press. within set limits.

.L BORE FLOW CONTROL .VE. Greater opening higher raising speed.

ANNULUS FLOW CONTROL VALVE. (closed for raising if 0% signal)

Pressure Test Points.

Drain Flow to tank at low pressure

Flow from pumps

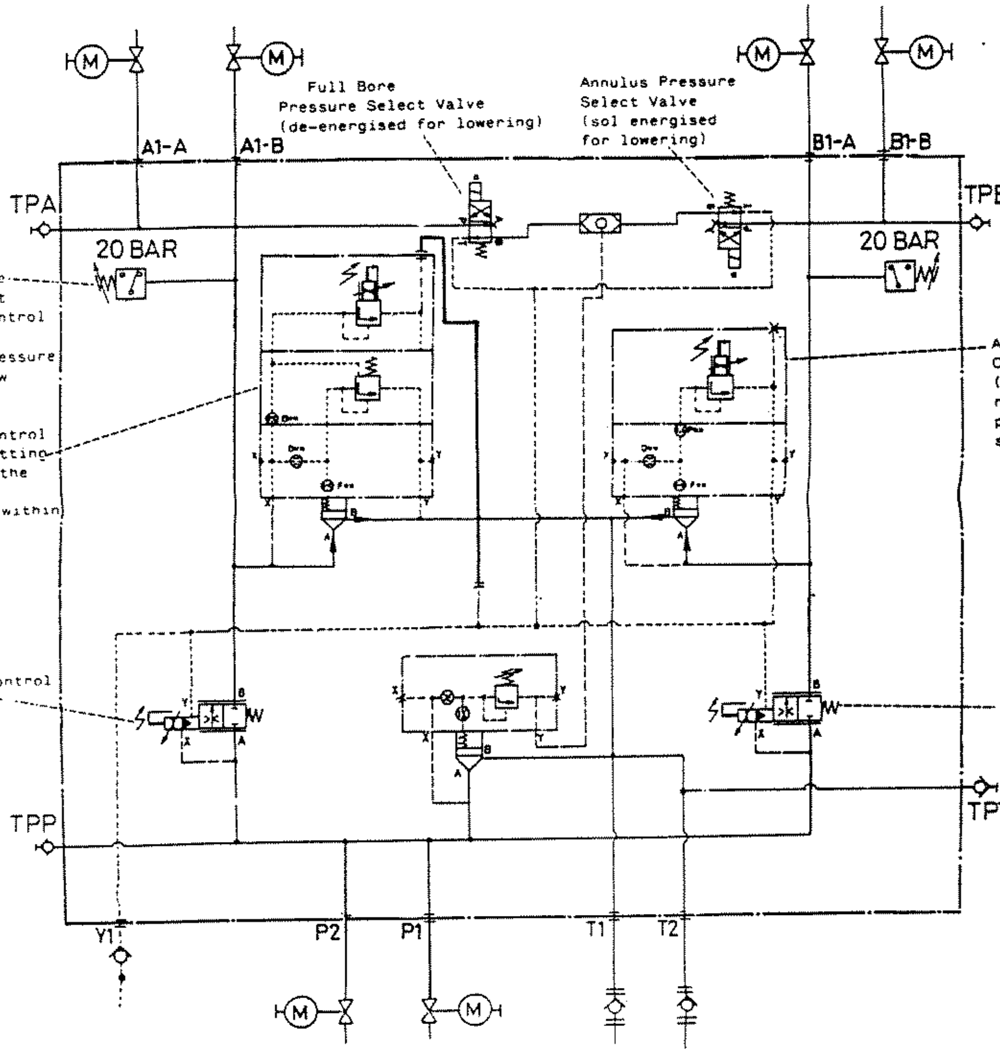
Flow to tank via Return Filters

Check valves prevent back flow into the manifold

Pressure compensator relief valve which opens at 10 Bar above the full bore pressure to keep a constant pressure drop across the full bore flow control valve. Also spills excess flow from the pumps to tank at 10 Bar above load induced pressure.

5.3 Fig 2

(2) MAIN MANIFOLD - LOWERING



Full Bore Pressure Select Valve (de-energised for lowering)

Annulus Pressure Select Valve (sol energised for lowering)

Full Bore Pressure Switch checks that full bore load control valve is actually causing a back pressure on the return flow

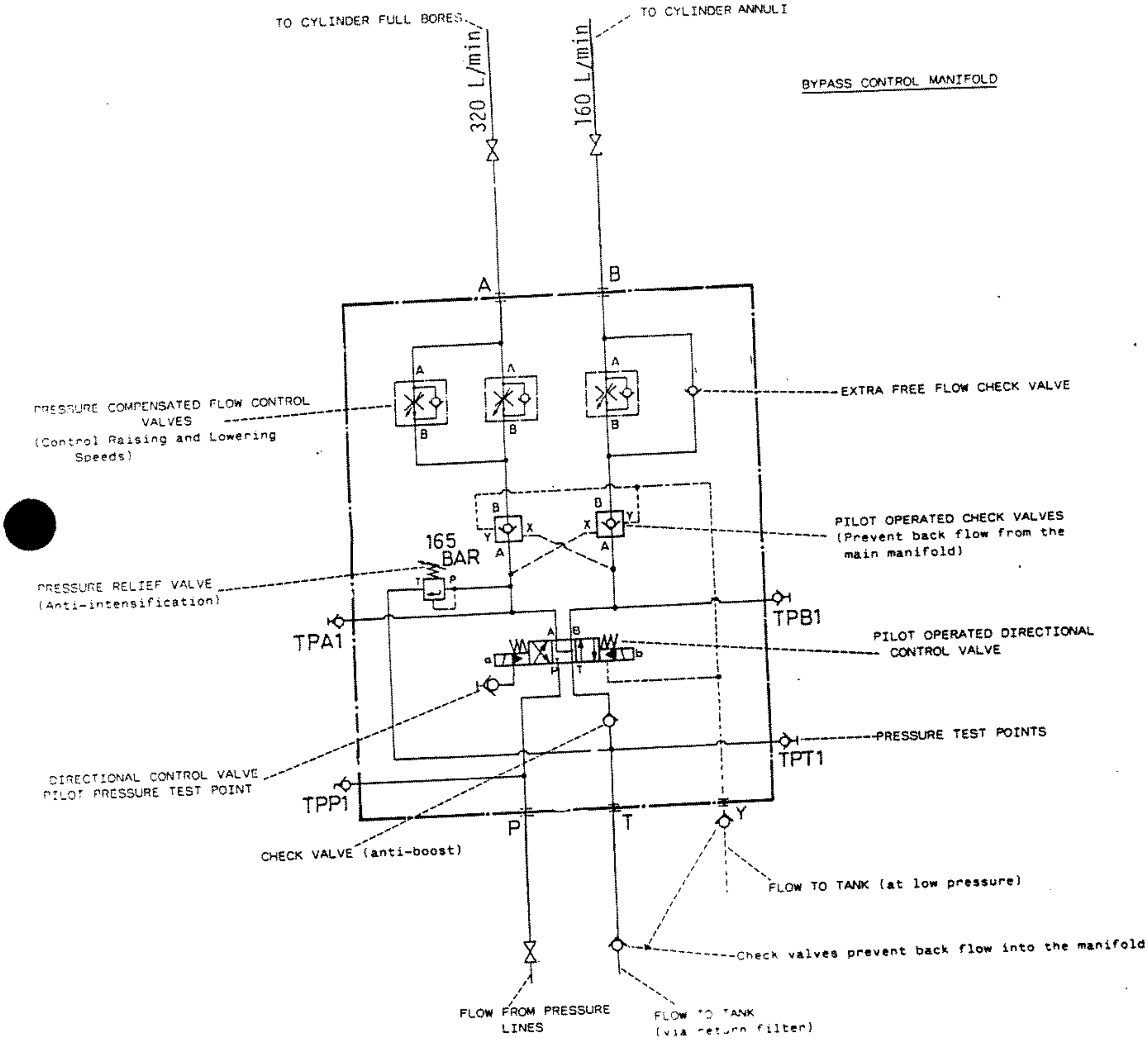
Full Bore Load Control Valve pressure setting [illegible]ontrolled by the [illegible] to keep the Annulus Pressure within set limits.

Annulus Load Control Valve (Held closed for raising, i.e. max pressure, 100% signal)

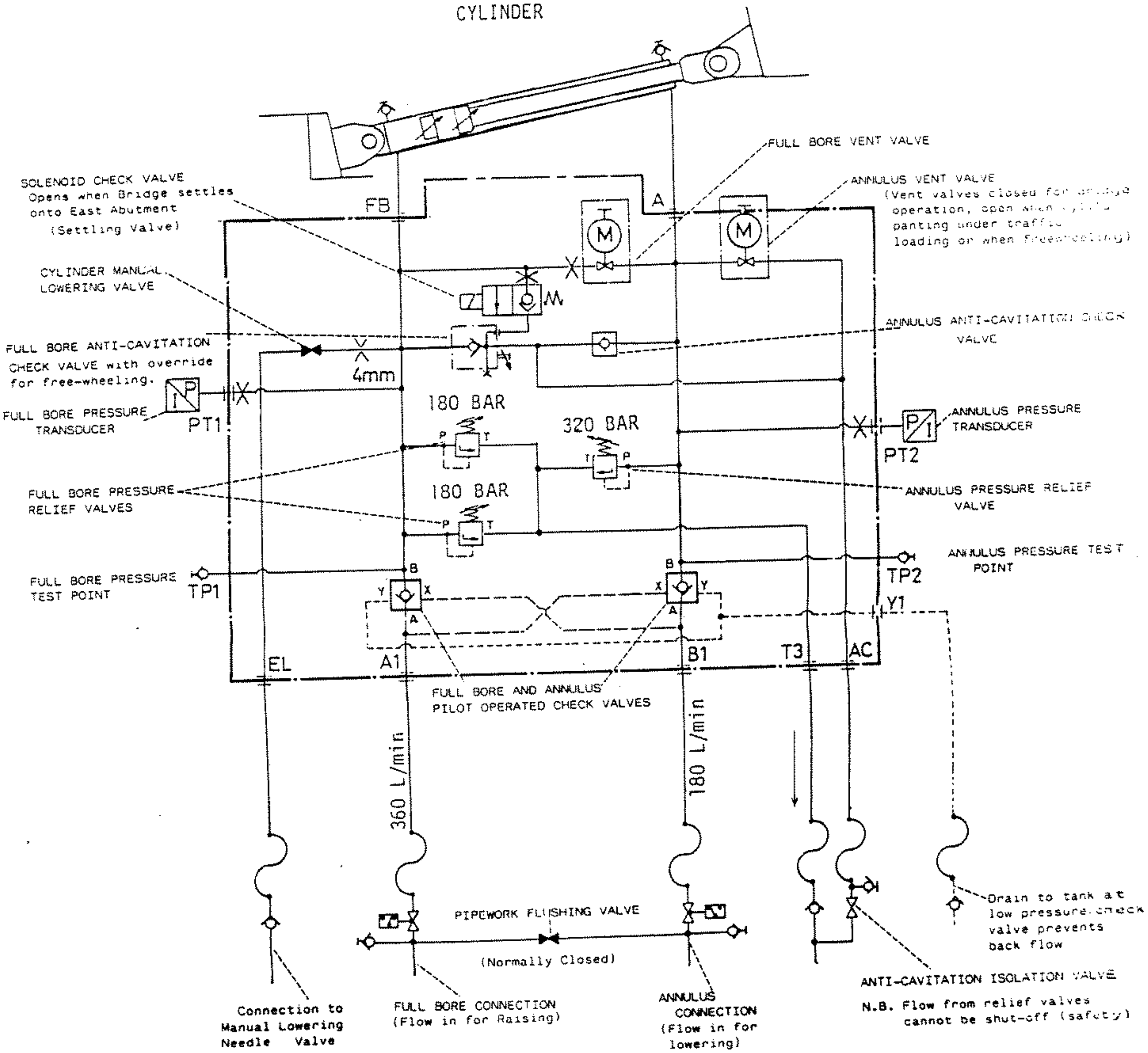
Full Bore Flow Control Valve (Closed for Lowering i.e. 0% signal)

Annulus Flow Control Valve Greater Opening = Higher Lowering Speed

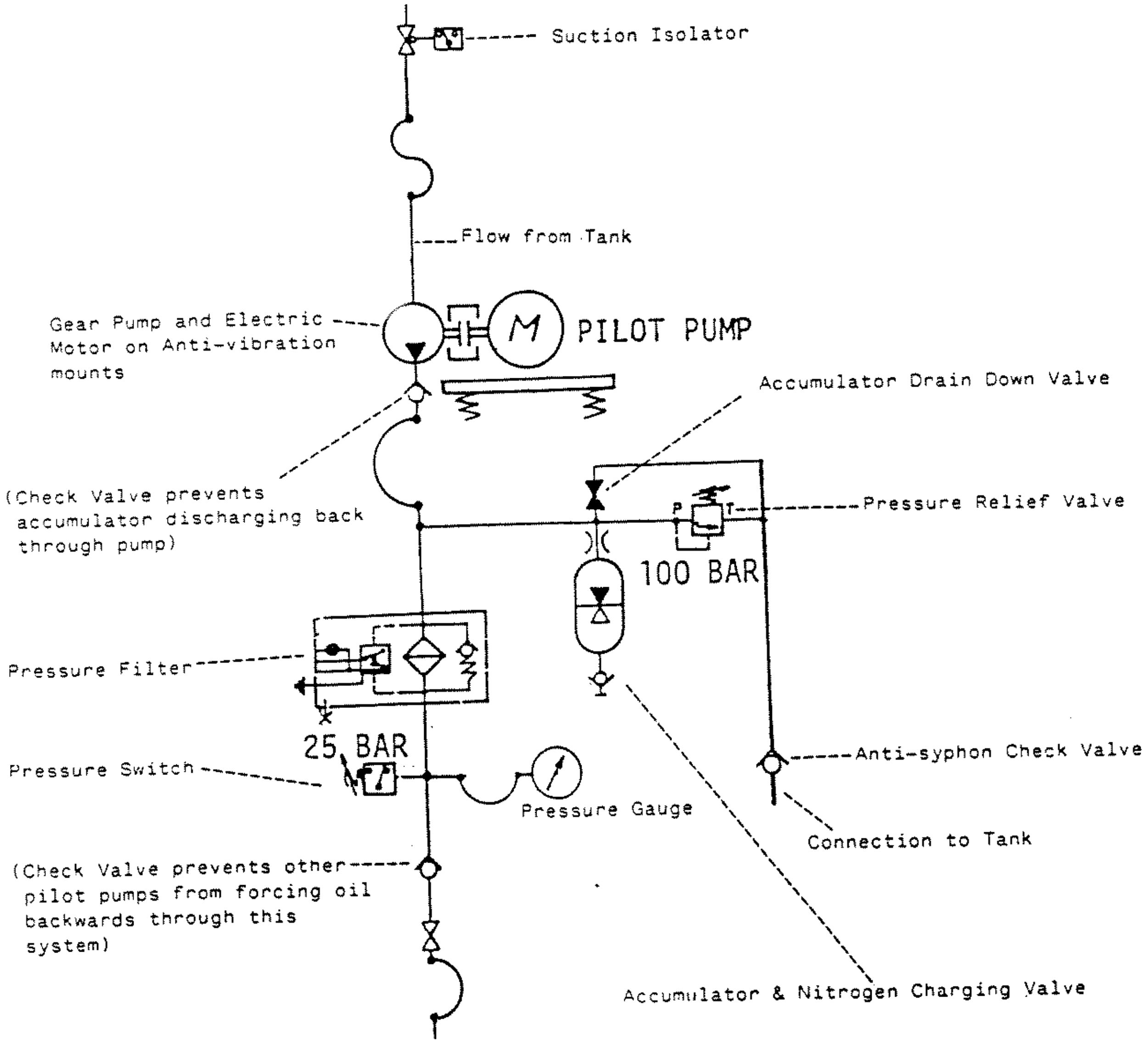
5.3 Fig 3


TO CYLINDER FULL BORES
TO CYLINDER ANNULI
320 L/min
160 L/min
BYPASS CONTROL MANIFOLD
A
B
A
B
A
B
A
B
PRESSURE COMPENSATED FLOW CONTROL VALVES
(Control Raising and Lowering Speeds)
EXTRA FREE FLOW CHECK VALVE
B
B
Y
X
X
Y
A
A
165 BAR
PILOT OPERATED CHECK VALVES
(Prevent back flow from the main manifold)
PRESSURE RELIEF VALVE
(Anti-intensification)
T
P
TPA1
TPB1
A
B
a
P
T
b
PILOT OPERATED DIRECTIONAL CONTROL VALVE
PRESSURE TEST POINTS
TPT1
DIRECTIONAL CONTROL VALVE PILOT PRESSURE TEST POINT
TPP1
P
T
Y
CHECK VALVE (anti-boost)
FLOW TO TANK (at low pressure)
Check valves prevent back flow into the manifold
FLOW FROM PRESSURE LINES
FLOW TO TANK
(via return filter)

5.3 Fig 4

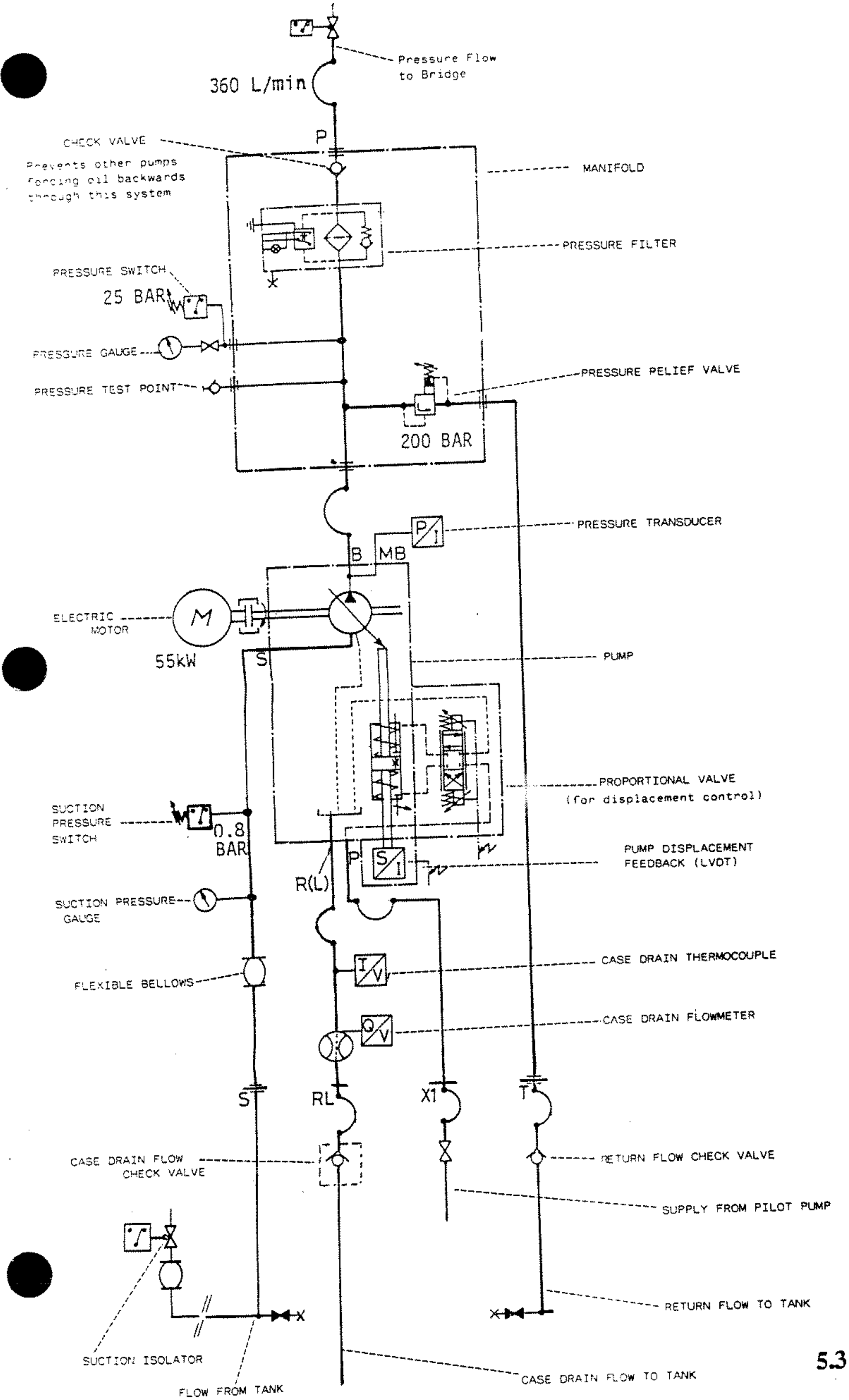

CYLINDER
FULL BORE VENT VALVE
ANNULUS VENT VALVE
(Vent valves closed for bridge operation, open when cylinder panting under traffic loading or when freewheeling)
SOLENOID CHECK VALVE
Opens when Bridge settles onto East Abutment
(Settling Valve)
FB
A
M
M
CYLINDER MANUAL LOWERING VALVE
FULL BORE ANTI-CAVITATION CHECK VALVE with override for free-wheeling.
ANNULUS ANTI-CAVITATION CHECK VALVE
4mm
FULL BORE PRESSURE TRANSDUCER
PT1
180 BAR
320 BAR
ANNULUS PRESSURE TRANSDUCER
PT2
FULL BORE PRESSURE RELIEF VALVES
180 BAR
ANNULUS PRESSURE RELIEF VALVE
P
T
FULL BORE PRESSURE TEST POINT
TP1
ANNULUS PRESSURE TEST POINT
TP2
B
Y
X
A
Y1
EL
A1
B1
T3
AC
FULL BORE AND ANNULUS PILOT OPERATED CHECK VALVES
360 L/min
180 L/min
PIPEWORK FLUSHING VALVE
(Normally Closed)
Drain to tank at low pressure. check valve prevents back flow
ANTI-CAVITATION ISOLATION VALVE
N.B. Flow from relief valves cannot be shut-off (safety)
Connection to Manual Lowering Needle Valve
FULL BORE CONNECTION (Flow in for Raising)
ANNULUS CONNECTION (Flow in for lowering)

5.3 Fig 5


Suction Isolator
Flow from Tank
Gear Pump and Electric Motor on Anti-vibration mounts
M
PILOT PUMP
Accumulator Drain Down Valve
(Check Valve prevents accumulator discharging back through pump)
P
T
Pressure Relief Valve
100 BAR
Pressure Filter
25 BAR
Pressure Switch
Pressure Gauge
Anti-syphon Check Valve
Connection to Tank
(Check Valve prevents other pilot pumps from forcing oil backwards through this system)
Accumulator & Nitrogen Charging Valve

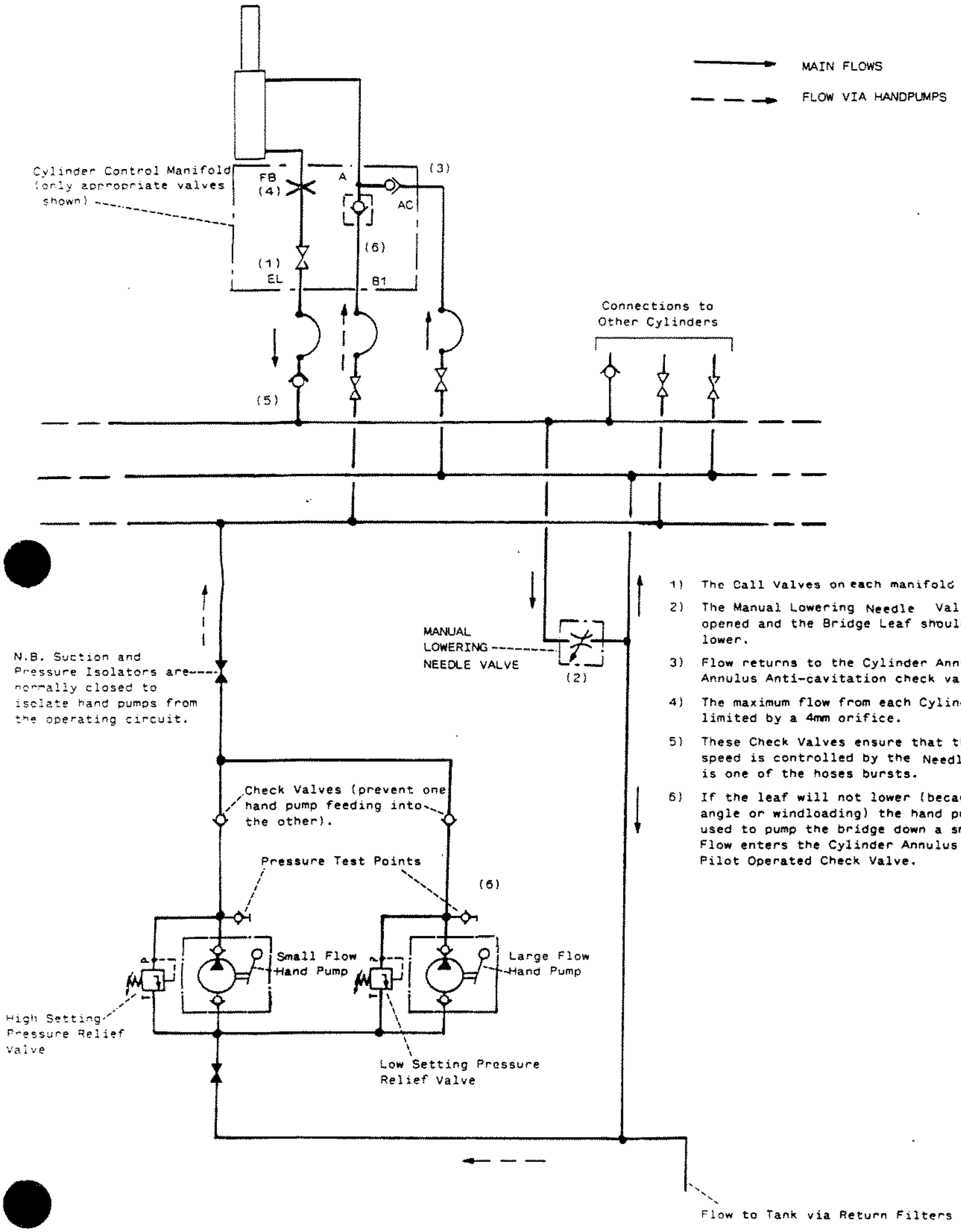
5.3 Fig 6

[redacted]



5.3 Fig 7

OPERATION OF BRIDGE EMERGENCY MANUAL LOWERING



1) The Call Valves on each manifold are opened.
2) The Manual Lowering Needle Valve is opened and the Bridge Leaf should start to lower.
3) Flow returns to the Cylinder Annuli via the Annulus Anti-cavitation check valves.
4) The maximum flow from each Cylinder is limited by a 4mm orifice.
5) These Check Valves ensure that the lowering speed is controlled by the Needle Valve is one of the hoses bursts.
6) If the leaf will not lower (because of its angle or windloading) the hand pumps are used to pump the bridge down a small amount. Flow enters the Cylinder Annulus via the Pilot Operated Check Valve.

5.3 Fig 8