Heavy Movable Structures, Inc.

SIXTH BIENNIAL SYMPOSIUM

October 30 - November 1, 1996

Doubletree Resort Surfside
Clearwater Beach, Florida

Hydraulic Slewing Drives for the Coleman Swing Span Bridge

by

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HYDRAULIC SLEWING DRIVES

for the

COLEMAN SWING SPAN BRIDGE

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Prepared 8/96

ABSTRACT

Many factors must be considered when choosing a reliable, efficient and environmentally acceptable bridge drive system. Control of speed, direction, and torque, reversing and braking, system efficiency and maintenance are just a few areas that movable bridge design engineers must address when evaluating a drive system. Hydraulic drives possess the necessary characteristics for a reliable bridge drive system.

INTRODUCTION

Today's modern hydraulic systems provide many features that are desirable for movable bridge applications. By their very nature, hydraulic drives provide a soft start characteristic negating harmful mechanical shock. When efficient driving and braking are required in both directions,the drives are generally known as four-quadrant drives. Hydraulic drives can accelerate, brake and reverse as a standard feature with braking torque effectively achieved with the hydraulic motor working as a pump against a hydraulic counterbalance.

Hydraulic drives generally require less servicing as they are enclosed units, protected from the environment with maintenance confined to periodic replacement of the hydraulic filter elements.

Simplicity of the back-up systems as well as flexibility of space engineering allow the hydraulic power unit to be placed in an optimized location. Major drive components such as the electric motor, hydraulic motor, pump, valving and electronic components are typically standard catalog items.

Engineers in the bridge industry are beginning to recognize the advantages of using hydraulic drives. Technological advances of the past decade have enabled hydraulic systems to enhance bridge machinery performance in many areas including operating flexibility, reliability, energy efficiency and long component life.

The purpose of this paper is to familiarize the reader with:

- Components of the slewing unit
- Center distance adjustment housing
- AAHSTO standards as applied to hydraulic systems
- Hydraulic circuit design and operation as applied to the Coleman Bridge
- Environmental responsibility

BRIDGE VITAL STATISTICS

The 3,750 foot Coleman Bridge is the largest double-swing bridge in the United States and the second largest in the world. It is part of Route 17 which traverses the York River at historic Yorktown, Virginia. The new bridge design was done by Parsons, Brinckerhoff, Quade and Douglas, Inc., of New York. The bridge was built for the Virginia Department of Transportation by Tidewater Construction Corporation of Norfolk, Virginia. The swing span hydraulic bridge machinery was engineered and supplied by FLENDER Corporation of Elgin, Illinois.

The twin swing span statistics are:

Length of swing spans	-	500 feet each
Weight of swing spans	-	4,128 tons each
Time requirements	-	270 seconds to fully open position
	-	270 seconds to fully close position

HYDRAULIC BRIDGE MACHINERY

The actuation of the individual swing span is accomplished by the use of four hydraulically driven slewing units. This provides redundancy as each slewing unit can be isolated from the hydraulic circuit by manually controlled ball valves and mechanically isolated by removing the respective pinion gear. The four slewing units are located in their respective quadrant such that their pinions are driving against an externally geared rack. The rack diameter is 601.60 inches.

Figure 1 shows a slewing unit which is comprised of three (3) integral elements. The low speed high torque radial piston hydraulic motor, the single stage planetary reducer with drive shaft, drive shaft housing and lower bearing assembly. A fail safe, pressure released, totally enclosed multi-disc brake is the third element integral to each unit.

The low speed high torque radial piston motor is a multi-cam lobe design; eight lobes with fifteen piston assemblies providing 120 power strokes per revolution for smooth ripple free torque output. It is an industrial class hydraulic motor for use in stationary applications. The cam ring is constructed of 17 CrNiMo6 (AISI 8620) gear steel which is carburized and ground for hardening. Pistons, also made of AISI 8620 gear steel, are carburized, and being mechanically free, operate with no radial load within its cylinder block bore. The dual, plate-type oil distributor ring design, produces the highest volumetric efficiency of any design and is free from damage caused by thermal shock. Distributor rings are constructed of 34 CrNiMo6 and are nitrited for wear resistance and long life. Cam follower roller bearings are large in relationship to the piston area, thus producing long life.

Few parts contribute to high reliability and simplicity. Mechanical efficiency of the motor is 93% starting and 96% running.

The planetary is a single stage torque multiplier, industrial class, with a 5.437:1 ratio. In combination with its hydraulic motor the resultant torque is 305,400 in-lb/1000 psi with a displacement of 1919 in^3/revolution. The planetary has a torque rating, of 699,000 lb-in. Planet and sun gears have spur gearing that are manufactured of alloyed case hardened steel and ground, the ring gear is made of quenched and tempered steel. Planetary gear design allows for large transmittable power ratings per unit size combined with low overall weight. Weight of the individual slewing unit is 6000 pounds.

A totally enclosed, pressure released, multi-disc brake is incorporated for use primarily as a parking brake. It is sized so that it may also be used as an emergency brake in the event that total electrical service to the bridge is lost. The span(s) will come to a controlled stop in five seconds under these conditions. Braking force for each pinion gear is 156,500 lb.-ft. A manually operated hydraulic pump is also provided. Its function is to release the brakes should main system hydraulic pressure not be available.

ANTI-BACKLASH HOUSING

The anti-backlash housing is a center distance adjustment fabrication which ensures proper bridge pinion and ring gear contact. The assembly is pictured in Figures 2 and 3. The slewing unit is lowered into and bolted to the backlash housing via flanges. The anti-backlash housing has its own pilot, bolt circle pattern and flange which is placed into position in the bridge span structure. The entire assembly is then slightly rotated until correct bridge gear tooth contact is achieved. The anti-backlash assembly is then firmly bolted in place. This technique allows for future adjustments to compensate for pinion and ring gear tooth wear. Maximum transmittable power is 288 HP per slewing unit, although all four slewing units are driven by one, 75 HP prime mover. This is due in-part to the conservative natural of the AAHSTO standards, allowable operating pressures, primarily designed for hydraulic cylinder applications on movable bridges.

AAHSTO ARTICLE 2.5.18 HYDRAULIC SYSTEMS and COMPONENTS
This article defines allowable system pressures as follows:
NORMAL OPERATION . . . . 1000 psi
OPERATION AGAINST MAXIMUM SPECIFIED LOADS . . . . 2000 psi
HOLDING AGAINST MAXIMUM SPECIFIED WIND LOADS . . . . 3000 psi

NORMAL OPERATION shall be defined as operation against Condition A loads specified in **ARTICLE 2.5.3.**

OPERATION AGAINST MAXIMUM SPECIFIED LOADS shall be defined as operation against Conditions B & C loads specified in **ARTICLE 2.5.3.**

HOLDING AGAINST MAXIMUM SPECIFIED WIND LOADS shall be defined as holding the movable span in the fully open position, static condition, against the loads in **Article 2.5.3.E.**

ANTI-BACKLASH HOUSING

(continued)

In the case of the Coleman Bridge, with an open gear ratio of 37.06, these operational conditions translate as follows:

CONDITION A of 1000 psi equals a gross torque load of 3832 kip-feet.

CONDITIONS B & C of 2000 psi equals a gross torque load of 6494 kip-feet.

CONDITION E of 3000 psi equals a gross torque load of 9227 kip-feet.

The swing span travels through its 90° arc to a fully open or fully closed position in 270 seconds. It takes 20 seconds to accelerate the span(s) to speed, 200 seconds at speed, 20 seconds to decelerate to a creep speed of 30 second duration to a fully open or fully closed position. Under emergency stop conditions the swing span(s) will decelerate to a full stop in five seconds. Span duty cycle is typically 36 minutes per 24 hour day.

HYDRAULIC CIRCUIT

The hydraulic circuit, shown in figure 4, is of the open circuit design utilizing counter balance valving for deceleration control and proportional, three position four way valving for directional and speed control.

The fluid power system incorporates redundancy at the power unit with an identical standby electric motor/hydraulic pump combination, which is isolated from the circuit by means of a check valve. The back-up pump/motor can be brought into service instantly by a control switch on the bridge operators control console. Design of the power unit, which is a heavy steel framed skid upon which is attached the redundant bed-plate mounted 75 HP electric motors and 266 cc hydraulic pumps, is shown in figures 5 and 6. The 400 gallon oil reservoir is of 316 stainless steel construction as well as is the manifold. Figure 7 shows the manifold block which contains the torque limiting cross-port relief valves, replenishing check valves, counterbalance valves and the attached proportional directional control valve. System monitors include:

MONITOR	**OUTPUT**	**LAMP**
Control Power	Lamp on	Green
Low Oil Level #1	Lamp on	Yellow
Low Oil Level #2	Lamp on & shutdown	Red
Oil temperature 110@F	Lamp on	Yellow
High temperature 150@F	Lamp on & shutdown	Red
Low oil pressure	Lamp on & shutdown	Red
High oil pressure	Lamp on & shutdown	Red

Hydraulic oil is filtered on the pressure as well as the return side of the circuit to an ISO 4406 cleanliness rating of 14/12. During cold weather operations the oil is warmed with a 5kW immersion heater.

Hydraulic control of the swing spans is accomplished by the interrelationship of a pressure compensated, horsepower limited, axial piston industrial class pump, counter balance valves, proportional directional control valves and cross-port relief valves. A discussion and explanation of the function of these components is as follows:

HYDRAULIC CIRCUIT
(Continued)

- **Pressured Compensated -** A pressure control valve whose primary function is to permit a pump to operate at minimum load. It is integral to the open circuit pump. Controlled by system pressure, displacement of the pump decreases as pressure increases, so that the pump output at the preset pressure is only sufficient to make up for leakage.

- **Proportional Directional Control Valve -** Typically a valve whose function is to direct flow through selected passages according to electronic reference signals. They operate in association with electronic driver cards which supply the proportional valves with the correct current signal to modulate valve spool position to the referenced signal, in this application a $\pm$ 10 volt DC signal. The electro hydraulic proportional control valves perform both directional and speed control functions, through their ability to position infinitely an internal valve element to create an infinitely - variable orifice. This variable orifice throttles fluid flow to control load speed. Directional control of the hydraulic motor is accomplished much like that of a conventional solenoid - operated three position, four way valve.

- **Hydraulic Counterbalancing -** A counterbalance valve installed in the outgoing fluid line to keep the load (swing span) from getting ahead of the fluid supply. The valve is piloted from the upstream or pressure side of the motor.

  The use of a counterbalance valve provides a back pressure on the motor outlet, when needed, to prevent the load from forcing the motor to over-run the oil supply, thereby keeping the moving span, in a controlled state. During normal operation, when the hydraulic motor is driving the span, the pilot signal derived from the pressure side of the motor pilots the valve open and removes all back pressure from the motor outlet. During periods of deceleration, inlet pressure to the motor drops to zero and the counter balance valve is then piloted open by back pressure from the motor outlet.

HYDRAULIC CIRCUIT
(Continued)

- **Horsepower Limiting** - Hydraulic horsepower is a function of pressure and flow. The limiting valve, typically integral to the pump, will destroke the variable volume pump when system pressure approaches a preset value, thereby allowing motion at a reduced speed without exceeding the horsepower rating.

- **Cross-Port Relief Valve** - Most fluid power systems are designed to operate within a preset pressure range. This range is a function of the forces that the actuators in the system must generate to do the required work. Being able to control and limit these forces is essential. Relief valves are the safeguards which limit maximum pressure (torque) in a system, by diverting excess oil when pressures exceed preset limits.

ENVIRONMENTAL COMPATIBILITY

As we all must be responsible for the health and well being of our environment it has become necessary for manufactures and suppliers in the hydraulic industry to attend to these matters.

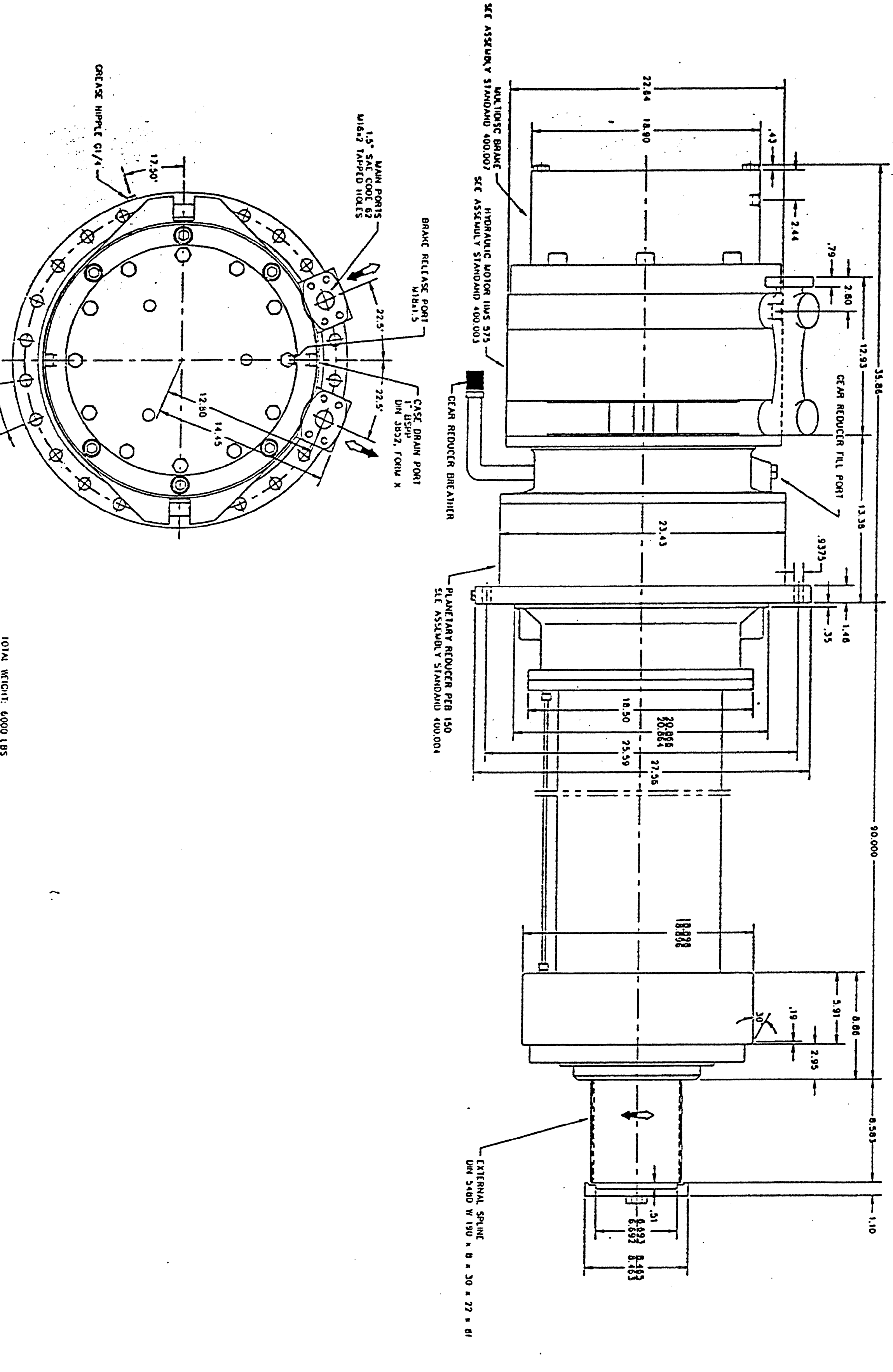
Tremendous advances in the area of reliability, efficiency and leak prevention over the last two decades have contributed significantly to this area of social concern. A recent development by major hydraulic oil manufacturers has brought to the market what is known as environmental awareness lubricants. They are biodegradable, virtually nontoxic anti wear hydraulic oils. These environmentally compatible oils provide characteristics necessary for today's hydraulic systems operating under moderate to severe conditions. They are formulated from high-quality, vegetable oils and additives, which provide specific properties required in hydraulic fluids while satisfying the stringent criteria for biodegradability and toxicity. This includes tests against EPA 560/6-82-003 and the European OECD 301 for biodegradability, which states that 60 percent minimum biodegradability for 28 days being recognized as readily biodegradable. The toxicity is also tested against the EPA 560/6-82-002 and the European OECD 203: 1-12. The environmentally compatible oils are presently available in ISO VG 32 or 46.

CONCLUSION

On May 6, 1996 the twin spans of the new Coleman Bridge were actuated for the first of a series of successful trial openings. The Virginia Department of Transportation accepted ownership of the bridge later that month. This modern four lane movable bridge is equipped with today's highly reliable, industrial duty hydraulic and electronic system componentary.

Long life, ease of maintenance, design flexibility, redundancy, environmental compatibility and operational assuredness are hallmarks of a desirable bridge drive system.

Whether a new or rehabilitated bascule leaf or swing span bridge is to be constructed, the use of robust, industrial class hydraulic bridge machinery is a proven consideration when choosing a drive system for dynamic control of a moving span.



MULTIDISC BRAKE
SEE ASSEMBLY STANDARD 400.007
HYDRAULIC MOTOR HMS 575
SEE ASSEMBLY STANDARD 400.003
GEAR REDUCER FILL PORT
GEAR REDUCER BREATHER
PLANETARY REDUCER PEB 150
SEE ASSEMBLY STANDARD 400.004
EXTERNAL SPLINE
BRAKE RELEASE PORT
CASE DRAIN PORT
MAIN PORTS
1.5" SAE CODE 62
M16x2 TAPPED HOLES
GREASE NIPPLE G1/4
TOTAL WEIGHT: 6000 LBS

Figure 1

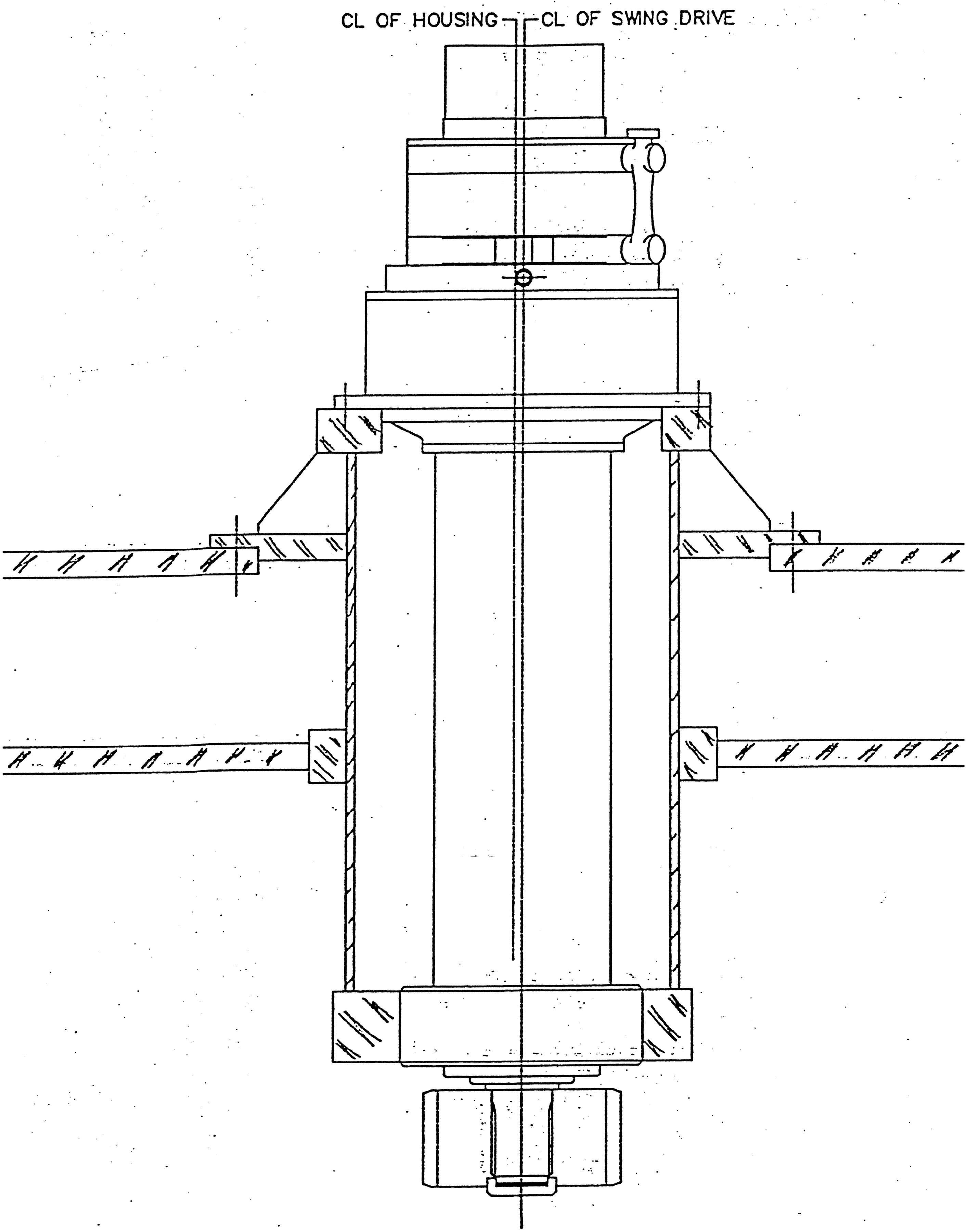
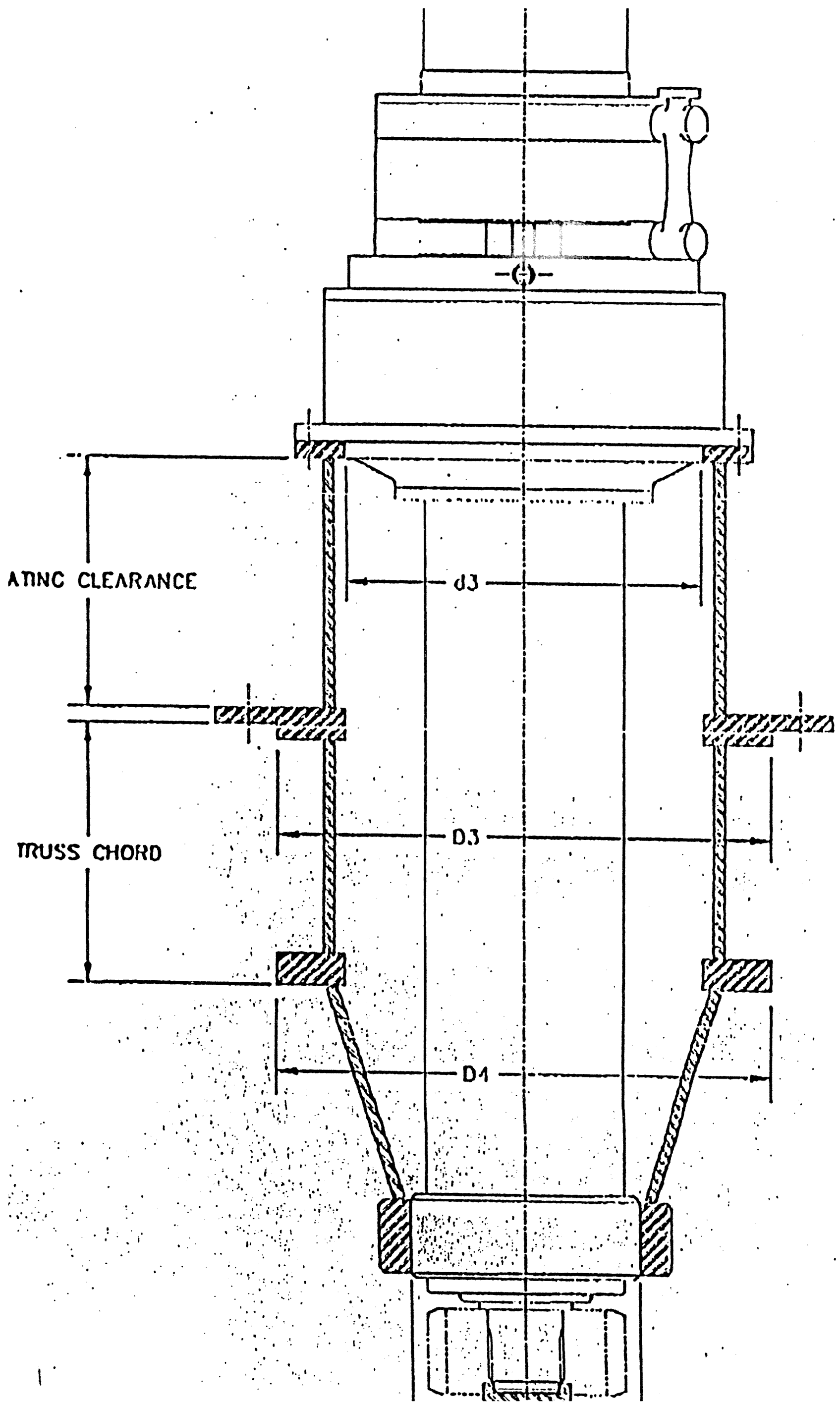


Figure 2



FLENDER PLANETARY SWING GEAR DRIVE
WITH BACKLASH ADJUSTMENT HOUSING

DIAMETERS d3 AND d4 ARE CONCENTRIC

DIAMETERS D3 AND D4 ARE CONCENTRIC

DIAMTERS d3 AND d4 ARE ECCENTRIC TO DIAMETERS D3 AND D4 BY .25 INCH

AFTER THE SWING DRIVE AND BACKLASH ADJUSTMENT HOUSING ARE ASSEMBLED, THE ASSEMBLY IS POSITIONED IN THE TRUSS CHORD AND ROTATED ABOUT THE AXIS OF DIAMETERS D3 AND D4 UNTIL BACKLASH IS SET. THE ASSEMBLY IS THEN SECURED BY THE MOUNTING FLANGE BOLTS ON THE FLANGE OF THE ADJUSTMENT HOUSING.

Figure 3

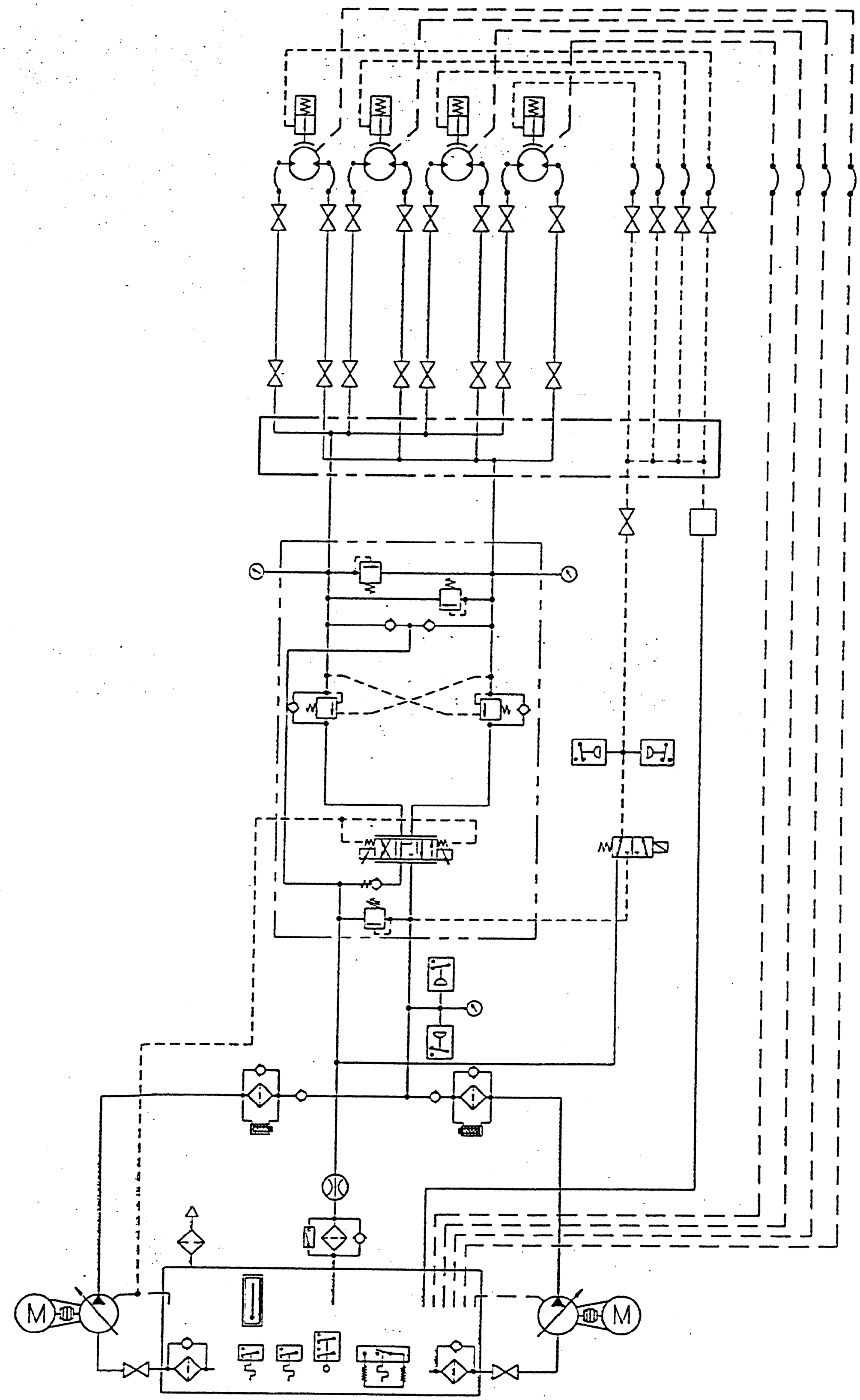


Figure 4

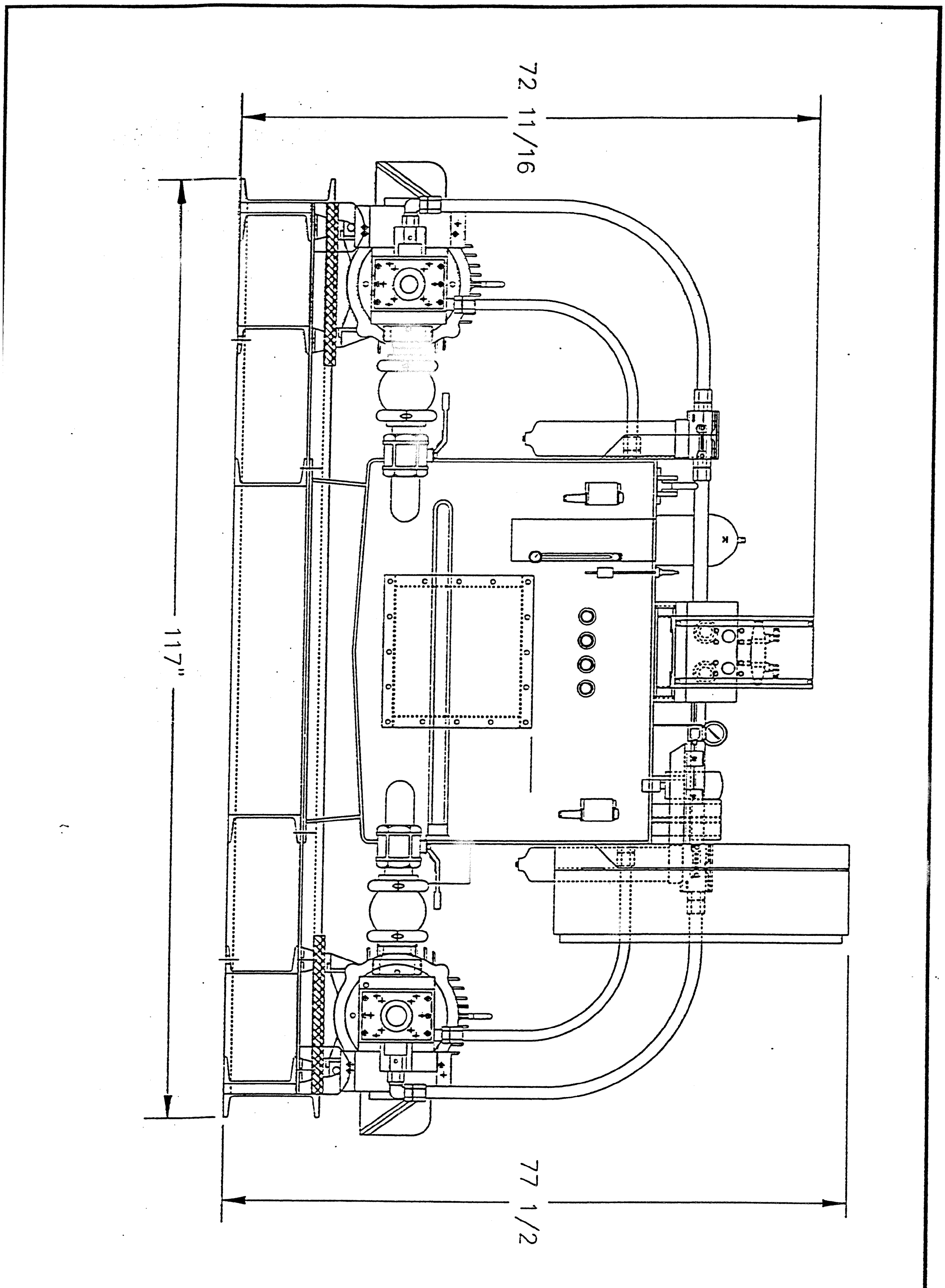


Figure 5

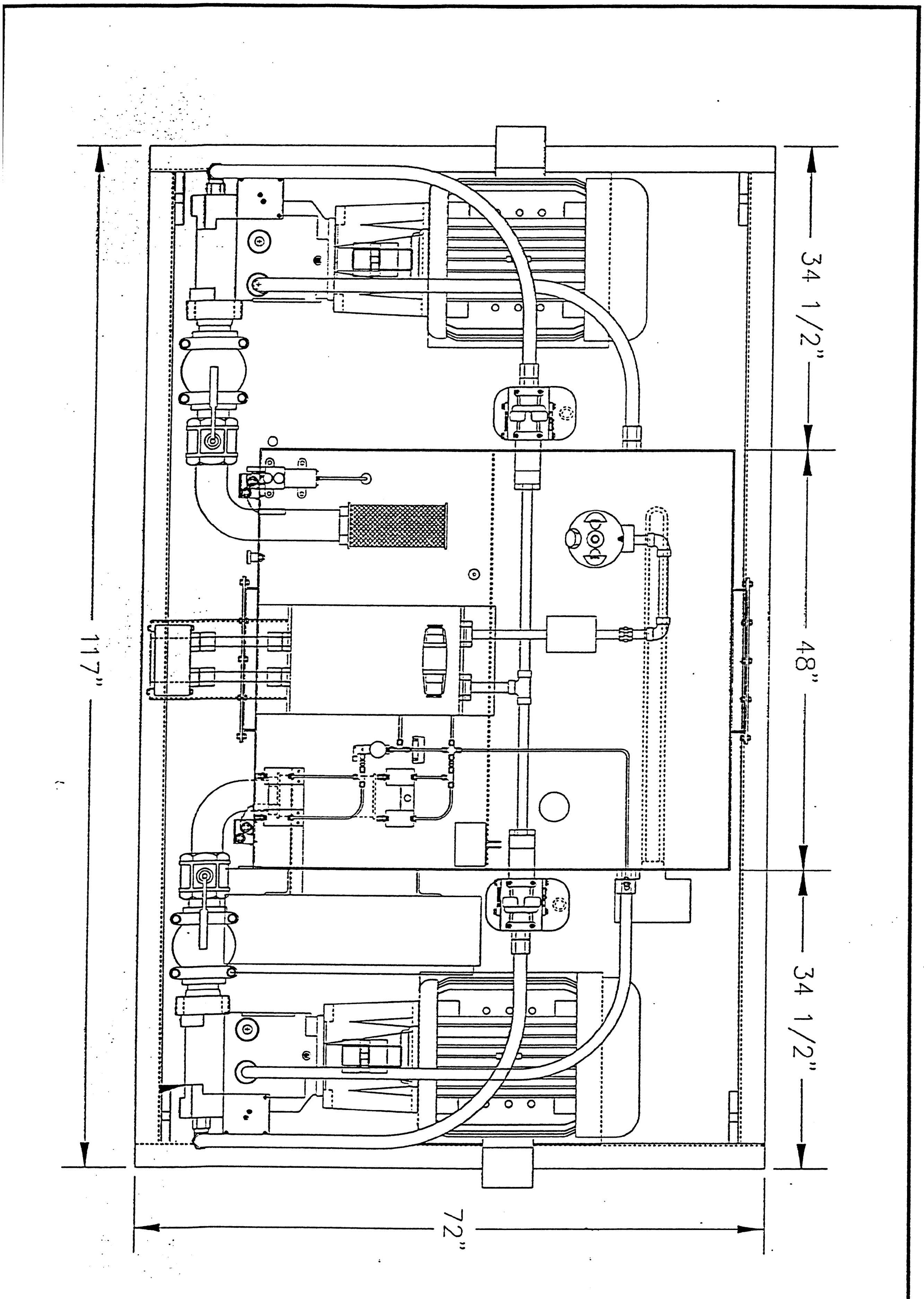


Figure 6

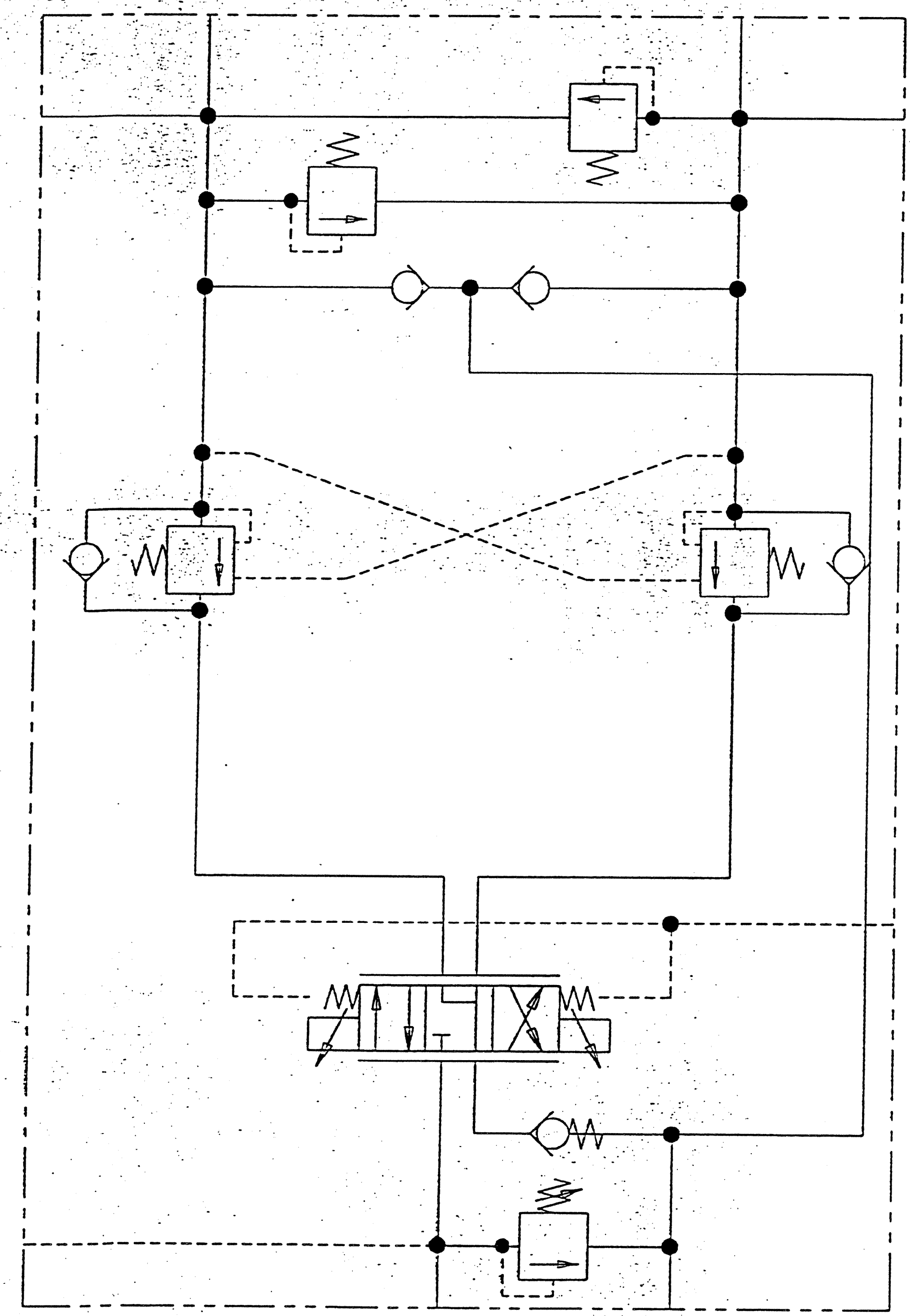


Figure 7