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MOVABLE BRIDGES AFFILIATE

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"Improved Braking for Movable Bridges with Hydra. Drive Mechanisms", M.A. Anleitner, HydraMechanica Corp.,Mich.

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IMPROVED BRAKING SYSTEMS
FOR MOVABLE BRIDGES
WITH HYDRAULIC DRIVE SYSTEMS

ABSTRACT:

Over the years, spring-set, electrically released brakes have been used in conjunction with mechanical drive systems for control of movable bridges. With the increasing trend to hydraulic drive systems both on new constructions and restoration, the need for modern braking systems has become apparent. The design, application, and control of large, spring-applied/hydraulically-released ("SAHR") multi-disc brakes is reviewed. Improved control capability of both static and secondary braking are discussed.

INTRODUCTION.

Over the past ten years, renewed interest, attention, and effort has been directed to the transportation system in the United States. While new means of transport have always been important, the emphasis has changed as technology changes.

In fact, the history of transportation construction shows that the shifting face of technology has been a major influence on transport systems. The United States faced a unique need for transportation technology from its birth. As Henry Adams noted, "No civilized country had yet been required to deal with physical difficulties so serious, nor did experience warrant conviction that such difficulties could be overcome."[1]

Initially, transportation was largely by water. Seacoasts and rivers were highways; population and economic development was linked to waterways. After Albert Gallatin's 1808 report on "Roads and Canals", interest increased in the development of better transportation. Next, private turnpikes and the National Road made wagons and stagecoaches the modern technology of this era. Following DeWitt Clinton's success with the Erie Canal, barges and artificial waterways enjoyed a brief but romantic reign as an innovative mode of transport. But the importance of canal building was greater in the developing the general concept of transportation systems as an American legacy.

In the two decades before the Civil War, railroads supplanted canals. The railroads ruled for nearly a century, as rail technology improved and a continental network was built. In the 20th century, the nation's love for the automobile led to massive construction of new roads. These road programs ultimately resulted in the interstate system that is so indispensable in America today. The latest transportation technology challenging the roads is air travel; the construction of airports, development of an electronic air control system, and the huge volume of air transports being built today attest to this contemporary evolution.

This historical review enables us to see several emerging trends. First, no new mode of transport ever replaced older forms completely; the newer forms have been overlaid on the existing systems. Second, the pattern of growth and change is undergoing a shift that is unprecedented. We have, to a large degree, conquered the distances and physical barriers that Henry Adams described.

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[1]. Henry Adams, *The United States in 1800* (Cornell University Press, 1957).

Transportation systems development is now limited by boundary factors such as congestion, environmental concerns, and fundamental physical barriers. A plot of the speed of commercial transportation from 1800 to 1950 suggests that travel at the speed of light is possible by the next century; but the confines of technology in the growth of transportation is already leading to a new era of engineering and science.

In particular, we are entering a new phase in which the *consolidation and incremental improvement* of existing systems will be the main theme. This can be seen in the drive to refurbish the so-called "infrastructure" of the U.S., and will likely be the central challenge in this field for years to come.

So, what are the connections with our meeting today? There are several that we should recognize:

-We will have increasing needs to develop methods that allow all of the sub-systems to operate with minimum constraints on adjoining sub-systems.

-It will be necessary to apply increasingly sophisticated and intricate engineering techniques to achieve these ends.

-Unprecedented standards for safety, reliability, durability, and cost-control will be created to achieve these ends.

-The need to rebuild, refurbish, and recondition existing structures will be the central means of achieving these ends.

These are themes which provide a backdrop for this presentation. Movable bridges are an excellent example of this process of development. Movable bridges may be as old as bridges—a log across a stream could be moved to allow a raft to pass. Today's movable bridges allow automobile and railway traffic to move across waterways with minimum interference. And most of these bridges have been in existence for many years; but they have to be upgraded and improved to meet the needs of the next generation. This process of reconstruction will require a new emphasis on cost-effective, versatile, and safe technology.

GENERAL REQUIREMENTS FOR BRAKES

Any device that moves must eventually be stopped[2]. This is accomplished through some type of braking system. And, at a basic level, a brake is a device that converts mechanical energy into heat. Since portions of a movable bridge must be stopped, a braking system is needed.

The important features of a brake system for a movable bridge can be summarized as follows:

1. The brake must have sufficient torque to stop the load while in motion, and to hold the load in a fixed position. In addition, it is desirable for the brake to allow controlled motion when overloaded, say by ice or other loads.

2. The brake must be capable of being applied both actively and passively, for normal control and for emergency control.

3. The brake must be able to dissipate the energy of motion whenever it is engaged dynamically.

4. The brake system should be integrated into the other mechanical systems in the bridge itself, comprising a highly reliable, low-maintenance, virtually "fool-proof" device.

BRIDGE POWER SYSTEMS

The majority of older movable bridges in the U.S. today are controlled by electric motors. Gear systems driven by electric motors cause bridge sections to move and return to their original positions. Over the years, flaws in these systems have become apparent. Electric motors that generate high levels of torque are large, expensive, and can be damaged by humidity and saline mist. Insulation materials are subject to gradual deterioration due to ozone generated by the large motors. And these systems require periodic application of lubrication to ensure smooth operation and long life.

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[2] . The Voyager spacecraft may be an exception.

In the past decade, hydraulic drive systems have been developed as a replacement for these older systems. While electric power is still used as the basic motive force, the need to control the output of the base electric motor is removed by the hydrostatic drive system. The central features of this type of system have been described elsewhere, but bear review for today's discussion:

-A central electric motor, operating at a fixed speed (i.e., an AC motor with minimal controls) powers a hydraulic pump.

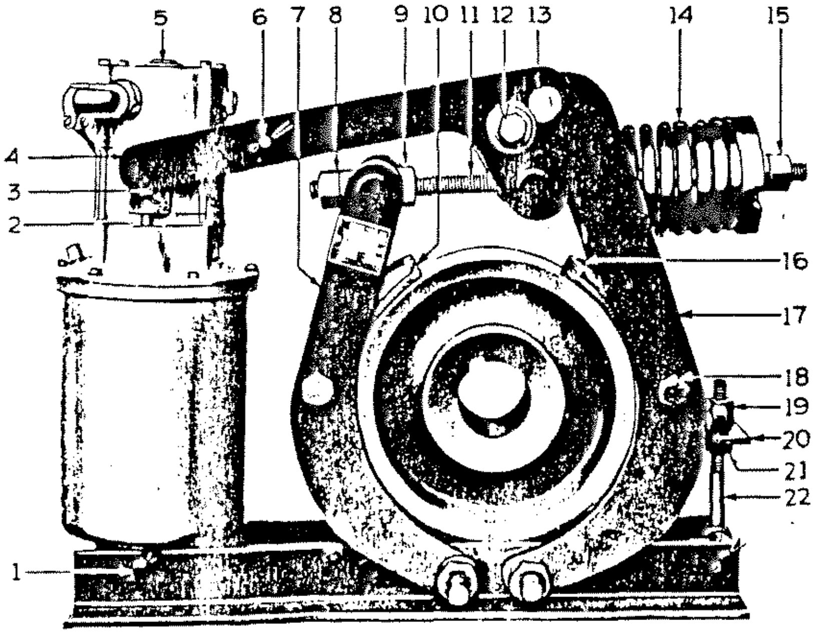
-The hydraulic pump forces mineral oil to one or more hydraulic motors, which drive large gear boxes. The pressure and flow of this fluid is controlled by valves to provide control of torque and speed.

-The use of hydraulic motors allows fluid power to move the bridge sections and to provide hydrostatic braking for dynamic stopping of loads.

-The use of a braking system to hold loads in position and to provide secondary or emergency braking in the event of electrical or hydraulic system failure.

THRUSTOR BRAKE DESIGNS

In older electric systems, braking was provided by a "thrustor" brake, shown below in Figure 1. The main features of this brake are relatively simple. The brake is a double-acting shoe type, coupled to the drive system through the drum. The main force for the brake is provided by a spring load, which forces the shoes into the drum surface. The brake is then released by a small electric motor which drives an impeller to provide oil pressure in a cylinder, which in turn raises a plunger. This plunger then counteracts the spring force and releases the shoes from contact with the brake drum.



1-Pin
2-Piston Rod
3-Adjusting screw
4-Lever
5-Motor
6-Collar
7-Yoke
8-Release nut
9-Release nut
10-Shoe
11-Spring bolt
12-Bolt
13-Pivot
14-Spring
15-Spring nut
16-Shoe
17-Yoke
18-Shoe bolt
19-Equalizing nut
20-Angle
21-Adjusting nut
22-Take up rod

Figure 1. Thrustor Brake.

This brake can be considered a type of "fail-safe" design. When electric power is interrupted, the oil pressure supporting the plunger will drop, the spring will push the plunger back into the cylinder, and the spring will apply the brake. However, it has numerous drawbacks, all of which compromise safety and reliability.

-Timing for emergency (or "passive") application, although adjustable in some versions of these units, is difficult to control. When adjustments are made, they must be made on the brake itself, not at a remote location.

-The brake itself is exposed to environmental contamination, and is vulnerable to corrosion. Although protective containers are often available with such brakes, they are cumbersome to install, and add considerable expense to the brake.

-The torque capacity of the brake is limited by spring size and drum size. The nature of the design is such that a very large physical size is needed to attain the very large torques necessary to provide braking for movable bridges.

-The use of a shoe-type design leads to high loading on the friction pads, which in turn causes significant rates of wear whenever the brake is engaged dynamically. These high rates of wear affect the spring load significantly, compelling frequent adjustments of travel to maintain specified torque.

-The inherent complexity of the thrustor mechanism leads to frequent maintenance. The travel of the plunger, the load applied by the spring, and the equalization of clearance on both shoes must be adjusted at regular intervals to preserve proper operating conditions. In addition, the electric motor which powers the thrustor requires annual lubrication of its bearings, the oil level in the thrustor must be checked and replenished regularly, and the bearing pins that cause the shoes to pivot must be oiled periodically. Again, all of these procedures must be performed on the brake itself, which can be difficult in many bridge designs.

-Due to the proclivities of shoe brakes, the brake cannot slip smoothly under over load conditions. In addition, the tendency of shoe brakes to fade under dynamic loading reduces safety and reliability in both over load slip cycles as well as emergency cycles.

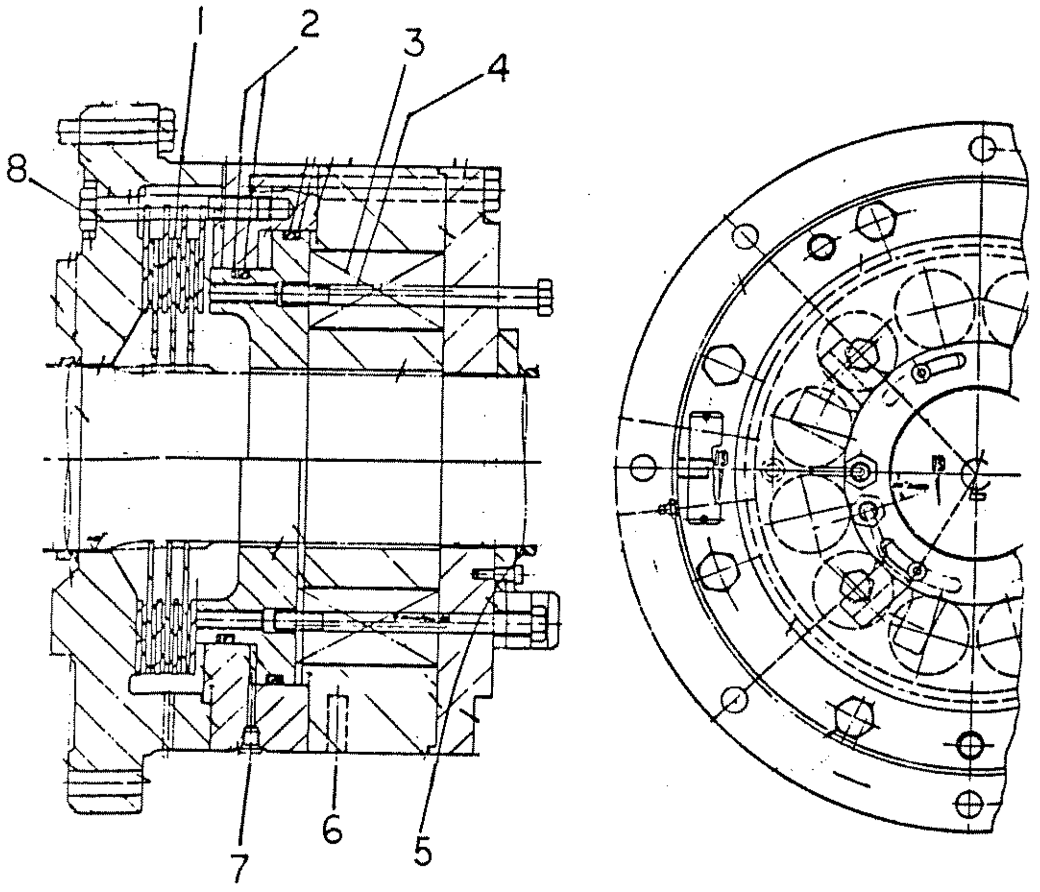
-Because friction linings are sensitive to temperature, and torque for shoe brakes is a non-linear function of coefficient of friction, brake performance can be quite variable from winter to summer. Again, a significant reduction in safety and reliability are a result.

-There are numerous mechanical parts, all of which are subject to fatigue, wear, or other modes of failure.

All in all, the thrustor brake has many flaws. It is a prime candidate for replacement in any re-designed or refurbished bridge project. Finding a suitable replace is a good example of an opportunity for incremental improvements in movable bridges.

SAHR MULTI-DISC BRAKES

The majority of the defects identified with the thrustor brake can be overcome with a spring-applied, hydraulically-released ("SAHR") multiple disc brake unit. A typical design is shown below in cross-section, with the important features identified:



1-Disc Pack
2-Piston & Seals
3-Springs

4-Manual Release Screw
5-V-ring Seal
6-Housing Drain

7-Pressure Port
8-Reaction/Assembly
Bolts

Figure 2. SAHR Multi-Disc Brake.

The essential elements of the brake are simple. Hydraulic pressure is supplied to the brake, causing the piston to overcome the spring force and relieving all clamp load from the disc pack, releasing the brake. When hydraulic pressure is diverted from the brake, either by deliberate control or by failure of the hydraulic system[3], the piston is driven by the springs into the disc pack. This clamp load causes friction between the discs.

The disc pack consists of alternating friction and reaction plates. The friction discs are driven by a shaft, which is connected to the gear system of the bridge, just as the drum is driven by a shaft in the thrustor brake. The reaction plates are mechanically grounded to the brake housing, and cannot rotate, although they are free to slide in the axial direction. When the springs push the piston against disc pack, friction between the rotating friction plates and stationary reaction plates creates braking torque.

The design is quite compact and has few moving parts. The motion of the piston is continuously lubricated by the supply of hydraulic fluid. The total area of friction material is very large in comparison with a shoe brake, leading to much lower demands on the friction material. This means the brake is much less sensitive to wear; in fact, in most bridge applications, such a brake can almost be considered to be wear-free[4]. The number of springs can be large, and the amount of torque possible in a given diameter is much larger than with a shoe brake.

Because the brake is a disc type, it is highly resistant to fade in dynamic use. In addition, because torque is a linear function of coefficient of friction in a disc design, variations in performance with temperature are minimized. This linear nature also allows a predictable torque, which is necessary to achieve a continuous drag in the event of overload on the bridge structure. The relatively thin plates in the disc pack are slightly flexible, providing excellent contact between the friction material and reaction surfaces; there is no lengthy burnishing required to obtain specified torque levels.

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[3] . This can consist of pump failure, line rupture, or even electrical failure of the main motor powering the pump.

[4] . Some wear is inevitable, but, given the design, almost negligible in effecting brake performance.

The basic design is closed and can be easily sealed; this dramatically reduces the possibility of corrosion or other environmental damage. There is a fine mesh filter plug in the bottom of the brake housing, which will allow any fluid (such as a small leak in the piston seals) to escape. Overall, the need for periodic maintenance is almost non-existent. There are no requirements for routine adjustments or lubrication in the brake.

Since the thrustor brake can be manually released by loosening the adjusting nut on the spring, a similar multi-bolt release mechanism has been incorporated in the design. If hydraulic pressure fails, the bolts are tightened, pushing on the piston and releasing the brake. This may be done gradually and safely by a maintenance worker, allowing the bridge to gently move into position in the event of a system malfunction. A locking collar has been added to prevent vibration from driving the bolts into the piston, which could interfere with proper function; a locking lever holds the collar in the correct position for normal operation. As we will see in the discussion of system elements, this is the only operation that must be performed on the brake physically; all others can be performed remotely by hydraulic controls. With an additional feature in the hydraulic circuit, this function can also be performed remotely.

SYSTEM INTERACTION BENEFITS

While the brake design itself represents a significant advance in comparison with a thrustor-shoe type, further benefits can be seen with a SAHR design when a hydraulic drive system is used for motion control on bridge sections. This occurs because the brake itself is an integral part of a hydrostatic drive system, and because fluid power is used for direct control of the brake.

The most substantial system benefit is the complete consolidation of braking function within the hydrostatic drive/brake system. Most movement of the bridge sections can be directly controlled through the hydraulic drive motors in the system. Motions that are opposed by gravity or system friction can be obtained by flow through the motor to obtain the correct clockwise rotation of the motor; with proper valving and controls, hydrostatic forces can even maintain the brake in a set position. Alternatively, the hydraulic motor can be used to move the section to the desired position, and the brake can be engaged to hold the section safely in that position.

Motions that are driven by gravity can be opposed by the hydraulic motor simply by reversing the flow direction from the pump to the motor. This relieves the brake of the most difficult task, of normal dynamic braking.

A very important safety integration also occurs with proper hydraulic circuit design. Because the brake is released when hydraulic pressure is applied, connecting the brake pressure port to the hydraulic source that powers the hydraulic motor insures a "fail-safe" engagement of the brake in the event of a hydraulic system failure. With proper controls, this can occur quickly and reliably in emergencies, but can also be controlled to apply slowly in the event a planned braking cycle is necessary.

The actuation port has a large diameter (SAE #5 o-ring port) that allows the hydraulic pressure to be dumped rapidly for emergency braking. The simplest, most reliable method of actuating this brake slowly is to meter the dump of hydraulic pressure using a throttle or needle valve. This slows the evacuation of hydraulic fluid from the piston cavity and delays application of spring force, slowly applying the brake. However, it is equally important to allow the brake to be released rapidly so that bridge movement can begin quickly after the braking cycle is complete.

This can be accomplished using either a pilot operated or solenoid dump valve in conjunction with a throttle valve. Figure 3 shows the operation with a pilot operated valve (which is generally considered to be the most reliable method for an SAHR brake), but the principle illustrated is similar for a solenoid dump as well.

When the pump provides pressure to the brake, the pilot pressure closes the spring load in the dump valve, and spools the valve to the first position. In this position, flow from the pump to the brakes can proceed rapidly. The dump to tank is blocked when the valve is in this position.

However, when pressure fails, the spring is released, spooling the valve into the second position. The pump flow is now blocked, and the fluid within the brake is pressurized by the springs. In the absence of any obstruction, the flow from the brake back to tank would be rapid, and the brake would engage rapidly. Using an adjustable throttle valve, this flow can be restricted over a continuous range. The slower the flow, the slower the engagement of the brake.

This arrangement has the added attraction of being adjustable through the throttle valve. The rate of application can be adjusted to fit the specific application. It can also be adjusted over the life of the brake, as wear of the friction material gradually changes the spring rate within the brake. Moreover, it is, like the brake, a "fail-safe" control system.

For rapid emergency stopping, a second dump valve can be placed between the brake and the primary dump valve. This valve would have no restriction on the release of fluid to the tank and can be engaged quickly for emergency. However, because the force of rapid shock loads may be detrimental in some bridge systems, such an arrangement is not always useful. Alternatively, a three way valve could also be used to replace the pair of sequential two way valves.

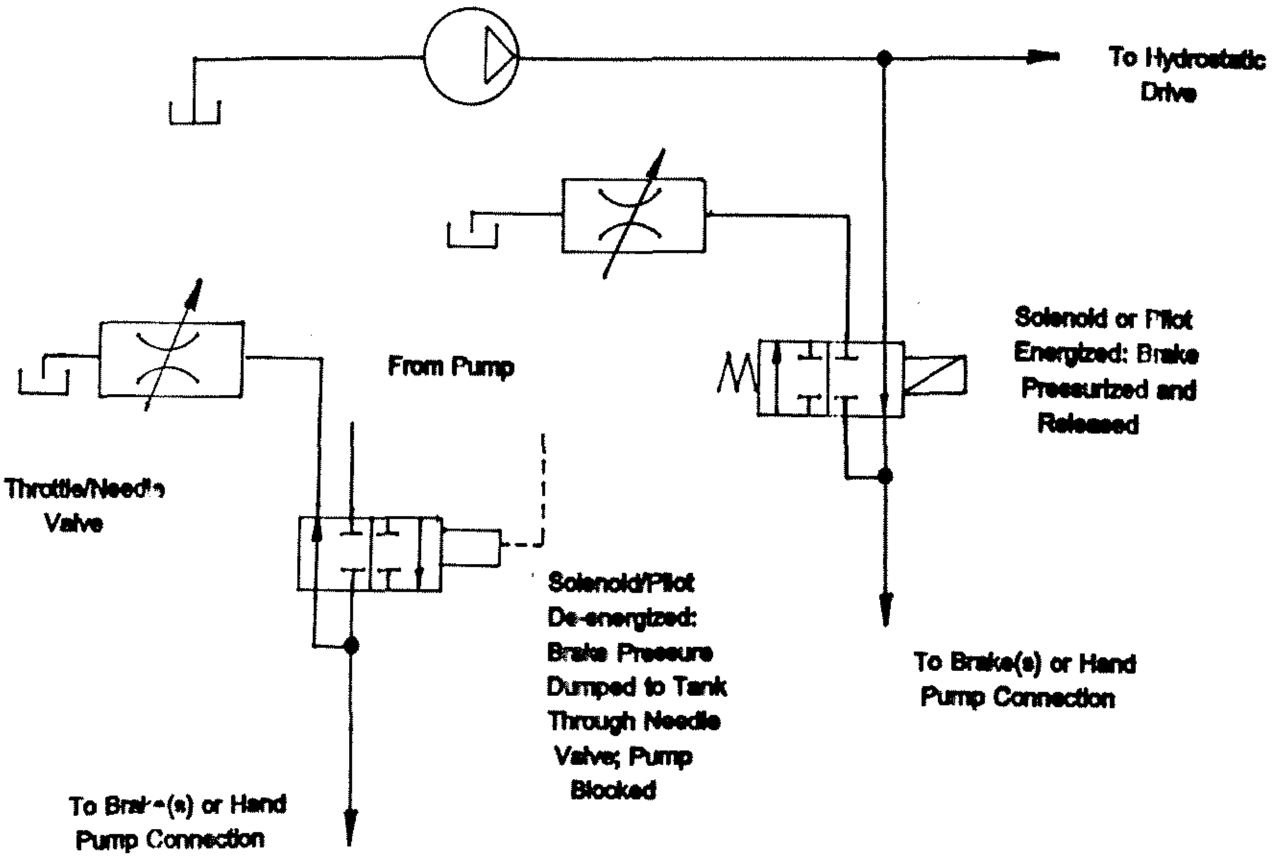

Figure 3. Hydraulic Circuit Options.

As a final hydraulic control possibility, a hand pump may be incorporated into the circuit to alleviate the necessity for releasing the brake mechanically with the screws as described previously. Such an option can allow total control of the brake from an operator's console, and eliminate the necessity to manually release the brake in the event of a hydraulic system failure, which could be dangerous in some systems.

A typical hand pump addition to the circuit is shown below in Figure 4. The automatic hand pump valve is another option which can add redundancy and safety to the system. This valve is used to prevent operator error when using the manual release lever on the hand pump. When the primary circuit is reactivated, the valve automatically dumps any hand pump pressure to tank and blocks the hand pump. This would prevent an accidental loss of brake capability if an operator uses the pump for a manual release but neglects to release pump pressure when normal operation is restored. It is even possible to specify a hand pump with this feature included.

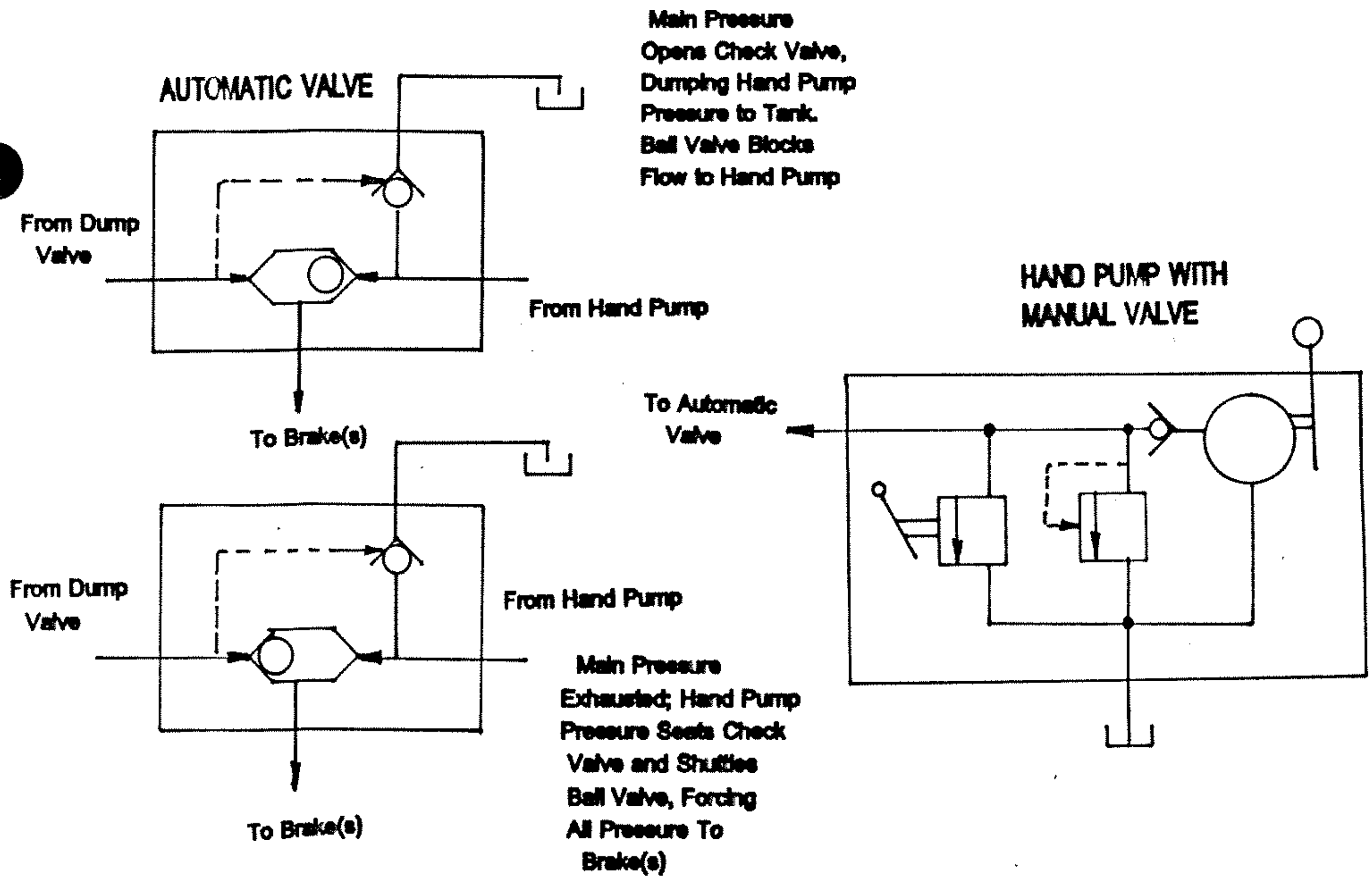

Figure 4. Hand Pump Control Schematic.

SUMMARY.

Historically, electrically controlled thrustor brakes have been used to provide static and emergency braking for electrically controlled movable bridge systems. These brakes have many design flaws, which compromise safety and reliability. With the advent of hydraulically controlled systems, the integration of a spring-applied, hydraulically-released multiple-disc brake can add a significant degree of safety and control versatility.

This addition of safety and versatility occurs from the integral design features of a SAHR design, but reaches its full level when it is integrated into the hydraulic controls for the complete bridge system. With proper system design, a highly reliable, durable, and redundantly safe control system for motion can be integrated into any movable bridge.

Such a device is an example of the process of consolidation and incremental improvement of existing transportation systems that will be a dominant theme in the coming decade. The improvements described for the control of a movable bridge allow greater utility of the bridge itself as well as enhanced utility in one small segment of the transportation system, permitting two sub-systems to operate with minimum constraints on adjoining sub-systems. This technology simultaneously upgrades safety, reliability, and durability with a refurbishment and reconditioning of existing structures. This type of reconstruction emphasizes cost-effective, multifaceted, and safe technology.