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Evolution of Modern Hydraulic Drive Systems for Movable Bridges

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1 Introduction

Movable bridges have been built for centuries. They are usually intended for linking roads across a waterway while, at the same time, allowing free navigation on the waterway. Alternative solutions like tunnels under the waterway or a fixed bridge at a sufficient height above the waterway are not always possible for technical or economic reasons. If we classify movable bridges purely on the basis of physical features, we would find three basic types: Bascule/draw bridges, swing bridge and lift bridges.

2 Historical development

Until the beginning of the twentieth century movable bridges were driven by man power. In the first half of the twentieth century more and more mechanical equipment became prominent. In Europe hydraulic actuators for movable bridges were first studied in the 1950s. A major reason for using hydraulics was because of the lack of ability of electromechanical drives to fulfill the law of motion for the bridges in a satisfactory way. The problem was this: in order to obtain a short moving time the normal speed of the bridge had to be rather high: On the other hand, it was necessary to have a smooth, slow approach to the end position of the bridge. The first solution to that problem was based on the skill of the bridge operator. By successively connecting and disconnecting the electromotor he more or less succeeded in obtaining an end position without excessive shocks.

A technically good and economically acceptable solution was looked for in the field of hydraulic equipment.

3 Bridge Types

A survey of the different types of bridges with special attention given to the characteristics of the driving mechanism.

3.1. Draw Bridges

It was on this type of bridge that the first experiments with hydraulic drives were carried out. The basic concepts of hydraulic drives have since been unchanged. Two cylinders are mounted horizontally parallel to the axes of the main girders in a shallow cellar under the road. A schematic view of a draw-bridge is given in **figure 1**. Bridges of this type are frequently used for spans up to 25 m. They have an unlimited pass to the navigation and need only a small underground structure. In its closed position the resulting moment of the counterweight is usually less than the moment of the bridge structure.

3.2. Bascule bridges

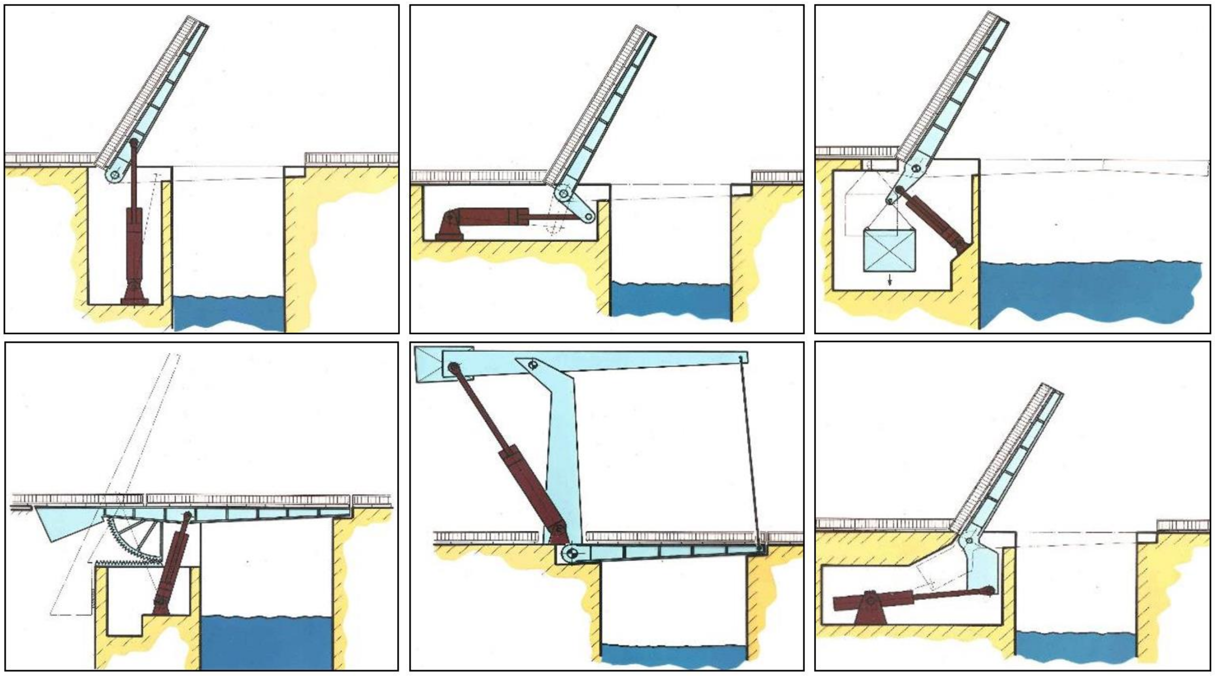


Figure 1: bascule bridge types

Bridge systems using a counterweight considerably reduce the drive power, together with the size of the cylinders and the costs for the hydraulic and electrical components.

The systems shown in **Figure 1** can only show the basic differences. There are, of course, numerous variations to each system, particularly in the arrangement of the drive. For example, these may be either hydraulic cylinders, oil hydraulic motors, or rack and pinion systems. Whether the hydraulic drive comes from a cylinder or a motor may be a further point of differentiation. All these bridge systems have one thing in common: when opening or closing, the load is continually variable in both direction and value. The reasons for this are geometry and wind forces. When designing the hydraulic drive, this change of load must be taken into consideration.

3.3. Swing Bridges

There is also a wide variety of swing bridge systems. The swing bridge shown in **Figure 2** is a symmetrical steel and concrete bridge mounted on a kingpost. The drive is transmitted via four single-acting cylinders working in opposed pair. An alternative is a drive via an oil hydraulic motor and a gearbox or a direct hydraulic drive without extra gearbox. Swing bridges have the same general criteria which must be considered:

- Reversing load direction
- Relatively large masses and short operational times.
- Bending under their own weight

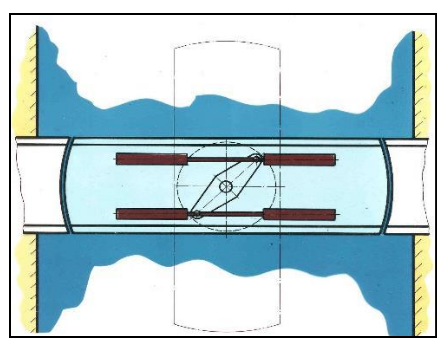


figure 2: swing bridge

3.4. Lifting Bridges

Whereas the previous types of bridges are opened by a rotation of the bridge around a horizontal axis, lift bridges are opened by a translation in the vertical plane. The forces needed to open lift bridges are independent of wind, which is a considerable advantage. The main constituents of these forces are

- the force needed to overcome the friction in the turning wheels of the steel cables connecting the bridge with the counterweight, and
- the force needed to overcome the unbalance, i.e. the intentional unbalance between the weight of the bridge and the counterweight and the unintentional unbalance due to snow load on the bridge.

Common to all cylinder driven lift bridges is the need to synchronize the movement of the four (or sometimes two) driving cylinders. The flow to each cylinder is then the same and a uniform movement of the bridge is achieved. Lift bridges driven by hydraulic cylinders are usually limited to a maximum lifting height of less than 10 m. For greater heights winch driven lifting bridges with steel cables are used. The winches are driven by hydraulic rotating axial piston pumps or by direct current, electronically regulated electric motors.

4 Conception and design considerations for hydraulic drives

It is obvious that every type of bridge and in fact every bridge, has its own specific conception and design. Some general considerations, however, can be given. In the design of driving mechanisms as in most engineering design, a general rule holds: the less complicated the better.

At first, hydraulic systems using constant flow pumps were considered. The speed regulation with that type of pump had to be achieved by applying flow-regulating valves. The real flow through such valves depended on the viscosity of the oil. At that time oil viscosity varied within great Limits depending on the ambient temperature which, for movable bridges, could vary a lot. Further difficulties resulted from the fact that, at low speed, an important fraction of the pump power is converted to heat in the flow-regulating valves necessitating the use of excessively large oil-containers or of oil cooling machinery. Therefore, the use of constant flow pumps was abandoned. Volumetric pumps with variable flow offered a solution.

When contemplating the very size of a movable bridge, one would note at the outset that there exists a requirement for smooth precise controllability. This as well as other parameters of their operation is very easily accomplished by fluid power systems. These parameters include:

- Smooth and accurate acceleration and deceleration;
- Positive locking in any position;
- Driving endlocks or pins;
- Capable of handling variable loading (wind, ice, etc...)

An inherent advantage in hydraulic systems, that can be advantageous to the design engineer, is that system components have an excellent power to weight ratio. Compared to electro mechanical components, they are smaller, lighter, easier to service, and in general are standard stock items available most anywhere. Most common means of powering movable bridges with fluid power are:

- Hydraulic cylinders = linear motion
- Hydraulic motors = rotary motion

4.1. Linear Actuators – Hydraulic Cylinders

The dimensions of the driving cylinders depend among other things upon the wind force and the snow load working on the bridge and upon the working pressure of the hydraulic system. Wind pressure is the main force acting upon drawn bridges and bascule bridges. It has been discovered that for bascule bridges with a span of over 60 m the wind load represents more than 90% of the load that the driving mechanism has to surmount. As those bridges have to be designed to be kept open in heavy weather, bolting mechanisms are calculated for a wind pressure of 1500 N/m². The working pressure in the hydraulic circuit is usually in the range of 210 to 230 bar. Components are calculated for a peak pressure of 1.5 times the working pressure.

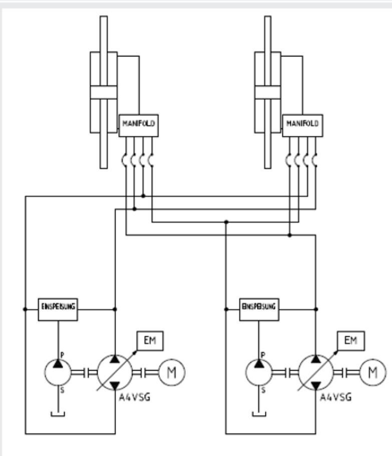
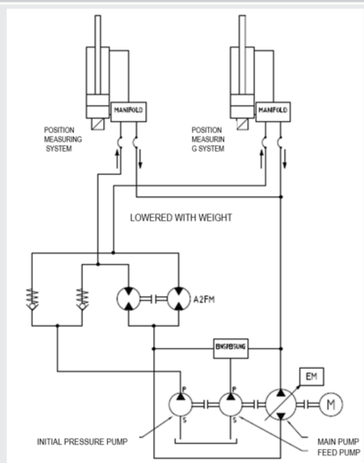
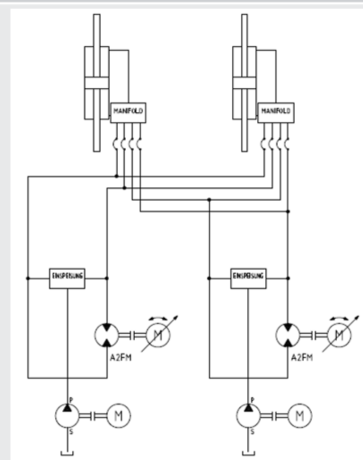
Pump Control	Hydraulic Synchronization	Frequency Control
▪ Electromotive control ▪ For use with double-rod cylinders ▪ Compensation for single-rod cylinders (motor/pump)	▪ pump control + flow divider ▪ coupled hydraulic motors of type A2FM	▪ frequency-controlled electric motor with A2FM hydraulic ▪ motor as pump in a closed circuit
		
▪ Easy to control ▪ Very robust & safe ▪ Proven technology=high reliability ▪ Easy to configure ▪ Easy to maintain ▪ No problem with changing loads thanks to closed circuit system	▪ Easy to synchronize thanks to electronic monitoring (position measurement system) ▪ Easy to make corrections ▪ Same robust and reliable character as with the pump control	▪ Simple hydraulic solution ▪ Small incrementation of soft-start function with respect to frequency control ▪ 4-quadrant operation possible ▪ simple and familiar electronic control

figure 3: comparison table

4.2. Rotary Actuators - Direct Hydraulic Drives

Electro-mechanical drives have in the past been the traditional drive in this industry when variable speed has been called for. Today the Hydraulic Direct Drive solution can in many cases be an alternative to the electro-mechanical drives. The hydraulic drives has proved to be a real alternative on applications where load sharing is essential and in applications where high starting torque is needed. Hydraulic drives are used in many applications with increased popularity and reduced maintenance. Hydraulic direct drives utilize standard components and are very easy to install on the driven machine shaft without the need of gear reducers or foundations.

Using the knowledge and experience available to utilize these features of direct hydraulic drive can help solve many puzzling failure problems from traditional Electro-Mechanical drive. The number of hydraulic drives in the Building and Construction industry is increasing steadily. In applications where variable speed is needed, high starting torque is required, power sharing is essential or where shock loads occur frequently, hydraulic direct drives should seriously be considered.

figure 4: direct hydraulic drive

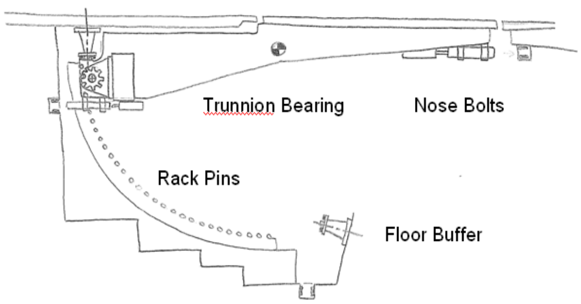
The closed loop hydraulic system has also proven to be insensitive to harsh environments which means a low maintenance cost for the drive. Direct Hydraulic drives have made Technological advancements and are getting more user friendly with increasing training efforts by industries.

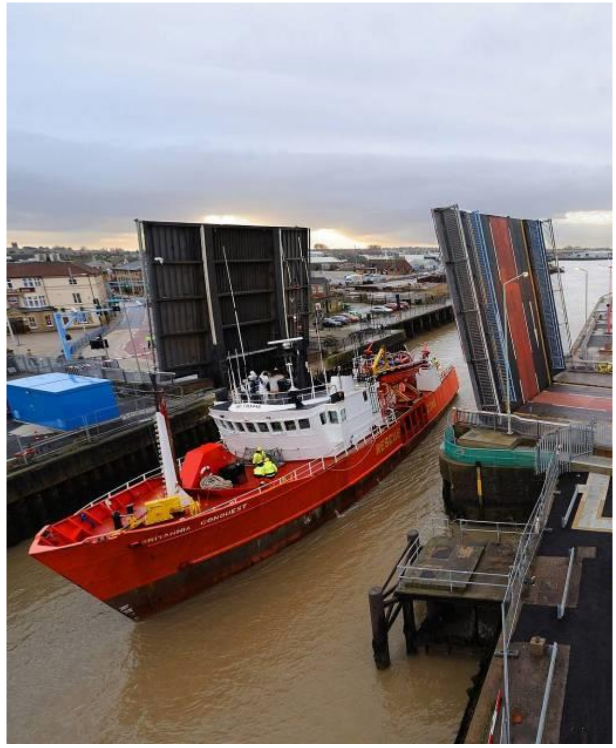
The major advantages with direct hydraulic drives are:

- Excellent control of moving structures using closed loop direct drive
- Frequent starts & stops are easily accommodated
- Good shock load protection
- Constant Torque Capacity Throughout the speed range of up to 1,400,000 Nm
- High mechanical efficiency / Very compact drive / high power density
- Good retrofit possibilities incl. torque arms, brakes and sensor

Either means has its own unique features and both can be depended upon to deliver about the same degree of reliability and accuracy. The retrofit of aged bridges with mechanical drives to modern state of the art hydraulic operation is the shortest route to life extension of the installation, and the installed cost is much lower than purchasing replacements for older mechanical drives in most cases. Most retrofits become permanent installations, once the operator has experienced the controllability.

Project Example: A12 Bascule Bridge, UK





5 Conclusion

Regarding the conception and design considerations for the driving mechanisms it is obvious that every type of bridge, and in fact every bridge, has its own specific requirements. For each basic type, various drive systems are available. The details of the design will be case specific, however the same criteria apply to the general design of the hydraulic system.

One inherent advantage in hydraulic systems is that system components have an excellent power to weight ratio. Compared to electro mechanical components, they are smaller, lighter, easier to service, and in general are standard stock items available mostly anywhere. Other advantages include smooth and accurate acceleration and deceleration, positive locking in any position, driving end locks or pins and being capable of handling variable loadings (wind, ice,… etc.).

The comparison demonstrates that the important characteristics of the various designs and drive systems need to be taken into account to accommodate the differences and advantages for use in different applications, either with hydraulic cylinders (= linear motion) and hydraulic motors (= rotary motion) or open loop and closed loop hydraulic systems.

Electro-mechanical drives have in the past been the traditional drive in this industry when variable speed has been called for. Today the hydraulic drive solution can in many cases be an alternative to electro-mechanical drives. The retrofit of aged bridges with mechanical drives to modern state of the art hydraulic operation can be a short route to life extension of the installation. The cost for a new hydraulic drive system can be much lower than purchasing replacements for older mechanical drives.

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