Miter Gate Machinery, Design Options and State of the Art

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Miter gates are used extensively on navigation locks. They usually can only be operated with equal or nearly equal head (water levels) on the gate. So, the forces that the machinery must overcome include the force needed to accelerate the gate, water resistance as the gate moves, frictional forces in the gate and machinery, and gate resistance due to small differential heads.

Linkages

Four different types of linkages are commonly used to driver miter gates. These are referred to as the Panama Canal Linkage, Fig. 1, the Ohio River Linkage, Fig. 2, the Modified Ohio River Linkage, Fig. 3, and the Direct Connected Miter Gate Cylinder, Fig. 4.

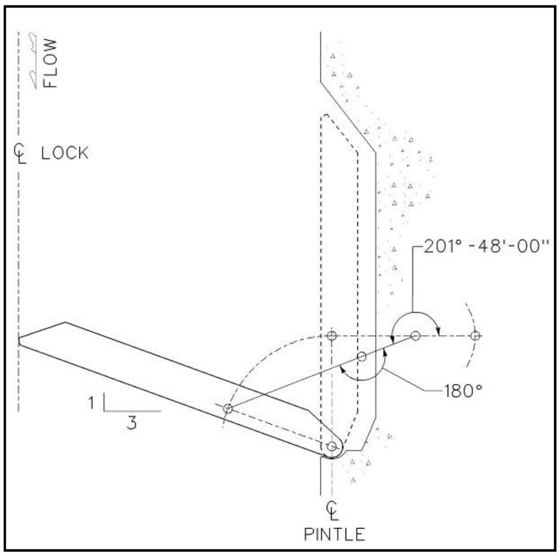

Fig. 1: Panama Canal Linkage

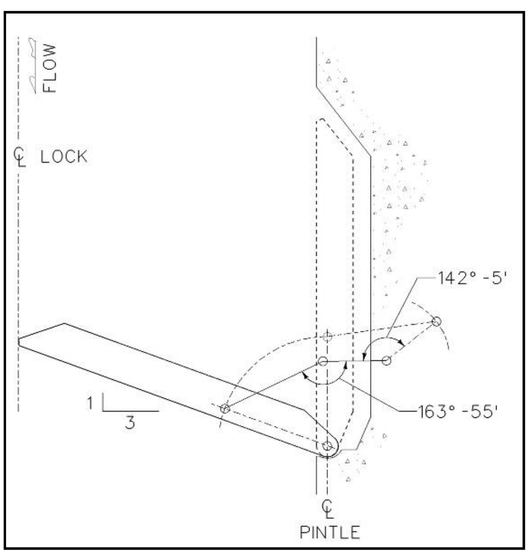

Fig. 2: Ohio River Linkage

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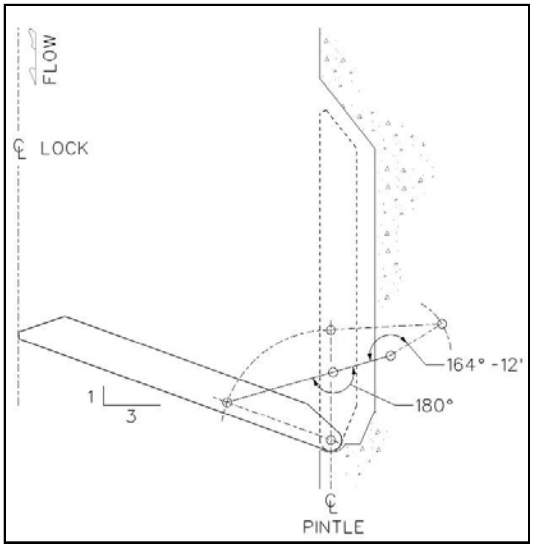


Fig. 3: Modified Ohio River Linkage


Fig. 4: Direct Connected Miter Gate Cylinder

The direct connected cylinder is used primarily on hydraulic drives. Three of the linkages, the Panama Canal, the Ohio River, and the Modified Ohio River, consist of a sector gear and arm with a strut connecting the sector arm to the gate.

The sector gear can be driven by an electric motor with gear reduction or by a rack attached to a hydraulic cylinder (see Figure 5).The Panama Canal Linkage has no angularity between the strut and sector arm in both the recessed and mitered positions. This linkage allows for uniform acceleration from miter or recess to the midpoint of travel and then uniform deceleration to miter or recess. The Panama Canal linkage also has an eccentric connection between the sector gear arm and the gate strut. The gate strut has to pass over the top of the sector gear.

Design guidance for these linkages is available from the United States Army Corps of Engineers Manual EM 2610.

The Modified Ohio River Linkage is similar to the Panama Canal Linkage. The linkage has angularity at the recessed position. The strut and sector gear, however, are located in the same elevation. This geometry eliminates the need for the eccentric strut and sector connection of the Panama Canal Linkage.

The Direct Connected linkage consists of a hydraulic cylinder with its shell (or body) supported in the miter gate machinery recess by a trunnion and cardanic ring assembly (or gimbal) and its rod connected directly to the miter gate with a spherical bearing type clevis.

The Ohio River Linkage has angularity between the strut and the sector arm in both the miter and recess positions. In the United States, the Ohio River linkage also utilizes a rack to drive the sector gear as shown in Figure 5. This system is used at locks that are submerged for months at a time and submerged on a yearly basis. The gears and rack can be quickly cleaned after being submerged. The hydraulic system is sealed even under submerged conditions.

Fig. 5: Ohio River Linkage with rack gear and sector gear

The Panama Canal, Modified Ohio River Linkage, and the Ohio River Linkage inherently decelerate as the gate moves to the miter and recess positions. This can be important if using a constant speed electro-mechanical drive. For the direct connected hydraulic cylinder drive, this deceleration should be provided for with automatic throttling of the oil flow.

While the Panama Canal and Modified Ohio River linkages offer greater deceleration at the miter and/or recess positions, greater forces can be induced in the linkage at these positions. Adjustments and compensation for temperature effects are more important with these two linkages.

The design of the Modified Ohio linkage at the miter position is critical since the linkage cannot be extended any further. End of travel adjustment is minimal and can usually only be accomplished by slight adjustments in the spring strut.

Electomechanical Drives on Panama, Modified Ohio River and Ohio River Linkages

Electromechanically driven miter gate drives in the United States and Europe have traditionally included an electric motor, gear reducer, sector gear, and a linkage which connects to the gate.

Some disadvantages of mechanical drives (as compared to hydraulic drives) include more complex operating machinery linkage and more pivot points for wear including greasing requirements (anchorage, etc). The drive is labor intensive for routine maintenance and for replacement. Components can be difficult to replace and remove, alignment can be critical, and if not done properly, the life of the machinery is shortened. The mechanical drives are generally more susceptible to shock load and barge impact (although barge impact is also an issue for direct connected hydraulic cylinders).

One of the advantages of mechanical drives (whether it is a miter gate drive, sector gate drive, culvert valve drive, etc.) over hydraulic drives is the proven design and reliability. These systems have been in place since the 1920’s and 1930’s in the United States and were originally installed on the Panama Canal. There is a reduced potential for significant oil contamination of the waterway at least in terms of volume. A hydraulic fluid line break or cylinder leak could result in a large quantity of hydraulic fluid being spilled into the waterway. This can be mitigated, however, by using environmentally friendly oil.

Mechanical drives, however, still have the potential for grease and oil contamination in the waterway. This is particularly the case for the open gearing, springs, and bearings. The lubricants used are transferred into the river by surge water and overflow, and consequently can cause a high degree of pollution to the waterway, which is generally unacceptable according to present day rules and regulations in many countries. Gearboxes used on mechanical drives should be raised to extent possible above flood levels or else sealed to minimize leakage.

Also, with mechanical drives, there is no longer sufficient availability assured for spare parts, such as gears. Operating components are generally custom built with long replacement lead time (ie gear box and open gears). These must be returned to the manufacturer periodically, in Europe every 10 to 50 years, for maintenance. There are limited sources for gear boxes, sector gears, screw rods, etc. and if these drives are damaged they must be repaired by the manufacturer.

When using an electro-mechanical miter gate drive, a method to dampen shock loading such as a strut spring should be incorporated to absorb forces from wave action, sudden starts or stops, or minor vessel collisions. This may be more important with an electric drive than hydraulic as the hydraulic drive can be designed with inherent shock absorption.

Use multi-speed motors or variable volume hydraulic pumps to allow a reduced (slower) gate speed at recessed and mitered position and to closely simulate the velocity profile or the Panama Canal or Ohio River linkage. The total gate operating time from recessed to miter or vice versa will depend on the gate size. For smaller gates, 25.6 meters (84-ft lock) an approximate time of 90 sec should be used and for the larger gates 33.5 meters (110-ft locks) an approximate time of 120 sec should be used.

Miter gates can usually carry water heads on one side only. In some delta areas, e.g. in the Netherlands, high water can appear on any of the two sides. In such cases, the drives or separate mechanical locking systems can be used to prevent the gate from opening by reverse water heads, see Figure 6.

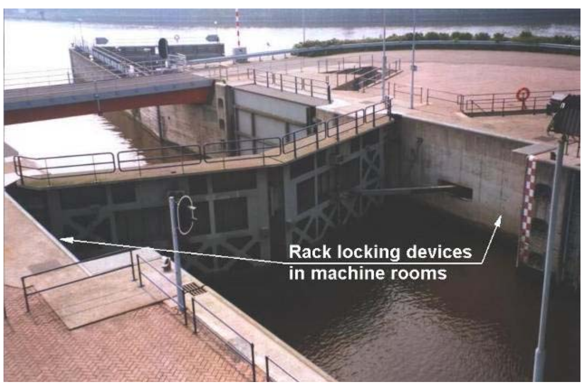


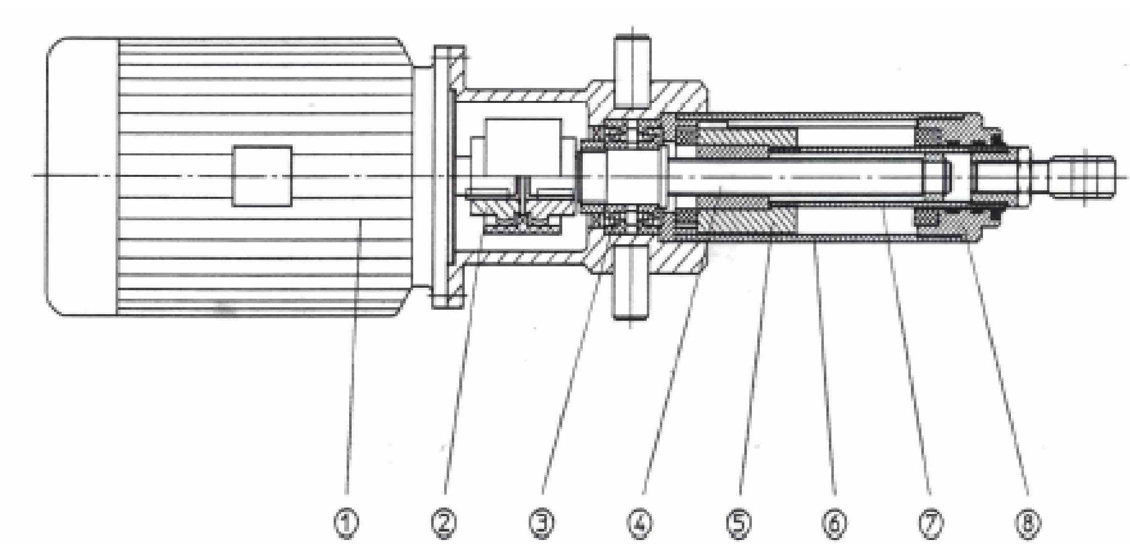
Fig. 6: Merchants' Lock in Den Helder, Netherland

Mechanical Linear Actuators

The linear mechanical electric actuator (Figure 7) is a completely encapsulated, electro-mechanical drive unit, consisting of a drive motor, screw drive with bearings, housing, and the extendable and retractable piston rod as the external power transmission element.

Mechanical linear actuators are an advancement of the mechanical drive systems traditionally used on navigation structures. The drive system is shown in more detail in Figure 8 below. The motor is designed to operate in two directions which then retracts the piston or extends the piston. The piston assembly connects to the gate similar to a direct connected hydraulic drive. A spring assembly protects the drive from minor gate impacts.

Fig. 7: Mechanical Linear Drive at a Miter Gate



1	Motor / Gearbox:	Induces torque at screw drive. Depending on the direction of rotation, it causes the actuator to travel forwards or backwards.
2	Spring assembly:	Integrated spring assembly, protects actuator against operational axial impact loads.
3	Bearing	
4	Screw drive /piston	The screw drive causes the actual move and generates axial force at torque.
5	Housing:	Its task is a general protection against external influences. The housing is used for guiding the piston.
6	Piston rod:	The piston is connected to the piston rod, which itself moves inwards and outwards.
7	Guiding of piston rod:	Its task is to guide the piston rod and at the same time it is a sealing element, also protecting against dirt and aggressive medium.
8	Swivel- / fork head:	Trough the pivot head / fork head, the power is fed to the part to be moved.

Fig. 8: Linear Electromechanical Actuator

With the mechanical linear actuator, forces to approximately 1,000 kN and a maximum (extension) of 5,300 mm can be transferred. The fundamental construction consists of an electric motor which actuates against the system. A screw drive brings this force linearly on the piston rod. Depending on rotation direction of the electrical motor, an ahead or back movement of the piston rod is realized.

The advantages of the linear mechanical actuator, compared with conventional mechanical drives, are documented by several references in the area of hydraulic steel structures. In general, the linear mechanical actuator will be simpler in construction and available as a standard item from multiple manufacturers. Lubrication and maintenance are reduced. It will eliminate the need to custom design and build a drive system.

The linear mechanical actuator is similar to the self-contained hydraulic actuator discussed later. The primary advantage of both types of units is that they are completely self-contained. This would also be the primary advantage of using the linear mechanical actuator over a typical hydraulic drive with a direct connected cylinder.

The totally enclosed, electric linear actuator, with specially selected materials of construction, long-life internal mounted screw drive and gear motor drive, has many fundamental advantages including:

- Lubricants cannot leak into the water due to the fully enclosed design and high-grade seals employed.
- The linear push-pull forces are generated electro-mechanically as opposed to a hydraulic drive system.
- Integrated adjustable controls provide for stroke adjustment and control of maximum thrust force to provide precise control of gate motion and firm closure.
- Maintenance costs are reduced substantially due to high wearing life of components and long interval lubrication.
- Standardized construction minimizes spare part requirements
- High mechanical efficiency drive system combined with power used only when operating means lower energy costs
- Low noise emissions <60dB (A) possible

Although the linear mechanical actuator can produce fairly significant torque, it is still limited when compared to a traditional hydraulic direct connected cylinder design or a traditional mechanical drive system.

The mechanical linear drive should contain an integrated package of disc springs to avoid hard axial impacts. The spindle system should be designed as a trapezoid thread or ball thread or a controlled planet role thread. The completely corrosion-protected piston rod fence is to be built against IEC Ingress Protection (IP) 68 as well as with dirt and ice wipers. The speed and torque supervision occurs with a frequency converter. An emergency hand service is made by through a hand wheel.

Stress analysis of load-transferring components is performed according to European Standard DIN19704.

Linear Hydraulic Actuators

Linear hydraulic actuators or cylinders are used throughout international waterways, including miter gates, various valve types, arresting mechanisms and other associated equipment. Cylinders may vary in size and construction depending on the application. Cylinders can come in different construction, tie rod, screwed, bolted, welded or a combination. The waterside applications dictate the need for a robust construction with specific attention made to the rod material and coating method and rod sealing systems. Cylinder heads may be of:

- Detachable cylinder end (bolted); the removable cylinder base is bolted to the cylinder.
- Butt welded cylinder end; no bending moments transferred.

For maximum fatigue strength, the second option is recommended.


Fig. 9: Large Cylinder operating a miter gate

Cylinders allow a link directly to the driven component avoiding intermediate linkages and all that is associated with them; including transmission losses, alignment, and additional maintenance. Hydraulic cylinders, provide high forces in a compact size, as well as reduced down time of the equipment replacement in the event of failure.

Location and hydraulic supply lines feeding the hydraulic cylinders can be challenging as is the potential of oil discharge from rod seals, resulting in contamination of the waterway.

Larger bore and stroke cylinders require consideration for handling, this may include special attachment points and adapters to facilitate maintenance and installing/removing.

All spare cylinders (including those awaiting to be installed) should be fully retracted and mounted vertically. If this is not possible, then the cylinder should be rotated by 90 degrees periodically. This is necessary so that the piston and rod seals do not generate flat spots due to the excessive weight of the cylinder rod and piston assembly. Otherwise, this will result in under-performing seals when put in service. It is also preferable to ensure piston seals are energized under pressure on both sides while not in use.

When designing a system, minimizing spare cylinders requires consolidating drive cylinders into a few sizes to match all applications across an installation. Careful attention should be given for proper design of force loading, especially when retrofitting existing mechanical installations.

Heavy Duty Mill type cylinders rated at 25 MPa (3625psi) design pressure, bolted/screwed construction will provide an extended life of operation when maximum system pressures are limited to 85% of the design pressure.

Low pressure cylinders (< 16 MPa) are not recommended. The reason is that the lighter cylinder walls are not suitable for corrosive environments.

Quality protective finish is strongly recommended because the high initial expenditure cost will be returned over time.

Base plates for connecting pipes and valves should be mounted directly on the cylinder prior to finish painting.

Pipe thread connection of cylinders should be considered only for cylinders with an inner diameter smaller than 180 mm and a maximum pressure less than 10 MPa.

For cylinders that will be extended for long periods of time, special attention should be paid to cleaning the cylinder rod. This includes providing a hard wiper seal at the rod end entry into the cylinder. Secondary wipers accommodating external discharge of material from the inner wiper seal should also be included.

Miter gate cylinders should have extended support to the rod, by providing high load bearings on the rod and piston seal areas.

The use of rod protective bellows, are to be avoided and not recommended. The bellows become split and trap material inside between the rod and the inside of the bellows. Over time, the trapped materials will damage the rod seals.

Compact Hydraulic Power Packs

A technology that has proven successful in German installations is a Compact Hydraulic Drive (CHD), which is a compact pumping system that can be placed near each component, generally a cylinder.

All compact drives, whether indoor or outdoor, are made as environmentally isolated systems in order to minimize the effects of humidity and contamination of fluid. No fluid changes are required during the life of the unit. Outdoor CHD units are equipped with an overpressure tank, where the fluid level can expand in the existing free space by compression of the air. This is done to absorb the pendulum volume of the hydraulic system and also the volume change due to temperature changes.

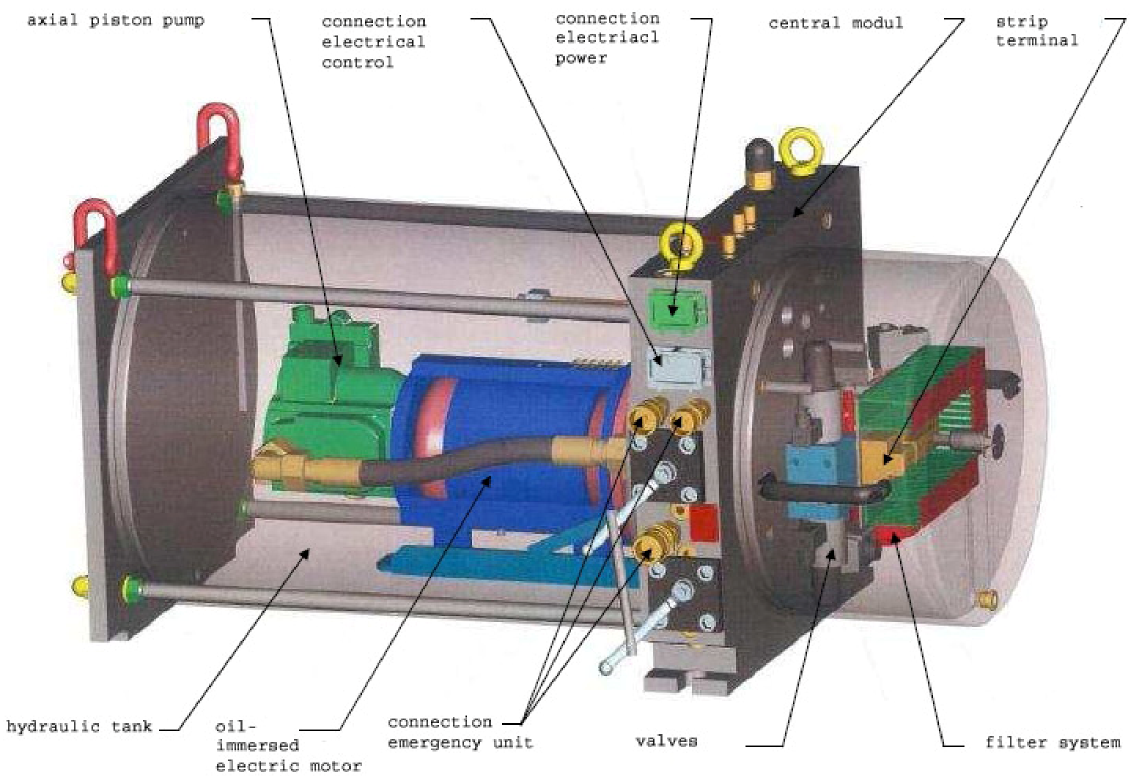


Fig. 10: Hydraulic Compact Drive unit - general arrangement

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The hydraulic compact units are driven by variable speed motors for adapting the speed of cylinders to the respective operational specifications. With variable speed motors, robust constant flow pumps and simple on/off valve techniques for compact units can be applied. In addition to the position sensing of the piston rod, further process parameters such as operation pressure, oil temperature, oil level and filter contamination are monitored by remote control so that disturbances and faults can be detected.

Piping/hosing is designed with hydraulic quick-release couplings, and the cabling is designed with plug contacts of enclosure type IP 68, which are safe against flooding. This permits quick and uncomplicated replacement of units within approximately. 10 minutes. Environmental grade fluid used in the unit is synthetic ester (water hazard class 0).

The hydraulic compact unit is composed of a drive module, a valve module and a connecting central module.

Fig. 11: Typical Hydraulic Compact Unit

The drive module serves as a tank for the hydraulic fluid as well as a drive unit. A pump combination, composed of an axial piston pump and a flange-mounted oil-immersed electric motor are arranged in the drive module.

The drive module operates without maintenance, and the fluid level is automatically checked. The drive module is connected to a central module. The central module serves simultaneously as an anchoring unit for the drive module as well as for all valves.

The central module is also the receiving unit for all electrical cables and plugs, all hydraulic power, control and emergency operation connections, and all control valves. Because of this arrangement, there is no requirement for piping since all hydraulic connections are provided by borings inside the central module. The valve module, also designed as a round vessel and mounted at the opposite side of the central module, is oil free and is composed of a pressure filter with contamination control, the two way-valves of the operation cylinder, and a temperature limiting switch. The interior of the valve module is designed in such a manner that a complete control module can be integrated. This means that the usual control boxes outside the drive are not required.

Electric plug connections (IP 68 rated) are mounted on the central module. Power and control cables, which run from an external control cabinet, are placed into these plug connections.

In the case of damage, quick disconnection can be achieved by releasing the plugs. The compact drives are constructed in weather-resistant aluminum in a water-proof, flood safe design. All outgoing hydraulic and electrical connections are made of stainless steel.

As with the compact units, the drive cylinders are connected by means of hydraulic quick-release couplings and electric plug contacts. These electric plug contacts are position sensing, and have a 24 V valve supply for emergency lowering of locking elements.

The mechanical interconnections of cylinders are designed in such a manner that they can be quickly removed from the maintenance-free bearings with a minimum of effort. Cylinder-specific functions, such as rapid extension at the gate and emergency lowering of the locking elements, in case of power failure of the cylinders, are taken over by the control block mounted directly on the cylinder. Because the cylinders each have their own control blocks with pressure limiting and load holding valves, adjustments at the compact unit are unnecessary. As a continuation of a maintenance-friendly drive concept, the magnetostrictive internal position sensing systems of both the gate and locking cylinders are equipped with a pressure tube, which allows replacement of the sensor without draining of pressure fluid.

Service-Board and Emergency Unit

A further important aspect of the design is the reliability concept of the drive. With the aid of the mobile service-board, it is possible to operate and monitor a compact unit during maintenance and overhauling work in the repair facility, as well as during complete failure of the lock control system. When necessary, simply decoupling the electric plug connectors will allow a controlled manual operation to be carried out.

Operation of the cylinders is also possible with the aid of the mobile emergency units. These can be easily connected to the respective compact unit by means of quick-release couplings without further reconstruction activities. Switching from normal to emergency operation is performed simply by pushing a ball valve. The emergency unit is composed of a basic frame on which is arranged a small gear pump–electric motor combination, manometer, manual valve with pressure limiting valve, as well as three hoses with attached quick-release couplings. The emergency unit can also be operated by means of a small emergency power generator.

All compact drives whether indoor or outdoor are made as environmentally isolated systems, so that neither dampness nor pollution can damage the oil. This kind of construction guarantees the whole life-cycle without oil changes, as the oil is protected against water and dirt entry and the oil properties will not degenerate.

To take the pendulum volume of the hydraulic system and also the volume change rate by temperature changes, the tank of the outdoor unit is constructed as an overpressure tank. Therefore, the liquid difference amount can be accommodated in the tank by compression of the air in it. With the indoor system, an additional outside and maintenance-free hydraulic compensator is used as an adaptable membrane or reservoir separator bag.

Self-Contained Hydraulic System

A self-contained hydraulic drive system combines a hydraulic power unit with a hydraulic cylinder to form a self-contained actuator that is completely sealed and submersible.

Instead of directional valves, the drive unit utilizes a bi-rotational gear pump mounted inside a sealed reservoir that is driven by a submersible and reversible electric motor. The speed and direction of each actuator is controlled by a variable frequency drive (VFD) which controls the speed and direction of the electric motor.

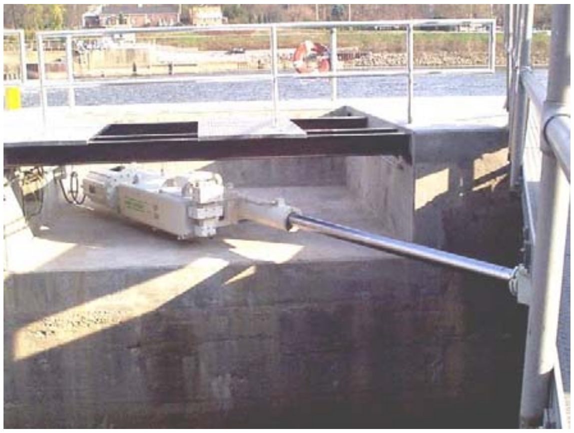

Fig. 12: Self-Contained Drive System – United States Army Corps of Engineers Pittsburgh District

The gear pump is a simple, rugged, positive displacement design. Gear pumps have a high tolerance for fluid contamination, good overall efficiency, and are relatively quiet. While these pumps provide a fixed volume at a given speed (rpm), their flow rate/speed characteristics are linear within their efficiency range. Speed and direction control of an actuator can therefore be provided by driving a reversible gear pump with a variable speed electric motor, which makes them ideal for self-contained type power units. Gear pumps are commonly used for pilot pressure applications. Gear pumps are generally restricted to less than 24 MPa (3,500psi) service.

Sealed reservoirs are primarily used for the power unit of a self-contained actuator. This consists of a power unit attached directly to the hydraulic cylinder it operates. These actuators can be configured in many different ways by changing the design (shape) of the reservoir and where and how it is attached to the cylinder. The direct connected miter gate actuators recently installed on several locks have long slender reservoirs, made from square structural tubing, bolted to brackets on the side of the cylinder.

Sealed reservoirs have a pump mounted inside and submersible motor mounted outside. Since these reservoirs do not have breathers or accumulators, the air pressure inside will vary with cylinder rod position and oil temperature.

The actuator should be designed so the normal pressure range in the reservoir is between 21 kPa and 69 kPa (3 and10 psig). Care should be taken to make sure the pressure never goes below atmospheric pressure or above 207 kPa (30 psig).

Advantages

- Completely self contained – no external piping or motors or hydraulic power units – sealed from dirt and moisture
- Piping friction losses are eliminated
- Reduced total space requirements
- Low maintenance
- Easily replaceable – plug and play
- Force and speed fully adjustable for each direction of travel
- Smooth vibration free operation
- Weather proof and can be provided as an explosion proof unit. Can be installed in various mounting configurations.
- Submersible

Disadvantages

- Limits to cylinder size

- A back-up unit needs to be stored on-site for replacement

Strut Springs

Spring type miter gate struts are commonly used with the Panama, Ohio River, and Modified Ohio River type linkages (Figures 1, 2, and 3). Springs are built into the strut assembly in order to, when compressed, act as a shock absorber to soften the loads transmitted to the operating machinery.

The spring-packages are also used to keep the miter gate leaves under a certain pre-tension in open position, to prevent them from moving under variable water loads. At least three types of springs have been used in this application. These include coil springs, ring or Belleville springs (Fig. 15), preferred in The Netherlands).

Fig. 13: Miter Gate Strut Spring

Miter gate strut springs can also act as a shock absorber for barge impact loads at least for smaller impact loads. Strut springs should also be designed for small amounts of travel adjustment of the linkage and for adjustment of tension.

Fig. 14: Miter Gate Strut Assembly

The advantage of strut springs is to decrease the transmission of shock into the machinery. This is particularly important in electro mechanical drives including miter gate linkages such as the Ohio River and Modified Ohio River.

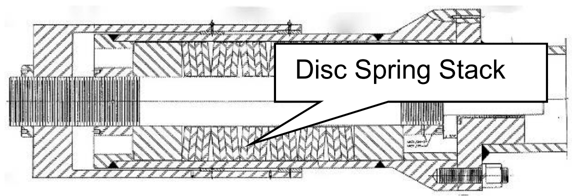

Fig. 15: Strut Spring Assembly

A disadvantage is that they require periodic maintenance and lubrication. Also, they are a common failure point in the miter gate linkage. When the spring breaks, it creates unrestrained movement or play in the strut and results in difficulties in positioning the gate either in the miter or recess position.

Coil springs take the most space but can be obtained from multiple manufacturers. Ring springs are highly efficient and have a high spring constant or a high capacity per unit of spring weight or volume. A disadvantage of ring springs is that they are available from a limited number of manufacturers.

It is important to maintain lubrication of the strut springs, particularly the ring spring and disc spring types, in order to ensure maximum life. Usually this means filling the spring chamber with grease.

If a strut spring is broken, causing play in the linkage, the exact position of the gate will be unknown unless sensed directly from the gate or from the machinery. This can be a problem if the position of the hydraulic cylinder or other component of the drive train is used to indicate gate position. This could then lead to a false indication of gate miter.

Supporting of Miter Gate Cylinders

Fig. 16, 17, and 18Fig. show the design of a cylinder support and the linkage of the cylinder to a gate, which is designed for a quick replacement of the cylinder.

Furthermore, this design is able to be used in existing drive pits at underground level, without the need for civil work. The existing steel foundations are utilized for the drive. The existing trunnions are removed and the new support structure is bolted to the steel foundation by means of a base plate.

Fig. 16: Supporting of gate cylinder for quick replacement

The cardan joint, where the drive cylinder is installed on its central axis, is designed as a closed, compact frame with bearing journal. The gate cylinder can be very quickly dismounted and replaced by simply pulling both exterior bearing journals.


Fig. 17: Cardanic support of cylinder, Bernhardsluis, Wijk bij Duurstede, Netherlands

Piston rods and gates are connected with a pin using a frictional connection. A spherical plain bearing is mounted on the piston rod end. The interior ring of this bearing is fitted with a tapered sleeve. This sleeve is pressed onto the taper of the floating gate pin by means of a bolted connection.


Fig. 18: Quick connect linkage of cylinder to a miter gate

When the hydraulic cylinder is to be separated from the gate, first the covering screen is dismounted, then the sleeve is pulled from the pin’s taper by means of an extractor screw, whereby the frictional connection is released. This design eliminates the need for precision insertion of the pin and spacers.

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