PROPERTIES AND APPLICATIONS OF ELECTRIC LINEAR ACTUATORS

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SUMMARY

Electric actuators or cylinders are an interesting alternative to hydraulic and pneumatic cylinders which are traditionally used. The following article gives a summary of the advantages, properties, and design features of electric cylinders and describes typical applications in movable bridges.

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1. INTRODUCTION

Electric cylinders have their major applications in plants or locations where compressed air or a hydraulic system is not readily available. They work reliably--even under extreme temperature conditions, such as outdoor installations in very low temperatures, or applications in tropical climates combined with a high air humidity. Demands for computer-controlled operation, reliability, and repeatability with a very high precision are additional reasons to use electric cylinders rather than other systems.

Even when compressed air or hydraulic power is available in a plant, it can be more economical to use electric cylinders for remote installations since electricity is normally available everywhere; whereas it can be quite costly to run a hydraulic line or a compressed air pipe system to a remote site.

Electric cylinders of industrial heavy-duty quality are available now with standard thrusts of up to 132,000 lb and with standard strokes of up to 78.7 in. A modular system (Fig. 1), available by one supplier, enables a large variety of combinations (Fig. 1A). All accessories can be built into the electric cylinder, which is totally weatherproof and suitable for continuous outdoor operation.

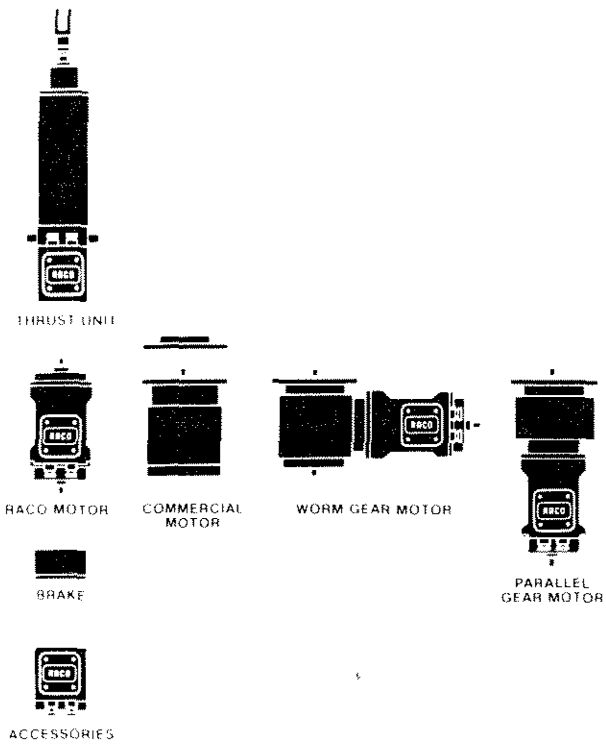


Fig. 1 Modular system of electric cylinders.

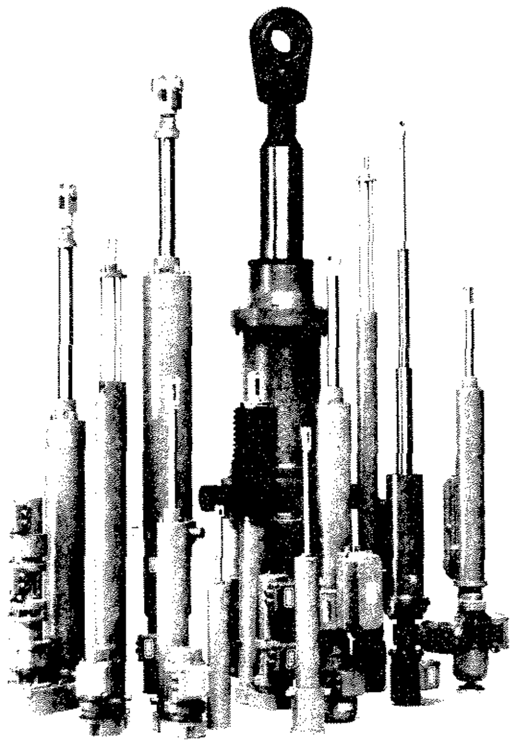


Fig. 1A: Different types of construction

An electronic thrust overload protection, especially developed for electric cylinders, protects the cylinder as well as the equipment of the user against structural damage due to an overload situation.

The advantages of a modular system allow a large selection of available drive motors, including helical gear motors, worm gear motors, servo motors, and stepping motors in combination with a large variety of different leads for the power screw for a speed selection between 0.05 and 12 in/sec. or higher at 60 cycles. AC and DC servo motors are available for variable speed requirements.

2. ADVANTAGES

It is obvious that no hydraulic pumps or compressors are required when using electric cylinders instead of hydraulic or pneumatic cylinders. Both of these items require a lot of maintenance, which is not only costly but also involves production downtime and reduced output. Electric cylinders are also more economical to use since they do not consume power when they do not operate--contrary to the traditional systems. They are also perfectly suitable for precise positioning applications, such as for slide gates with many intermediate positions to control the flow of bulk materials. They are able to hold any position accurately and reliably, and there is no drifting problem.

Hydraulic and pneumatic cylinders do not develop a breakaway thrust larger than the nominal thrust, which would be of advantage for most applications. The special design features of some electric cylinders, however, offer a breakaway thrust up to three times the nominal thrust (Fig. 2).

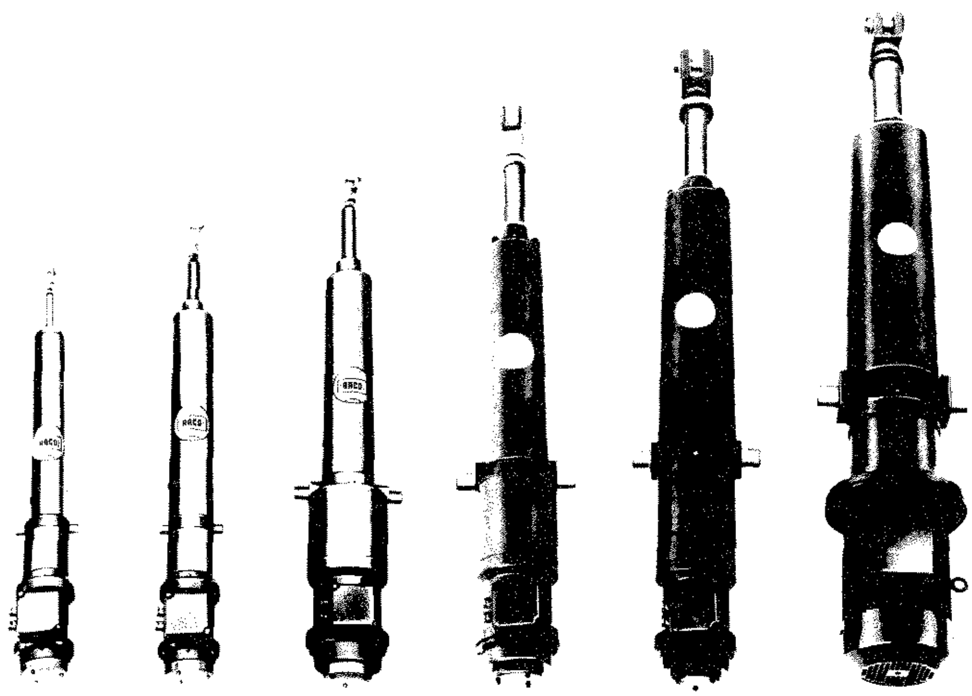


Fig. 2: Electric cylinders for thrusts from 220 lb up to 17,600 lb

Air and hydraulic cylinders present a continuous maintenance problem, whereas electric cylinders require no maintenance except for lubrication once a year.

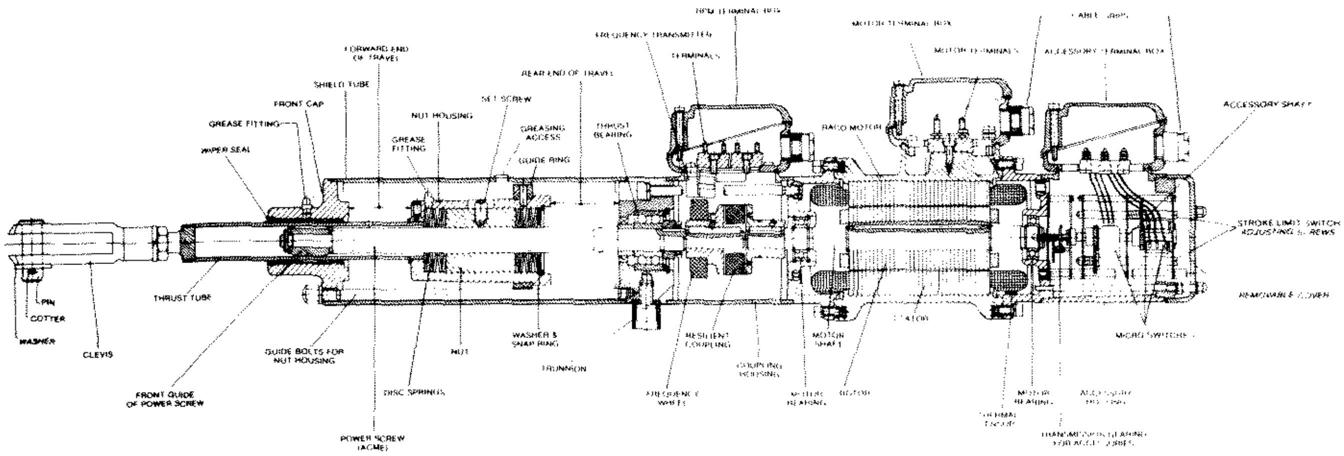
It must be mentioned that electric cylinders can be more expensive as an initial investment than the competing systems. However, they are an interesting alternative for applications where reliability, repeatability, and precision are involved; and due to their inherent advantages they are more economical to operate in the long run.

3. OPERATING PRINCIPLE

An electric cylinder in a modular system consists of a thrust unit providing the linear motion, connected with a coupling housing which incorporates the coupling between motor and thrust unit, with a flange at the rear which can accommodate nearly any type of drive motor. The accessories, such as adjustable gear-driven limit switches, potentiometers, position emitters and others, can either be incorporated into an accessory housing at the rear of the motor, driven by the rear end of the motor shaft; or they can be incorporated into an accessory housing located on top of the coupling housing, driven with a timing belt.

Fig. 3 shows a cutaway drawing of a typical electric cylinder. The electric motor drives a screw, which can either be an acme screw or a ball screw, depending on the application. A nut within a nut housing, which is connected to the thrust tube, travels over the screw in both directions depending on the rotational direction of the motor. Since the nut housing is blocked from rotation, it moves automatically in an axial direction once the drive motor is activated.

Fig. 3: Cutaway drawing of electric cylinder equipped with shock overload protection, electronic thrust overload protection, and built-in adjustable stroke limit switches



In some electric cylinders, the nut is cushioned within the nut housing between two sets of disc springs, which allows a very efficient shock overload protection. During normal operation, the disc springs will not be activated. They are designed to work only in case of shocks exceeding the nominal thrust of the cylinder. This system has the advantage that shocks can be absorbed before they reach the nut and the screw, so that these two items will not wear out prematurely.

Some electric cylinders have the interesting additional feature that the screw is allowed to have a limited rotation within the nut housing. Although the motor is already operating, the actuator does not yet move during the few fractions of a second the nut is allowed to rotate. By the time the rotation of the nut has reached its limit, the drive motor has developed the full rpm and the electric cylinder starts to produce linear motion. This system produces an additional breakaway thrust and a hammerblow effect known from rotary actuators, which helps to overcome the initial load inertia.

4. THRUST UNIT

The thrust unit of an electric cylinder provides the linear motion. It contains the driven screw, which can be either an acme screw or a ball screw. The acme screw has the advantage that it is self-locking and that it will hold a load higher than the nominal load without a brake being required. For some vertical installations subject to vibration and for positioning applications it is recommended, however, to use a brake motor even for an acme screw. The advantages of an acme screw versus a ball screw are the lower price and the self-locking properties; the disadvantage is the lower efficiency, which is 30 to 35% versus 90 to 95% for a ball screw.

This makes it necessary to use only ball screw actuators for high thrust requirements, since otherwise the capacity for the drive motor would be too high. For example, an electric cylinder with a thrust of 8,800 lb and an acme screw needs a drive motor of 4 HP; the same unit equipped with a ball screw requires a drive motor of 1.5 HP only. A ball screw must also be chosen for high-duty cycles. Typical duty cycles for an electric cylinder with an acme screw are approximately 250,000 operation cycles, whereas a ball screw unit can reach between 2 and 3 million operation cycles or even more when it has been designed accordingly. Also for fail-safe applications, where a gate or valve must be opened or closed automatically during a power failure by means of a spring or a counterweight, a ball screw must be selected. In this case the self-locking properties of an acme screw would be a disadvantage.

The thrust unit also contains the trunnions necessary for a trunnion mounting, which is the most common type of mounting for an electric cylinder since it allows the unit to pivot between the two trunnion mounting brackets. Different types of trunnions are available. An adjustable trunnion mount is a fixture built around the shield tube of the thrust unit which can be tightened in any location. The tightening screws for an adjustable trunnion mount, however, can get loose under vibration which might destroy the electric cylinder. A solid trunnion mounting, where the trunnions are incorporated into the bearing housing, is a better technical solution since those trunnions are firmly installed into the cylinder, can never get loose, and will absorb all forces at a point which has been designed for that purpose.

5. DRIVE UNIT

Care must be taken to select an appropriate motor to drive an electric cylinder. Not every electric motor is suitable for this application, since it is not a typical application for a standard electric motor which is designed normally as a constant running motor. Electric cylinders do not operate continuously; they typically have a jogging service with short operation cycles and many starts and stops. This can easily destroy a standard AC motor since a high frequency of reversals can lead to severe overheating and to structural damage in the motor windings.

One company has developed a special actuator motor considering the above criteria. This motor has a low starting current and inertia so that rapid and repeated jogging and plugging service, which might be destructive to a standard motor, do not affect this type of motor. The housing of this motor is made of aluminum which will, due to the high thermal conductivity, conduct the heat developed by the motor. It is always TENV (totally enclosed/non-ventilated), since it does not need the additional protection of a fan. Those motors come with insulation class "F" as a standard.

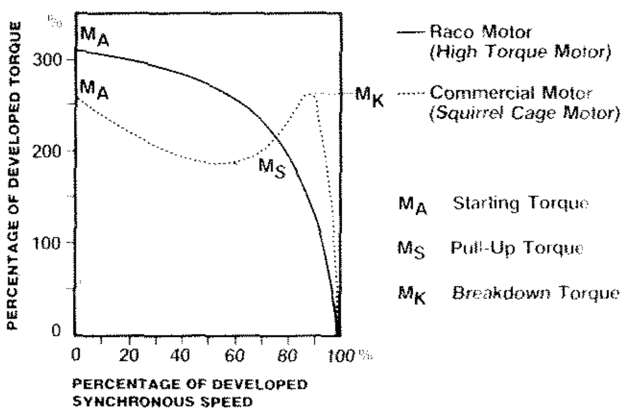


Fig. 4: Characteristics of different AC motors for electric cylinders

Fig. 4 shows a comparison between the characteristics of a special actuator motor (RACO motor) and a typical electric motor. It shows very clearly that the starting torque of the actuator motor is much higher than that of any commercial motor, which means that the electric cylinder can also develop a higher breakaway force.

In case of an overload situation, which can easily occur when a gate is jammed, a typical electric motor will slow down in speed very rapidly until the breakdown torque is reached at approximately 85 to 90% of the nominal speed. At this moment, where more torque is required to handle the situation, the torque output of a standard electric motor will drop drastically, causing it to become weaker and to burn out quickly if the overload situation is not removed or the motor is not de-energized.

The special actuator motor does not have a breakdown torque, but develops an ever increasing amount of torque as more and more load is applied to it (see solid line in Fig. 4). It will also burn out eventually--as any AC motor--if the motor is allowed to remain energized during a locked rotor or stalled condition, unless the electric cylinder is equipped with a reliable thrust overload protection, which will cut off the motor automatically in case of an overload.

6. THRUST OVERLOAD PROTECTION

Electric cylinders should be equipped with a thrust overload protection to cut off the motor automatically if it reaches a locked rotor condition due to overload. The typical way of doing this is to install a set of disc springs at the end of the screw, which will trip a switch if they are compressed for a certain distance due to overload. The disadvantage of this system, combining the shock overload protection with the thrust overload protection, is that the electric cylinder will shut off in case of a shock overload. This can happen when a solid piece of rock hits a gate which is in the process of being closed. Also, continuous heavy shocks can wear out the Belleville springs, changing their characteristics, so that this type of overload protection becomes less and less reliable. Even if it can be readjusted, it must be realized that in practical operation the maintenance personnel will seldom check the cylinder to make these adjustments.

A more reliable way to control the overload situation of an electric cylinder is to monitor the motor speed electronically. In the electric cylinder as per Fig. 3, there is a frequency wheel mounted on the motor shaft within the coupling housing, which rotates exactly at the same speed as the motor. The frequency transmitter is located on top of the frequency wheel. As soon as the motor slows down due to an overload situation, this transmitter will sense the reduced speed and will cut off the motor automatically when it reaches a critical limit. No readjustment is ever necessary and no wear will occur since there is no contact between the frequency wheel and the frequency transmitter. The amount of overload allowed to the electric cylinder can be adjusted in a relay on the control panel.

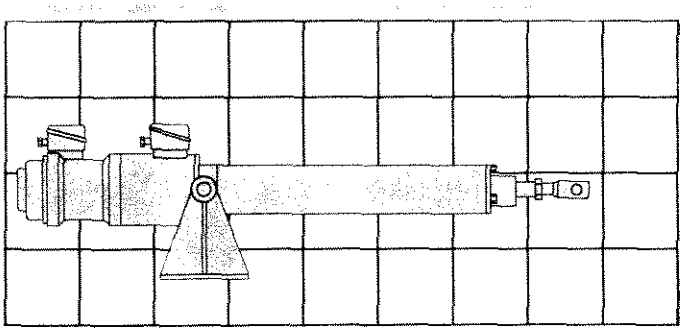
Furthermore, this system is combined with a thermal motor protection replacing the standard thermal switch with three thermistor sensors, which are faster reacting and intrinsically safe. This system can also be used to achieve a positive seating force by cutting off the motor due to an overload situation when, for example, a safety valve has to be closed positively.

7. TYPES OF CONSTRUCTION

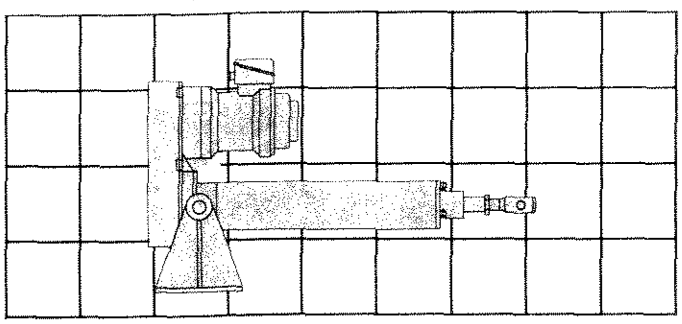
Electric cylinders are normally available in the type of configuration chosen by the supplier. A modular system, however, allows the combination of many different types, which is of importance when the space available for the electric cylinder is limited. Instead of using a parallel helical gear motor, for example, a right angle worm gear motor can be used in order to reduce the overall length of the unit. The motor can even be built parallel to the thrust unit by installing a vertical transmission housing at the end of the thrust unit, driving the motor by means of a steel reinforced timing belt. The transmission ratios can be changed easily by using different wheel diameters, which gives an even larger flexibility concerning available speeds.

Following please find the most important types of construction for electric linear actuators:

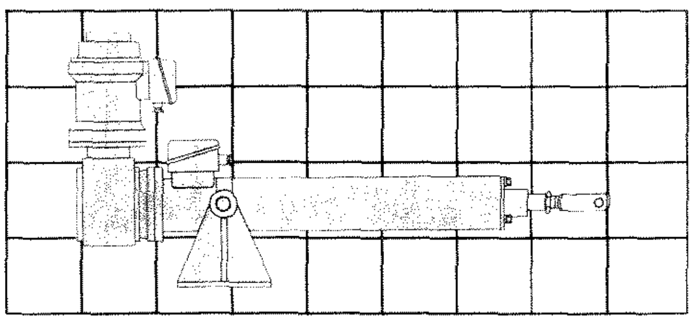
Electric Linear Actuator + RACO direct drive motor



6 Electric Linear Actuator type "C"
+ RACO direct drive motor



5 Electric Linear Actuator
+ RACO or commercial right angle gear motor



8. VELOCITIES

The wide variety of available speeds for electric cylinders makes them suitable for nearly every application. The speed is the direct result of the rpm of the drive motor and the lead angle of the screw. Both criteria can be changed easily, so that a speed range is available from 0.05 up to 20 in/sec. Experience has shown, however, that a longer lifetime can be achieved by not exceeding a speed of approximately 12 in/sec.

Variable speed requirements can be handled easily with either AC or DC servo motors, which have the advantage that they develop full torque at any speed. They also make the electric cylinder perfectly suitable for computer-controlled operations where different speeds can be selected automatically by the processor. This can be of importance for positioning operations involving a long stroke, where ideally most of the distance will be traveled at maximum speed, and the final precise positioning can be done with slow speed.

9. FAIL-SAFE FEATURE

Electric cylinders equipped with a ball screw instead of a self-locking acme screw can also be used for fail-safe applications to close a gate automatically in case of a power failure. In this case, the motor must be equipped with a special brake which is released automatically when the power is off. A counterweight system or a spring system can then be used to retract or extend the actuator to the desired final position. This can be a critical requirement for all loading operations since it can be crucial to have a power failure and not be in a position to close the gate. Most electric cylinders can also be equipped with an optional handwheel for manual operation, which would also enable a cylinder equipped with an acme screw to have a gate closed manually (Figs. 5 & 6).

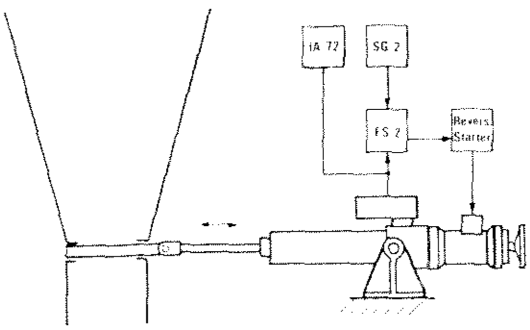


Fig. 5: Metering slide gate, remote-controlled with remote position controller, dial-position controller, and position indicator; the electric cylinder has trunnion mounting brackets and a handwheel for emergency manual operation

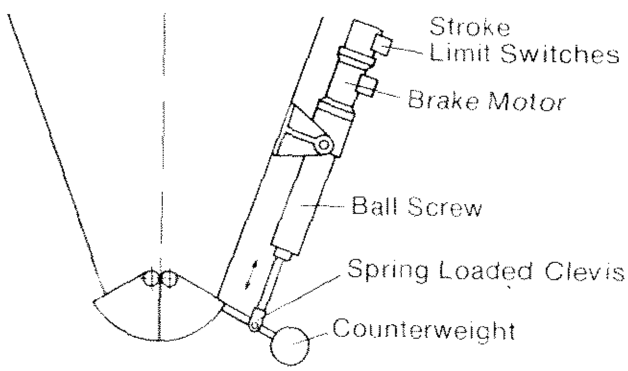


Fig. 6: Safety application for a bin gate; the counterweight closes the gate automatically in case of power failure

10. ACCESSORIES & CONTROLS

Contrary to controls for hydraulic and pneumatic cylinders, there is no conversion necessary to change signals from a different type of energy into electrical energy. This eliminates a number of potential problems. In the modular system, all signal, measuring, and control elements are incorporated into the electric cylinder so that they form one unit and are completely protected.

Electric cylinders are normally operated with reversing starters and push button controls, and the stroke can be changed by means of the adjustable built-in limit switches. For certain applications, especially for automated operation or for installations in an inaccessible location, possibilities of a remote control are a desirable option. Dial position controllers can be used to select any position within the total stroke manually, in combination with a position indicator which works with a potentiometer installed onto the gear-driven limit switches, showing the effective position of the cylinder. For computer-controlled operation, relays are available to work with a 4 to 20mA input signal, and for a closed loop system a high-quality electric cylinder can also produce a 4 to 20mA feedback signal. Also, electronic end limit switches are available for up to three positions, where the stroke can be adjusted on the control panel instead of having to change the limit switches in the electric cylinder.

11. APPLICATIONS IN MOVABLE BRIDGES

Typically, electric actuators can be used wherever hydraulic or pneumatic cylinders are applied, although the space requirement for electric actuators is somewhat larger. Normally that does not represent a problem for bridge applications.

Most of today's applications of electric linear actuators in bridges are as a locking pin operator. The locking pin takes the shear load from heavy vehicles passing over the bridge, forms a structural member of the bridge and increases the stability by preventing the ends of the span from deflecting. A typical locking pin is 4" wide by 6" high, and it is moved from one span of the bridge into a pocket at the other span of the bridge by an electric linear actuator.

Easy installation, freedom of maintenance, and elimination of leakage are the most important advantages of electric actuators for this application. Every hydraulic system would leak sooner or later, with the potential of heavy environmental damage. There is nothing that can leak in an electric actuator, provided it is an electro-mechanical actuator and not an electro-hydraulic actuator or servo actuator.

Another potential application for electric actuators is to lift the span of a bridge, similar to the use of hydraulic cylinders at the Miami Avenue bridge in Miami, Florida. In order to synchronize two actuators perfectly, they can be driven by a center gear motor with two output shafts, connected to the actuator by drive shaft and flexible couplings. The efficiencies of the center gearbox, the gearboxes on the actuators, and the screw within the actuator can be designed so that the actuator system is self-locking and cannot be backdriven in case of a power failure. This provides a larger degree of safety rather than using ball screw actuators, which are not self-locking, and hold them in a position with an electro-magnetic brake.

The installation of the actuators would be extremely easy; there is practically no maintenance required and the lifetime can easily exceed 30 years when the whole system is designed properly.

Furthermore, electric actuators offer an interesting alternative when existing gear systems used to lift the bridge span have to be overhauled or replaced. Depending on the design of the bridge, preparations can be made to install replacement actuators overnight and to have the new system running in the morning. Sometimes hundreds of thousands of commuters can save time-consuming detours by just having a bridge out of operation for one night.

12. CONCLUSION

Nothing is perfect in this world, and normally a higher price has to be paid for a better product. This also applies to electric actuators and is, in fact, the only reason why they do not yet cover the majority of applications in linear movement actuators. Often, however, one discovers that the total price of an installed system, which involves a minimum of engineering work, is less expensive than the total price for competitive systems. Even if the initial investment whould be higher, electric actuators are more economical in the long run due to their long lifetime, their reliability, and the low maintenance requirements.