

Future Technology to Move and Control Heavy Structures

Abstract

Today's industrial and marine technology brings forth a myriad of options for future bridge planners and contractors. Insight into failure modes and the onset of failsafe design have led to many of the advances in heavy lifting devices, including their actuators. The sophistication of energy efficient electric motors and simplified VFD control is replacing many of the original hydraulic systems in both the industrial and marine environments. The advent of cost effective programmable logic computers and MicroSoft™ Windows' based applications for control lead to easing operator control systems and allowing for remote activation and troubleshooting. This paper is a review of technologies currently being employed in bridge design and those leading edge technologies that may soon lend themselves to future designs.

Mechanical Advances: Aside from the relative ease it has become to model a project's components and run analyses on the working components, the components themselves have been advanced using special alloys and composites. The castings of old are quickly replaced with forgings of increased strength and machinability. New and improved locking devices and brakes are being added to systems to enhance safety and load handling capabilities, while shock absorbers and cushions are being employed to mitigate catastrophic failure. Bearings are employing new coatings and sealing that require little or no maintenance.

Electrical Advances: Variable frequency drive (VFD) systems are becoming more common in the marketplace, allowing for motor speed control without the use of drive gears or speed reducers. These motors are reliable for producing high torque at low speeds, and are currently being used to replace screw jacks with fine-tuned linear actuators that will display their position or high/low loading faults within the system. Although the power density of linear electric motors are not yet to equal what can be accomplished with a hydraulic cylinder, their technology has proven effective in high speed and heavy vertical lift conditions.

Control Advances: Although it is always preferable to some for having direct operator control, the advances and small sizes involved in PLC controls have introduced graphic human machine interfaces (HMI) and touch screen displays. Smart relays and remote PLCs alleviate the need for multiple conductor runs over long distances. Handheld radio controls along with satellite and cellular communication extend the operating range of PLC controlled systems. Landline remote supervisory control and data acquisition (SCADA) is to a point where a Wi-Fi service is all that is needed to operate a system or troubleshoot a failure. This leads to the ability to centralize littoral, port, riverine, or canal control and maintenance of structures and bridges.

This report is only a sampling of the ways in which moveable structures may be enhanced with cost effective and proven technologies; all with the potential of reducing the total cost of ownership and increasing longevity. We have yet to even scratch the surface where "Green" technology and environmental friendly lubricants become common and economically feasible to pursue.

Author: Chip Griepenstroh, VP of Operations
Supreme Integrated Technology, Inc.

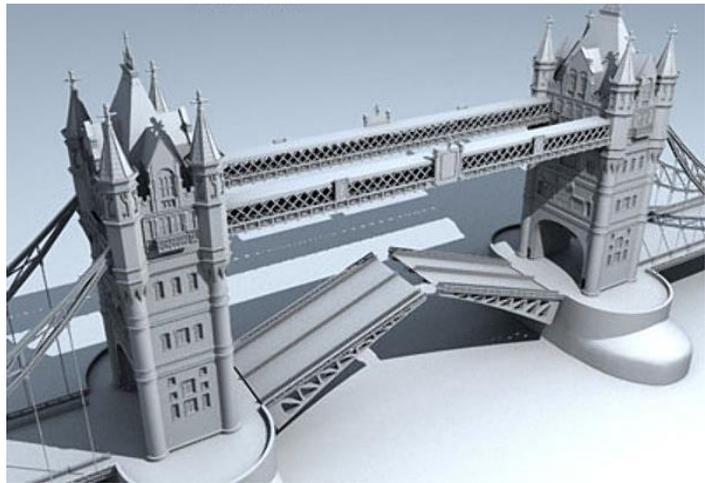
Introduction

Today's advances in technology come at a staggering pace, and it is difficult to keep up with all of the ways things have changed over the last 50 years. Rapid advances in materials, both metallic and non-metallic, add strength and longevity, reduce friction, and function better in harsh environment applications. Along with the advances in materials, come the advances in the mechanical, electrical, and control interfaces made possible by discoveries in all scientific and engineering disciplines. When turned into commercial off the shelf (COTS) products, these discoveries and advances enhance the opportunities for economic advantages gained from initial purchase, risk mitigation during operation, and total lifecycle costs. This paper is a review of technologies currently being employed in bridge design and those leading edge technologies that may soon lend themselves to future designs.

Mechanical Advances

Reducing cost with 3-D modeling...

3-D Modeling software has advanced the ability of engineers and designers to model structures, machinery, components without fear of potential interferences involved in limited 2-D drawings. It has become so prominent and economical to use, that animated systems are used to convey information across various fields of understanding in support of operational analyses and designs for human machine interfaces. Weights, material, piece marks identification, boundaries, and loads can be captured or imposed that produce accurate representations of strain and deflection



when used in finite element analysis. Power and stress calculations can be assessed readily from a review of loads imposed by the structure, the environment, and the power source itself. Once a model is created and as-built drawings are released, the current design can be evaluated for future modifications and upgrades. In a relatively easy manner, these designs are coupled with graphical overlays and exploded simulations for removal and replacement.

Where castings were necessary in the past to produce components of specific shapes and sizes, they are always difficult to create in a short period of time, namely due to the mold lead times, the availability of the cast material alloy in today's world, and the low probability of successful NDT after casting. The main issue is porosity in the final product, no matter the process, and the fact that castings have low strength and hardness/ductile characteristics. Today's alloys allow forged and extruded products to be produced with great strength and hardness, without being brittle. Currently modeling techniques have generated a whole product line of various 3-D CNC machines that can remotely machine a complex product block in a matter of hours, versus waiting weeks/months for castings. The CNC machine process does not damage the infrastructure of the material or detract from the materials original strength, inherent hardness or ductility. If surface hardness requirements are necessary, the finished pieces need only undergo a heating and quenching process to capture the original desired properties. Welding is no longer limited to brazing cast components to structural assemblies, and both structure and mechanical components can be

considered of the same strength without fear of overloading a single structural area due to its raw material properties.

Locking mechanisms are more advanced...

The above allows for greater design diversity in the application of swivels, bearings, hinges, pins, trunnions, locking mechanisms, catches, and braces. Increased advances in the means of locking and securing system components are met via electro-hydraulic, electro-mechanical, and strictly electrical methodologies in means different than the past. In a hydraulic circuit, it can typically be assumed that a hydraulic cylinder or a hydraulic motor moves a locking pin in two directions (drive or withdraw) or rotation (clockwise or counterclockwise), to catch or unlatch, respectively. In an electrical system, the same motions are conducted using a linear actuator, or electrically driven screw jack, or an electrical low speed high torque motor. The options today include self-contained electro-hydraulic cylinders. These cylinders contain internal power through a small motor-pump combination which uses internal fluid source, porting, and valves to extend or retract the cylinder without a centralized power unit or external piping runs. In situations where cylinder actuation is independent and displaced from other cylinder activities, this makes a lot of sense and is the most economical to install.

The advancement of electro-mechanical linear actuators includes VFD motor controlled smart actuators. Speed of movement can be controlled via PLC control where the actual position of the actuator is available as a feedback to the PLC, or can be controlled by a VFD controller acting as a PLC with limited inputs/outputs and programming memory. Brakes, if desired, can be added to lock the shafts, similar to a rod lock on a hydraulic cylinder. The advent of linear motors and electro-magnetic actuators moving the lock, load, or mechanical interface through a series of electro-magnetic pulses are pushing the boundaries of current commercial use. Rotating equipment currently employs encoders to track its range of rotation and/or number of rotations to track position or count the number of rotations to ensure a latched, unlatched, cable out/in, or distance traveled from origin. Brakes can be employed in any given circumstance to ensure that the brakes are engaged during lack of power or based on the acceleration of a falling load.

Protection mechanisms more critical

Shock absorbers and cushions are being engineered and designed not just to mitigate the loading of normal operation and end of cycle, but to actually protect the entire system from emergency influences of catastrophic failure or shut down. Where a structure comes to rest at full power and speed in between cycle completion currently requires some form of staged relief component to slow a hydraulic system, and requires a dynamic braking capability for electrical systems. Both exist - however when a structural component reaches end of cycle under full power without benefit of limiting devices, greater care needs to be employed to slow and stop the dynamic action within seconds of structural failure. This means that a tolerance approaching 0.001 inches in cushion design with progressive length of cushion needs to be employed at the ends of hydraulic cylinder travel and/or linear actuator travel. Springs and resilient materials have typically been used at the end of travel for normal operations however another method to ensure that that the structure does not impact another structural component is the use of dynamic shock absorbers being designed for catastrophic impacts. Forces generated by free fall or full powered engagement need to be deciphered for each potential failure. The forces can then be counteracted by reinforcement of structure and use of shock absorbers in the size and number needed to mitigate any and all structural failure. Of note, and hopefully never used, the devices and the structures can only tolerate a certain number of cycles that impose large impact speeds and forces. Limited attempts by operators and engineers should be made to test such devices, unless the intent for repetitive testing is built into the system with hardened devices.

Bearing materials and surfaces are constantly being improved to handle higher loads, zero maintenance, and sealing against grit and water intrusion. Military interests have always been in search of materials and methods that:



Thordon Bearing

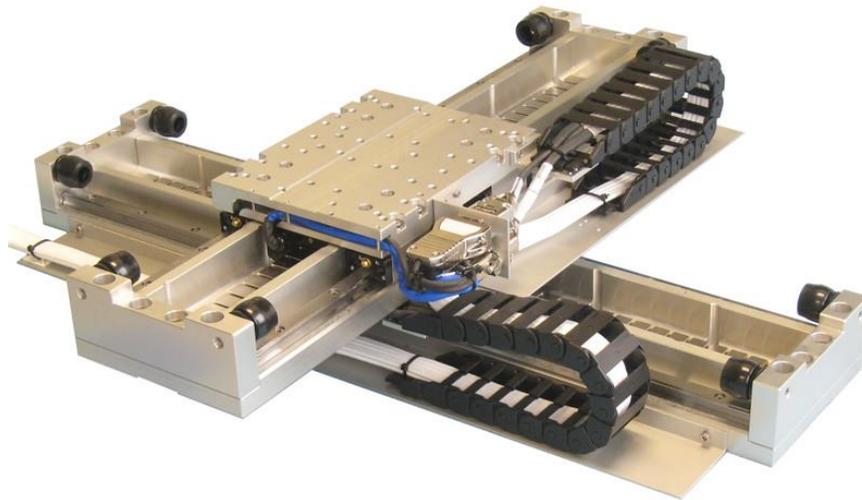
- Protect against the forces of thrust and rotation
- Remain impenetrable to vibration and catastrophic shocks greater than 80 to 120 G forces,
- Accept some degree of offset greater than a pressed fit
- Reduce maintenance
- Comply with temperature changes causing expansion and retraction against base materials,
- Restrict water intrusion, and
- Provide consistent lubrication or friction free operation between base materials.

The current military bushing or bearing material of choice is that manufactured by Thordon with an environmentally-safe polymer. Such materials will assist in the design efforts of US Army Corps of Engineers and State Departments of Transportation to isolate the movements of disparate base materials and enhance the freedom of motion in articulating structures.

Electrical Advances

As mentioned earlier, 3-D design and analysis tools are currently available to assist the engineers and designers to automate a system's architecture and provide protection against failures and acts of God. These new systems provide recognition for the need for protective devices and the location best suited for employing them.

As noted earlier, VFD motors and their controllers are becoming more common and cost effective. These devices allow for speed control without the use of drive gears or speed reducers, and still produce high torque at low speeds. Because of the nature of a variable frequency device, and its necessarily smart system of control, the newer motors come with a long list of available feedback sensors and control devices, including torque, speed, rotation counters, temperature, voltage, frequency, amperage outputs, and a brake release output. They have become self-monitoring concerning load faults and position. Currently methods are used to daisy chain motor controllers to react and respond, such as an Ethernet port, connected to a programmable logic computer (PLC), and the use of MicroSoft™ Windows based software straight from a laptop or other device for control and feedback. All of the parameters of the device can be set up ahead of time and monitored at any given time, with the opportunity of data logging if desired. Additionally, should the same size motor be utilized in multiple locations, the same motor control center module can be used to control each via PLC/VFD command. All of these benefits ease the requirements for external sensors, feedback circuits, and interlocks.



Linear Motor Stage for Industrial Applications

Current interests with replacing electro-hydraulic systems with an all electrical system have also set up a trend towards new electro-magnetic actuators and electric linear motors. Whether on a rail system or internal to a linear motor, electro-magnetic pulses have been used to move heavy objects with fewer losses due to lower rotation friction forces and limiting electrical polarization effects.

Despite these advances, applications still see greater losses due to technological infancy, available materials, and machine tolerances. These losses are caused primarily by gap inefficiencies, leaving the linear motor currently only 85-90% efficient. However, the item in motion, or its actuator, is basically isolated from many sources of friction and becomes more efficient. An example is a high speed rail service which uses a levitating magnetic force with pulsed pulling forces in the desired direction of movement to accelerate without friction and uses that same methodology to slow, stop, and reverse travel. Of course, bridges, railway trains, and certain elevator systems are located in the weather and would need protection from wind-driven rain and flooding, but moveable bridges, locks, and dams could look to use this same technology.

Until studies are conducted that create materials more suited for greater repulsion or attraction within an electro-magnetic field, the power density local to the point of movement may never equal that of a hydraulic actuator, but the overall cleanliness of the system is a proven matter and the power usage and size of the equipment overall reaches common densities.

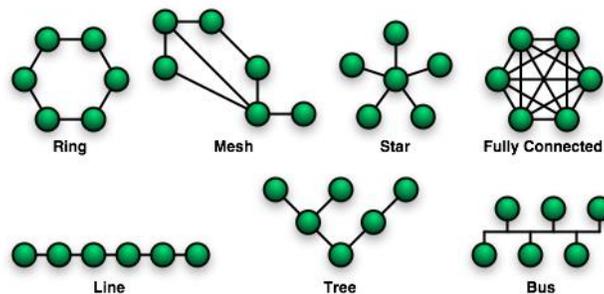
Control Advances

System control is a monetary decision based on function, limits, safety, complexity, maintainability, personnel, stations, and costs. Simple systems without feedback are easily manipulated by manual hydraulic or electrical controls - locally at the equipment or remotely (via mechanical extensions or electrically via relay logic). These solutions are excellent for simple systems however as system complexity increases with a greater number of functions (ex. lock/unlock, raise/lower, swing open/swing closed), a greater number of limits or feedback devices are imposed (ex. locked/unlocked, raised/lowered, near open/near closed) dictating when a function is allowed to occur or modify the performance factors of the function, is when the system starts to require programmable logic computers.

Expense of old technology...

Using hardened, higher voltage (480/220 VAC) switches and relays in the design and retrofit of bridge systems is getting increasingly expensive. Current proportional control valves and many normal control valves are non-existent in the higher voltages. While 480/220 VAC, 3 phase power is available to the variable frequency motors in an electrical drive system, VFD controllers alone, or those using PLCs, are powered by 24 VDC and can control the motor brakes, direction, speed, and torque while allowing feedback of the same information plus position. Hydraulic proportional valves are powered by 24 VDC and controlled by 4-20 mA, + or - 10 VDC, or 0-10 VDC, and are now built with internal amplifiers and programmable controllers to accept feedback from outside sources to limit their performance. Almost all hydraulic cartridge and bang-bang valves can be controlled by 24 VDC solenoids.

The 24 VDC system is becoming less expensive as commercial off the shelf (COTS) smart relays monitor all sorts of local parameters and report back via Ethernet cable to a remote PLC that transmits information and receives commands from the primary PLC via a similar high speed connection, even fiber optics. A large array of means exists to interconnect the controlling devices, the brains, and the sensors to protect the system from power surges, losses and/or produce redundant means of communication between the system components. Human Machine Interface (HMI) touchscreen displays can also allow for multiple screens so multiple operator functions and statuses can all view the same information. The screens can provide control through screen pushbuttons programmed momentary, hold to operate, or sliding scale for speed or direction. Windows within the screen provide system status and alarms. Other screens can be used to calibrate the system or diagnose the PLC, remote PLCs, or smart relays. Many of these systems are promoted as hardened or worldly (ex. Siemens and Allen Bradley), however many cost effective industry standard icons are already field proven and available (ex. IDEC).



Communication Network Topologies

Cost vs. benefit equation to choose the right system...

The cost of designing a system lies in the design and the programming involved. It is important to consider the application and evaluate the choice for simpler systems that produce more limited control via Windows based software. Basic systems such as these remain operator friendly, working similar to the PLC, but use a laptop to convey control and feedback. For any of these newer systems, PLC and Laptop Operating Systems, the beauty is that connectivity is no longer limited to cables and wires. As long as power is available, communication between smart devices can be linked by wireless modems or Wi-Fi, satellite communication through service providers, or simple cell phone communications. It is all a matter of speed of information required and the distance between devices, operators, and monitors that dictate the type and costs within the communication network. Data logging is another feature that can be carried out locally at the operating site or remotely by another office or monitor. Many sites can be linked to a single monitoring or operational site, both by land line or wireless, to promote redundancy in Supervisory Control and Data Acquisition (SCADA) systems.

Remote accessibility of a system provides 24/7 assistance to operators and maintenance because of access by managers, engineers, programmers, and technicians. Camera systems tied into each site allow for equipment observation and physical security checks. Computer and network security is always a concern however there are many ways to restrict access to networks, and encryption and isolation of each site's security protocol is key to preventing a loss of control. If done correctly, and should it be desired, each state could monitor all waterways, bridges, locks, dams, ports, and roads to enhance control and maintenance of its assets.

Conclusion

Although the costs of maintaining infrastructure has the potential to rise each year, the advent of new technology can lower the total lifetime operating costs, when spread across the life of a heavy moveable structure and applied in a strategic manner across the state's entire network of assets. Commonality in design features provides commonality in sparing, maintenance and training. Many of the older bridges still rely on technology that is 45 years plus in age, and the manufacturers and part numbers of components are no longer available. By planning for the future, and removing the fear of change from managers, engineers and operators, a fully optimized plan of upgrades and budget could be put in place to bring the infrastructure projects into the 21st century.

This report covers only the beginning of possibilities to make heavy movable structures safer, more reliable and more efficient through advances in electrical, mechanical and control technology. Technology in other industries points to much greater possibilities such as artificial intelligence security systems, back up sensors on vehicles, and drone use for shipping - the future of advances in infrastructure in our nation is limited only by our imagination.