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FLUID POWER ON VACATION

Wherefore art thou, Hydraulics?

By **Brad Smith**
Delta Computer Systems

Hydraulics-powered set with sophisticated control updates production of *Romeo and Juliet*.

During the famous balcony scene, the hydraulically operated platform functions as a minimalist balcony.

Romeo and Juliet is Shakespeare's most-performed tragedy. It's not surprising, then, that directors continue to experiment with new, inventive productions of this perennial favorite. The Oregon Shakespeare Festival, Ashland, Oreg., launched its 68th season in 2003 with a modern, artistic production of *Romeo and Juliet* that uses electrohydraulic controls to set the stage — literally.

The designers responsible for set construction devised a stark, modern set with a movable platform. The platform serves as Juliet's balcony, a surface on which swordplay between the Montagues and Capulets takes place, and other functions throughout the play.

The platform is positioned by four hydraulic cylinders that are controlled as two motion axes. The hydraulic cylinders reconfigure the platform in full view of the audience. In fact, in the course of the famous balcony scene, the platform is moved into position — changing from simulating a stairway to a balcony — while Juliet stands on it. To ensure safety as well as visual appeal, this requires a motion controller capable of coordinating smooth acceleration and deceleration.

The movable platform is a 12- × 7-ft steel stage. One hydraulic actuator is mounted close to each of the four corners of the platform. The cylinders are controlled in pairs — an upstage pair and a downstage pair — each operating in tandem to evenly lift or lower the corresponding end of the platform. Another, smaller platform (called the *anti-rake*) is built into the main platform. It can be tilted independently of the main platform to form special platform shapes; it's used in making Juliet's balcony.

The hydraulic platform extended in position as Juliet's balcony. The small electrically-driven "anti-rake" platform is visible at the top of the main platform.

The smaller platform is operated by an electrical servo motor.

Although the movable platform was designed specifically for use with the 2003 production of *Romeo and Juliet*, it can be reconfigured for use in other productions in the future.

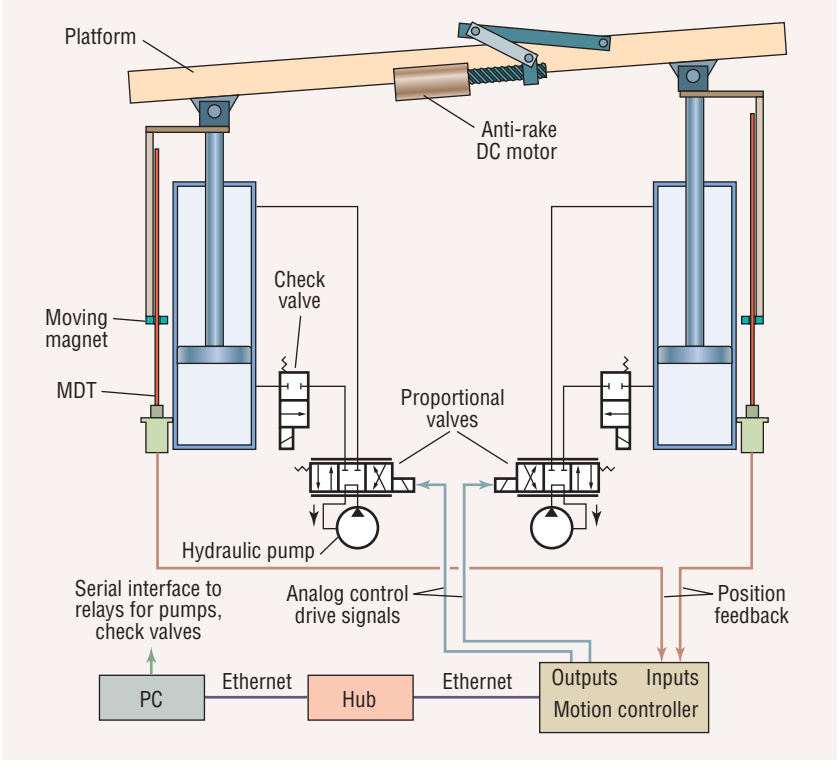
Selecting and designing the hydraulics

The design team worked with hydraulics distributor Hydra-Power Systems, Inc., Portland, Oreg., to specify the hydraulic components for the movable platform system. The main criteria were holding the equipment costs down while ensuring smooth, reliable motion. In addition, it was important that the hardware be simple to operate and maintain.

For simplicity, each pair of cylinders has its own hydraulic pump. Each pump has an integrated pressure tank that is optimized for pump capacity. To minimize noise that would distract the audience, the pumps are operated only when the platform is being moved. Counterbalance valves in the hydraulic lines ensure that cylinders that hold the platform up don't lose pressure and settle between times when the pump is operating. To minimize the amount of audible noise emanating from the hydraulic system, the designers put foam pipe insulation around the hoses and put the pumps in a muffled cabinet that is bolted to the wall three floors below the stage.

The designers chose proportional hydraulic valves (Bosch Rexroth NG6 directional control valves) to allow for smooth motion, acceleration, and deceleration. Discrete (often called "bang-bang") valves would have caused the platform motion to start and stop with a jerky motion that was unacceptable visually, as well as from a safety aspect — actors are sometimes standing on the platform when it moves.

To ensure smooth motion, the hydraulic system also requires closed-loop control, with continuous position feedback of the hydraulic motion axes provided to the motion controller. In this application, hydraulic actuator position information comes from magnetostrictive linear displacement transducers (MLDTs). MLDTs measure position by detecting the magnetic field produced by a magnet attached to the cylinder. These devices (Balluff BTL5-M1-M2186-P-KA10s), mounted next to one cylinder of each pair, provide a discrete position value to the motion controller, signalling how far that pair of cylinders is extended. In addition to providing precise position information, MLDTs' frictionless operation also gives them



System block diagram shows hydraulic circuit and electrical connections to the motion controller and the show control PC.

the advantage of long operating life compared to other position transducers.

MLDTs in all four cylinders would have provided the tightest control of cylinder position, but the budget wouldn't allow this. A separate valve for each actuator was also traded off for a single proportional valve to control each pair of cylinders. As a result of these cost-performance tradeoffs, there was a possibility that the two cylinders corresponding to each axis might differ in position slightly — a difference of a ¼- to ½-in. This discrepancy is acceptable, as the motion of the platform is relatively slow and the connections between the actuators and the platform can accommodate a slight "racking" of the platform. Between motion steps, the positions of the two cylinders for each axis can be resynchronized by retracting all cylinders to place the platform flush with the stage floor.

Selecting a motion controller

To control the motion of the hydraulic axes, the system designers needed an electronic motion controller that fulfilled several key requirements. Though the Shakespeare Festival has employed hydraulics in the past with PLC and manual controls, this was electrical engineer Stuart Cotts' first automated motion system development. Cotts, who has 25 years of theatrical lighting and electrical experience, wanted a controller that was easy to program and just as importantly, simple to tune in order to optimize his design.

Another key requirement for the motion controller was that it fit easily into Cotts' vision for an automated "theater of the future" design. This networks motion, sound, and lighting control systems via Ethernet, allowing easy reconfiguration for this and other theater productions as time goes on. In addition, Cotts looked for a motion controller that would interface directly to the system's MDT position sensors and proportional valves, to ease system construction and minimize interfacing costs.

The electrohydraulic motion controller that filled the bill was the RMC100 from Delta Computer Systems. The RMC100 provided all the right interface connections and can be programmed as easily as using a computer spreadsheet — by entering motion parameters into a register table within the controller. The high-level motion commands are generated by a software package called RMCWin provided with the controllers. Because a single RMC100 can control up to eight motion axes, only one unit was required to control all the hydraulics in this application.

Connecting the elements

Referring to the block diagram on the facing page, motion controller program development and the operation of all the automated hardware during performances is done on a personal computer plugged into the theater network. The Ethernet network also connects to other show control computers for audio and lighting, as well as DC servomotor controllers that control the hands of a large clock on the back wall of the stage and the platform anti-rake. The theater network runs throughout the building, enabling Cotts to go to any Ethernet port and plug in his show control computer. He can develop the application in his office.

The show control computer can also plug directly into a serial interface that operates a series of relays that turn the hydraulic pumps and counterbalance valves on and off. These relays are activated by decoding specific serial numbers output by the show computer. The motion controller's interface flexibility means that a future enhancement to the system electronics could simplify the design. In the future, the separate serial connection to the show computer could be eliminated, allowing the show computer to control everything over an Ethernet link.

Programming and tuning

The show control computer runs a sequencing application that was developed by the theater engineers for the *Romeo and Juliet* production. It's cue-based custom software has two operating modes: a programming mode and an operating mode.

Above, the platform is part of the Capulet's house when the audience first sees Juliet. Below, it is part of the tomb scene at the end of the play after Romeo and Juliet have died.

The operating mode incorporates virtual buttons. During the production, the operator presses a button (using a mouse or keyboard key) to go from one cue to the next, which causes the stage platform to move to the position that is specified for the next segment of the play.

During the development process, the system designers went to Delta Computer Systems for help. Initially, they had some problems with vibration of the system and overshoot of the target axis positions. Delta's engineer showed Cotts the plotting function supported by RMCWin. RMCWin's plotting function compares the actual motion profile of an axis with the target motion profile. The proportional, integral, and derivative parameters (PID) of the control loop can then be tweaked to minimize axis overshoot, ringing, and accumulated error. Some of the control problems the designers initially experienced may also have been due to the long hoses between the proportional valves and the cylinders, which resulted in undesired effects due to fluid dynamics and elasticity of the hoses. By adjusting the PID parameters and tolerances on the target position values, the engineers were able to smooth out the motion.

The Delta RMC100 controller is a self-contained unit, with flexible interface options. The model shown connects directly to Ethernet and multiple MDTs.

Hydraulics part of the future

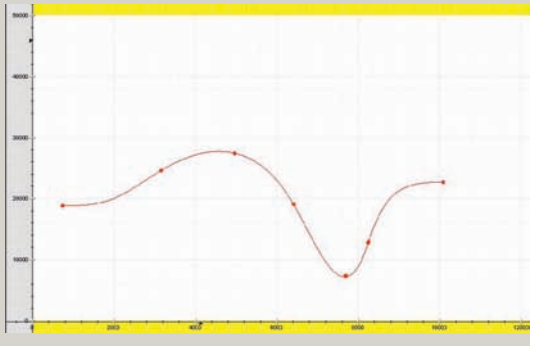
This hydraulic system is just one part of a fully automated theater of the future design. The electronic motion controller was key to the system's success. The controller satisfied the need for smooth motion and actor safety, but also met another requirement — repeatability. With this system, the motion is the same each time the play is performed and the system can be operated by someone who is not familiar with the details of the hydraulics.

Given more time, Cotts says he would automate the calculation of motion parameters so that motion programming could be done using real-world input values (e.g., the time for a particular motion operation) rather than raw register values. He would also like to explore the use of some of the RMC's more advanced capabilities for simplifying the generation of smooth motion profiles. Also, in the future, Cotts intends to migrate his show control application to Visual Studio software in order to gain the benefit of the latest tool developments.

DELTA COMPUTER SYSTEMS Motion Control

Contact Brad Smith of Delta Computer Systems, Inc., Vancouver, Wash., at 360-254-8688 or visit www.delta-compsys.com.

Throwing a curve



The RMCWin development software package comes with a curve tool that dramatically simplifies motion controller programming and tuning. Using the tool, an engineer uses mouse clicks to graphically place key coordinates for acceleration, deceleration, speed, and position over time to represent motion of an axis. The tool automatically connects the coordinates with a smooth motion profile using a third-order cubic spline algorithm, generating a sequence of high-level instructions which are downloaded into the company's RMC motion controllers to affect the motion. This compares to typical tools in which the engineer must program all five functions per point, then calculate the third-order splines between each point.

The curve tool also supports simultaneous programming of multiple axes, in which the curves are linked such that one axis' motion profile can be slaved or electronically geared to the other axis. The engineer can time-scale the motion by simply selecting the curves and stretching them, changing the rate of motion while keeping the axes synchronized. This capability of synchronizing multiple axes simplifies the task of developing coordinated multi-axis robotics systems. The smooth motion that results from the use of spline function interpolation extends the life of the machine and can provide higher quality production output, leading to higher machine productivity.