

“In a business where time is money, every second shaved off a load-cycle translates to hours or even days off the entire fatigue test.”

Figure 1B.



Figure 1A.

Joint Strike Fighter Aces the Test Using Delta Computer Systems Motion Controller



Test systems have long been excellent applications for hydraulically powered motion control. Cyclic fatigue testing requires the precise and repeatable control of high loads over multiple cycles. The goal of such testing is to simulate a lifetime of wear in a shorter period. In a business where time is money, every second shaved off a load-cycle translates to hours or even days off the entire fatigue test. The use of hydraulics has the additional advantage of delivering large forces while acting in smaller spaces than would be possible with other technologies.

A case in point is a six-axis hydraulic test stand developed by Emprise Corp. of Kennesaw, Georgia for military contractor

Curtiss Wright to test the Ordnance Quick Latch System (called the OQLS) used in the F-35 Joint Strike Fighter. It is critical that the latching mechanism maintain integrity even as the aircraft sustains many G's in various directions during tactical maneuvers. Curtiss Wright commissioned Emprise to design two test stands: one for acceptance and qualification testing of production units, and one to perform durability testing of the design. Figure 1 shows the durability test stand.

The OQLS holds another component called a bomb release unit (BRU) for the duration of a flight. The BRU releases the ordnance such as a bomb or a missile. The OQLS securely holds the payload using three different mechanisms: hooks, snubbers and a dagger pin. The hooks carry the weight of the payload, and the snubbers apply force to hold the payload tightly against the hooks. The dagger pin centers the BRU for capture by the hooks and snubbers. It also

serves to resolve loads incurred in the forward, aft, inboard and outboard directions. The test stand delivers load to the various components with a series of lever arms and flexure plates actuated by hydraulic cylinders. The test stand runs a load spectrum, which is a kind of script or sequence where each testing step represents six simultaneous axis setpoints.

To control the six hydraulic axes, Emprise selected the RMC150 motion controller from Delta Computer Systems, Inc. of Vancouver, Washington (Figure 2). The OQLS test system is actually the second F-35 related application of a Delta motion controller by Emprise. The first was on the F-35 Leading Edge Flap Actuator (LEFA) test stand. "We initially tried to do the motion control for the LEFA test stand using another vendor's motion controller interfaced to a PC," said Emprise engineer Bill DuBose, "but we couldn't get the performance we needed. Now, PC-based software

still does the human machine interface (HMI), test sequencing and data collection, but we leave the motion control to Delta controllers and our performance has been excellent.”

This multi-axis system only requires one motion controller because the Delta RMC150 can control up to eight motion axes simultaneously. A purpose built, custom software suite designed by Emprise Corporation logs test information and plots force data coming from the various axes (see Figure 3) on a personal computer running the LabVIEW software package by National Instruments of Austin, Texas. The PC connects to the Delta motion controller via an Ethernet card, and Delta Computer Systems’ RMCLink software.

Load cells mounted on each of the hydraulic actuators measure force. Signal conditioners connected to the load cells provide feedback to both the NI hardware

and the motion controller. Application software developed by Emprise reads a load spectrum file, which specifies loads to the various components, and then calculates the setpoint values needed to deliver the required loads through the lever arms, accounting for the mechanical

advantage and weight of the lever arms. RMCLink then transmits the calculated setpoints from the Emprise LabVIEW program through the Ethernet connection to the RMC150. The RMC then actuates the hydraulic servo valves associated with each cylinder. When each of the six motion axes reaches its target load, the Delta RMC sends an “at setpoint” bit back to the Emprise LabVIEW program through RMCLink. Upon receiving all six “at setpoint” bits, the Emprise LabVIEW program proceeds to the next load step; and the process repeats through the million-point load spectrum. Control axes approach setpoint at roughly 3,000 lbs/sec. Load steps occur approximately once per second.

Hooks and snubbers receive vertical load from the middle of moment arms that



Figure 3.

receiving block attached to the table juts up between the moment arms to engage the dagger pin. The purpose of the flexure table is to isolate the X and Y-axis loads from each other mechanically but still deliver each separate load through one interface point (the dagger pin.)

The load spectrum mentioned above consists of over a million load points representing an entire life cycle of operation. The OQLS test article has to endure several life cycles in a complete test sequence. In order to acquire the proper cyclic fatigue data in a timely manner, it is critical that the test move swiftly through the spectrum. “This is where the quick cycle times of the Delta motion controller came in handy,” says Bill DuBose.

Debugging the application was a relatively simple process. Emprise engineer DuBose would simply run a small sample spectrum repeatedly and watch the execution, tweaking the software depending on what he saw. Debugging took about a week. The tuning took only 1-2 hours. Surprisingly, the devil in the details is the load polarity. The load spectrum file uses one coordinate system based on the orientation of the test article in the aircraft. The feedback has a different polarity based on compression and tension of the load cells. The command signal to the servo valves has yet another polarity convention based on the hydraulic plumbing to the actuators. Not all axes respond in kind with their respective feedbacks. Then to top it off, a moment balance equation translates the feedback, and another moment

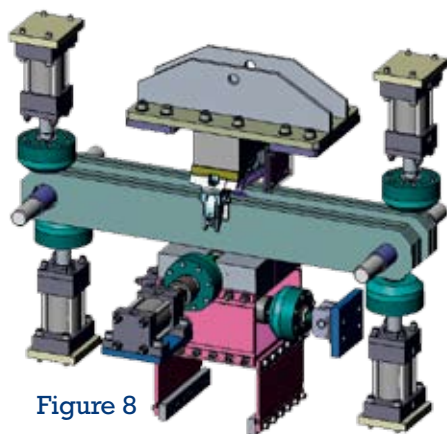


Figure 8

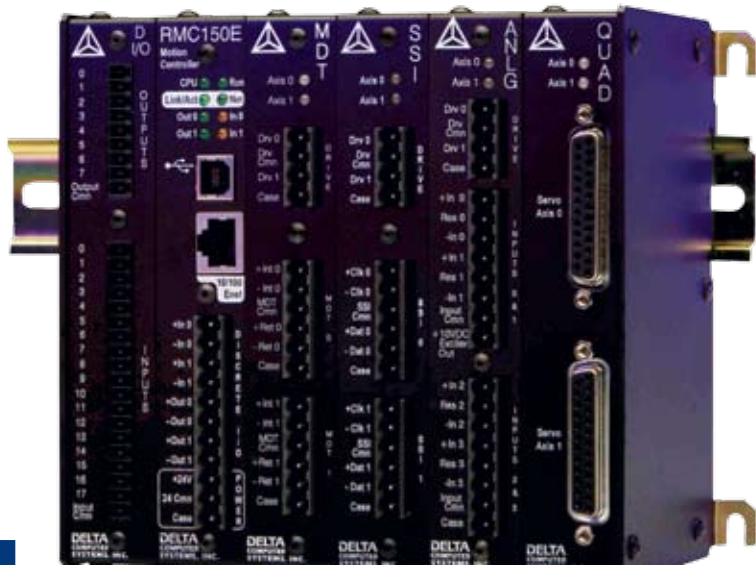


Figure 2.

$$\sum Mo = 0 = F_{app}L_{app} - F_{cg}L_{cg} - F_{cyl}L_{cyl}$$

$$\therefore$$

$$F_{cyl} = \frac{F_{app}L_{app} - F_{cg}L_{cg}}{L_{cyl}}$$

and

$$F_{app} = \frac{F_{cg}L_{cg} + F_{cyl}L_{cyl}}{L_{app}}$$

Figure 5.

$$\sum Mo = 0 = F_{app}L_{app} + F_{cg}L_{cg} - F_{cyl}L_{cyl}$$

$$\therefore$$

$$F_{cyl} = \frac{F_{app}L_{app} + F_{cg}L_{cg}}{L_{cyl}}$$

and

$$F_{app} = \frac{F_{cyl}L_{cyl} - F_{cg}L_{cg}}{L_{app}}$$

Figure 7.

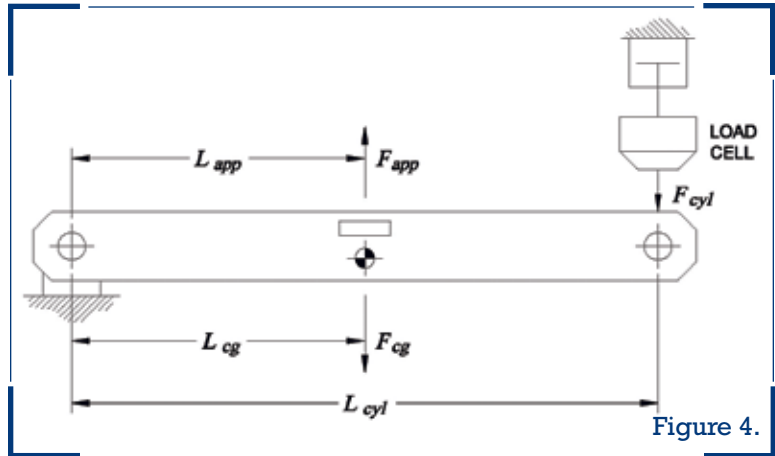


Figure 4.

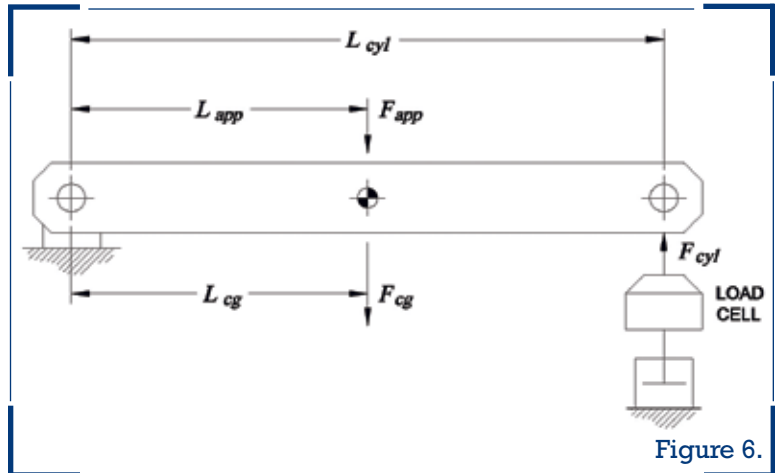


Figure 6.

balance equation converts the command signals to account for the fact that the load experienced by the load cell is different from the load experienced by the test article. Figure 5 and Figure 7 contain the moment balance equations. The polarity of the load required for the equations depends on point of reference and differs from the load command required at the controller. The actual programming of the communications interface between the LabVIEW code and the motion controller using Delta’s RMCLink software was straightforward.

The Delta motion controller assures precise test results because it is capable of running control loops as tight as once per millisecond. “I’ve never seen a system that can control as tightly as the Delta can,” said Emprise engineer Bill DuBose. “We will very likely continue to use the Delta / NI hybrid architecture on all future projects requiring high speed motion control.”

Figure Identifications

Figures 1A & 1B: Two views of the Emprise OQLS Durability Test Stand. A few of the load cells (blue) are visible, mounted on hydraulic actuators (black).

Figure 2: RMC150 Motion Controller. The RMC150 motion controller can control up to eight motion axes simultaneously.

Figure 3: Durability Test Operator Screen. The operator screen, implemented using LabVIEW, plots the loads applied to the hooks, snubbers, and dagger pin over time.

Figure 4: Hook Load Moment Balance Diagram. The hooks receive downward force through a moment arm from a hydraulic actuator mounted vertically. The hooks engage the rectangular pocket at the center of the arm. The load cell measures the force (F_{cyl}) exerted by the cylinder. F_{app} is the resulting force experienced by the hooks. The hook moment arms oppose each other so that the hydraulic cylinders do not interfere with each other.

Figure 5: Hook Load Moment Balance Equations

Figure 6: Snubber Load Moment Balance Diagram. Similar to the hooks, the snubber moment arms oppose each other, applying upward force to the snubbers.

Figure 7: Snubber Load Moment Balance Equations

Figure 8: Moment Arm and Flexure Table, Hydraulic Cylinder Arrangement. The cylinders on the top apply loads to the hooks. The two cylinders under them apply load to the snubbers, and the two in the bottom middle apply load to the dagger pin. The mechanical advantage offered in this arrangement was not the progenitor of this idea; rather, this lever arm configuration solves the problem of applying high loads in a small space. It would have been impossible to squeeze actuators small enough and strong enough in that little space to apply the large loads required.