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DATA ACQUISITION SYSTEM DESIGN FOR DELTA IV TEST PROGRAM

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DATA ACQUISITION SYSTEM DESIGN FOR DELTA IV TEST PROGRAM

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ABSTRACT

This paper describes the architecture of the new commercial data acquisition system planned to support the Delta IV test program. The description includes details about its design, implementation, and cost savings expected over the test program. The design section describes the development effort, overall system architecture as well as design detail. The implementation section describes how the unique features of the new system design will support the Delta IV test program. The cost savings section describes the expected savings in labor and material costs compared to the system used for the Delta III test program.

KEYWORDS

system, data, acquisition, VXI, strain, Delta IV, HP, telecom

INTRODUCTION

The Delta IV structural test program requires measuring more than 3000 strain gage channels. The program has several separate tests with channel counts varying from 100 to 800 channels. These tests qualify the structural strength of all the primary structure on Delta IV launch vehicles. To maintain an aggressive test schedule, the strain gages will be installed on a noninterference basis during the manufacture of the structure. When the test structure arrives at the Structural Test Laboratory in Huntington Beach, California, the major work remaining for the instrumentation technicians will be connecting strain gage lead wires to a data acquisition system.

The data system specified for the Delta IV test program uses a new Hewlett-Packard (HP) VXI-based system. This new system is very similar to the components and software that supported the Delta III program. The system, however, will incorporate a major enhancement to the sensor-input interface (front end). The new front end is designed as a remote multiplexing signal conditioner (Figure 1). This paper provides details on the design of the new HP system, describes implementation plans to support the Delta IV test program, and discusses the projected cost savings compared to the system used to support the Delta III test program.

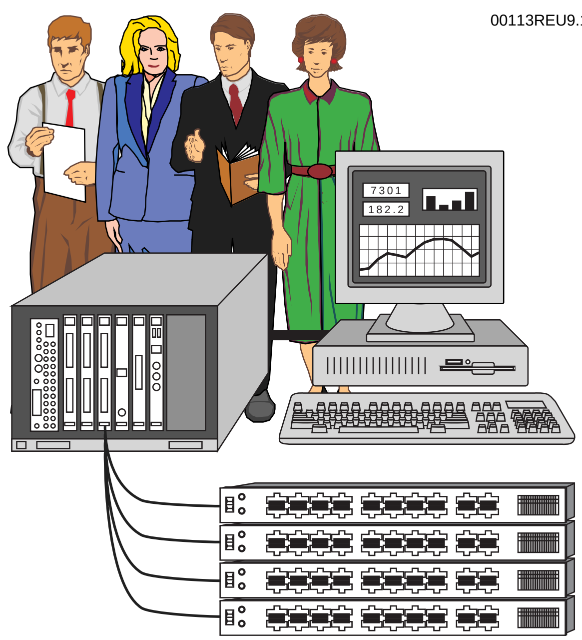

Figure 1. Computer Linked to a VXI Chassis with a Data Acquisition Control Card. Four Remote Bridge Conditioning Front Ends Connected to the Control Card

DEVELOPMENT EFFORT

HP launched a project to develop and market a signal conditioning system to augment their data acquisition product lines. The main design objective was to create a high-channel-capacity system that would cost less and be easier to use than other systems currently on the market. System design was leveraged by using the E1415A Scanning A/D Algorithmic Controller product as the “brains” controlling the new data acquisition hardware. The E1415A card (Figure 2) is a programmable, deterministic computer with the architecture to support many different input/output signal requirements.

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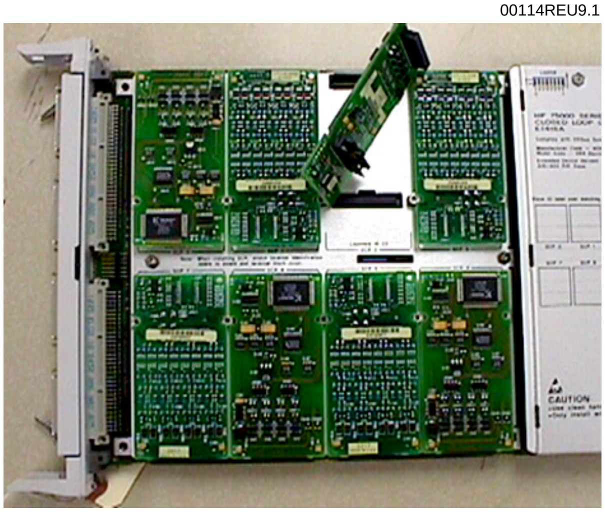

Figure 2. E1415A with SCPs Exposed

The VXI card has space for eight daughter circuit boards, called Signal Conditioning Plug-on (SCP) modules, that provides a compact area for special sensor signal conditioning circuits. Different modules are available to support varied sensors and devices. The algorithmic control card is ideally suited to perform closed-loop control and sensor data acquisition.

The Huntington Beach Structural Test Laboratory adopted the E1415A card as the standard data acquisition card because it performs data acquisition as well as specialized control functions. It is a one-card solution that supports the instrumentation needs of the laboratory. The instrumentation team has learned to program the card for applications including strain gage data acquisition, hydraulic actuator control, and liquid nitrogen (LN_2) tank pressure/level control. Ease of programming the E1415A is also augmented by using the HP Visual Engineering Environment (HP-VEE). Software development and modification is now completed in hours, not weeks.

The Boeing Structural Test Laboratory recently completed the Delta III test program with a data system using E1415A cards. The system was a major contributor to the success of the test program. When HP engineers inquired about ways to improve the product, the engineers at Boeing did not hesitate to become involved. From experience gained using the system, Boeing engineers provided many constructive suggestions on system improvement. A key suggestion was to improve the physical architecture to better support large-channel-count installations. Boeing requirements included reducing the number of long cables, allowing independent setup of channels without using control-room equipment, and reducing the number of networked computers.

HP’s most recent data acquisition product is a modified E1415A that features remote multiplexing strain-bridge conditioning front ends. HP assigned the product number E1422A to the VXI card (Figure 3), E1529A to the remote front end, and E1539A to the SCP module that provides the interface from the E1529A to the VXI card.

Together, these products result in a system with an architecture that enables simple installation and support of a large-channel-count data system in a structural test laboratory.

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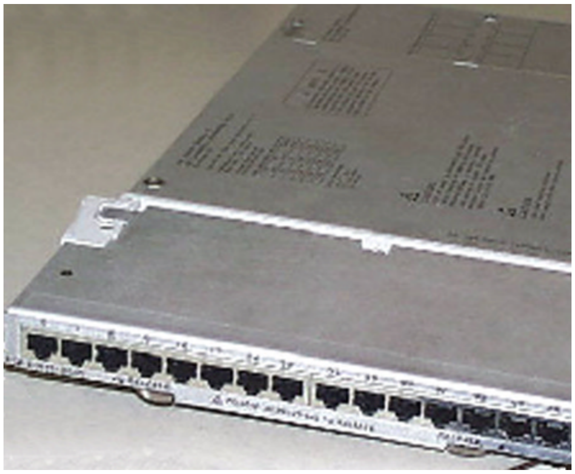

Figure 3. 512-Channel Remote Multiplexer Control Card (E1422A) with Telecommunications Connector Terminal Attached

DESIGN DETAIL

HP has designed capabilities into the E1422A product for use in large structural test laboratories. Tests performed in structures laboratories typically have many channels of sensors located hundreds of feet from the measuring electronics such as the E1422A. The tests are performed in places such as aircraft hangars, where sensitive electronics must be protected from dust, moisture, and hydraulic oil. The HP front end is packaged to operate in these environments, so it can be located adjacent to the test article (Figure 4).

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Figure 4. Front Corner of the E1529A Showing Drip Edges

By placing the system close to the test article, the massive cable bundles that are normally routed to control rooms are eliminated. Internally, the product combines sensor excitation circuitry with signal amplification and filtering circuitry (Figure 5).

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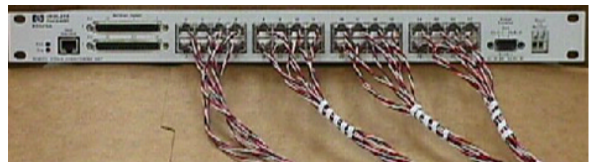

Figure 5. Remote Signal Conditioning Front End with 32 Channels of Strain Gage Lead Wires Attached

The combination meets the signal conditioning requirement for strain gage sensors, bridge-type sensors, and externally excited high-level sensors. These types of sensors cover all the sensors that are typically used in a structural test laboratory (strain gages, bend beams, string pots, linear pots, pressure transducers, load cells, and dc-powered LVDTs.) The target sensor for the remote multiplexing system is the quarter-, adjacent-half, and full-bridge strain gage sensor. HP targets the strain gage sensor because it is connected to the majority (over 75 percent) of the data acquisition channels used in a typical structural test laboratory.

The E1529A system has circuitry to multiplex sensor signals and programmable sensor signal conditioning. One unique feature of system design is that each module has connectors for 32 sensor channels. The system routes sensor signals to the control room through one small cable (Figure 6). This is accomplished by multiplexing the sensor signals in the module and transmitting the signals serially over the cable. A reduction of 32 long cables to one long cable eliminates the material and labor costs required to install large bundles of cables. To reduce the overall cable length requirement for the test, the multiplexing unit (front end) should be placed near the sensors.

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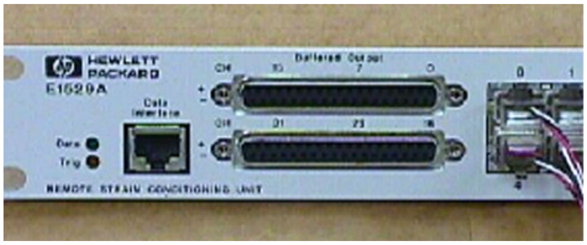

Figure 6. Left Side of E1529A Remote Front End Showing Data Interface and Buffered Output Connectors

The front ends can be located up to 1000 ft from the E1422A Controller.

The E1529A multiplexing unit has the necessary circuitry (Figure 7) to provide sensor excitation and signal amplification. The excitation circuit supports quarter-, half- and full-bridge sensors as well as high-level sensors such as dc-powered LVDTs. The unit can monitor both the sensor output and the sensor excitation voltages, which is a powerful feature when setting up each channel and diagnosing problems. In fact, the E1422A Controller can monitor both the health and calibration of each multiplexing unit as it does with all of its SCP modules. Special sequences reside on board the E1422A to perform end-to-end tests and calibration checks. The VXI card then adjusts its internal values to maintain the accuracy of the hardware.

Channel setup is uncomplicated. The system has one shunt resistor and multiplexes it across all the channels, reducing the metrology effort required to maintain system calibration. For bridge-type sensors, the system performs the shunt calibration. Other sensors can be set up using the slope values from metrology calibration data sheets. The E1422A card uses the calibration constants to convert electrical

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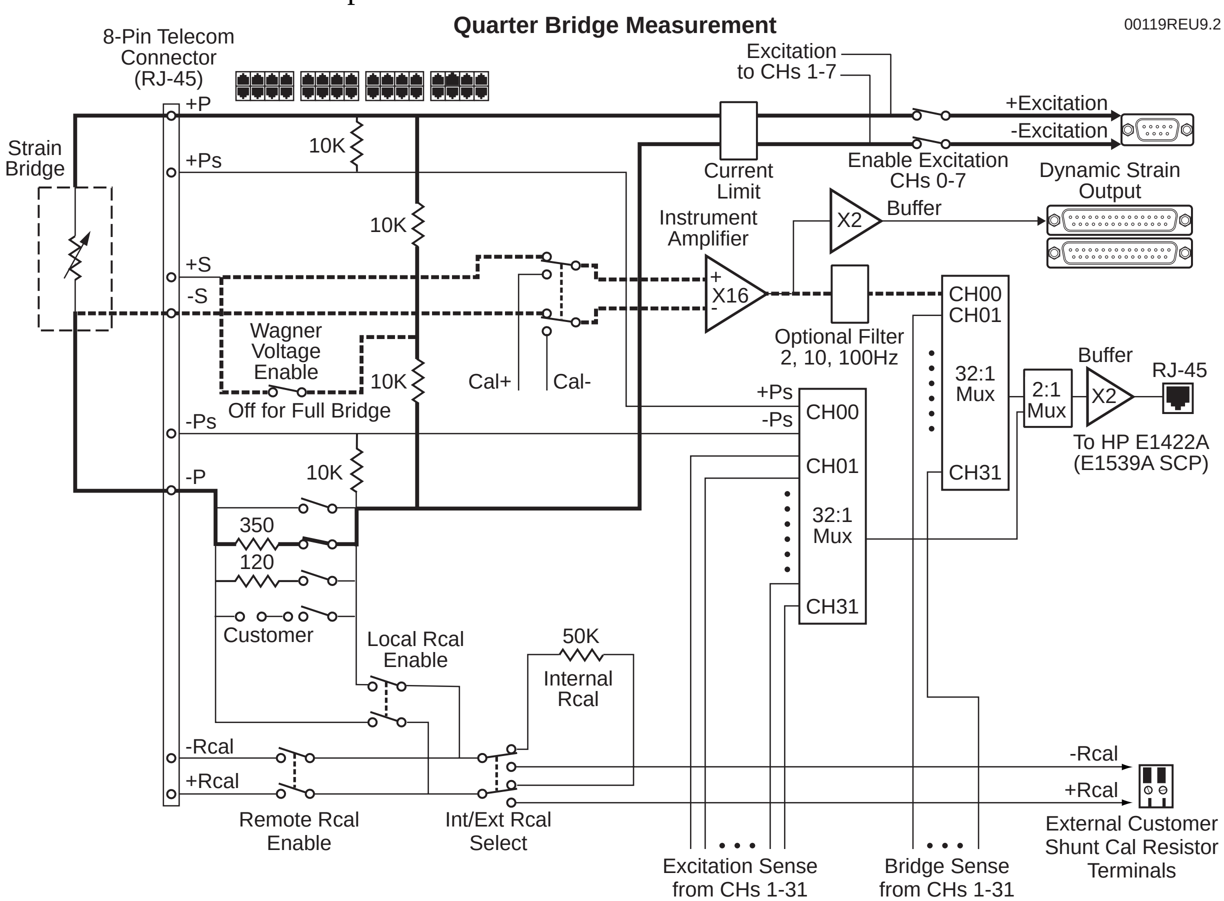

Figure 7. Schematic of the E1529A Signal Conditioning Circuit with Quarter-Bridge Strain Gage Connected

signals into engineering unit values such as microstrain, inches, etc.

The module has an internal power supply for its operational amplifiers and logic circuits. Sensor excitation power is supplied through a connector mounted on the front panel (Figure 8). The connector has four pairs of connections for sensor excitation power. Each sensor excitation connection supplies power to a bank of eight channels. Each channel has current-limiting circuitry to protect the power supply system from a large current drain caused by a short circuit in the sensor or sensor cabling.

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Figure 8. Right Side of E1529A Unit Showing Last Eight Channels of Inputs, the Sensor Excitation Input Connector, and the External Shunt Resistor Terminals

The system can safely manage a variety of excitation schemes. One scheme may have one power supply connected to all channels on the data system, while another scheme may have one power supply dedicated to each bank of eight channels. Each scheme has advantages. A single-supply design is very simple and easy to implement. A multiple-power-supply design provides redundancy and makes a selection of voltages available for different sensors that are connected to the system. For example, load cells used in the laboratory have two bridges for redundancy. A system must excite each bridge with a separate power supply to make load-cell signals independent and redundant. Because the data system can operate properly with any number of power supplies, it is up to the system integrator to exercise preference.

Sensor inputs utilize a telecommunications-type connector, RJ-45 (Figure 9). These connectors have gold contacts and are readily installed. They also have demonstrated years of reliable service. Engineers at HP have completed extensive mechanical and environmental tests on the connectors and established connector reliability. Each connector has eight positions with a metal shell to carry the shield. The standard cable has four twisted pairs with an overall shield. This cable is used to connect full-bridge sensors such as load cells, pressure, and full-bridge strain gage installations to the multiplexing unit. This same cable design is used to connect the unit to the E1422A Controller card. The quarter-bridge strain gage installation requires only three-conductors. The telecommunications connector easily handles three-conductor connections reliably. The connector works with either PVC- or Teflon-insulated strain gage lead wire, which can be terminated with or without jacket and shield.

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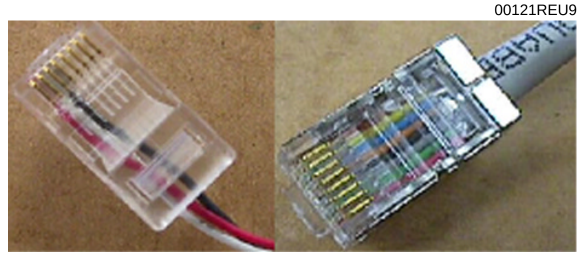

Figure 9. Photo Collage Showing an Unshielded Connector Used to Terminate Strain Gage Lead Wire and a Shielded Connector Used to Connect Full-Bridge Sensor Cables to the E1529A

The E1422A product, just like its relative the E1415A, handles an assortment of Signal Conditioning Plug-on (SCP) modules. These modules provide signal conditioning for both input and output signals. The input SCP modules provide a selection of filter and gain levels, while the output SCP modules support a large variety of signal types. The selection includes sensor excitation, analog voltage, analog current, pulse-width modulation (PWM), relay contact, and digital I/O interface.

SYSTEM IMPLEMENTATION

Figure 10 shows the HP front end multiplexer connected to strain gages and to a computer/instrumentation system. This is considered the setup configuration. A technician uses this computer/instrumentation system to set up the conditioning circuit in the multiplexing unit for each particular sensor. Once set up, the technician can check each channel for offsets and shunt voltage values and measure gage and lead resistance for each channel. A test of 500 channels of sensors requires 16 multiplexing units. Having the ability to check out each unit separately speeds up the test setup process by not requiring any interaction with control-room operations. Frequently, control-room equipment is supporting another test or operation and is available only a short time before starting the new test. This configuration allows the technicians to set up and test all the multiplexing units, sensors, and cables early in the test setup phase and requires the control-room checkout process to check only the connection and setup of the 16 units.

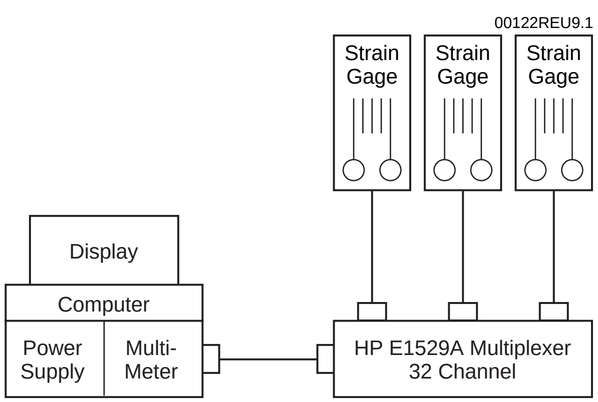

Figure 10. Block Diagram Showing Equipment Used to Set Up the E1529A

The HP system is designed to handle large numbers of sensor channels (Figure 11). Each

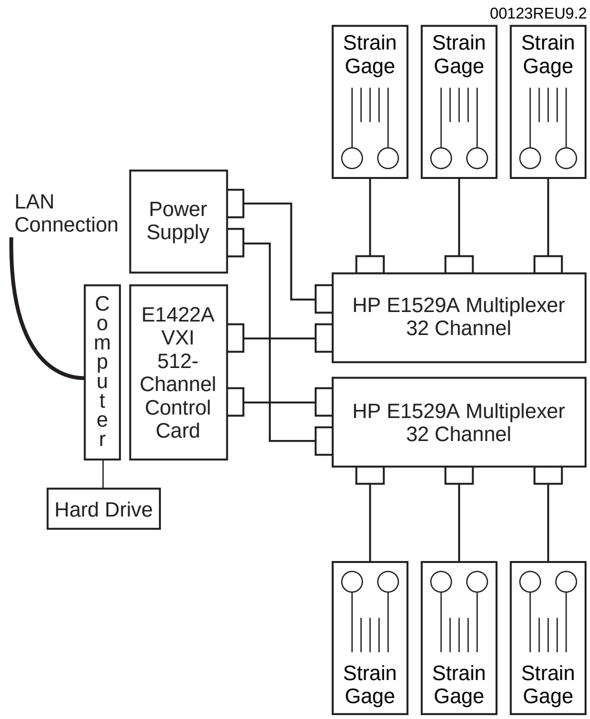

Figure 11. Block Diagram Showing System Setup Using the E1422A Controller with a Networked Computer that Sends Data to Remote Displays Used by Stress Analysts

E1422A card can acquire 512 channels at a scan rate of up to 50 scans per second. A plan exists to add nonvolatile memory to the multiplexing unit. This memory would serve as a scratch pad for information about the unit's setup. As the technician connects and checks each channel, he or she enters data to be saved for future use through the E1422A data acquisition system.

This location of data for bookkeeping purposes eliminates the effort usually required to re-enter data into many different systems and enables each multiplexing unit to perform system cross-checks. The operator can use this information to verify the setup on the main data acquisition system as well as when setting up each unit. The following information may be stored in memory: multiplexing unit identity, test name, setup date, channel number, signal conditioning circuit setup, gage name, gage factor, transverse sensitivity, shunt value, gage resistance, bridge type, cable label, cable resistance, gage manufacturer, and model and lot number. The list is partial and can be modified to include other information. For example, load cell sensor data might also include the certificate number, slope, and offset provided by the metrology laboratory.

The multiplexing unit includes the capability to scan and measure excitation voltage for each sensor, separately or concurrently, with sensor signal output voltage. This capability aids sensor diagnostics and calibration. As an additional benefit, the bridge excitation sensor inputs can be used to measure other high-level voltage sources such as dc-LVDT sensors or auxiliary outputs from other instrumentation systems.

The remote multiplexer has an additional output for each channel, called the dynamic signal output (see Figure 6). This is a 32X amplified output that is available for a high-frequency system such as the E1432A digitizer. The signal can also be connected to a 34970A data logger or any other instrumentation system. The multiplexing unit provides a shunt operation to allow easy setup of the secondary instrumentation. The unit has one internal 50-kΩ resistor, as well as a connector for an external shunt calibration resistor. The E1422A Controller can convert sensor signals to engineering units (EU) such as strain, KIP, etc. and uses the linear equation "mX+b" for conversion.

SYSTEM SELF-TESTS AND CALIBRATION

The new front ends incorporate self-tests and calibration functions that are well-known for the E1415A instrumentation series. The self-tests are diagnostic operations controlled by the E1422A card and include checking the proper functioning of relays, multiplexing switches, and other electronic circuits. Because the self-test operation is readily activated and quite thorough, the system can be evaluated regularly to maintain a high confidence in system reliability.

The system also has an automated calibration function that facilitates calibration. With one command, the E1422A system performs an end-to-end calibration and measures and compensates for gain and drift in all filter and amplifier stages for each input channel. Every multiplexer has a stable 100-mV source. Each channel has circuitry to short and connect the input to the 100-mV source to measure amplifier offset and gain. Because large systems have so many components that are critical to operation, having an automated test and calibration scheme is vital.

COST SAVINGS

The new HP data acquisition system has some remarkable cost-saving features compared to an E1415A system with equivalent capacity and capability. HP markets the new hardware at a very competitive price. Also, the new system requires no extensive labor investment to build interface panels supporting sensor connection to the system.

Because each E1422A card can support 512 channels of sensor inputs, the hardware purchase cost comparison includes all the parts to support 512 channels. The new data system requires the purchase of the following hardware:

- One E1422A VXI Card.
- Eight E1539A SCP Modules.
- Sixteen E1529A Front Ends.
- Two DC Power Supplies.

The mainframe, system computer, and bus interface are not included in this comparison because they are required for both systems being compared. Total hardware cost is $113,000, or $221 per channel. To make the system useful, the laboratory needs to design and build a power distribution network to supply dc power to all the channels and fabricate 16 data communication cables. The estimated effort to build the cables and panels is approximately 100 labor-hours.

If an E1415A system such as the one that supported the Delta III test program were to be purchased instead, the following components would be needed:

- Sixteen E1415A Controllers.
- Sixty-four Bridge SCPs.
- Sixty-four Analog SCPs.
- Thirty-two I/F Panels.
- Thirty-two Pairs I/F Cables.

The cost for these components totals $234,000, or $457 per channel. The laboratory would need to expend 1,800 labor-hours to build 512 cables and 32 I/F panels to make the equipment useful. This comparison shows the E1415A system costs $121,000 more and requires 1,700 additional labor-hours to prepare the system for use in the laboratory.

The E1422A system design requires less control room space because it acquires 32 channels of signals through one small cable. A 512-channel test setup requires only 16 cables to be routed to the control room and connected to the VXI card. The data system computer can acquire data from up to 12 E1422A cards or 6144 channels simultaneously. The system is small enough to be integrated into the test control center rather than an instrumentation room and thus eliminates the need for remote computer control over the computer network.

Using low-cost, simple-to-install connectors saves labor each time new sensor wires are connected to the system. These connectors can replace the expensive circular connectors used on previous systems costing over $5 each. The telecommunications connectors cost approximately $1.50 for the shielded version and $0.50 for the unshielded version. Typically, the unshielded version is used for the quarter-bridge strain gage sensors, which constitute 75 percent of the data acquisition channels. These connectors also have a second very important feature: They require very little labor to install. Technicians can terminate the three-conductor strain gage lead wire in a matter of seconds. The circular connectors that use crimp pins cannot be installed in seconds, they usually require several minutes for each cable. With 3000 channels of strain gages, the Delta IV test program will save more than 300 labor-hours.

Eight-conductor full-bridge cable fabrication is a little more tedious. It takes more effort and attention to strip the round cable and place the conductors in a designated order to terminate in the crimp-on shielded telecommunications connector. Boeing has found vendors that supply prefabricated and tested cables at a very competitive price compared to in-house labor. Current plans are to purchase the terminated eight-conductor cables from vendors for approximately $30. With the material cost alone for these cables totalling over $20, it is difficult to justify an in-house make.

Because the cabling cost is so low, it may be more cost effective to eliminate the labor costs incurred to recover the cables during test tear-down. Disconnecting the cables from the equipment, rolling them up into one big bundle, and disposing of it may take less effort than unthreading each cable from the bundle of cables in the cable trays and coiling them for storage. Further evaluation will be required to determine the most cost-effective approach supporting test tear-down.

Boeing engineers have studied alternatives for placement of the E1529A units. The scenarios range from spreading out the multiplexing units throughout the test structure to locating the units in one place close to the test fixture. Each alternative has merit. Scattering the units reduces cabling congestion and installation effort. The all-in-one-spot alternative makes servicing the E1529A easier but increases sensor cable length requirements.

A new concept to be explored is strapping the compact front ends to the test article during strain gage installation. By installing the front ends during the strain gage installation process, technicians can evaluate the strain gage sensor quality, connect the lead wire directly to the data system, and enter setup information directly to memory inside the front end. This eliminates handling the lead wire and entering setup data twice. For the present, every test setup will be evaluated individually to determine which alternative is best.

The E1422A system is so versatile that instrumentation engineers can use it for almost all tasks performed in the laboratory. By using the same piece of equipment for a variety of jobs, the engineers become more familiar with its capability and can support unusual test requirements in less time.

The many features described above make the E1422A system an extremely cost-effective data acquisition solution.

CONCLUSION

HP designers have done an excellent job of lowering the cost of purchasing and operating a superb data acquisition system. This new system is an extension of the high-quality scanning data acquisition equipment available from HP. HP has responded to the suggestions provided by the engineers working in structural test laboratories. The attributes making this the system of choice for the Boeing laboratory are its physical architecture and flexibility. The system reduces the number of long cables that run from a test article to the control room. The remote multiplexing front ends also have circuitry to perform calibration and diagnostics. Because of the many advantageous features offered by the E1422A system, the Boeing Structural Test Laboratory has selected it to support the upcoming Delta IV test program.

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