A stress screening program
for circuit cards with automotive applications

By MARK PEABODY
Director of Engineering
LOWELL ANDERSON
Project Engineer
BRUCE STARK
Principal Mechanical Engineer
and MARTY JEIDE
Olin Aerospace Company
Redmond, Washington
and
GEORGE HENDERSON
President
GHI Systems, Inc.
San Pedro, California

The use of repetitive shock excited machines—sometimes erroneously referred to as 6DOF machines—for environmental stress screening (ESS) has improved the quality and reliability of transportation-related products ranging from automotive to aircraft electronics. It has also significantly reduced the time needed to find design- and production process-related problems that would otherwise limit the useful life of products. This paper describes an ongoing stress screening program at Olin Aerospace Company that is being applied to production lots of multi-layered circuit boards. The end objective of the Olin program is to produce products with greatly reduced infant mortality and higher overall reliability. Economic justification is based on reducing the costs of servicing cards installed on commercial airliners.

The same processes as described here are being used within the big three automotive manufacturers' electronics production facilities with some slight modifications. In these applications, repetitive shock machines are also used to quickly establish end of life due to fatigue accumulation of both new and existing designs.

Of significance in this program is the combination of very high-rate thermal stress ramps with multi-axis high-frequency vibration in order to increase the probability of defect precipitation in short times. Thermal changes on the product approaching 60 degrees C per minute are used. Vibration, as monitored at the fixture/product interface, is measured as fatigue accumulation rate intensity, not gRMS.

Because of the nature of repetitive impact machine excitation, special engineering techniques were applied to the design of circuit board mounting fixtures to minimize energy losses.

Program

The majority of the military and commercial aerospace programs at Olin use the standard 48- to 96-hour ESS consisting of sinusoidal vibration and thermal changes of a few degrees per minute. When quantities are relatively small and unit material costs relatively high, this method does not greatly affect the unit cost. However, for large production quantities requiring high reliability and low unit cost, such a test approach is not a viable method. Olin recently received a program in which the cost to remove and replace the product far exceeded its value. On this basis, workership and infant mortality screening were a necessity. Rapid test screening times were desired to minimize product cost. The economic justification of highly accelerated ESS, therefore, played a strong part in the selection of the new stress screening method.

The program has been so successful that presently all the high-volume products in this development unit at Olin are using similar screening programs. Olin created a dedicated production facility with a focused production team for this particular product line. As a result, installation of new screening chambers and associated facility requirements was not difficult to accommodate.

Facility

The stress screening facility at Olin is located adjacent to the circuit card production area. Two four-door Hanse Environmental Chambers, Model TVC-9 with their attendant power and control electronics panels, are situated for easy loading and unloading of circuit cards. Figure 1 shows the arrangement of the two chambers.

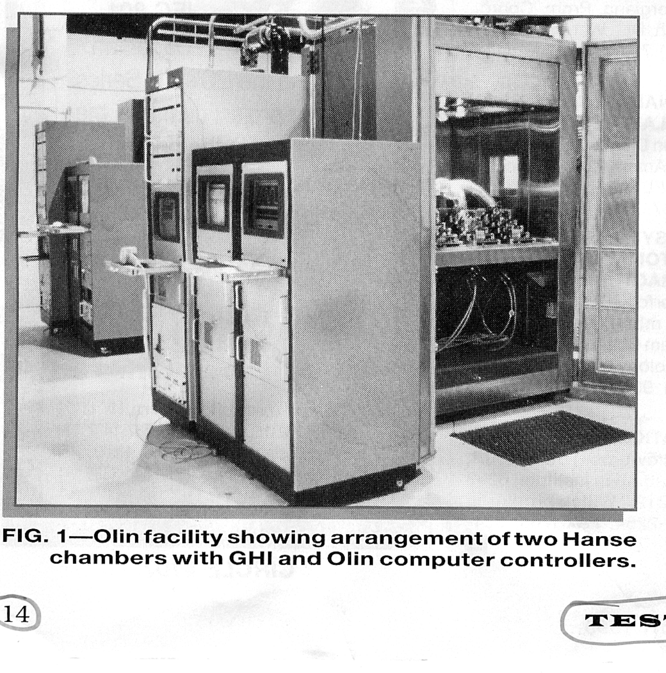

FIG. 1—Olin facility showing arrangement of two Hanse chambers with GHI and Olin computer controllers.

An external 9300-gallon liquid-nitrogen tank feeds LN2 to the chambers via vacuum-jacketed lines. A vapor bleed-off is located on the vacuum lines at each chamber to ensure that LN2 is available immediately upon command. The LN2 tank is serviced by a local LN2 supplier who monitors the tank level and dispatches a tanker when needed.

Compressed air for the impact hammers at a line pressure of 90 pounds per square inch is provided by a scroll-type compressor located in the chamber facility at 75 SCFM.

Figure 1 shows the placement of environmental air ducting from the source chamber. These ducts direct the air flow over the fixtured circuit card surfaces for more uniform and rapid thermal ramping.

Printed circuit cards are loaded into fixtures that are designed to maximize the transmission of excitation with minimum loss. The fixtures are constructed of 1.25-inch Al machined plate and are bolted directly to the TVC-9 tables. Each fixture is designed to accommodate up to 24 circuit cards at a time. Automatic test equipment (ATE), designed specifically for the Olin circuit boards, is connected to each card by cabling that passes through access ports in the chamber walls.

Specially designed expansion insert clamps that wedge between each card edge and corresponding mounting slot are the key to transferal of the chamber's vibration screening energy. This tight wedge causes a firm, low-loss, interface between the fixture and the circuit card. Figure 2 shows the fixtures with cards and ATE cables installed, while Figure 3 shows one of the special card insert clamps.

Overall chamber operation is controlled by a GHI RS-CAT system that also interfaces with the ATE system. The RS-CAT is a graphics-based profile controller for combined thermal and vibration. In addition, it is a multi-channel spectrum analyzer with specialized analysis tools for auto-spectrum, FFT, peak stress amplitude probability distributions, and fatigue rate assessment. Closed-loop vibration control is performed by the RS-CAT using its wide-band spectrum analyzer data acquisition input for sensing product or table response. From this raw data, gRMS or fatigue rate is compared with command profiles in order to execute control. From one to 16 channels can be averaged for control.

Thermal control is performed by passing setpoints from the RS-CAT graphic screens to a dual PID loop J.C. 620 Fastrac.™ A new setpoint is passed at least once in every five seconds, depending on screen length, and the temperatures for plenum air and monitored part are read back. The readback temperatures are then over-plotted on the setpoint profile screen in order to log performance. Figure 4 shows the RS-CAT graphic split screen test profiles for the Olin HASS tests. Monitored temperatures are shown in different colors to aid easy identification, as is vibration performance. Screens may be designed to be repeated. In this way, long-duration tests with complex interactions involving thermal and vibration periods may be used. At the end of each test, an HP DeskJet 560™ prints out a duplicate of the graphics screen, in color, for full test documentation.

The ATE system performs 13 cycles of card tests during the 35-minute, six-thermal-cycle, five-nested vibration screen stress profile. It also performs a test prior to any application of environmental stresses. This phase is used by the operator to weed out boards that are already defective prior to the start of the stress screen. Real-time SPC data is collected during the first, fifth, ninth, and 13th test. A logic line between the RS-CAT and the ATE system, assigned as a JC-620 "event," tells the test equipment that a card test sequence may begin.

The ATE equipment used to test the circuit cards was designed at Olin. The test equipment consists of a rack of 24 identical test cards controlled by a 486 PC. Each card is dedicated to one of the 24 units under test (UUTs). The test rack also includes a GPIB-controlled UUT power supply, keyboard, monitor, barcode wand, printer, and DC-powered supplies to power the test cards.

Each test card contains a 16-bit microprocessor with RAM and ROM, A/D converter, RS485 and RS232 interfaces, power supply loads, and interface circuitry. The test cards interface directly with the UUTs and apply stimulus and monitor the response of all of the UUT functions.

Each test card occupies an address location within the test rack, and test status and results are passed to the PC on an RS485 serial data bus. Failure reports defining UUT serial number, test date, test location, and the test failure and corresponding HASS cycle are printed on a printer located in the test rack.

The PC used to control the test cards and provide the user interface has a GPIB interface controller card, bar code want interface, and dual RS485 bus controller card installed.

The test equipment rack provides a Graphic User Interface (GUI) that uses color menu-driven screens to guide the test technician through the wanding, installation, testing, and removal of UUTs.

By comparing the time base of the environmental profiles from the RS-CAT with the card failure logs on the ATE equipment, engineers can determine the environmental conditions existing leading up to and at the time of failure.

Screening profile

Figure 5, a printout from the system printer, shows one stress screen profile being used at the facility. This split-screen plot mirrors the display on the control computers' CRT. The upper portion of the plot shows the repetitive thermal stress cycles. The temperature change is from -30°C to +80°C, giving a swing of 110°C. The temperature change rate on the profiles is equal to 60°C per minute. The dwell periods are short and are needed only to ensure that all parts reach the extreme temperatures. It is believed that high stresses are caused between materials with different coefficients of thermal expansion during rapid temperature changes, and these stresses, in combination with vibration, increase the probability of defect precipitation.

The wider and color-contrasting portions of the thermal profile show the time-related positioning (nesting) of the vibration excitation profiles during the thermal profile.

One constant fatigue rate vibration profile is shown in the lower portion of Figure 5. In order to servo control, it is first necessary to "ping" the systems at several excitation levels in order to estimate the response transfer function of the table and its load. Once this is accomplished, the system has the data it needs in order to control.

As the screen progresses, the monitored temperatures (supply air and product) and fatigue rate level are plotted against the graphic command profiles. At the end of the test, the profiles are printed out as permanent records of chamber and screen performance.

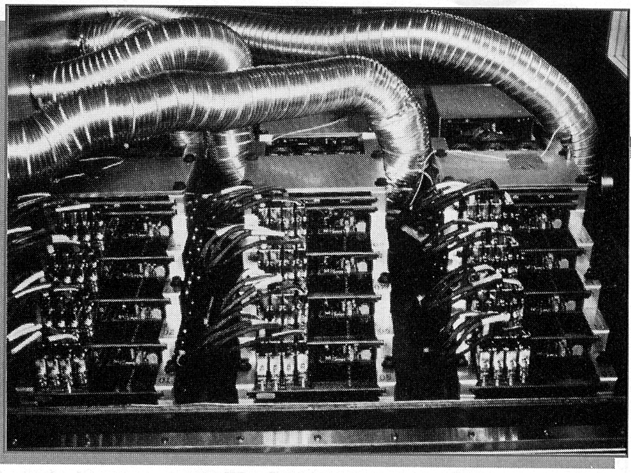

FIG. 2—Interior of Hanse chamber showing special fixtures and air ducts. This photo shows 15 of 30 cards under test in one setup.

Program results

The main accomplishment of the program has been a significant reduction in test time by reducing the standard burn-in time. Because of the high reliability requirements and repair costs associated with airborne electronics, most avionics equipment is subjected to a 96-hour burn-in cycle to reduce infant mortality and improve reliability. Burn-in cycles typically include simultaneous vibration and temperature cycling. Olin purchased the HANSE chambers and reduced the cost to the overall program. The use of the HANSE chambers reduced the burn-in time to 35 minutes and allowed Olin to ship high-volume, high-reliability parts on schedule.

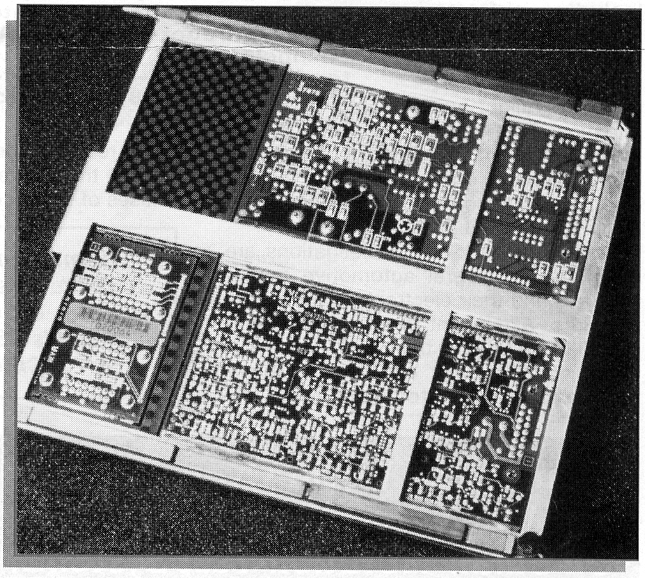

FIG. 3—Illustration of a single card with expansion clamp attached prior to loading into chamber fixture.

To date, the Olin system has been used to screen more than 20,000 units within a four-month period. Current component failure rates resulting from this screening are running approximately three to four percent, with the trend lowering as upstream processes are improved based upon failure analysis data. At the start of the program, some initial failures were found to be related to the amount of solder paste screened on the circuit card assemblies (CCAs). The past thickness, alleviating the failure. The environmental screening has also resulted in "discovery" of at least one potential trend regarding specific component reliability, which is currently under engineering investigation.

Units screened by this method are not yet fully fielded, with only approximately 2,000 currently in service. It is therefore too early to draw any conclusions regarding any

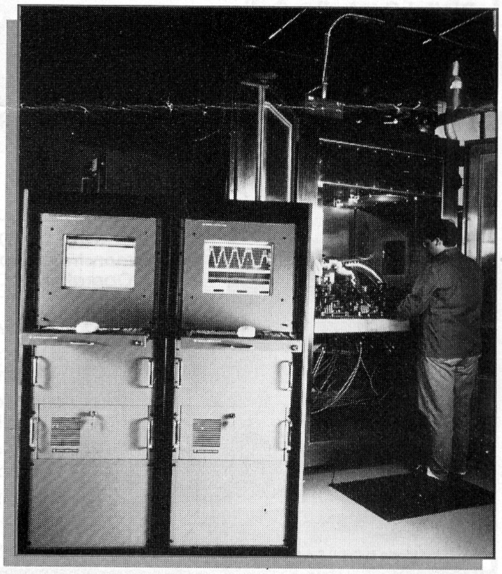

FIG. 4—Olin (left) card monitor and defect detection computer and GHI (center) graphics screen controller showing active thermal and vibration profiles in use on Olin tests. These two systems take handshakes to control the entire screening and detection process.

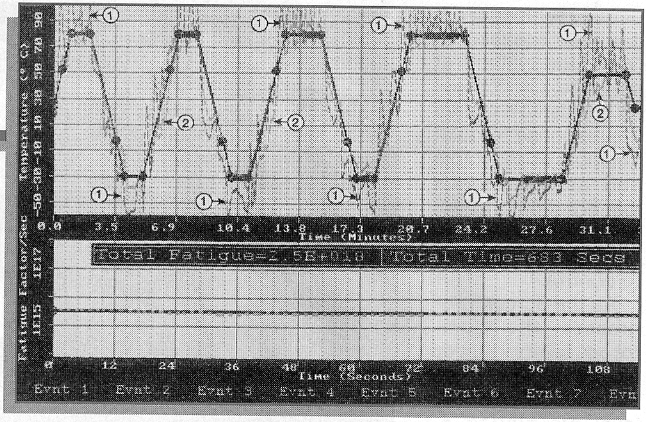

FIG. 5—GHI RS-CAT performance printout showing the five-cycle thermal profile running from -30° C to +80° C. The measured chamber air temperature is shown by the dotted lines (1), while the measured part temperature shows as (2). The command profile is the solid dark line. Special setpoints where thermal boost may be changed are large dots. The lower screen is the fatigue rate measured from the fixture/product interface. An average of four channels is used. The Total Fatigue is shown at the top of the profile—2.5E+18 over a vibration time of 683 seconds (11.38 minutes) for the combined total screen experience.

increase in product reliability that has resulted. Early information is promising, however.

Olin has now increased utilization of the testing methodology from the initial product to four other product lines based upon the successes experienced with the initial trial. Indications from customers, including airframe manufacturers, are that this methodology will be required on all future inflight applications. This environmental screening method is the process of choice based on reduced infant mortality, shortened production cycle time, and increased product reliability.

Similar methodology investigations are underway at several automotive manufacturers and their electronic components suppliers. A different profile of cost and reliability standards than those found in the aviation industry exists in the high-volume/low-cost automotive area. For these reasons, the technology is currently moving through reseach and development phases of these companies.

For more information about Olin's screening program CIRCLE #162
GHI's RS-CAT system CIRCLE #155