empfasis

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The EMPF is a U.S. Navy-sponsored National Electronics Manufacturing Center of Excellence focused on the development, application, and transfer of new electronics manufacturing technology by partnering with industry, academia, and government center and laboratories in the U.S.

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In This Issue

High G MEMS IMU

Precision guided weapons have made a significant impact in recent armed conflicts. These weapons offer increased accuracy resulting in the destruction of a greater percentage of enemy targets along with lower probability of collateral damage. Extending this precision guidance capability to munitions fired from Navy ships would allow precision strikes on enemy targets from a position over-the-horizon. Like many organizations, the military looks for ways to do more with less. Smaller and smarter munitions are becoming the candidates for in-flight guidance, such as the plan to use the Global Positioning System (GPS) guidance in Army artillery shells and in Navy deck gun projectiles. Microelectro-Mechanical System (MEMS) based inertial measurement units (IMUs) provide needed inertial guidance to the munitions complimenting GPS. However, advanced weapon systems must also meet stringent mission requirements in the areas of lethality and especially in the areas of extending gun survivability from 30,000 g to 40,000 g forces for future guided munitions. High speed launchers such a rail-gun will raise the survivability bar to 50,000 g in the future. Therefore, it is extremely important to develop packaging techniques that allow electronic modules to withstand the high-g forces encountered during a gun launch. MEMS-based IMUs can provide the required accuracy and small size at an affordable cost while surviving the high-g environment of gun launches.

Figure 1-1 MEMS IMU

A U.S. Navy ManTech program, supported by Office of Naval Research (ONR) and Program Executive Office for Integrated Warfare Systems (PEO-IWS) that focuses on improving the manufacturing technology and supply base for MEMS based IMUs for use in precision guided munitions, was initiated in 2004. Both BAE Systems and EMPF have participated in this program. To date, BAE Systems delivered several prototype IMUs (SiIMU02) to the Navy for evaluation. ACI has been managing this program for the U.S. Navy as well as performing related technical work in the form of IMU and MEMS storage life testing as well as a high-g design and packaging evaluation. The photo above shows a currently developed IMU unit from BAE Systems. The BAE units have survived initial high-g tests and are considered the finalists for Excalibur Low Rate Initial Production (LRIP). It is the desire of

continued on page 2

High G MEMS IMU
(Continued from page 1)

both Extended Range Guided Munitions (ERGM) and Excalibur to have a minimum of two viable MEMS IMU suppliers in order to ensure price competition and reduce delivery risk. Therefore, the development of an IMU supply chain is critical. It is also advantageous to have the same IMU suppliers for multiple precision guided munitions (PGM) programs in order to attain higher overall volumes and to reduce IMU pricing. It is expected that the IMUs produced by BAE will meet the reliability demands of DoD precision guided munitions programs. The SiIMU02 is expected to exhibit a higher performance and a more versatile form/fit than the current BAE SiIMU01 product, while retaining all the key advantages offered by the SiIMU01 model. This will make it available to a wider range of insertion opportunities, thus allowing it to be mass produced at a lower cost. Initial test reports indicate the SiIMU02 has shown the desired high-g survivability. This Navy ManTech program has successfully improved the produce-ability and reduced the manufacturing cost of these IMUs.

In order for IMUs to survive shock forces during the gun launch, these components will be extensively tested during the qualification trial. In general, shock is defined as a sudden change that affects the location, velocity, acceleration or forces in a structure. A blast or shock wave due to a near-miss explosion can obviously cause sudden deflection and high strain rates in electronic components and printed wiring boards, but this is by no means the only type of shock loading engineers must be concerned with. To identify the major failure modes of electronic systems under shock, EMPF has been compiling information from government agencies, IMU manufacturers, and research groups. The failures occurred in electronic systems under shock are primarily due to: high stress, which can cause permanent deformation; crack extension or failures; large deflections, which can cause collisions between objects such as adjacent wire-bonds, components, and circuit boards. Even though many packaging failure modes exist, only a few of them have been identified by researchers and users in the high-g packaging community.

Through an investigation with the support from several companies and researchers, two major failure modes were identified:

- Component/soldering pad lifted off from the circuit boards
- Cracked components

For example, two design versions (flip-chip and wire-bond) of digital portion of GPS receiver multi-chip modules (MCM) were tested at an artillery lunch condition of 12,000 g; the packaging limits identified were associated with standard surface mount (SM) components. The SM components (without encapsulation) showed selective failure where the circuit pads lift off the circuit board substrates. Only high mass components, which had sufficient inertial torque at the mounting pads, exhibited these failures. Other organizations have reported that cracks were observed in the capacitors and inductors at g-level reaches above 20,000~25,000 g in gun shock testing and other tests including centrifuge testing.

In order to conduct on-site high-g shock tests, EMPF purchased a Model 23 Shock Test System with a dual mass shock amplifier and a high-g shock accelerometer. This system has been installed. At the start of a shock test, an electric hoist raises the shock table until it reaches the programmed drop height, which was easily preset by the operator using the control system. The test table with mounted samples is then released and will make an impact with a program material to control the shock during on the base. At the same time, the shock pulse will be recorded by an electronic data acquisition system. A seismic base provides a precision impact surface and also isolates high shock loads from the floor and surrounding areas.

EMPF has created a design of experiment (DOE) model that will be used to evaluate the factors such as the component type, component size, lead pitch, component orientation on the board, the board substrate material, encapsulate, and under-fill material. The DOE was generated using a JMP program from the SAS Institute that utilizes algorithms based on providing the optimized design space for a given number of runs. Field test limitations only allowed the experimental design to provide 24 runs with 6 replications for a total of 30 runs, the equivalent of ¼ factorial. The four factors designed into the experiment are:

1. **Substrate** – Two Levels
   (FR4 and flex) The differences in material properties will allow for a robust assessment of rigid vs flexural behavior

2. **Orientation of the PCB in the Mold** – Two Levels
   (X and Y) as an orientation to the applied force

3. **Encapsulant** – Three Levels
   Silicone, polyurethane, and epoxy resins will be used to determine if the Elastic modulus and other characteristic properties of those resins have an impact. The selection allows for a low, mid, and high range modulus values

4. **Underfill** – Three Levels
   A low and a high-modulus underfill will be utilized. The third level will not have any underfill, only the encapsulant.

The model will allow detection of variability for all the main effects, as well as substrate, encapsulant, and underfill interactions. The design diagnostics show good D, G, and A efficiency, which essentially will capture variability for test points in the extreme ranges, as well as the interior points. The design is randomized, and blocks will be added for assembly and test sequences. The *(Figure 1-2)* shows a test board used at ACI with populated components. The boards will be subjected to either high-g drop tests at EMPF or later will subjected to air-gun shock testing at US Navy's Dahlgren facility.

continued on page 3

High G MEMS IMU
(Continued from page 2)

EMPF, as the Navy's Center of Excellence for Electronics Manufacturing, working with BAE Systems, has successfully reached a milestone with the delivery of four (4) cost-reduced, (MEMS)-based IMUs. MEMS-based IMUs are an enabling technology for PGMs. These units have been delivered to PEO-IWS for further evaluation. ACI continues to work with selected suppliers and manufacturing partners to apply electronics miniaturization to high-g DoD applications.

Author of article: Charlene Yao - *Charlene* is an Engineer at ACI. Comments or questions pertaining to this article can be sent to cyao@aciusa.org

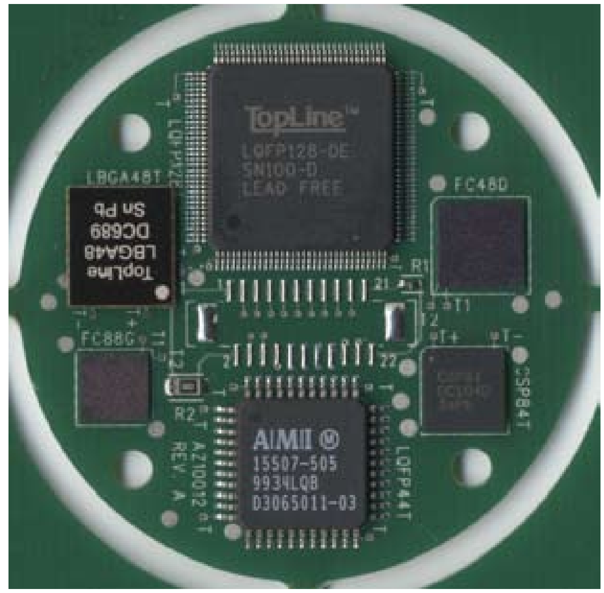


Figure 1-2 Test Board

A-600 Inspection and Reliability

The American Competitiveness Institute/EMPF is an Approved Certification Center for Instructor/Inspector Training to the IPC-A-600, "Acceptability of Printed Boards",and schedules this class at its facility located in Philadelphia on a monthly basis. Certified IPC Specialist training/certification can be scheduled as a custom course at the ACI Philadelphia facility or on-site at the customer's facility.

The IPC-A600 Document, "Acceptability of Printed Boards" is one of several publications of the IPC, "Association Connecting Electronics Industries", which sets the standard for acceptance of a process or product within the electronics manufacturing industry. The IPC-A600, "Acceptability of Printed Boards", defines the preferred, acceptable, and non-conforming attributes that are either externally or internally observable in the examination of printed circuit boards. The IPC-A-600 presents the visual interpretation of the level of acceptance based on the classification of the product, (printed circuit board), as established by other printed board specifications such as the IPC-2220 Design Standards Series and the IPC-6010 Qualification and Performance Series as well as the IPC-J-STD-003 Solderability Tests for Printed Boards. The photographs, drawings and illustrations in the document represent criteria particular to current IPC specifications requirements. To this end, the visual acceptance criteria are intended to provide implements to be used in the evaluation process of printed board manufacturing process variations and are related to specific requirements. These characteristics can be evaluated visually and may be measured or can be subjected to automatic inspection, X-ray or Acoustic Microscopy examination. The document for convenience of use is divided into three sections, Section 1 – Introduction, which defines the scope, purpose, application and supporting documents, Section 2 – Externally Observable Characteristics – conditions detected on or from the external surface of the board and Section 3 – Internally Observable Characteristics – conditions which may require microsectioning or possibly X-ray analysis/Acoustical Microscopy.

The IPC-A-600 Certified IPC Trainer/Inspector, (CIT) course is a three-day course with the presentation divided into four modules:

continued on page 5

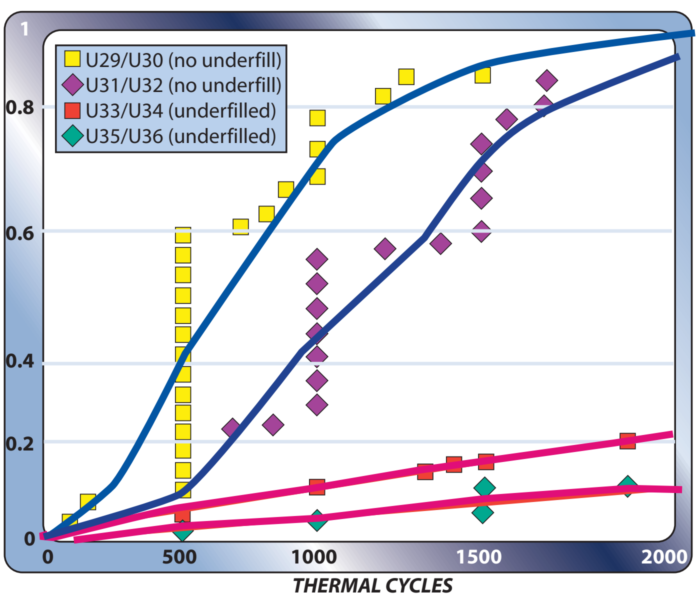
Ask the EMPF Helpline!

A customer called into the EMPF Helpline asking the criteria for determining if a BGA device should have an underfill.

The criteria for using an underfill depends on the environment and stress the BGA device will experience. When exposed to thermal cycling, a BGA or Flip Chip will expand or contract differently than the substrate on which it is mounted due to each material's Coefficient of Thermal Expansion or CTE. This differential length creates a stress on the device solder connection. Underfill is used as a "stress reliever", spreading the expansion and contraction effects and increasing the reliability of the device.

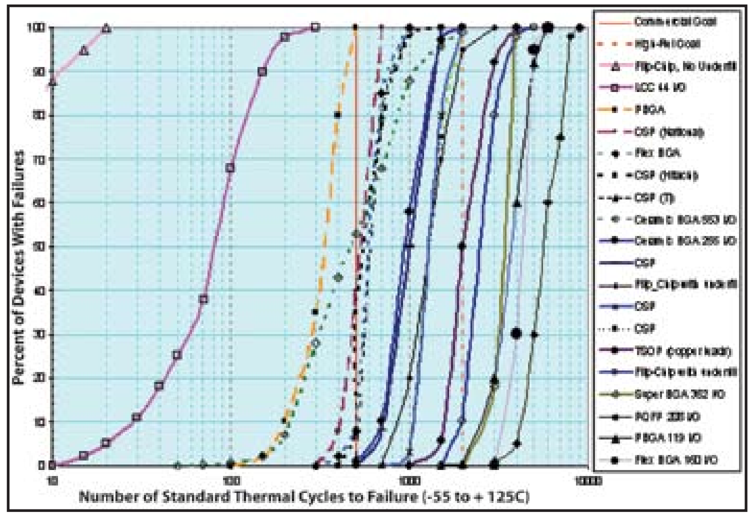
For Flip Chip components, the requirement for underfill is clear. In the EMMA (Electronics Miniaturization for Missile Applications) Program, ACI along with Raytheon, Rockwell Collins, NSWC-Crane, Marquette University, and Georgia Tech Research Institute, evaluated commercial electronic packaging technologies. The results, published in the Technical Applications Guideline (TAG) Handbook, show a statistically significant and dramatic improvement in solder joint thermal cycle reliability for Flip Chip components when an underfill is used *(Figure 1)*. The CTE of the underfill material and the solder were similar minimizing the solder joint strain in the vertical direction. In addition, underfill materials also improved the vibration reliability for Flip Chip components by increasing the mechanical connection between the component and the board.

Figure 1. Effect of Underfill on Flip Chip Fatigue Life

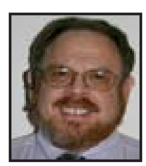


For BGA components, the criteria for underfill is not as clear. The larger the BGA ball and solder joint, the higher the stand-off, and the lower the strain at the connection. This allows a higher number of thermal cycles before failure occurs. Several BGA packages without underfill were also tested in the EMMA program. As shown in *Figure 2*, many pass the Commercial Goal in number of thermal cycles to failure and some even pass the High Reliability Goal.

Figure 2. Component Thermal Cycling Results



To determine if the reliability of your BGA device would be significantly improved by underfill, testing with the device (or a similar "dummy" BGA) in a similar environment must be performed. This is a service that ACI can provide. Manufacturer's specifications may also provide reliability data on their components from thermal cycle and vibration testing that they performed.



Author of article: Paul Bratt - *Paul* is an Engineer at ACI. Comments or questions pertaining to this article can be sent to pbratt@aciusa.org

A-600 Inspection and Reliability
(continued from page 3)

Module 1: Contents
- Introduction & Establishing/Maintaining Certification Program Integrity, (Common Procedures and Policies).
- Foreword, Applicable Documents, & Handling.
- etc., Introduction (Section 1.0 of the Document).

Module 2: Contents
- Surface Imperfections
- Subsurface Imperfections
- Imperfections in Conductive Pattern
- Hole Characteristics
- Marking Anomalies
- Solder Resist Surface Coating Imperfections
- Dimensional Characteristics

Module 3: Contents
- Conductive Patterns:
- Over Etching
- Under Etching
- Conductor Width
- Minimum conductor Width
- Etch Condition Definitions
- Problems Caused by Poorly Drilled Holes

Module 4: Contents

Introduction to cover board types.
- Flexible
- Rigid-Flex
- Metal Core
- Flush, (land patterns flush to the board surface).

Note: The entire IPC-A-600 Specification is covered in the presentation.

Upon successful completion of the course, the student will receive an CIT Training Kit containing: 1. IPC-A-600 Standard, 2. IPC-6012, 3. CIT Instructor Guide, 4. A-600G-CD for training CIS, 5. Written Exam Kit, 6. IPC-A-600 Sample Board. The Presentation is followed by two Certification Tests: a Closed Book Test and an Open Book test. Successful Certification requires an average grade of 80% with no grade below 70%. The Certification will be valid for a period of two years from the completion date. The IPC-A-600 Certified IPC Specialist, (CIS), course is approximately 20+ hours in duration and is presented in Modular form, however the CIS program contains optional modules with Module 1 being mandatory and modules 2, 3 and 4 being optional as to the particular needs of a customer. The duration depends on the modules presented.

Module 1 (Mandatory) Contents:
- Introduction/Overview, (Certification Policies and Procedures).
- IPC-A-600 document organization and general requirements

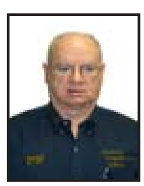
Module 2. (Optional) Contents:
- External Observable Characteristics, (external elements of a printed board that can be inspected with localized magnification).

Module 3. (Optional) Contents:
- Internal Observable Characteristics, (characteristics which appear internally in the printed board).

Module 4. (Optional), Contents.
- Miscellaneous, (Other printed board types).
- Flexible
- Rigid-Flex
- Metal Core
- Flush (Circuitry)

Each Module Presentation is followed by a Certification Test which requires a minimum score of 70% in order for the student to be certified to any of the modules. Successful completion of Module 1 is a prerequisite to certification to any or all of the Optional Modules. Upon successful completion of the Training/Certification Program, the Student will be awarded a certificate valid for two years from the completion date.

If you require additional information on the IPC-A-600 Training/Certification Program, wish to register for an upcoming course or require a quotation for a custom course presented at your facility, please contact the EMPF Helpline at (610)362-1320 or contact Mary Jane Crawford at (610)362-1200 Ext. 250.



Author of article: Riley Northam - *Riley* is an Technician/Instructor at ACI. Comments or questions pertaining to this article can be sent to rnortham@aciusa.org

20,000 G Test Facility

EMPF is pleased to announce the addition of a 20,000 g shock testing machine (for test loads less than 80 lbs.) to its array of reliability and failure analysis services offered to DoD and industry. The shock testing machine is part of a broad program initiated at EMPF to assess and develop new packaging techniques for electronics designed for use in precision guided munitions and other high shock environments. In these programs electronics modules are routinely subjected to impacts in the range of 10,000 – 50,000g. While such testing is not a substitute for the expensive field testing of military systems, it is important to have low cost screening methods that quickly root out components and packaging techniques that cannot withstand this severe environment. Impact testers provide a quick and effective means for performing such screening in a controlled environment. When combined with other environmental tests, lifetime assessments can be made.

Shock and vibration testing services perform testing on finished products or components using shock, sine, and other dynamic test conditions. Typically a battery of tests is performed in accordance with published standards from organizations such as Underwriters Laboratories (UL), American Society for Testing of Materials (ASTM), and International Safe Transit Association (ISTA). Shock and vibration testing for military equipment is covered under MIL-STD-810F and 901D. These tests may be used to determine the effects of aging, bounce, creep, decompression, fatigue, fire, humidity, pyrotechnic shock, radiation, sterilization, stress, thermal cycling, ultraviolet radiation and weathering. Examples of products that might require testing include: aerospace and avionics equipment, automotive parts, electronics and microelectronics, electrical distribution devices, combustion and hazardous location equipment, industrial machinery, and instrument sensors. Shock and vibration test testing may also be required for valves and pumps, pneumatic and hydraulic systems, healthcare and medical devices, batteries, and energy products.

Shock testing of electronic assemblies as defined by both MIL-STD-810F (Method 516.5) and JESD22 standards has precipitated a demand from the electronic industry for reliable testing sources to meet the spec requirements. As important as the equipment and facilities are in contributing to shock test quality, it is equally critical that the nature of test be understood to provide the correct operating conditions, and optimal response.

As currently specified in the MIL-STD-810F, materials or assemblies weighing less than 20 lbs are required to undergo drop heights of at least 30 inches, at velocities of 304 in/s to simulate the required material functionality before, or after being inadvertently dropped. This can be an individual electronic package, module, or circuit board, for example, prior to the full assembly or integration. Once the full box assembly is completed, an additional transit drop requirement may be needed which requires multiple drops at a minimum of 4 ft. The shock tester should have the ability to produce the substantial displacement and velocity requirements needed to produce the minimally required trapezoidal pulse shape.

For certain military applications, where forces can exceed 10,000 g, the complexity of the transient waveform requires a shock response spectrum analysis capability that is needed to ascertain more complex transient shock events. Versatility is an important element in the capability of the shock system and should include features to determine half sine, trapezoidal, and terminal peak saw tooth pulses that can generate reproducible results.

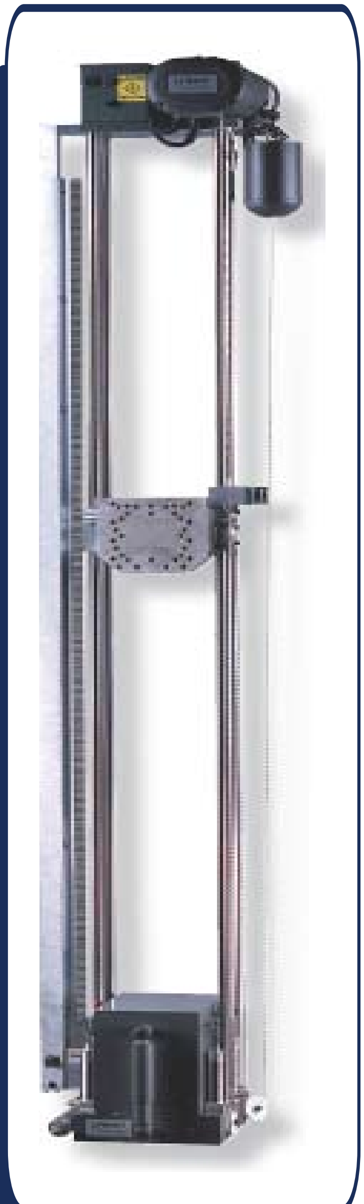


Figure 2-1: Lansmont Model 2 3D Shock Test System

EMPF has responded to the need for reliable shock analysis by building a shock test facility to house the Lansmont Model 23 Shock Test System shown in *Figure 2-1*. The System features an electronic hoist lifting system capable of producing drops from a 96 inch height with velocity changes of up to 432 inches/sec. The shock pulse can produce durations from 0.2 msec to 60 msec at forces of less than 5000 g, and time durations of less than 0.1 msec for shock levels approaching 30,000 g. This model is designed for testing products weighing up to 80 lbs, using a 9” x 9” high strength aluminum shock table. To attain high impact levels, the Model 23D machine is outfitted with a dual mass shock amplifier. The data is transmitted to a Partner 3 data acquisition system for analysis, where a detailed Shock Response Spectrum can be produced. In addition, the software can perform an FFT analysis, a shock response animation in both 2D and 3D modes, a shock response analysis with programmable model F_n and damping, and tolerance band overlays with selectable Mil-Spec and programmable pulse parameters.

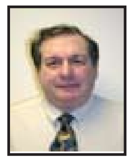
To reduce the amount of background noise, the Lansmont system is fitted with a floating seismic reaction mass, which can isolate the

continued on page 7

20,000 G Test Facility
(continued from page 6)

shock energy to the surrounding environment. Various buffering materials can be inserted between the shock base and the floating seismic reaction mass to produce a range of transient duration times at any given drop height. As the material quality and thickness of the buffering pads changes, the displacement of the sample will increase or decrease, producing changes in the amplitude and duration of the shock pulse. The accelerometer is also critical for producing reliable and reproducible data and should be rated for the amount of potential force that the sample may encounter. The shock tester is equipped with an ICP accelerometer that is rated to 50,000 g, and can be retro-fitted to mount various assemblies. Fixtures can be produced that can generate data on all three orthogonal axes, which is a requirement in the MIL STD testing.

To complement the impact test, EMPF also offers vibration testing using a Labworks vibration table. Shock and vibration testing can be combined with storage in environmental chambers including thermal cycling or thermal shock, temperature/humidity storage, HAST, salt-fog, or high temperature storage. ACI affords the user a comprehensive level of support including additional materials and failure analysis services. Failure analysis can be performed invasively (cross sectional analysis) or non-invasively (X-ray imaging). Our experienced staff is knowledgeable in both the technical and quality aspects of producing, interpreting, reporting, and combining shock data with other reliability testing that is appropriate to your needs.



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Manufacturer's Corner
AOI Equipment

Inspection challenges associated with high reliability electronic manufacturing can often be mitigated by investing in automation. With the ever increasing demand to drive down material waste, costs and maintain quality, Automated Optical Inspection (AOI) equipment is well recognized by electronic manufacturing management as a cost-effective process solution. Within the last five years advancement in AOI technology has resulted in the availability of extensive range of real-world solutions to meet the ever-changing requirements facing electronic manufacturing centers and production facility. Today's generation of Automatic Optical Inspection (AOI) equipment efficiently addresses density, diversity, and quality requirements, eliminating the subjectivity and variability found with manual visual inspection processes. Advanced optical inspection systems detect errors during the assembly of the electronics, and enable measurement and process control at the highest speed and accuracy. Inspection coverage encompasses solder paste, pre-reflow and post-reflow/wave inspection of SMT and mixed technology boards. Features and benefits drive the selection and purchasing process of new equipment acquisition. Equipment features should include comprehensive integrated optical inspection solutions with off-line programming capabilities, flexible repair solutions, extensive SPC tools, and provide the user an inspection platform to support inspection of product anywhere in the process, this enabling accurate and repeatable real-time process measurement and process control. AOI equipment today must provide to management a configurable software-solution SPC package to achieve real-time process feedback, manage, analyze, filter, display measurement output as well as statistical analysis of defect information on the part and board level; Key areas of real time measurement should include Paste: area , pad area coverage (%), height (micron), volume (x) / Pre-reflow: x and y offset (micron), rotation (degrees) / Post-reflow: x and y offset (micron), rotation (degrees), solder fillet size (%) all of which allows process engineers to understand the process window and recognize process shifts as they occur.

Paramount to the management team of electronic manufacturing centers is meeting client contract requirements of product traceability and real-time data logging; a typical application is output in a spreadsheet format for use in programs such as Excel. Data outputs should be automatically generated, configured to client/contract requirements, collected in real time and be sent to a host automatically after each inspection.

Real-time data analysis helps identify process problems, for example placement translation and rotation, which can be detected, and corrected, at the source.

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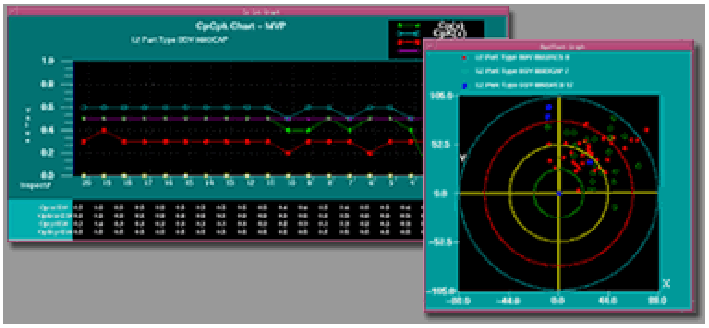
Manufacturer's Corner
AOI Equipment (continued from page 7)



AOI Equipment at EMPF
MVP has developed a new 3D inspection approach by integrating the latest available high-speed smart cameras into the existing design of the AutoInspector Series. The MVP

AutoInspector Supra offers a high performance package with excellent resolution and thru-put capability. The MVP Supra provides defect detection coverage for paste, pre-solder, and post-reflow inspection, is designed for the medium volume/high mix platform market and continues to be an excellent inspection solution at a reasonable price.

The Compact Tabletop Inspection System is the first inspection system released in the GEM Series of inspection solutions. The Compact offers the same inspection capabilities as the AutoInspector inline systems, but in an off-line, small, portable package. Using the same software as the AutoInspector, MVP's Compact brings accurate, extensive defect detection at a price point conducive to those facilities requiring a valuable tool in their manufacturing process.

For additional information on the MVP Automatic Optical Inspection equipment or to schedule a demonstration, please contact Robert N. Berta, American Competitive Institute, by telephone at 610-362-1200 ext 253 or via e-mail at rberta@aciusa.org.

Author of article: Robert Berta - *Robert* is an Bus Dev at ACI. Comments or questions pertaining to this article can be sent to rberta@aciusa.org

Tech Tips... 901-D Shock Testing and Hardening

Electronic equipment installed and operated aboard Navy ships is required to withstand significantly greater mechanical shocks than those encountered in commercial use. Designers and manufacturers of such equipment need to take special note of these unique Navy shipboard shock requirements and the approaches used to meet them. The standard for Navy shock testing is documented in MIL-STD-901D - Shock Tests, High Impact Shipboard Equipment, Machinery, and Systems. MIL-STD-901D states its scope as: "to verify the ability of shipboard installations to withstand shock loadings which may be incurred during wartime service due to the effects of nuclear or conventional weapons." In contrast, commercial shock loadings are often confined to much lower drop, earthquake, transportation, or crash hazard levels of mechanical shock.

1. Determine the category of equipment being designed. MIL-STD-901D cites three categories of light, medium, and heavy equipment. The size and weight of the equipment determine the category. For light or medium electronic equipment, the 901D tests vary only slightly from commercial requirements, and can be set up and run under laboratory conditions.

2. Heavy equipment requires the expensive outdoor MIL-STD-901D "barge test." This test requires heavy equipment such as the PCMs (Power Conversion Modules) for IFTP (Integrated Fight Through Power), to be mounted onto a floating barge and have an explosive charge detonated at a designated distance from the barge *(See Table 4-1)*. PCMs are to be used on DD(X) and CVN-21. The resulting "g" forces (each "g" equals one times the acceleration of gravity) exerted on the equipment are orders of magnitude higher than the most severe earthquake shock that could be experienced by a commercial installation. Typically, commercial equipment is

Test conditions	Standard floating shock platform	Large floating shock platform
Depth of explosive charge below water surface (for all shots)	24 feet	20 feet
Explosive charge weight/ composition	60 lbs./HBX-1	300 lbs./HBX-1
Shot direction [1]:		
Shot 1	Fore-and-aft	Fore-and-aft
Shots 2, 3, and 4	Athwartship	Athwartship
Standoff [2]:		
Shot 1	40 feet	110 feet
Shot 2	30 feet	80 feet
Shot 3	25 feet	65 feet
Shot 4	20 feet	50 feet

Table 4-1 "Barge Test" specifications from MIL-STD-901D

rated to withstand 10-15g mechanical shock loading. The challenge here is to reduce the shock applied to the COTS components desired in the military hardware to below the 15g level while the overall military housing is subjected to the full 901D barge testing shock.

3. Barge Test the equipment. This has been successfully accomplished in large, heavy, shipboard cabinetry by a company in Tallman, NY coincidentally named "901D," and its subsidiary, ShockTech Inc. 901D is involved in barge testing often enough to offer the possibility of lower cost per test by populating each barge with several customers' cabinets. By using judicious placement of shock absorbing materials and/or assemblies into the cabinet that houses the commercial and

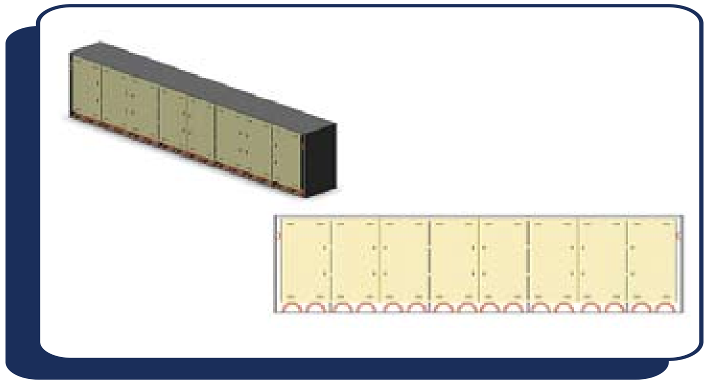


Table 4-2 Standard Shipboard Navy Electrical Cabinetry built 901-D Shock Tech shock absorbing material

military gear, 901D company has been able to "cocoon" embedded COTS gear so that the COTS experiences less than the 15g shock it is designed to withstand while the Navy shipboard cabinet that houses it experiences the full force of the MIL-STD-901D testing. 901D cabinetry, housing communications, radar, and sonar applications, is being used successfully in Navy shipboard applications today, some utilizing embedded COTS equipment, as the result of just such "cocooning" of the commercial gear. *Figure 4-2* below shows a typical 901D cabinet installation, showing the ShockTech shock isolation scheme. Note the inverted "u" shaped shock mounts shock isolating the interior equipment racks at the bottom and sides of the cabinet from the external cabinet frame. COTS equipment would be located in the interior area.

4. Improve the models for higher payloads. A further challenge will be to sufficiently shock mount the IFTP PCM cabinets for DD(X) and CVN 21, as they will require significantly higher payloads than existing shipboard cabinet installations that have been used for radar, sonar, and communications. This will require application of the barge testing simulation models to the larger cabinet payloads required for the PCM units, and then the design, barge test, and sea trials to qualify the new cabinetry for shipboard shock loading to MIL-STD-901D requirements.

Author of article: Fred Verdi - *Fred* is an Engineer at ACI. Comments or questions pertaining to this article can be sent to fverdi@aciusa.org

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R&D: Thermal Battery for Munitions

During the past year, EMPF at ACI conducted a Thermal Battery Development project which was funded by the U.S. Navy ManTech. This Thermal Battery Development project is an example of the various partnerships the EMPF/ACI has with industry, academia and government laboratories. Specifically, this program showcases EMPF's role in the identification and solution of manufacturing technology issues affecting batteries and power electronics systems used in DoD applications. Other power system projects ACI has conducted are the SDV battery, PRC-112 radio battery, MOFA reserve battery, and REPTILE power systems.

This U.S. Navy ManTech program was developed in response to military demands for munitions batteries with long shelf lives. The program goals were to demonstrate thermal battery manufacturability and to develop test data criteria for qualifying new thermal battery manufacturers. Specific objectives project were the identification of manufacturing processes that pose challenges to any new supplier of thermal batteries and the documentation of baseline test processes and test data to use as a reference for interested new market entrants.

Thermal batteries are single use batteries that are inert at room temperature. They are referred to as "Thermal Batteries" because their internal temperature must be raised above 400°C before they become electrochemically conductive (active). Another name for thermal batteries are "molten salt" batteries. These batteries belong to the "Primary Reserve" class of batteries. Primary batteries are discharged once and discarded afterward. A consumer market example of a primary battery is an alkaline flashlight battery. Secondary batteries, commonly called "rechargeable batteries," can be reused after charging. Typical consumer market secondary batteries include lead acid batteries, NiCd batteries, NiMH batteries, and lithium ion batteries. Reserve batteries are batteries designed to be stored for years, even decades, without performance degradation. Reserve batteries are stored in an inert state and can be activated within a fraction of a second with no degradation of battery capacity or power. The demand for reserve batteries by the consumer market place is minimal.

Thermal battery cells typically have an alkali or alkaline earth metal anode, a salt electrolyte, and a metal salt cathode. A pyrotechnic heat source is inserted between the cells in the battery stack. At room temperature, the salt electrolyte is a solid. The battery is activated by a lighting an internal fuze that in turn lights the internal pyrotechnic materials. The pyrotechnic materials raise the internal battery temperature to between 400 – 700°C. Once the internal temperature is above the 400ºC, the electrolyte melts and the battery becomes active (electrochemically conductive). The time the cell is active and produces power is called the run time and it can be no longer than the time the electrolyte remains molten. Run times are usually under 10 minutes, but some designs allow for run times of up to several hours. The battery returns to an inert state as the battery cools below 400ºC and the electrolyte again becomes a solid.

Applications for thermal batteries

Thermal batteries are suitable for applications where the battery may be stored for years, or even decades, with no maintenance prior to use. They are good for applications where the battery must withstand extreme temperature storage conditions and high g forces. For example, this condition occurs when a munition is shot out of cannon. Yet despite this abuse, the battery must provide high rate power discharge within a fraction of a second after activation and have no degradation from the original performance design. Typical applications for thermal batteries are aircraft ejection seats, countermeasure devices, guided artillery, mines, torpedoes, guided bombs, and missiles.

Advantages and disadvantages of thermal batteries

The advantages of using thermal batteries are that they have long shelf life and do not need maintenance while in storage. Once they are hermetically sealed, they are electrochemically stable. Thermal batteries do not outgas or swell. They can be stored for decades. They can operate in a wide range of environmental temperatures (-65°C to +75°C). They can withstand high G forces and they deliver high power levels. After they are used and have cooled down, they are inert and can be safely stored prior to disposal.

The disadvantages of thermal batteries are that they are primary batteries and can only be used once. For critical applications, this raises a reliability issue because it is impossible to confirm the performance of each thermal battery prior to use. Samples from the manufacturing lot can be tested, but not the specific battery.

Another disadvantage is that when they are activated, the battery is very hot. Typical surface temperatures exceed 260°C and the internal temperature range is 400°C to 700°C. The munitions system must be designed to withstand the heat and yet not transfer heat away from the battery. Premature cooling of the battery will reduce run time and reduce the power available to the system. It is best to thermally isolate the electronics and the munition from the thermal battery. In addition, thermal batteries are susceptible to activation when shot or pierced by enemy fire. If enemy fire pierces a thermal battery, the pyrotechnic material may light and prematurely activate the battery which in term

continued on page 11

R&D Thermal Battery for Munitions
(continued from page 10)

could activate the munition.

The final disadvantage is the cost and the limited supply of thermal batteries. There are limited commercial uses for thermal batteries and as a result there is a lack of commercial incentive to create large scale production lines with sophisticated automation technology. Thermal batteries are typically made on small production lines in small lots using a mixture of automated and hand assembly manufacturing techniques. For example, the electrode pellets are typically cold pressed. Cold pressing pellets limits how thin the electrodes can be made. Cold pressed thin pellets are not as robust as thick pellets and are susceptible to cracking and breaking. Thinner electrodes would improve discharge rate and voltage stability under discharge load. In addition, thinner electrodes would allow the smaller thermal batteries to be designed for miniature munitions electronics. There have been recent research and development advances to create thinner electrodes by utilizing hot pressing and plasma spraying methods. However, due to small sizes of orders for thermal batteries, thermal battery manufacturers are reluctant make the investment in manufacturing automation that would be needed to implement these advances, since there would be little or no return on this investment. Producers of raw thermal battery materials, such as the powders for the pellets, do not cater to thermal battery manufactures. Thus, the purity of materials can vary from batch to batch and the battery manufacturers must purify and lithiate the powders, which also adds to the cost.

The future

Recent advances in other battery technologies have made it possible to consider other battery chemistries for some thermal battery applications. For example, recent advances in lithium ion batteries have significantly raised the discharge rates that lithium batteries can be designed for. Along with advancements in reducing charge time, it is possible to consider using rechargeable lithium batteries for some critical applications where testing the battery prior to application is preferable and where the lack of battery maintenance is less critical.

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