empfasis

A publication of the National Electronics Manufacturing Center of Excellence *September 2004*

American Competitiveness Institute

ISO 9001-2000 Certified

American Competitiveness Institute
One International Plaza
Suite 600
Philadelphia, PA 19113
(610) 362-1200 • **FAX**: (610) 362-1290
HELPLINE: (610) 362-1320
WEBSITE: www.empf.org
www.aciusa.org

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 centers and laboratories in the U.S.

EMPF Director
Michael D. Frederickson
mfrederickson@aciusa.org

In This Issue

Office of Naval Research Manufacturing Technology Program

ONR Program Officer
Richard Henson
hensonr@onr.navy.mil

Next Generation Aircraft Carrier Power Initiatives

The power requirements for the next generation carriers are complex and have many variables and possible solutions. The complexity of the power distribution system is immense and requires much higher power densities than a standard utility distribution system. Today's conventional power electronic systems and design practices result in systems that are 10X too large and heavy for application on the next generation carrier. The EMPF is working closely with the Office of Naval Research (ONR), DARPA, PEO Carriers, Penn State, and the Navy ManTech Electro-Optics Center of Excellence to develope viable alternatives for power distribution and pulsed power generation and usage in the next generation carriers (CVN-21, Figures 1-1 & 1-2) and electric warships (Figure 1-3).

Figure 1-1 CVN-21 Model[3]

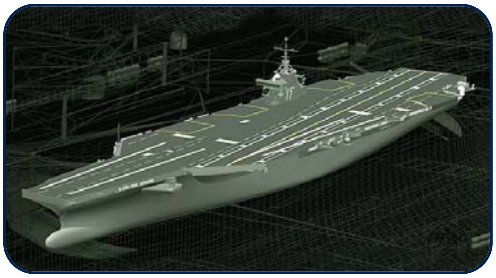

Figure 1-2 CVN-21 Model[7]

The first of the next generation aircraft carriers is scheduled to undergo construction in 2007 and be placed in commission in 2014. The CVN-78, of the CVN-21 class carriers, will replace the USS Enterprise (CVN-65), which by then will be 53 years old. The next generation carriers and electric warships will be able to generate up to 104MVA (mega volt amps) of power. That is equivalent to a small electric utility power generation facility, or the energy required for approximately 80,000 average US households (907 kWh/month), per DOE statistics.

Figure 1-3 Electric Ship Model[2]

This power is required for new systems such as the Electromagnetic Aircraft Launch System (EMALS), Electromagnetic Aircraft Recovery System (EARS), electromagnetic (EM) weapons, pulsed energy and laser weapons. All of these systems have at least one thing in common. They all require high energy electric pulses. How these pulses are generated and distributed is a new and novel problem that must be solved. In addition, conventional power electronic systems and design practices result in systems that are 10X too large and heavy for application on the next generation carrier.

The generation and distribution of pulsed energy is a critical component in the power distribution system. The current idea for generating pulsed power is through the use of advanced flywheel technologies. Each flywheel system is heavy and bulky. If each system that requires pulsed power has its own local flywheel system, this will place heavy equipment in areas of the carrier that are

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Next Generation Aircraft Carrier Power Initiatives (continued from page 1)

not optimal. Both weight and center of gravity are critical concerns of the next generation design. Placement near upper decks of the carrier are not desirable, so lower decks are preferred. Sharing some of the components of the pulse power supply, mounting them lower in the ship for better weight distribution, and distributing the lighter, weapon specific components closer to the guns and launchers are possible solutions.

How can the weight and size of power conversion equipment be reduced? The weight of a transformer made from iron and copper can potentially be reduced by using a solid-state transformer. This combines power electronics with a transformer that is reduced in size due to the operating frequency of the power electronics. Another possible advantage of this technology would allow the output voltage to be better regulated with fluctuations of the input. The development of wide band gap (WBG) semiconductors is presenting a possible paradigm shift in semiconductor power density. WBG devices operate at higher temperatures and require less cooling. They also have higher blocking voltages than conventional silicon devices and operate at higher switching frequencies, thus allowing for the use of smaller transformers and inductors (magnetics). The EMPF has worked with Virginia Tech and Sandia Labs to develop the Emitter Turn-off Thyristor (ETO), an enhanced Gate Turn-off Thyristor (GTO) design with an integrated gate drive that operates at higher switching frequencies and allows for snubberless operation. Improved thermal management of semiconductors and passive components through upgraded packaging techniques would allow more current to be handled by a given device and lead to improved power density designs. Changes in cabinet designs have resulted in devices being mounted directly to advanced technology heat exchanger plates, providing a 25% increase in power density. The new design improves maintainability and reduces the number of cabinets required at unit cost parity. Advancements in power electronics such as these will allow for higher power densities, which translates to lower weight and size for equivalent power ratings. A significant change in power density would change the space and perhaps weight required to convert power on the ship.

The increased usage of motors and power electronics raises the concern of poor power factor loads along with possible high harmonic loads. Both of these issues are a burden on the power generation equipment and affect the overall efficiency of the power distribution system. Conventional distribution system designs and power conversion equipment would be a cause of degradation in the power factor that the shipboard generators would see. The power requirements may be better managed to enable the generator to achieve a net power factor of 1.0 by 1) replacing wire-wound power conversion systems with solid state transformers, 2)adding active harmonic filters, and/or 3) utilizing innovative rectifier configurations 12-pulse, 18-pulse, or active pulse width modulations (PWM).

There are many ways to distribute 104MVA. Is AC or DC distribution the best solution or is there a combination of both that makes better sense? Each has its own distinctive advantages and disadvantages. In a standard utility power distribution system, AC distribution is the only viable option in almost all cases. That is not the case on the next generation carrier. Variable Frequency Drives (VFD) and power electronics used to generate AC power all use DC voltage as their input. Because of these types of systems, DC distribution is probably a better solution.

Lead acid batteries used for energy storage for uninterruptible power supplies (UPSs) are another major concern aboard the carriers. Alternates for lead-acid batteries could be fly wheels, fuel cells, super-caps or lithium ion batteries. Will any of these technologies make a better solution than lead acid batteries? The total lifetime cost must be evaluated along with the concern of logistics and replacement.

The Navy has plans for advanced and integrated power electronics in future platforms. To fully exploit the electric power available on these new platforms, a fundamental change in how electric power is converted, delivered and managed will be required. These next generation warships will depend highly on the ability to rapidly shift power to major loads to support tactical needs. The EMPF is working to address the science and technology issues that must be addressed at the material and component levels to ensure this capability can occur in a timely and affordable manner.

References

1) Empfasis February 2004/ October 2002.

2) http://www.onr.navy.mil/media/extra/fncs_fact_sheets/electric_ships.pdf.

3) http://www.navsource.org/archives/02/78.htm.

4) http://www.onr.navy.mil/sci_tech/engineering/334_shiphull/by_thrust/aeps.htm.

5) IEEE Industrial Applications Society Annual Meeting Rome, Italy, October 8-12, 2000, "Power Electronic Transformers for Utility Applications".

6)http://www.eia.doe.gov/neic/quickfacts/quickelectric.htm.

7) http://www.globalsecurity.org/military/systems/ship/cvx-gallery.htm

Author of article: *Jim Hagerman*- Jim is an Engineering Manager at ACI. Comments or questions pertaining to this article can be sent to jhagerman@aciusa.org.

Ask the EMPF Helpline!

A Help Line customer submitted a large potentiometer that is used in military electronics as both a switch and a variable resistor. The potentiometer had a cold in-circuit failure that showed momentary opens during system testing. The customer requested an identification of the cause of failure.

The EMPF began the analysis with basic electrical probing of the leads and determined that there were two regions of the potentiometer rotation that had momentary opens during resistance readings. These occurred near 470ohm and 4400ohm as the device was rotated in one direction, and at slightly lower values (differing by 20ohm) as it was rotated in the opposite direction.

The EMPF disassembled the potentiometer to inspect the resistance tract and found that it did not display any abnormal wear. The component consisted of two main pieces, which were the wiper and the resistance tract. The resistance tract is a ceramic based material that has a set resistance value per "square" or length.

The wiper (Figure 2-1) is a small black carbon/graphite piece that rides in a guide tract with a spring behind it that forces contact. The spring force that is used must satisfy two fundamental requirements. The spring force must be 1) strong enough to maintain continuity under even moderate vibration, and 2) as small as possible in order to avoid wearing the wiper or the resistance tract.

Figure 2-1 Carbon/Graphite Wiper

The wiper is typically composed of graphite and displayed some wear on the dual contact side. There are formulations that can be used to determine the hardness and lubrication of a composition. These compositions have mixtures of graphite and wax binders that automatically adjust the lubrication of the components. As the material wears, slippery graphite layers are deposited on the resistance tract and provide lubrication.

A potentiometer functions in many applications as a voltage divider, distributing a ratio of voltages. As the device rotates, the distance from the base contact point to the wiper contact point increases, and hence, the resistance increases for one pair of terminals and decreases for the other pair of terminals. A potentiometer may also function as a rheostat when used as a variable resistor. In this application, the potentiometer uses the varying distances of the resistance strip to control the voltage and power loads that are applied to devices. A large amount of power is distributed applying heat to the resistance tract. Early model potentiometers have a tendency to exhibit intermittent loss of contact between the wiper and the resistance tract. If a circuit cannot withstand a loss of continuity, an extra wire may be placed in the circuit between the pole and the outer terminal. If a momentary open occurs at the wiper, this wire bypasses an open circuit and enables the potentiometer to provide maximum resistance and distribute power loads across the end terminals.

In harsh environments such as those in military situations, small vibrations will cause mechanical wear of the potentiometer components. If the potentiometer is kept in one position for a long time, the resistance tract and conductive pathway can begin to wear. In addition to poor reliability in vibration environments, potentiometers also suffer from large hysteresis (i.e. adhering to one particular value while rotating).

Inspection of the metal resistance tract (Figure 2-2) showed one area of excessive wear. This area most likely was the depression on the tract that caused the momentary discontinuity. Based on the various readings that were measured while increasing and decreasing resistance during testing, it is probable that the wiper skipped and opened momentarily due to the depression. There was also excessive dark colored material on a portion of the tract which may have caused the wiper to rise off of its path regardless of the spring pressure.

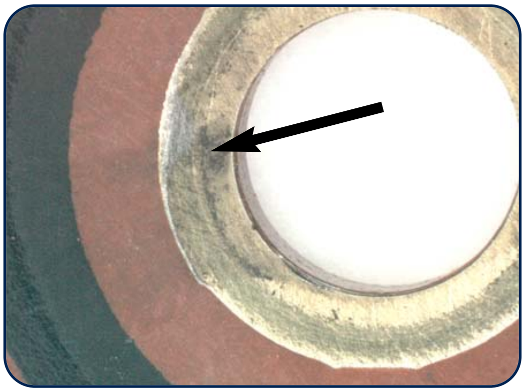

Figure 2-2 Worn Potentiometer Resistance Tract

The recommendation to the customer was to contact the manufacturer of the potentiometer and ask them to examine their pin-on-disk tests of the wiper base material when used on copper. This material should wear at a greater rate than copper areas. A chemical analysis of the ratios of graphite to binder material should be examined and compared to that of a product that performs adequately. Examination of the difference between the copper used in functioning and defective products should also be considered. The possibility exists that the copper was exceptionally soft and wore prematurely.

Author of article: *Anthony Vigliotti*- Anthony is a Materials Engineer at ACI. Comments or questions pertaining to this article can be sent to avigliotti@aciusa.org.

Failure Analysis and Reliability Testing Course

The EMPF Training Center offers a course entitled Failure Analysis and Reliability Testing, which is tailored to address the most prevalent electronic components, manufacturing and packaging issues. The objective of this course is to prepare the participants to make informed decisions when troubleshooting an electronics manufacturing problem as well as to understand and work within an analytical or failure analysis lab. The continuous miniaturization of components and increasing board complexity makes it crucial to understand what techniques and equipment provide the resolution required for accurate analysis.

The standard Failure Analysis and Reliability Testing course provides both novice and experienced participants with a wide range of topics relating to failure analysis and reliability. Failure analysis engineers learn both standard industry proven methods as well as current state of the art techniques for determining the cause and solution for a number of electronics manufacturing related issues. Quality control engineers, manufacturing engineers, managers and technicians that either perform failure analysis or collaborate with analytical labs gain knowledge that can be used to improve their product or manufacturing process. The course is designed to provide an excellent learning experience that relates directly to a broad range of failure analysis and reliability issues.

The most prevalent electronics manufacturing related issues are the focal point of the course. Also covered are topics that are process or component specific. The program is based on IPC, ANSI, ASM, ASTM, ISTFA, EDFAS and IEEE test methods and specifications.

The EMPF's own experience as a failure analysis lab, center of learning, and manufacturing process facility helps to supplement the material presented. The instructors have an extensive knowledge base on the subject, resulting in productive Q&A sessions. Included in the curriculum is the operation of the instruments and a review of the techniques used to troubleshoot failures as well as the identification of common failure modes and mechanisms. Some of the topics covered include:

- Failure analysis methodology
- Processing failures
- Integrated circuit failure analysis
- Microsectioning
- Microscopy
- Solderability
- Thermal analysis
- Accelerated reliability tests and analysis
- Cleanliness testing
- Electro-static discharge (ESD) analysis

Topics such as material properties, thermal expansion, advanced packaging failure, cyclic fatigue, integrated circuit fault isolation and spectroscopy are also discussed in depth from an analytical viewpoint.

Case studies provide the forum for problem formulation, investigation, and resolution. These case studies encourage independent thinking and group discussion. As with many of the other courses offered at the EMPF Training Center, students are trained with a combination of lecture and hands-on lab exercises. Course participants will get exposure to:

- Scanning electron microscopy (SEM, Figure 3-1)
- Optical microscopy
- Decapsulation of integrated circuits (Figure 3-2)
- Scanning acoustic microscopy (SAM)
- Fourier transform infrared spectroscopy (FTIR)
- Transmission X-ray
- Differential scanning calorimetry (DSC)
- Shear/ pull testing
- Solderability testing

Figure 3-1 Scanning Electron Microscope (SEM)

A customized course curriculum can be developed for any individual organization that will include the topics mentioned above, as well as additional material to address specific issues. Additional topics can be added that are most important to the customer's manufacturing environment. Examples of new focus areas could be:

- Equipment related process issues such as the use of new focused ion beam systems in wafer level cross-sectioning and defect analysis
- Specific packaging information on ball grid arrays, flip chip and surface mount technology involving high power applications
- A more ground-up approach for training in semiconductor fabrication processes or a basic introductory packaging tutorial that could assist in training new personnel

The vast resources of the EMPF Training Center, analytical laboratory and demonstration factory together provide an expansive database of information from which to draw upon for the formation of specialized classes.

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Failure Analysis and Reliability Testing Course (continued from page 4)

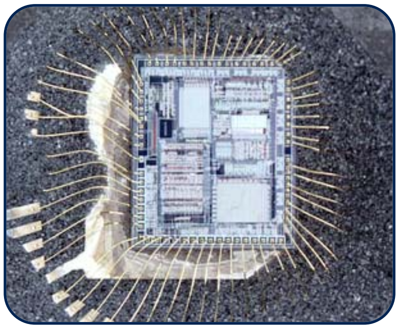

Figure 3-2 Decapsulation of Integrated Circuits

In summary, the EMPF Training Center can provide instruction for either the standardized "Failure Analysis and Reliability Testing" course or a customized training class that can address very specific customer needs and be taught at the customer's facility. The three-day standard course layout provides the proper format for a comprehensive understanding of the subject. The goal is for each participant to complete the course with a better understanding of manufacturing related issues related to failure analysis and reliability issues.

Author of article: *Mark Allemang*- Mark is a Failure Analysis Engineer at ACI. Comments or questions pertaining to this article may be sent to mallemang@aciusa.org.

Lead-Free Workshop

The Navy's National Electronics Manufacturing Center of Excellence will be hosting the Indium Corporation Lead Free Workshop and Symposium on December 7th, 8th and 9th, 2004. This "hands-on" program will focus on the "how-to" of implementing lead free processing into a electronics manufacturing center and will include several case studies of lead-free implementation. Motorola, a top producer of cellular telephones, will be participating in the case studies.

♦ Presented by Indium and hosted by the EMPF ♦ For registration please contact the EMPF Helpline at 610-362-1320 and reference the "Pb-Free Workshop"

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Manufacturers' Corner…
Finding the Right Marking System

Electronic assembly and component identification is critical to electronics manufacturers to monitor and control production lots and to enable the traceability of a product throughout its useful life. This traceability is particularly useful when attempting to identify the root cause of pervasive product failures in the field, substantiating warranty claims, determining the need for product recalls, and maintaining overall quality control of the production process. The EMPF utilizes an ASYS $ALS0_3$, CO_2 laser marking system to identify mission critical electronic components used in military survival radios, rechargeable battery packs and charging systems. Selecting the most effective marking system is dependent on a manufacturer's specific application and requirements and there are three widely used marking technologies available to meet the needs of the electronics manufacturer: 1) inkjet marking systems, 2) labeling systems, and 3) laser marking systems.

Inkjet Marking Systems

Inkjet systems have become very popular in the chip and IC industry, where mostly white ink is being used to mark the black IC bodies. They are also used to mark PCBs. With the variety of colored inks available, it is not difficult to apply a mark with excellent contrast, thus avoiding any verification problems. Variations in the surface color of products have a minimal impact on marking quality. Another advantage of inkjet marking is that quick drying inks allow users to handle products in a down-stream process immediately after marking, and without the risk of smearing the code. Inkjet systems are traditionally one of the faster marking technologies available.

The disadvantages with the inkjet marking method are that inkjet marking is not considered a permanent mark, and the precision of the inkjet mark is dependent upon maintaining a constant distance between the inkjet nozzle and the product. A PCB with variances in thickness or one that has been affected by warpage could possibly generate distorted marks. The precision variables can be avoided by utilizing a system that is able to compensate for different production parameters.

Labeling Systems

Labeling Systems are commonly used to mark PCBs. Typically, a thermo-transfer printer prints a black code on a white label. The advantage here is that there is always excellent contrast. The label is then peeled off the liner material, picked up at a feeding edge, and then placed on the PCB. Depending on the printed code, cameras or scanners might require a blank area around the code, requiring a larger label than the code printed on it.

One of the challenges with using this method is the lack of available surface area on highly integrated circuit boards. The label application system must therefore be extremely accurate. Some consideration should also be given to the down-stream process, as paper labels cannot be re-flowed without turning brown and losing contrast. Bar code labeling is certainly not a permanent mark, but this attribute is sometimes quite useful in case of a printer malfunction or an unreadable code. The operator may simply peel the label off of the circuit board and re-apply another. Some systems include a verification scanner to make sure only readable labels are being applied. Some operators may prefer to verify that label codes are accurate and readable prior to application. If a label is found to be faulty, the printer can re-print and feed another to replace it. Alternately, if the label is applied prior to verification and is later discovered to be unreadable, an additional rework process is required.

Laser Marking Systems

Laser Marking, the most preferred and most recently developed marking technology, is used at the EMPF. A laser source creates a beam that is deflected by a galvo head. When the laser strikes the target material, a chemical reaction occurs that colors the material and creates the mark.

Depending on what materials need to be marked, two different lasers can be used: CO_2 or YAG lasers. To mark PCBs, most engineers prefer the CO_2 laser, as it produces a good contrast on the organic FR4 material. The YAG laser is normally used for components or metallic materials. As with the inkjet, the accuracy and precision of the laser mark strongly depends on maintaining a constant distance between the product and the galvo head. One of the obstacles in using a laser to mark a code directly onto a PCB is that PCBs involve the use of various coatings. Using one set of laser parameters does not ensure consistent contrast on differently coated PCBs. Those operators who employ multiple PCB suppliers will have a greater amount of difficulty with this situation.

Laser marking technology offers a cost competitive solution. While the initial capital investment is definitely larger than that associated with a label applicator, the operating expenses are significantly lower. For example, expenditures on labels would be eliminated and the maintenance requirements on a laser are extremely low. The typical lifetime of a CO_2 laser source is approximately 20,000 hours. The replacement cost can be offset by the lower cost per individual mark when compared to other systems. Cost savings and rapid cycle times make laser marking a preferred method in the electronics manufacturing industry.

Since marking systems are process machines and have a significant impact on product traceability, systems providers must consult with and assist engineers in determining the proper technology for their applications. In choosing a marking system, it is important to weigh available resources, the parameters of the product, and the need for traceability.

Author of article: *Jeff Stong*- Jeff is the Equipment Advisory Board Coordinator at ACI. Comments or questions pertaining to this article can be sent to jstong@aciusa.org.

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For details, please contact Jeff Stong, the Equipment Advisory Board Coordinator, at (610)362-1200, extension 224.

Tech Tips... Selection of Small Gage Wire

Careful consideration in the selection of small gage wire that is used in electronics manufacturing is critical for the quality and reliability of products. Small gage wire is typically any solid or stranded conductor that has an overall outside diameter of <0.012 inches or is <28 AWG (American Wire Gage). These conductors are used in electronics manufacturing for numerous applications. One common application for small gauge wire is for attachment to terminals such as gold cups or turret terminals. Another common use is for the soldering of discreet circuitry such as jumper wires used for rework, repair or modification of an original design. Regardless of the application, the selection of the correct gage is critical.

Improper selection of small gage wire often results in defects ranging from melted or burned insulation to laminate damage. Proper selection of small gage wire used in manual soldering operations will greatly reduce costly and time consuming changes during manufacturing and over the life of the product. Excessive and unnecessary rework and repair operations can be eliminated, thereby reducing the high cost and lost labor encountered as a result of improper design. Following some basic guidelines during the design phase will help improve the quality of the product and result in increased customer satisfaction.

Wire selection should only be made after a thorough design review that addresses the following issues:

- current handling requirements
- wire type and size
- conductor and insulation materials
- minimum electrical clearance
- stripping methods
- wrap/ attachment requirements
- cleaning materials and process
- material compatibility
- wire routing
- dielectric strength
- resistance to abrasion
- staking/ bonding
- soldering tools and equipment

The selected wire must be able to carry the required current for the circuit. The wire with the smallest diameter that can carry the required amount of current should be used. The size of terminals and plated thru holes must also be carefully selected. Terminals cannot be modified to accept a conductor, and plated thru holes must have a conductor to hole diameter ratio of 1:1.5.

The most common conductor used in wire is copper. The IPC recommends a solid, insulated copper wire with tin/lead plating. When using stranded conductors, tinning is necessary to prevent strand separation and oxidation. If flux is used for tinning, cleaning processes need to be documented.

The insulation material needs to be able to withstand the temperatures of the soldering process, cleaning methods, and the environment to which it is subjected to. The dielectric strength of the insulation should be equal to or better than that of the board insulation material. For example, polyvinyl chloride (PVC) would not be a proper selection for soldered terminations since it has a maximum insulation temperature of 105°C. PVC insulated conductors are more commonly used for mechanical attachments such as crimped connections. Teflon insulation is able to withstand temperatures between 200°C and 260°C, making it the most popular choice for soldered attachments. Resistance to abrasion, flexibility and water submersion requirements must also be considered.

The minimum electrical clearance must be maintained between any non-common conductors including uncoated traces, adjacent components and hardware (this should be stated in the assembly drawings). Requirements for minimum electrical clearances can be found in IPC-2221, Generic Standard on Printed Board Design.

When staking or bonding materials are used to secure jumper wires, the materials and methods used must be compatible with subsequent processes such as cleaning and conformal coating application. Assemblies using jumper wires for rework or modification should be uniform in routing. Wire length, direction of conductors, and staking or bonding requirements need to be documented and available to assembly technicians. Wrap and attachment requirements for jumper wires can be found in Section 11 of the IPC-A-610-C, Acceptability of Electronic Assemblies. Proven procedures for jumper wire attachments can be found in IPC7721.

Chemical, mechanical and thermal stripping methods can be used for the removal of insulation. When using a chemical stripping method, a cleaning process must be employed to remove harmful and corrosive residues.

In working with much smaller wires and conductors, the availability of special tools and equipment is usually needed. Special fixtures and holding devices may need to be designed.

In today's industry, businesses cannot afford the cost associated with lost labor, scrap and dissatisfied customers. With a proper design review, the proper selection of high reliability, small gage wiring can easily be achieved.

Author of article: *Tracy Clancy*- Tracy is an Instructor at ACI. Comments or questions pertaining to this article can be sent to tclancy@aciusa.org.

Cut here and save!

Condition Based Maintenance in Power Applications

Today, many companies choose to operate their power system equipment until it malfunctions. They believe the system being considered for maintenance can not be removed from service, even for a short period of time. Also, many think that since no prior breakdowns have occurred, the potential for future operational interruption is somehow mitigated. Such an approach assumes that when a failure occurs, the resulting outage and repair costs will be less than the investment required for a preventive maintenance program. Ultimately, breakdown maintenance will be cost effective only if no catastrophic failures occur. Of course, such an approach leaves the system open to major catastrophes because no precautions are taken to prevent them. Preventive maintenance (PM) is currently the most widely accepted approach to maintaining electrical equipment. PM is a calendar based program in which very comprehensive test routines are applied to off-line equipment. There are two very significant differences between the way the data is used in corrective maintenance (CM) and PM programs. In a preventive maintenance program:

- Data is collected during both on-line and off-line times. Off-line times are intentionally scheduled for the implementation of preventive maintenance procedures.
- When it is discovered that equipment needs repair, that equipment will be scheduled for outages to implement those repairs.

However, the principal problem with preventive maintenance programs is financial in nature. PM returns cannot be measured unless a catastrophic outage occurs. When such an outage occurs, the value of a maintenance program can be compared directly to the cost of the outage.

Maintenance has evolved over the years from simply reacting to machinery breakdowns (CM), to performing time-based PM, to today's emphasis on the ability to detect early forms of degradation in predictive maintenance (PdM) practices. Condition based maintenance (CBM) has been defined as maintenance actions based on actual condition obtained from in-situ, non-invasive tests, operating and condition measurement. The CBM approach is characterized by understanding the stressor levels intended during the machinery design process, measuring suitable parameters to quantify the existing stressor levels, and correcting operating environments to make these levels compatible with economic production versus equipment lifetimes.

U.S. Navy Applications for CBM

One of the Navy's ongoing needs is to reduce life-cycle costs as they relate to manning and equipment breakdown and repair in order to enhance mission readiness. Working with the Navy, the EMPF has been defining a CBM system based on fiber optic sensor technology for next generation shipboard electrical power plants. The overall objective of this project is to minimize these costs from an overall life cycle cost perspective by implementing CBM to monitor conditions of a power conversion module. A more specific goal is to develop methods for the diagnosis of electronic components for electric distribution equipment.

The EMPF is currently working with PEO carriers, PEO ships, ONR, Airak, and NSWC Philadelphia on the evaluation of fiber optic sensor networks to monitor power levels and to provide input to be utilized by a CBM system. This effort will involve the production and testing of a prototype system to demonstrate the feasibility of fiber optic technology for use in the monitoring of a ship-board power conversion unit. The utilization of fiber optics presents a number of significant possibilities in the development of a smart power level monitoring and feedback system.

CBM consists of PdM and real-time monitoring. PdM takes advantage of proven cause and effect relationships to predict the need for corrective action. PdM is comprised of methods which attempt to predict or diagnose problems in a piece of equipment based on trending of test results. PdM primarily uses non-intrusive testing techniques to measure and compute equipment performance trends. Real-time monitoring uses current performance data to assess machinery condition. CBM replaces arbitrarily timed maintenance with maintenance that is scheduled only when warranted by the equipment condition. Continued analysis of equipment condition data allows for the planning and scheduling of maintenance activities or repairs prior to functional failure. PdM utilizes CBM systems to detect fault sources well in advance of failure, making maintenance proactive rather than reactive. The concept is based on the belief that if equipment can be evaluated and yet still remain in service, the overall cost of maintenance will go down.

CBM adds two enormously important dimensions to classical PdM. First, CBM deals with the entire system as an entity. This holistic approach to maintenance represents a major shift from the piecemeal technologies of the past. While CBM can be implemented in single steps, its greatest potential is realized when it is applied consistently and evenly across the entire range of system maintenance concepts. The second added dimension is the concept of ignoring or extending maintenance intervals.

CBM, which is a relatively new approach to maintenance, uses data gathered during standard operations and/or on-line and off-line maintenance intervals to forecast the need for additional or future maintenance. Normal maintenance systems mostly rely on average engine or plant statistics such as mean time between failures (MTBF) and scheduled maintenance activities.

CBM systems, on the other hand, are a combination of visual and manual inspections, on-line monitoring of the mechanical condition (i.e. through built-in sensors), system efficiency data and many other indicators. When all this information is entered into the CBM system it is possible to accurately determine the actual overall system status, condition and the maintenance need.

Combining CBM with a traditional PM schedule (i.e. a time-driven schedule which is the most economical approach for

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Condition Based Maintenance in Power Applications (continued from page 8)

certain wear components) results in a very cost-efficient total maintenance system that predicts the maintenance need. It minimizes unplanned down-time while maximizing safety and operational availability. Such a system also has a positive effect on logistical support by enabling "just-in-time" systems and keeping parts in stock at a practical and cost-efficient level. With CBM, a very important factor is the prospect of saving as well as earning money. Three important areas can be identified:

- Minimizing inspection overhauls
- Replacing parts at the optimal time
- Being able to tune the maintenance with other business factors

Figure 4-1- Airak Fiber Optic Current Sensor

CBM Examples

Some applicable systems that would be covered by CBM include turbine engines, gear trains, hydraulic actuators and pumps, electric motors, valves, air conditioning systems, diesel engines, generators and electronics. Some application examples for CBM include automated throttle controls for ship systems and electro-hydrostatic actuators for aircraft and spacecraft. Airak, a manufacturer of fiber optic sensor products and an EMPF partner on a power conversion R&D project, has developed a fiber optic current sensor (Figure 4-1) to monitor electric current on Navy ships. This is important for the shipboard powerplant because by combining CBM and optical monitoring, the Navy will be able to reduce weight and manpower needed to service bulkier components (such as current transformers), while simultaneously improving safety and EMI immunity over the existing system.The operational demands and high procurement costs of systems in these applications require a high degree of "uptime" and high reliability. Unexpected failures are costly to correct at best. At worst, such failures are catastrophic. In spite of this general need, highly effective, state-of-the-art diagnostic and prognostic systems have not been implemented. Safety-critical and mission-critical systems often employ special purpose, ad hoc, and redundant systems to provide marginal to limited protection. Automation systems are being applied to more complex and safety-critical systems and there is a commensurate need for increased safety and reliable operation. The driving force for some of the programs being sponsored by the Office of Naval Research is to facilitate a growth environment for CBM technology and applications that will return multifold benefits such as:

- Reduced maintenance costs through minimizing requirements for time directed maintenance as well as improved maintenance planning and logistics support
- Reduced logistics footprint through decreased sparing and transportation requirements
- Improved operational flexibility achieved by accurate prognostics that will enable operators to make tactical, mission specific decisions with full knowledge of the remaining useful life of vital equipment

Constant efforts to develop engine components with longer maintenance intervals are now paying off. An example is the introduction of engine-mounted computers, which has made cabling much more efficient with the possibility to include safety checks. Other vital parts of an automation system are sensors. In addition to their increasing reliability, new types of sensors and sensor communicating systems are being developed. Development of communication technology now covers much more than just engines. Now that mobile phones, other handheld devices and satellite communication are becoming more price competitive, a ship can today be "connected" in the sense of having access to information through the internet and intranets. Some vendors have worked out a complete CBM concept based on these developments. In addition to utilizing and combining available systems like engine-mounted sensors, remote-monitoring and diagnostics systems, the concept also involves setting up a CBM organization.

Conclusion

The introduction of the CBM concept will affect new maintenance layouts. In general, inspections will be performed less frequently even though some inspections will always be needed. Looking at the long-term cost statistics, CBM offers a substantial cost advantage and will be substantially less expensive as it conforms more closely to the equipment owner's operational availability requirements.

Factors such as rising costs, reduced budgets, competitive market structures, complex equipment and employee attrition have all added to the complexity and difficulty of successfully completing the electrical maintenance mission. Implementation of CBM has been delayed in many companies by the perception that it is expensive, difficult, or both. After reviewing recent progress being made in CBM systems, it can be demonstrated that they are not difficult to implement, nor are they initially expensive. The philosophy of CBM systems is ultimately driven by how to find the perfect balance between preventive and predictive maintenance.

Reference

1) Presenation, “An Optically-Interconnected Heat-Pipe Cooled HVIGBT MW Inverter Building Block for DER Application”, P. Duncan, Airak, Inc., Oct. 26, 2003.

Author of article: *John Finn*- John is a RF Engineer at ACI. Comments or questions pertaining to this article may be sent to jfinn@aciusa.org.

X-Ray Analysis

As the technological achievements in electronic component packaging continue to develop, circuit design has become more miniaturized, and as a result, has become more difficult to troubleshoot and/or inspect. These achievements allow circuit board manufacturers to take full advantage of the latest circuit design and packaging techniques. With the reliability of electronic production directly related to solder joint quality, the daunting task of troubleshooting printed circuit boards (PCBs) puts a strain on product quality control. The rate of advancements in quality control must be at or above the level of technological changes in order to keep pace. X-ray analysis, initially used as an inspection technique, can provide the capabilities to improve product quality control in an effort to sustain product reliability.

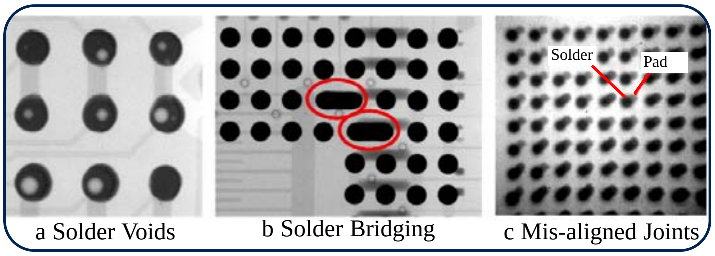
X-ray transmission is an inspection method that utilizes X-rays to view the thin layers of a circuit board as well as its soldered connections. This method exploits the variation in object densities to determine the shapes of different objects. Objects of higher density produce a darker X-ray image. The gray-scaled images that are produced through X-ray analysis can reveal indications of board defects Including:

- Board shorts
- Solder voids
- Solder opens
- Solder bridging
- Missing solder
- Mis-alignment of solder joints
- Minimal electrical clearance violation
- Void percentage with respect to pad area
- Grey value and diameter deviations
- Fuzzy edges (insufficient re-flow)

X-ray analysis is also used to verify that board measurements meet specified manufacturing criteria of acceptance. These measurements include the following:

- Trace width
- Solder ball diameter
- Solder width
- Solder volume
- Oblique view pad wetting analysis

With solder images appearing much darker than other objects, solder voids appear as bright spots within a solder ball or joint (Figure 5-1a). Solder bridging appears as non-uniform dark spots as in Figure 5-1b. Mis-aligned solder joints appear as dark spots either lying beside board traces or board pads (Figure 5-1c). Incomplete board etching, solder bridging, mis-alignment of solder joints, intersecting board traces, or any combination of such, are all probable causes of circuit board shorts.



a Solder Voids b Solder Bridging c Mis-aligned Joints

Figure 5-1 X-ray Images Showing Solder Faults

High level X-ray systems are able to produce two-dimensional (2D) X-ray images of PCBs with simulated three-dimensional (3D) capabilities such as:

- High magnification up to 10,000x
- Oblique views up to 61°
- Voltage levels up to 225kV
- Detail detection down to 200nm (0.2 micron)

The image depth through a PCB sample is controlled by the kilovolt (kV) level and the image contrast is controlled by the micro-amp (μA) level. Systems possessing higher kV levels have an increased board navigation depth. Slanted or oblique views give excellent information in the vertical direction and they enable the user to directly view open BGA solder joints.

High level X-ray systems have adaptable measuring and evaluation software available for quad flat pack (QFP) and micro-lead frame (MLF) type solder joints. Such systems with comprehensive capabilities allow testing for the following:

- Bridges and electrical clearance
- Opens
- Side overhang co-planarity
- Voiding percentage
- Lead footprint
- Joint width and toe overhang
- Quality of heel, side and toe fillet

How does X-ray Inspection Work?

Electrons are emitted from a heated filament in a vacuum tube and are accelerated in the direction of an anode. Upon entering the anode, the electrons pass through a magnetic lens. The magnetic field produced within the magnetic lens redirects the electrons to a single focal point on a specified target. This target consists of a thin tungsten layer deposited on a light metal plate. When the electrons collide with the tungsten layer they abruptly decelerate and an X-ray source is created. The X-rays that pass through a sample board strike the image intensifier where they are translated into gray-scaled images. Since a light source is not present within the sample board and is not used in the imaging process, colored X-ray images are not possible. Figure 5-2 is a basic illustration of the X-ray process.

continued on page 11

X-Ray Analysis (continued from page 10)

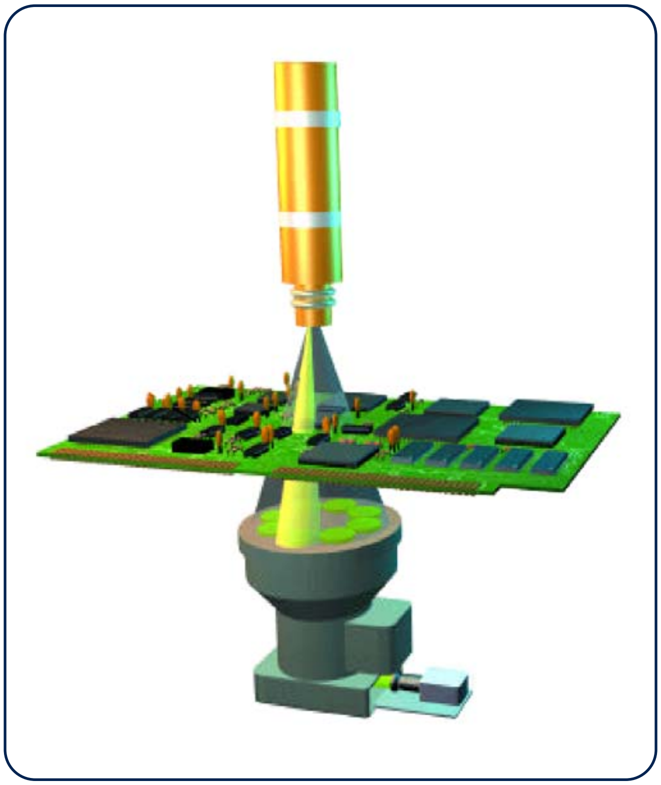


Figure 5-2 Illustration of X-ray Process

With the use of automated X-ray inspection systems as opposed to dated manual diagnostic analysis methods, board measurements and possible defects are detected in a minimal amount of time. The benefits of automated inspection are 1) increased consistency in results, 2) near real-time return of results, and 3) the ability to handle a high volume of circuit boards. Assuming proper setup by the user, the results obtained from this method are superior to results obtained from manual inspection but automated equipment can generate considerable setup and processing costs.

Transmissive Radiography Versus Laminographic Radiography

There is much debate as to whether two-dimensional analysis (transmissive radiography), which has a well defined history, is more beneficial than three-dimensional analysis (laminographic radiography). Transmissive viewing of a sample board on an angle relative to the perpendicular plane of the X-ray beam gives a two-dimensional image that can be mapped to a simulated three-dimensional representation (Figure 5-3). Disadvantages of the transmissive method are its difficulty in detecting cracks and its inability to clearly distinguish objects on different layers. The laminographic method allows for the viewing of solder joint volume including the respective component lead and pad. Although laminographic radiography is primarily associated with ball-grid array (BGA) inspection and can provide ball-to-board connection point images, transmissive imaging can determine if there is a defect in the connection itself.

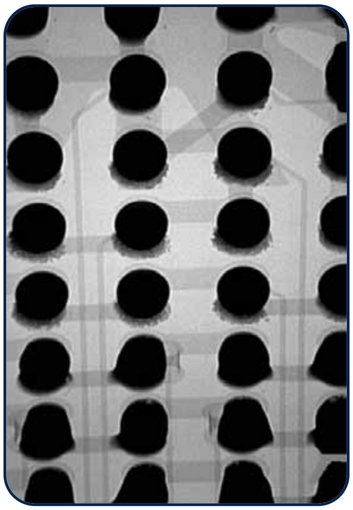


Figure 5-3 A 3D Representation of an X-ray Image

X-ray analysis can be an effective process control tool for the electronics manufacturer. Its ability to reliably detect board defects and to verify critical board measurements during the production process is invaluable in maintaining quality control standards for world class manufacturers. X-ray analysis is a key resource on the EMPF's demonstration Factory floor due to the advancements in available equipment and the effectiveness of the process. The pace of technological change in electronic assembly design will continue at an aggressive level creating an ongoing need for advanced analytical tools, such as X-ray analysis, on the factory floor.

References

1) Martin,Perry L. Electronic Failure Analysis Handbook. New York: McGraw-Hill publishing, 1999.

2) McClure, Doug (1999), X-ray "How it Works", Nischolet Imaging Systems. http://www.teradyne.com/prods/cbt/products/library/xray/wp_xrayhow.pdf.

3) More than counting black dots (2004), The Technical Knowledge Base For You. http://www.tkb-4u.com/articles/inspection/Xray1/countingdots.php.

4) A guide to solder joint inspection and analysis (2004), Phoenix X-ray. Phoenix X-ray brochure: http://www.microfocus-x-ray.com/frameset.php?PageName=company&Language=en&Issue=1&NavigationId=3.

Author of article: *Eric Myers*- Eric is an Engineering Co-Op at ACI. Comments or questions pertaining to this article can be sent to emyers@aciusa.org.

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issue:09-04

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