SAVIAC
Shock and Vibration Information Analysis Center

JUNE 2006

CURRENT AWARENESS

Defining Design Margin Using Accelerated Random Vibration Testing

Editor's Note: This article was contributed by David A. Jahnke, NAVSEA Keyport. NAVSEA Keyport is one of this year's featured organizations. This article is intended to educated the community on the capabilities of this featured organization.

As T&E Engineers and Managers for DOD, we are constantly required to verify operability, qualification, or acceptance testing. One often overlooked issue is the products' Design Margin (DM) - the difference between the capability of the product and the intended use environment. Recent advances in technology now allow test equipment to accelerate the vibration environment in a multi-axis controlled application. Using acceleration factors, Miners Rule [E1] can be used to calculate cumulative damage, from which Design Margin (DM) and product reliability is found.

INTRODUCTION - The products lifetime of damage accumulation can be summed by identifying each damaging force and number of application times of each force over the products lifetime. Accelerometers gather field data in each axis x, y, and z. For each accelerometer, a power spectral density (PSD) measurement displayed for each damaging moment in time. Advances in computers allow a field Grms [E2] calculated from the PSD measured in the field. Testing a minimum of three products to failure, one each at three different accelerated Grms levels (Multi-axis Vibration), based as a factor of field measured Grms. Multi-axial test machines used are both the repetitive air hammer shock tables installed in HALT/HASS [E3] machines and the electro-dynamic 3-axis systems, such as that installed at NAVSEA.

LIFE CYCLE DAMAGE ACCUMULATION - First identify each type of force within the product's life cycle. For example, a torpedo first experiences packaging/handling stresses and then forklift/truck transportation stresses prior to being installed on a ship. Once installed in the field, shipboard vibration stresses and thermal heating/cooling stresses occur on the product during shipboard storage. When the torpedo is fired, launch and water entry stresses and then the operational stresses occur while the torpedo heads for its target. Next, generate a histogram of each applied force. Identify the most extreme condition that can occur at each force level. This is the extreme user. Assemble a composite histogram of the extreme users for the lifetime of the product [1]. This is the worst of the worst. Figure 1 shows a histogram of extreme users in a torpedo lifecycle. Each type of stress at a particular worst case level is plotted with respect to the time on stress or the number of stress applications. At each extreme user stress, measure the product's response of each particular stress. For field random vibration, measure the power spectral density (PSD) and calculate Grms of each force type occurring during one lifetime. Figure 2 shows arbitrary values as an example of different frequency energy levels a product may experience at each different force application.

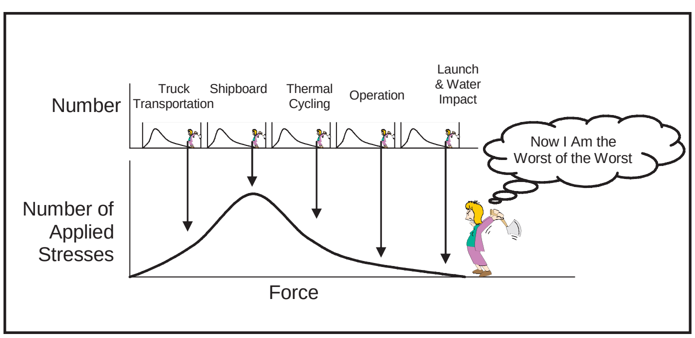

Figure 1: Histogram of Extreme users in a Typical Torpedo Life Cycle

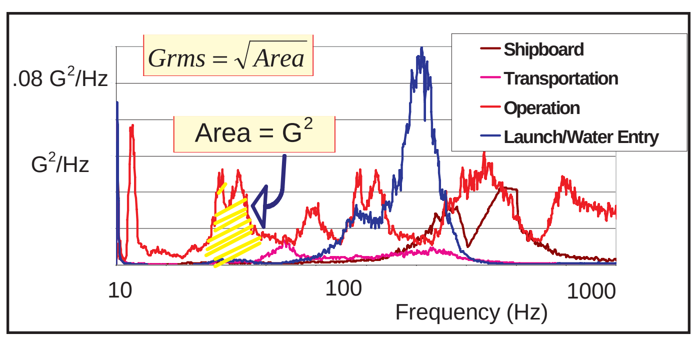

Figure 2: Power Spectral Density Plot (PSD)

FATIGUE STRESS-LIFE MODELS - Apply the appropriate Life-Stress models most suitable for each of the force types based on failure mechanisms [1]:

Inverse Power Model for fatigue and voltage effects
Arrhenius Diffusion Model for elevated temperature testing
Coffin-Manson Model for thermal cycling based thermal fatigue
Norris-Landzberg Model for high ramp rate thermal cycling
Arrhenius-Peck Model for accelerated humidity testing

Since our random vibration failures are a fatigue effect, we will apply the Inverse Power Model.

CALIBRATING THE ACCELERATED VIBRATION TESTS BY APPLYING THE INVERSE POWER MODEL- Calibrated accelerated vibration testing can be roughly approximated with the following version of the Inverse Power Equation: From Eq. (1) and Eq. (2), Eq. (3) and Eq. (4) are created.

$$\text{Acceleration Factor} = \frac{\text{Life}_{normal}}{\text{Life}_{accelerated}}$$

Equation (1)

$$G_{accelerated} = G_{normal} \times \left[\sqrt[m]{\frac{\text{Test Time}_{Normal}}{\text{Test Time}_{Accelerated}}} \right]$$

Equation (2)

$$\textit{Acceleration Factor} = \left(\frac{Grms_{accelerated}}{Grms_{normal}} \right)^m$$

Equation (3)

$$\left(\frac{Grms_1}{Grms_2} \right)^m = \frac{\textit{Time to Failure}_2}{\textit{Time to Failure}_1}$$

Equation (4)

Our accelerated vibration level assumes the use of the same PSD, just at a greater magnitude. Exponent m is chosen from the particular failure type noted. For example, m = 4 for connectors, m = 6.4 for aluminum leads on components, m = 5 for steel fatigue, if force or strain is used instead of vibration level then use 6.5 for steel [2]. Sources of exponent values are found in References [2], [3], and [4].

TEST TO FAILURE USING ACCELERATED MULTI-AXIS RANDOM VIBRATION -
Test to failure three products in multi-axis vibration, one each at a different accelerated Grms levels of random vibration environment using a Highly Accelerated Life Test (HALT) machine in Figure 3 or a 3-Axis Electro-Dynamic system shown in Figure 4.

Figure 3: HALT Chamber

Figure 4: NAVSEA Keyport's 3-Axis Electro-Dynamic Vibration Test System

Plot these failure points on a log-log scale. Draw a line through the failure data points creating the Life-Stress plot shown in red in Figure 5.

Torpedo Damage Accumulation

Force	Grms	Life
Transportation (A)	0.15	3.E+08
Shipboard (C)	0.5	9.E+06
Operation (E)	1.75	800
Launch & Water Entry (G)	10	0.1

Incomplete Data – For Example Only

Table 1: Example of Field Life Data

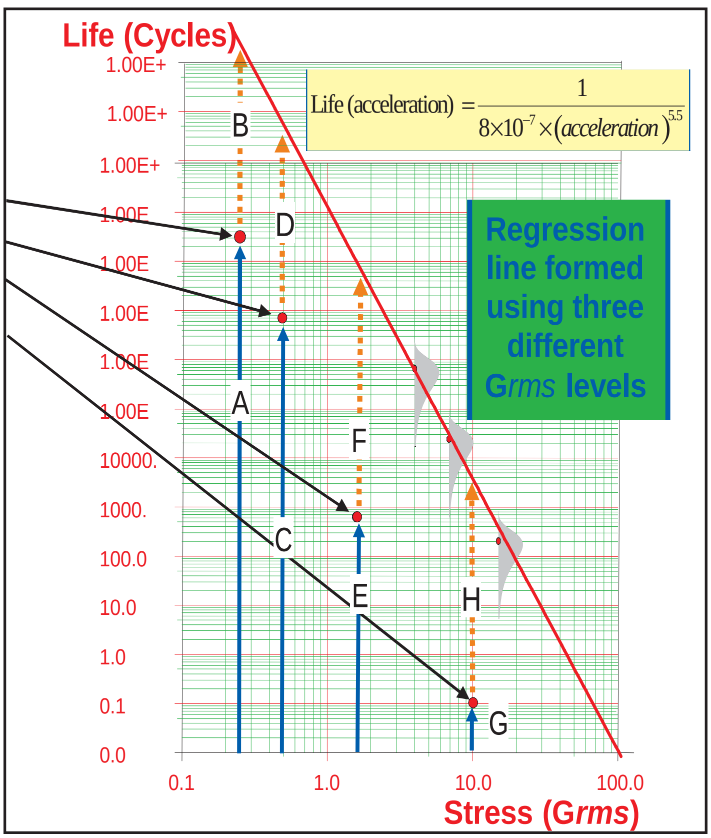

Figure 5: Life Vs. Stress plot using Miners Rule

Table 1 shows the measured values from Figures 1 and 2. These are plotted on the same Life-Stress plot of data previously tested to failure. Using Miner's Rule, the cumulative damage can be calculated (as seen in the torpedo environment) using Equation 5.

$$\text{Cumulative Damage} = \frac{A}{A+B} + \frac{C}{C+D} + \frac{E}{E+F} + \frac{G}{G+H}$$

Equation (5)

DESIGN MARGIN & PART RELIABILITY

Using the same data from Table 1, and using the Life-Stress plot in Figure 5, we can find the cycles of life available, percentage of life used up as shown in Table 2. From the stresses totaled in Table 2 using Miner's Rule, we see the cumulative damage for our lifetime torpedo example is 43.3%. The last column shows the total number of cycles necessary if the total damage accumulation of 43% was placed at that stress level. Using these same equations, a single accelerated stress level could be chosen to be used as a random vibration stress screening level.

Field Force	Field Stress in Grms	Stress in Cycles of Life Used Up	Cycles of Life Available From S-N Line	Percentage of Life Used Up With This Stress Level	Cycles of Testing Necessary If Total Cumulative Damage Was Placed At This Stress Level
Transportation	0.15	3.00E+08	4.25E+10	0.7059%	1.84E+10
Shipboard	0.5	9.00E+06	5.66E+07	15.9099%	2.45E+07
Operation	1.75	800	5.76E+04	1.3896%	2.49E+04
Launch & Water Entry	10	1	3.95E+00	25.2982%	1.71E+00
Cumulative Damage From All Stresses =				43.3036%	Data For Example Only

Table 2: Torpedo Lifetime Damage Accumulation

In this example, 43.3% of the lifetime available damage was used up. Therefore, the Design Margin (DM), defined as the difference between the capability of the product and in intended use environment, is equal to one minus 0.43 = 0.57. Figure 6 shows this relationship graphically [1].

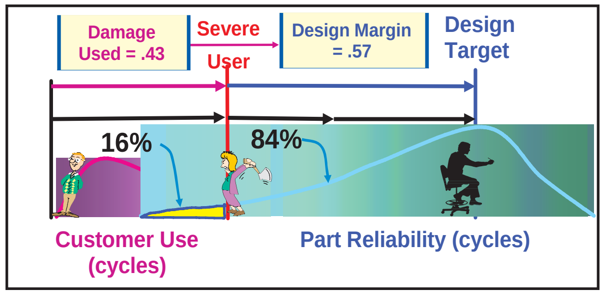

Figure 6: Capability of the Product and the Intended Use Environment

CONCLUSIONS- This paper applies damage accumulation of random vibration experienced in the field environment to design margin based on Grms accelerated test levels. This method assumes the same-shaped PSD plots at accelerated levels as seen in the field environment. Random vibration design margin can be applied to verify the product's Reliability and Design Margin, develop an equivalent single accelerated stress used for screening of delivered products prior to delivery, and can assist with Reliability Centered Maintenance (RCM) programs.

REFERENCES -

E1. *Editor's Note* - Miners Rule is a simple cumulative damage rule for irregular repeated loading (with respect to metal fatigue). Full name is Palmgren-Miners cumulative damage rule. It has been applied to other applications also in the vibration field.

E2. *Editor's Note* - Peak Acceleration x .707 = Grms / 1.414 x Grms = Peak Acceleration

E3. *Editor's Note* - HALT (Highly Accelerated Life Testing) / HASS (Highly Accelerated Stress Screening)

1. Edson, Larry, "Calibrated Accelerated Life Testing Presentation" dated September 12, 2003, shown in training class titled "Demonstrating Reliability Requirements with Accelerated Testing", http://www.hobbsengr.com/index.htm

2. Steinburg D.S., 2000, *Vibration Analysis for Electronic Equipment*, Third Edition, Wiley, NY.

3. George A. Shinkle "Automotive Component Vibration: A Practical Approach to Accelerated Vibration Durability Testing" by, SAE Technical Paper Document #840501

4. "MIL-STD-810F Annex B", January 2000

FREE
Summer Shock & Vibration Seminar

SAVIAC invites you to attend a FREE seminar on Shock & Vibration. The course will be held on June 28, 2006 at the Hyatt Regency Monterey in Monterey, CA in conjunction with the 77th Shock & Vibration Program Committee Meeting. SAVIAC and the featured experts in their disciplines have organized this seminar to introduce you to the SAVIAC community, while providing a valuable educational experience.

7:00 -7:45	Registration / Continental Breakfast	
7:45 -8:00	Welcome / Introduction to SAVIAC	Mr. Drew Perkins, SAVIAC
8:00 -8:45	Simple Tools for Simulating Structural Response	Mr. Fred Costanzo, NSWC Carderock
8:45-9:30	Gun Recoil	Dr. Andrew Littlefield, US Army REDCOM-ARDEC Benet Labs
9:30-9:45	**BREAK**	
9:45-10:30	Durability Assessment Accelerated Life Testing	Mr. Gary Zook, NUWC Keyport
10:30-11:15	Analog Pre-filtering of Shock and Vibration Data	Dr. Patrick Walter, TCU/PCB
11:15 -Noon	Naval Shock Problems	Dr. Young Shin, Naval Postgrad School
Noon -1:00	**LUNCH**	
1:00 -1:45	Multi-Shaker MIMO Testing	Mr. Russ Ayers, Spectral Dynamics
1:45 -2:30	Overview of Progressive Collapse Design & Analysis	Ms. Margaret Tang, Weidlinger
2:30 -2:45	**BREAK**	
2:45 -3:30	The Pseudo Velocity Shock Spectrum	Dr. Howard Gaberson, Consultant
3:30 -4:15	WOX Overview, Background & Testing	Mr. Jamie Howell, NSWC Dahlgren
4:15 -4:30	Wrap-up & Questions	

Please forward this invitation to anyone you know who may be interested in attending this program.

The seminar is free, but you must register to attend and **space is limited**. You may register online at **www.saviac.org/77th_Symposium/seminar_registration_form.htm**, or RSVP to Darnise Johnson, (804) 282-5570 or **darnise.johnson@saviac.org** to assure your space and note packet. SAVIAC reserves the right to substitute topics and/or instructors when necessary. This schedule is subject to change. For more information about SAVIAC please visit our website at http://www.saviac.org/s&v_seminar.htm.

77th S&V Symposium Featured Organizations

ABAQUS,Inc

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ABAQUS, Inc makes engineering analysis software that simulates the physical response of structures and solid bodies to load, temperature, contact, impact, and other stresses. Its finite element analysis tools are widely used in the aerospace, automotive, consumer goods, electronics, and manufacturing industries, among other fields. The company also provides related engineering, legal, technical consulting, and training services. Customers include Boeing, Bosch, DaimlerChrysler, Dana, Johnson Controls, Lockheed Martin, Medtronic, Motorola, and Valeo. For additional information, please visit: http://www.abaqus.com

Idaho National Lab

In operation since 1949, the INL is a science-based, applied engineering national laboratory dedicated to supporting the U.S. Department of Energy's missions in nuclear and energy research, science, and national defense.

The INL is operated for the Department of Energy (DOE) by Battelle Energy Alliance (BEA) and partners, each providing unique educational, management, research and scientific assets into a world-class national laboratory.

Their mission is: “We continue to tackle complex missions for the nation in a safe and cost-effective manner, including: Delivering science-based engineered solutions to challenges in the Department of Energy's mission areas , and enhancing the INL's scientific and technical talent, facilities and equipment to best serve the nation”.

The U.S. Department of Energy has a clear vision for Idaho National Laboratory to become the pre-eminent nuclear research, development and demonstration laboratory. INL is working to a strategy that commits the lab to make important contributions in nuclear energy, national & homeland security, and science & technology. For additional information, please visit: http://www.inl.gov

Naval Undersea Warfare Center, Division Keyport

The Naval Undersea Warfare Center (NUWC) Division, Keyport, Washington, is a shore Command of the United States Navy under the Naval Sea Systems Command, Washington, D.C. It is one of two divisions of the Naval Undersea Warfare Center which is headquartered at Division Newport, Rhode Island.

The main facility is located at Keyport, Washington, in the Puget Sound region near the major components of the Fleet that they support. They have Detachments located near their Pacific Fleet customers in Lualualei and Pearl Harbor, Hawaii and San Diego, California. Fleet testing and logistics sites are located at Nanoose, British Columbia, and Hawthorne, Nevada.

Naval Undersea Warfare Center (NUWC) is the Navy's full-spectrum research, development, test and evaluation, engineering and fleet support center for submarines, autonomous underwater systems, and offensive and defensive weapons systems associated with undersea warfare. One of the corporate laboratories of the Naval Sea Systems Command, NUWC is headquartered in Rhode Island, and has two major subordinate activities -- Division Newport (also in RI) and Division Keyport (in Washington State). For additional information, please visit: http://www.nuwc.navy.mil

Spectral Dynamics, Inc.

Spectral Dynamics is a leading worldwide supplier of systems and software for vibration testing, structural dynamics and acoustic analysis. Spectral Dynamics' products are used for design verification, product testing and process improvement by manufacturers of all types of electronic and mechanical products. A privately held corporation with more than 100 employees, Spectral Dynamics has offices in San Jose and San Marcos, CA, Detroit MI, Baltimore MD, France, Germany, and the United Kingdom as well as sales and service representatives worldwide.

Spectral Dynamics, Inc has an impresive list of innovative products, including: Single-Exciter Closed Loop Vibration Control, Multi-Exciter Closed Loop Shaker Control, Data Acquisition/Analysis, and PC-based Analysis Software.Spectral Dynamics has an extensive network of field service and application engineers available to go to your site to calibrate, repair and upgrade your Spectral Dynamics test system. Annual hardware service plans are available to meet your requirements and budget. Technical support for your Spectral Dynamics test system is only a phone call away. Spectral Dynamics has experienced application engineers available to assist you in offices throughout the U.S. A Premium Software Support contract provides unlimited toll-free telephone and fax assistance and automatic software updates. For additional information, please visit: http://www.spectraldynamics.com

Conference & Short Course Announcements

The Pennsylvania State University
Modern Protection Structures Training
July 17-21, 2006

Building and retrofitting structures to withstand a terrorist attack is a relatively new problem in the United States. The Modern Protective Structures short course will present the entire problem--from understanding the nature of threats to analysis and design--and will provide engineers and architects with practical information on performance and design requirements for hardened facilities. In addition, a review of blast damage assessment issues will provide forensic and rescue personnel with information that is vital to rescue and investigative efforts after a catastrophic structure failure.
The course will examine these topics: fortification science and technology, analysis, design, assessment, and retrofitting, industrial explosive safety, antiterrorist design, hazard sources, physical security and blast damage assessment. The course will feature hands-on, guided analysis and design activities, including case studies and simulations. Participants will be given computer programs to assist in the analysis and design of protective structures, as well as a design manual and reference materials. The instructor, Dr. Theodor Krauthammer, professor of civil engineering and director of the Protective Technology Center at Penn State, is an internationally renowned expert on enhanced structural performance and safety. In 2002 Dr. Krauthammer was recognized by the U.S. Army Engineer Research and Development Center--the research branch of the U.S. Army Corps of Engineers--for his outstanding contributions to the plan to rebuild the Pentagon following the September 11, 2001, terrorist attack. He is currently the chairman of a task committee on structural design for physical security, working for the American Society of Civil Engineers' Structural Engineering Institute. For complete information about the course and registration, please go the following web site www.outreach.psu.edu/C&I/protectivestructure

IEST
Online Education: Personnel in Cleanrooms
July 26, 2006 @ 11am CDS

“Personnel in Cleanrooms” will be presented on Wednesday, July 26, 2006 at 11:00 AM Central Daylight Savings Time. Learn from your desk, conference room, or auditorium without travel expenses. The per-site fee has no limit on the number of students who may participate at each location. This course presents a comprehensive overview of the considerations for staffing and operation of cleanrooms and controlled environments for microelectronics and precision assembly. Many of the subjects covered can be equally applied to pharmaceutical and biomedical controlled environments, but aseptic concerns are not specifically addressed. The course follows these considerations in basic chronological order and includes the topics of: Hiring Procedures; Hygiene/Health; Training/Compliance; Gowning; Entry Procedures; Behavior; Change Rooms; Monitoring/Auditing; Gowning System Management; Exiting/Emergency Evacuation. A question-and-answer session will follow the presentation. This online environment will allow for personnel around the world in the contamination control industry to take advantage of this educational opportunity. More information is available online at www.iest.org or by calling IEST at (847) 255-1561.

Random Vibration and Shock Testing Training
September 19-21, 2006
Montreal, Canada

A short course on practical vibration and shock testing, measurement, analysis and calibration, also HALT, ESS and HASS.This course is needed by engineers and technicians who conduct developmental and production vibration and shock tests. Also by designers of products that must survive tests AND rigorous service conditions. Also by metrologists who measure vibration and shock on automobiles, aircraft, etc. Also by sales/applications engineers involved in the sales of equipment used in test (shakers, shock test machines, etc.) and measurement (transducers, data acquisition etc.). Course details can be found at http://www.equipment-reliability.com/course7.htm.Toregister,visit: http://www.equipmentreliability.com /regist_form.htm.

NTS
Seminar and Open House
July 12 and 13, 2006

NTS New Jersey Division will be hosting a seminar and open house for our clients and other interested parties. The purpose of this seminar is to generate awareness of our Military and Telecommunications Testing capabilities. We will be providing valuable insight on some of the hot topics for our clients in these industries. Each day will include a BBQ and Clambake as well as a tour of our laboratory. Space is limited, register today. Seminar registration fee is $100 per person. If you would like to attend the Open House only, feel free to stop by the facility anytime between 9:00 a.m. and 5:00 p.m. on the 12th or the 13th. Contact Lori Gaynor via email, call 732.936.0800, or go to our website, click on NTS Open House to fill out response form. Accommodations may be obtained by calling the Sheraton Eatontown at 732.542.6500, be sure to mention you are attending the NTS event.Seminar Topics include: July 12 - Military Testing,Seminar Highlights - MIL-STD-461E Review & Testing Needs, MIL-STD Electronics Cooling, MIL-STD 810F, July 13 - Telecommunications Testing .Seminar Highlights - GR-1089-14 - Electronics Cooling for NEBS. GR-63-13 - Product Safety.

77th Shock and Vibration Symposium

We are continuing to accept:

TUTORIAL ABSTRACTS

PAPER ABSTRACTS

TRAINING ABSTRACTS

PANEL ABSTRACTS

DEDICATED SESSION AND DISCUSSION GROUP FORMS

The original due date of June 1, 2006 has expired. However, SAVIAC will continue to accept your abstracts. Visit www.saviac.org to submit!!

Industry News

Spectral Dynamics
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San Diego, CA

Spectral Dynamics, Inc. is pleased to announce the sale of two large Specialty Acoustic Systems through the Spectral Dynamics (SD) France office in Paris, France. The systems, valued at several million Euros, incorporates systems from the Signal Processing Systems (SPS) Engineering Division of Information Systems Laboratories (ISL) in San Diego and SD, France, for delivery to the French Navy. SPS, formerly a Division of Spectral Dynamics/Scientific-Atlanta, is a science and Engineering innovator in the fields of communications and adaptive signal processing. "This is an exciting program for SD" said Stewart Slykhous, President of Spectral Dynamics. "We have been a long term partner of SPS/ISL and the French Navy has shown great confidence in SD and SPS/ISL by purchasing another Fast Time Analysis System from us and contracting with SD, France for long term Service support". This is a full spectrum acoustic processing and display system. Systems are scheduled for shipment in Q3 and Q4 of 2006. For additional information on this innovative new product please go to Spectral Dynamic's website at www.spectraldynamics.com.

IEST
Three ISO Cleanroom Documents Now American National Standards

ISO 14644-3 specifies test methods for designated classification of airborne particulate cleanliness and for characterizing the performance of cleanrooms and clean zones. Performance tests are specified for two types of cleanrooms and clean zones: those with unidirectional flow and those with non-unidirectional flow, in three possible occupancy states: as-built, at-rest and operational. The test methods recommend test apparatus and test procedures for determining performance parameters. For some of the tests, several different methods and apparatus are recommended to accommodate different end-use considerations. This part of ISO 14644 is not applicable to the measurement of products or of processes in cleanrooms or separative devices. *ISO 14644-5* aims to provide basic requirements for operating and maintaining cleanrooms and associated controlled environments to meet the standards of the particular cleanroom as designed, built, and used. This standard addresses requirements that are basic to the operation of all cleanrooms regardless of the application. Topics include operational systems that must be in place; selection and use of appropriate cleanroom garments; training and monitoring of personnel and activities; installation and use of equipment; requirements for materials used in the cleanroom; and maintaining the cleanroom environment in a clean, usable condition conforming to design standards. *ISO 14644-7* specifies the minimum requirements for the design, construction, installation, testing and approval of separative devices in those respects where they differ from cleanrooms as described in ISO 14644-4 and 14644-5. Separative devices range from open to closed systems. More information is available online at www.iest.org or by calling IEST at (847) 255-1561.

LMS,
Southern Research Selects LMS Test.Lab for its state-of-the-art NVH engineering laboratory

Southern Research has selected LMS Test.Lab as the new standard testing solution for its new NVH (Noise Vibration and Harshness) engineering laboratory in Birmingham, AL. Southern Research is a full-service contract research and development organization which conducts advanced engineering research for automotive, aerospace and industrial clients. The LMS Test.Lab system also allows Southern Research engineers to conduct standard and advanced NVH testing jobs with a single solution, eliminating time-consuming data transfers and the need to learn and maintain multiple software tools. "There are further efficiency increases through the intuitive user interface," said Dr. Wang. "The workflow-based approach allows us to systematically capture all the required steps of routine NVH testing jobs, resulting in shorter test cycles and higher data consistency. The advanced analysis tools in LMS Test.Lab support our efforts to analyze the different sources and complex transfer paths that determine vibration comfort and sound quality." For additional information contact Kim Winkler at (248) 952-5664 or email at kimberly.winkler@lmsna.com

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VIP SENSORS
Announces -Model 5005 Vibration Signal Conditioner

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In the June 2006 Current Awareness Newsletter

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