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Standard Guide for Application of Acoustic Emission for Structural Health Monitoring[1]

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1. Scope

1.1 Structural Health Monitoring (SHM) is a field of engineering that deals with diagnosis and monitoring of structures during their operation. The primary goal of SHM is detection, identification, assessment, and monitoring of flaws or fault conditions that affect or may affect the future safety or performance of structures. SHM combines elements of nondestructive testing and evaluation, condition/process monitoring, statistical pattern recognition, and physical modeling.

1.2 The acoustic emission (AE) method uniquely fits the concept of SHM due to its capabilities to periodically or continuously examine structures and assess structural integrity during their normal operation.

1.3 In this guide, the definitions and fundamental principles for applying the AE method for SHM tasks are elaborated. This includes:

1.3.1 Terminology and definitions of SHM by the AE method,

1.3.2 Outline the recommended process of AE-SHM, and

1.3.3 Fundamental requirements regarding development of the SHM procedures, including selection of appropriate AE apparatus, data acquisition and analysis methods, diagnosis, monitoring and prediction.

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

E543 Specification for Agencies Performing Nondestructive Testing

E1316 Terminology for Nondestructive Examinations

2.2 *ISO Standards*[3]

ISO/DIS 10303–226 Industrial Automation Systems and Integration—Product Data Representation and Exchange

ISO 9712 Non-destructive Testing—Qualification and Certification of NDT Personnel

2.3 *Other Referenced Documents*

ANSI/ASNT CP-189 Standard for Qualification and Certification of Nondestructive Testing Personnel[4]

NAS-410 NDT Certification[5]

SNT-TC-1A Personnel Qualification and Certification in Nondestructive Testing[6]

3. Terminology

3.1 *Definitions:* See E1316 for terminology related to this practice.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *diagnosis, n*—a process of detection, identification, and assessment of flaws, and identifying properties or conditions that may affect the future safety or performance of a structure.

3.2.2 *diagnostic AE, n*—an acoustic emission methodology capable of achieving the goals of diagnosis.

3.2.3 *fault, n*—an abnormal condition or defect at the component, equipment, or sub-system level which may lead to a failure. **Worden et al.**[7]

3.2.4 *monitoring, n*—a process of observing or detecting changes in the condition of a structure.

3.2.5 *prediction, n*—a process of estimation of the possible future flaw or fault deterioration based on results of monitoring, diagnostics, or numerical modeling, or a combination thereof.

[1] This test method is under the jurisdiction of ASTM Committee E07 on Nondestructive Testing and is the direct responsibility of Subcommittee E07.04 on Acoustic Emission Method.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] Available from International Organization for Standardization (ISO), 1, ch. de la Voie-Creuse, CP 56, CH-1211 Geneva 20, Switzerland, http://www.iso.org.

[4] Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036, http://www.ansi.org.

[5] Available from Aerospace Industries Association of America, Inc. (AIA), 1000 Wilson Blvd., Suite 1700, Arlington, VA 22209-3928, http://www.aia-aerospace.org.

[6] Available from American Society for Nondestructive Testing (ASNT), P.O. Box 28518, 1711 Arlingate Ln., Columbus, OH 43228-0518, http://www.asnt.org.

[7] K. Worden, C. Farrar, G. Manson, G. Park, "The fundamental axioms of structural health monitoring", Proceedings of the Royal Society A, Vol. 463, 2007, p. 1639-1664.

3.2.6 *sensing*—a process of detection of acoustic emission and conversion of measurements into data used during diagnosis.

3.2.7 *structural health monitoring (SHM), n*—a process of diagnosis and monitoring the condition of structures, normally performed during their operation.

4. Summary of Guide

4.1 The guide describes the AE-SHM process and provides a set of fundamental assumptions recommended in the application of the AE method in SHM tasks.

5. Significance and Use

5.1 This guide can be used in the development of acoustic emission applications for structural health monitoring.

5.2 Accuracy, robustness, and efficiency of AE-SHM can be enhanced by following the steps and fundamental principles described in the guide.

6. Basis of Application

6.1 The following items are subject to contractual agreement between the parties using or referencing this guide.

6.2 *Personnel Qualification:*

6.2.1 If specified in the contractual agreement, personnel performing examinations to this standard shall be qualified in accordance with a nationally and internationally recognized NDT personnel qualification practice or standard such as ANSI/ASNT CP-189, SNT-TC-1A, NAS-410, ISO 9712, or a similar document and certified by the employer or certifying agency, as applicable. The practice or standard used and its applicable revision shall be identified in the contractual agreement between the using parties.

6.2.2 *Qualification of Nondestructive Testing Agencies*—If specified in the contractual agreement, NDT agencies shall be qualified and evaluated as described in Specification E543. The applicable edition of Specification E543 shall be specified in the contractual agreement.

7. The Process of Structural Health Monitoring by the Acoustic Emission Method

7.1 The process of AE structural health monitoring can be divided into the following typical stages:

7.1.1 AE-SHM procedure development,

7.1.2 Sensing,

7.1.3 Diagnosis,

7.1.4 Monitoring, and

7.1.5 Prediction.

7.2 *AE-SHM Procedure Development*—The first stage of procedure development starts with the collection of all necessary information regarding the structure, its design and materials, operational conditions, statistics of failures, etc. In addition, laboratory or full scale tests, or both, are conducted on structures with known flaws or faults, at a known stage of development in order to develop the ability to detect, identify, and assess specific flaws or faults. Based on the collected information, the optimal instrumentation, methods of data acquisition and data analysis, and loading procedures are established.

NOTE 1—Results of laboratory testing of small scale specimens, and especially signal features derived therefrom, are not directly applicable to full scale structures due to such influences as sensor frequency and sensor mounting or spacing; wave propagation or reflections in small specimens versus large plate structures; noise backgrounds not replicated on small specimens; complex emission mechanisms that involve stress corrosion cracking, hydrogen embrittlement cracking, creep development, and the like that involve difficult-to-control environments in the lab. Specimen testing may be used to model the behavior and relative emissivity of mechanisms in materials, but may not be directly transferred to full scale structures for life prediction.

7.3 *Sensing*—Sensing is a process of data capture and measurement. It involves measurement of AE as well as parametric data such as pressure, temperature, strain, and other information according to the developed SHM procedure. There are several important aspects to address during the sensing stage. It is important to check that data collected during the data acquisition process is valid and can be satisfactorily used for the purposes defined in the developed SHM procedure. If this is not the case, additional measurements with a different setup or loading, operational or environmental conditions or both, may be required. Also, during the sensing process, a short evaluation of the structure should be performed to identify, or rule out, possible conditions that may threaten the structure immediately or in the short term.

7.4 *Diagnosis*—Diagnosis is one of the primary tasks of the SHM process. It effectively distinguishes typical noise-related AE from SHM-related AE. The objectives of the diagnosis process are not only to detect and locate flaws or faults as in typical NDE but also to identify and assess them. Diagnosis is performed based on collected data, numerical modeling including finite element analysis, history of the inspected structure, local application of different NDE methods, material and other relevant investigations.

7.5 *Monitoring*—Monitoring is performed to assess the condition of a structure over time. It is performed periodically or continuously, depending on the particular application. For best results, it is recommended to identify quantitative or qualitative AE characteristics, or both, that are changing with the flaw or fault development. It is important to perform monitoring under normal operational and environmental conditions of a structure. If a change in stress or operational or environmental conditions occurs for any reason, or a structure has been subjected to extreme conditions and trauma, it may require a change in the monitoring policy. Another important goal of monitoring is to identify conditions causing flaw or fault origination and development in the inspected structure. Examples of such conditions are fatigue, mechanical and thermal overstresses, etc.

7.6 *Prediction*—The goals of prediction can include:

7.6.1 Assessment of suitability for continued service of structures when a proven and statistically valid experience or database is gathered.

7.6.2 Defining an appropriate re-inspection or monitoring policy based on diagnostic and monitoring results.

7.6.3 Providing information necessary for condition-based maintenance decisions.

7.6.4 Prediction, which is normally carried out based on diagnostic results, several monitoring cycles, and in conjunction with information about the structure, its history and all known measurable or non-measurable risk factors.

8. Fundamental Assumptions of AE Structural Health Monitoring

8.1 AE-based structural health monitoring, as with any other scientific concept, is based on a set of fundamental assumptions that are normally self-evident and do not necessarily have to be scientifically proven. The role of assumptions is to define a systematic basis for a concept or theory. A set of such fundamental assumptions of SHM by the AE method is proposed. It cannot be claimed at this moment that the set of assumptions is complete and thus further modifications and corrections over time could be required. Fundamental assumptions are divided into four groups: AE-SHM procedure development, structure diagnosis and monitoring, data analysis, and prediction and recommendations.

8.2 *Assumption Group 1: AE-SHM Procedure Development*

8.2.1 An optimal SHM procedure is one that ensures a maximum probability of flaw or fault detection while minimizing false negative findings.

8.2.2 Development of new AE-SHM applications is essentially based on a learning process. This includes collection and analysis of information about:

8.2.2.1 Structural design, history of operation, repairs and results of previous inspections,

8.2.2.2 Material properties,

8.2.2.3 Applied loads, operational and environmental conditions,

8.2.2.4 Typical flaws or faults that can develop in the inspected structure,

8.2.2.5 AE characteristics of flaws or faults to be detected, assessed, and monitored,

8.2.2.6 Wave propagation characteristics in the material and geometry of the inspected structure including propagation modes, attenuation, dispersion, scattering, and other characteristics,

8.2.2.7 AE instrumentation appropriate for the particular application, and

8.2.2.8 Optimal loading or environmental conditions, or both, for performing SHM, are considered those under which flaws or faults naturally originate and develop in the inspected structure.

8.3 *Assumption Group 2: Structure Diagnosis and Monitoring*

8.3.1 A specific AE methodology can be considered diagnostic if essentially it allows:

8.3.1.1 Detection,

8.3.1.2 Location,

8.3.1.3 Identification, and

8.3.1.4 Assessment (qualitatively or quantitatively) of flaws or faults in the inspected structure.

8.3.2 Acoustic emission (AE activity and AE waves themselves) can be flaw- or fault-stage-material specific, i.e. different flaws and faults at different stages of their development in different materials may have different AE waveform characteristics as well as different AE rates.

8.3.3 During flaw or fault assessment, a conservative approach should be taken in case of uncertain results.

8.3.4 Comparison of loading, operational or environmental conditions or both, with AE activity or AE characteristics reflecting kinetic characteristics of flaws or faults development can be used to identify conditions causing flaw or fault origination, development, acceleration, or arrest.

8.3.5 Flaw or fault monitoring is possible when quantitative or qualitative AE characteristics, or both, changing with flaw or fault development are identified.

8.3.6 Reliable comparison of data collected during different monitoring periods is possible when monitoring is performed under similar stress, operational, environmental, and sensing conditions.

8.4 *Assumption Group 3: Data Analysis*

8.4.1 The process of data analysis in AE-SHM necessarily includes the following steps:

8.4.1.1 Analog or digital signal filtering, or both,

8.4.1.2 Initial feature extraction,

8.4.1.3 Feature selection and dimension reduction,

8.4.1.4 Clustering (unsupervised classification) or discrimination (supervised classification), or both, and

8.4.1.5 Interpretation.

8.4.2 Signal features selected for data analysis should be a minimum set of statistically significant features necessary for the specific SHM application; filtered whenever possible so that the influence of background noise is minimized and data measured at different times and different locations is comparable.

8.4.3 Features used in data analysis should have an established relationship with physical phenomena being measured during AE-SHM in order to assure correct diagnosis of the inspected structure.

8.4.4 AE activity distinguishable from AE background noise should be considered as flaw or fault related activity unless proven otherwise.

8.4.5 All detected AE activity distinguishable from AE background noise should be analyzed regardless if it is locatable or not. All efforts should be taken to identify and filter out burst AE signals related to mechanical impacts and friction.

8.4.6 Flaw or fault detection and location typically can be done using unsupervised or standardized conventions available in AE computerized systems. Identification may be accomplished by structural location, response to stimuli (load, temperature, etc.) and signal feature analysis—such as feature distributions and signal feature crossplots. In some cases supervised learning classification algorithms may be appropriate using multiple domain features (for example, time, frequency, cepstral, autocorrelation and the like), but must be shown to be robust in the intended application. Since signal features are dominated by source type, wave propagation effects, source position, and excitation risetime, among others, variable geometries may confound the effort to produce robust supervised learning classification algorithms.

8.5 *Assumption Group 4: Assessment, Prediction, and Recommendations*

8.5.1 A non-developing flaw or fault cannot cause a failure unless there is a change in loading, operational or environmental conditions, or both. A flaw or fault can be considered non-developing when no geometrical changes occur and there is no increase of plastic deformation near a flaw, as in the case of metals, or when a flaw is not subjected to conditions that can lead to a stress rupture scenario, as in the case of composite materials.

8.5.2 Optimal re-inspection interval is such that a risk of unexpected failure is reduced to the minimum acceptable probability, defined for the specific application. Defining optimal re-inspection intervals should take into consideration the economics of inspection, various usage (stress, temperature, time, load cycles, etc.) models, and fracture mechanics predictions based on usage profiles and assumed flaw detectability characteristics. The re-inscription interval should be reconsidered in case of significant changes in stress or operational conditions, major repairs, or other factors that affect structural integrity of the examined structure.

9. Keywords

9.1 acoustic emission; AE; diagnosis; fault; monitoring; SHM; structural health monitoring

BIBLIOGRAPHY

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