meaningful because only active features (e.g. crack growth) are highlighted. The ability to discern between developing and stagnant defects is significant. However, it is possible for flaws to go undetected altogether if the loading is not high enough to cause an acoustic event. Furthermore, AE testing usually provides an immediate indication relating to the strength or risk of failure of a component. Other advantages of AET include fast and complete volumetric inspection using multiple sensors, permanent sensor mounting for process control, and no need to disassemble and clean a specimen.

Unfortunately, AE systems can only qualitatively gauge how much damage is contained in a structure. In order to obtain quantitative results about size, depth, and overall acceptability of a part, other NDT methods (often ultrasonic testing) are necessary. Another drawback of AE stems from loud service environments which contribute extraneous noise to the signals. For successful applications, signal discrimination and noise reduction are crucial.

A Brief History of AE Testing

Although acoustic emissions can be created in a controlled environment, they can also occur naturally. Therefore, as a means of quality control, the origin of AE is hard to pinpoint. As early as 6,500 BC, potters were known to listen for audible sounds during the cooling of their ceramics, signifying structural failure. In metal working, the term "tin cry" (audible emissions produced by the mechanical twinning of pure tin during plastic deformation) was coined around 3,700 BC by tin smelters in Asia Minor. The first documented observations of AE appear to have been made in the 8th century by Arabian alchemist Jabir ibn Hayyan. In a book, Hayyan wrote that Jupiter (tin) gives off a 'harsh sound' when worked, while Mars (iron) 'sounds much' during forging.

Many texts in the late 19th century referred to the audible emissions made by materials such as tin, iron, cadmium and zinc. One noteworthy correlation between different metals and their acoustic emissions came from Czochralski, who witnessed the relationship between tin and zinc cry and twinning. Later, Albert Portevin and Francois Le Chatelier observed AE emissions from a stressed Al-Cu-Mn (Aluminum-Copper-Manganese) alloy.

Fig: Modern Tensile Testing Machine (H. Cross Company)

The next 20 years brought further verification with the work of Robert Anderson (tensile testing of an aluminum alloy beyond its yield point), Erich Scheil (linked the formation of martensite in steel to audible noise), and Friedrich Forster, who with Scheil related an audible noise to the formation of martensite in high-nickel steel. Experimentation continued throughout the mid-1900's, culminating in the PhD thesis written by Joseph Kaiser entitled "Results and Conclusions from Measurements of Sound in Metallic Materials under Tensile Stress." Soon after becoming aware of Kaiser's efforts, Bradford Schofield initiated the first research program in the United States to look at the materials engineering applications of AE. Fittingly, Kaiser's research is generally recognized as the beginning of modern day acoustic emission testing.

AE Sources:

As mentioned in the Introduction, acoustic emissions can result from the initiation and growth of cracks, slip and dislocation movements, twinning, or phase transformations in metals. In any case, AE's originate with stress. When a stress is exerted on a material, a strain is induced in the material as well. Depending on the magnitude of the stress and the properties of the material, an object may return to its original dimensions or be permanently deformed after the stress is removed. These two conditions are known as elastic and plastic deformation, respectively.

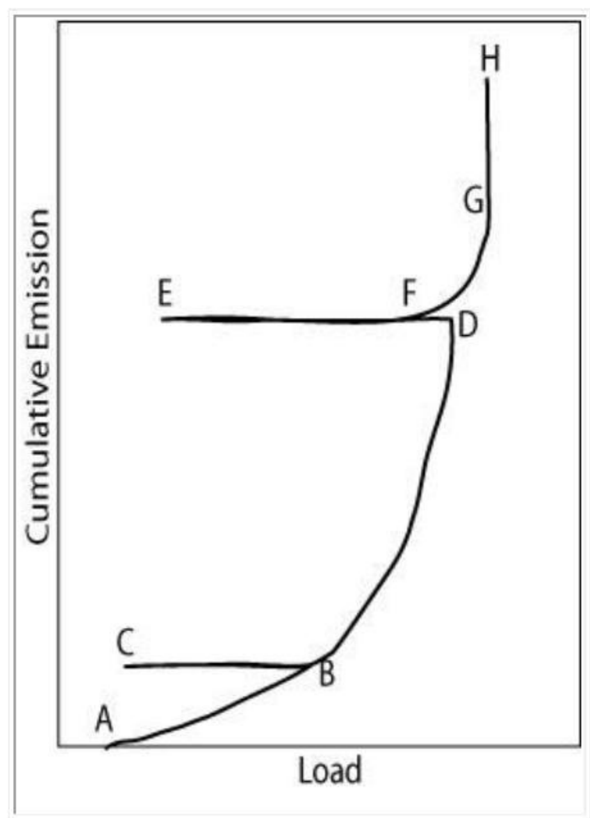
The most detectible acoustic emissions take place when a loaded material undergoes plastic deformation or when a material is loaded at or near its yield stress. On the microscopic level, as plastic deformation occurs, atomic planes slip past each other through the movement of dislocations. These atomic-scale deformations release energy in the form of elastic waves which "can be thought of as naturally generated ultrasound" traveling through the object. When cracks exist in a metal, the stress levels present in front of the crack tip can be several times higher than the surrounding area. Therefore, AE activity will also be observed when the material ahead of the crack tip undergoes plastic deformation (micro-yielding).

Two sources of fatigue cracks also cause AE's. The first source is emissive particles (e.g. nonmetallic inclusions) at the origin of the crack tip. Since these particles are less ductile than the surrounding material, they tend to break more easily when the metal is strained, resulting in an AE signal. The second source is the propagation of the crack tip that occurs through the movement of dislocations and small-scale cleavage produced by triaxial stresses.

The amount of energy released by an acoustic emission and the amplitude of the waveform are related to the magnitude and velocity of the source event. The amplitude of the emission is proportional to the velocity of crack propagation and the amount of surface area created. Large, discrete crack jumps will produce larger AE signals than cracks that propagate slowly over the same distance.

Detection and conversion of these elastic waves to electrical signals is the basis of AE testing. Analysis of these signals yield valuable information regarding the origin and importance of a discontinuity in a material. As discussed in the following section, specialized equipment is necessary to detect the wave energy and decipher which signals are meaningful.

Activity of AE Sources in Structural Loading:



AE signals generated under different loading patterns can provide valuable information concerning the structural integrity of a material. Load levels that have been previously exerted on a material do not produce AE activity. In other words, discontinuities created in a material do not expand or move until that former stress is exceeded. This phenomenon, known as the Kaiser Effect, can be seen in the load versus AE plot to the right. As the object is loaded, acoustic emission events accumulate (segment AB). When the load is removed and reapplied (segment BCB), AE events do not occur again until the load at point B is exceeded. As the load exerted on the material is increased again (BD), AE's are generated and stop when the load is removed. However, at point F, the applied load is high enough to cause significant emissions even though the previous maximum load (D) was not reached. This phenomenon is known as the Felicity Effect. This effect can be quantified using the Felicity Ratio, which is the load where considerable AE resumes, divided by the maximum applied load (F/D).

Basic AE history plot showing Kaiser effect (BCB), Felicity effect (DEF), and emission during hold (GH) 2

Knowledge of the Kaiser Effect and Felicity Effect can be used to determine if major structural defects are present. This can be achieved by applying constant loads (relative to the design loads exerted on the material) and "listening" to see if emissions continue to occur while the load is held. As shown in the figure, if AE signals continue to be detected during the holding of these loads (GH), it is likely that substantial structural defects are present. In addition, a material may contain critical defects if an identical load is reapplied and AE signals continue to be detected. Another guideline governing AE's is the Dunegan corollary, which states that if acoustic emissions are observed prior to a previous maximum load, some type of new damage must have occurred. (Note: Time dependent processes like corrosion and hydrogen embrittlement tend to render the Kaiser Effect useless)Noise.

The sensitivity of an acoustic emission system is often limited by the amount of background noise nearby. Noise in AE testing refers to any undesirable signals detected by the sensors. Examples of these signals include frictional sources (e.g. loose bolts or movable connectors that shift when exposed to wind loads) and impact sources (e.g. rain, flying objects or wind-driven dust) in bridges. Sources of noise may also be present in applications where the area being tested may be disturbed by mechanical vibrations (e.g. pumps).

To compensate for the effects of background noise, various procedures can be implemented. Some possible approaches involve fabricating special sensors with electronic gates for noise blocking, taking precautions to place sensors as far away as possible from noise sources, and electronic filtering (either using signal arrival times or differences in the spectral content of true AE signals and background noise).

Pseudo Sources

In addition to the AE source mechanisms described above, pseudo source mechanisms produce AE signals that are detected by AE equipment. Examples include liquefaction and solidification, friction in rotating bearings, solid-solid phase transformations, leaks, cavitation, and the realignment or growth of magnetic domains (See Barkhausen Effect).

Wave Propagation

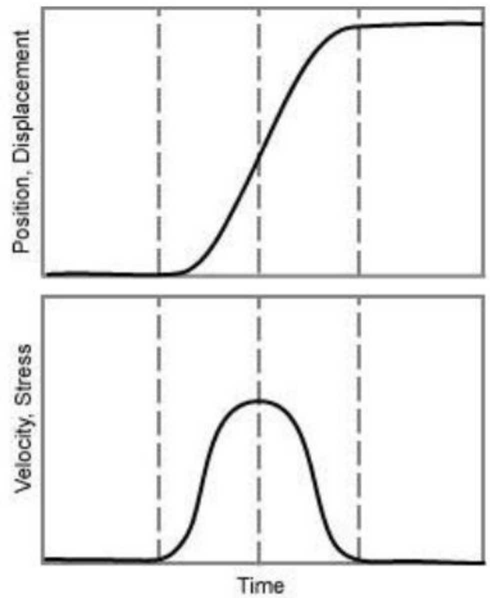
A primitive wave released at the AE source is illustrated in the figure right. The displacement waveform is a step-like function corresponding to the permanent change associated with the source process. The analogous velocity and stress waveforms are essentially pulse-like. The width and height of the primitive pulse depend on the dynamics of the source process. Source processes such as microscopic crack jumps and precipitate fractures are usually completed in a fraction of a microsecond or a few microseconds, which explains why the pulse is short in duration. The amplitude and energy of the primitive pulse vary over an enormous range from submicroscopic dislocation movements to gross crack jumps.

Waves radiates from the source in all directions, often having a strong directionality depending on the nature of the source process, as shown in the second figure. Rapid movement is necessary if a sizeable amount of the elastic energy liberated during deformation is to appear as an acoustic emission.

As these primitive waves travel through a material, their form is changed considerably. Elastic wave source and elastic wave motion theories are being investigated to determine the complicated relationship between the AE source pulse and the corresponding movement at the detection site. The ultimate goal of studies of the interaction between elastic waves and material structure is to accurately develop a description of the source event from the output signal of a distant sensor.

However, most materials-oriented researchers and NDT inspectors are not concerned with the intricate knowledge of each source event. Instead, they are primarily interested in the broader, statistical aspects of AE. Because of this, they prefer to use narrow band (resonant) sensors which detect only a small portion of the broadband of frequencies emitted by an AE. These sensors are capable of measuring hundreds of signals each second, in contrast to the more expensive high-fidelity sensors used in source function analysis. More information on sensors will be discussed later in the Equipment section.

The signal that is detected by a sensor is a combination of many parts of the waveform initially emitted. Acoustic emission source motion is completed in a few millionths of a second. As the AE leaves the source, the waveform travels in a spherically spreading pattern and is reflected off the boundaries of the object. Signals that are in phase with each other as they reach the sensor produce constructive interference which usually results in the highest peak of the waveform being detected. The typical time interval from when an AE wave reflects around the test piece (repeatedly exciting the sensor) until it decays, ranges from the order of 100 microseconds in a highly damped, nonmetallic material to tens of milliseconds in a lightly damped metallic material.

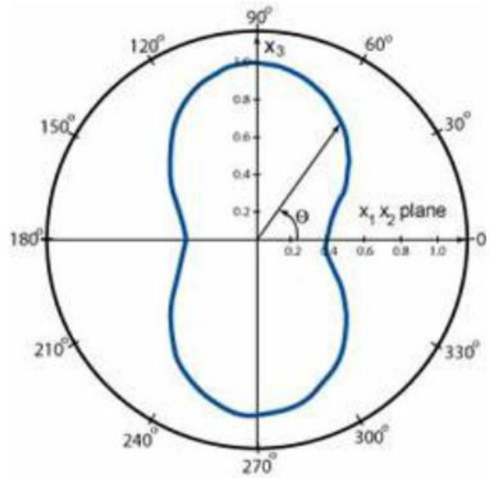


Primitive AE wave released at a source. The primitive wave is essentially a stress pulse corresponding to a permanent displacement of the material. The ordinate quantities refer to a point in the material.

Attenuation

The intensity of an AE signal detected by a sensor is considerably lower than the intensity that would have been observed in the close proximity of the source. This is due to attenuation. There are three main causes of attenuation, beginning with geometric spreading. As an AE spreads from its source in a plate-like material, its amplitude decays by 30% every time it doubles its distance from the source. In three-dimensional structures, the signal decays on the order of 50%. This can be traced back to the simple conservation of energy. Another cause of attenuation is material damping, as alluded to in the previous paragraph. While an AE wave passes through a material, its elastic and kinetic energies are absorbed and converted into heat. The third cause of attenuation is wave scattering. Geometric discontinuities (e.g. twin boundaries, nonmetallic inclusions, or grain boundaries) and structural boundaries both reflect some of the wave energy that was initially transmitted.

Measurements of the effects of attenuation on an AE signal can be performed with a simple apparatus known as a Hsu-Nielson Source. This consists of a mechanical pencil with either 0.3 or 0.5 mm 2H lead that is passed through a cone-shaped Teflon shoe designed to place the lead in contact with the surface of a material at a 30 degree angle. When the pencil lead is pressed and broken against the material, it creates a small, local deformation that is relieved in the form of a stress wave, similar to the type of AE signal produced by a crack. By using this method, simulated AE sources can be created at various sites on a structure to determine the optimal position for the placement of sensors and to ensure that all areas of interest are within the detection range of the sensor or sensors.

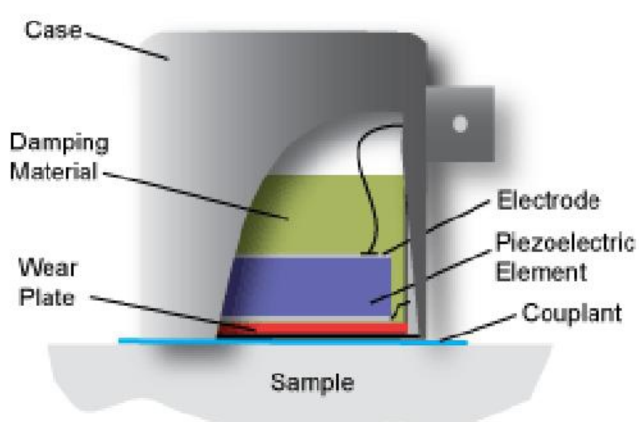


Angular dependence of acoustic emission radiated from a growing microcrack. Most of the energy is directed in the 90 and 270°directions, perpendicular to the crack surfaces.

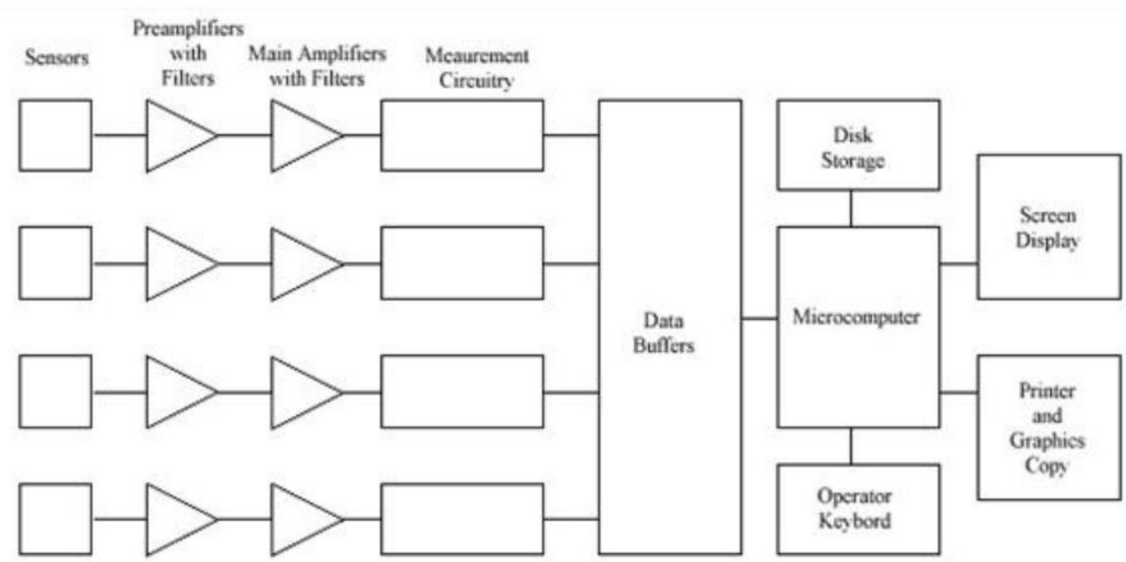
Wave Mode and Velocity

As mentioned earlier, using AE inspection in conjunction with other NDE techniques can be an effective method in gauging the location and nature of defects. Since source locations are determined by the time required for the wave to travel through the material to a sensor, it is important that the velocity of the propagating waves be accurately calculated. This is not an easy task since wave propagation depends on the material in question and the wave mode being detected. For many applications, Lamb waves are of primary concern because they are able to give the best indication of wave propagation from a source whose distance from the sensor is larger than the thickness of the material. For additional information on Lamb waves, see the wave mode page in the Ultrasonic Inspection section.

Equipment:



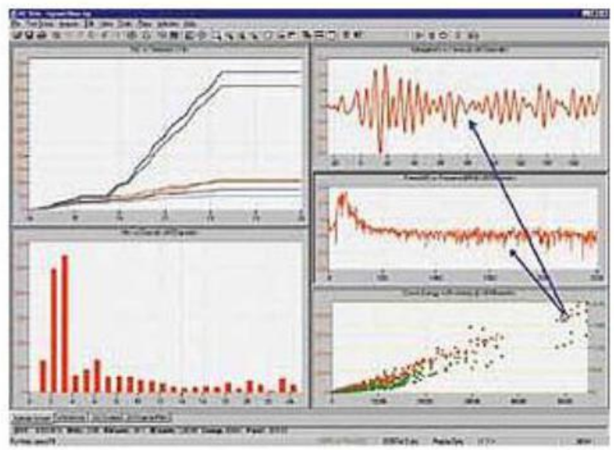
Acoustic emission testing can be performed in the field with portable instruments or in a stationary laboratory setting. Typically, systems contain a sensor, preamplifier, filter, and amplifier, along with measurement, display, and storage equipment (e.g. oscilloscopes, voltmeters, and personal computers). Acoustic emission sensors respond to dynamic motion that is caused by an AE event. This is achieved through transducers which convert mechanical movement into an electrical voltage signal. The transducer element in an AE sensor is almost always a piezoelectric crystal, which is commonly made from a ceramic such as lead zirconate titanate (PZT). Transducers are selected based on operating frequency, sensitivity and environmental characteristics, and are grouped into two classes: resonant and broadband. The majority of AE equipment is responsive to movement in its typical operating frequency range of 30 kHz to 1 MHz. For materials with high attenuation (e.g. plastic composites), lower frequencies may be used to better distinguish AE signals. The opposite holds true as well Ideally, the AE signal that reaches the mainframe will be free of background noise and electromagnetic interference. Unfortunately, this is not realistic. However, sensors and preamplifiers are designed to help eliminate unwanted signals. First, the preamplifier boosts the voltage to provide gain and cable drive capability. To minimize interference, a preamplifier is placed close to the transducer; in fact, many transducers today are equipped with integrated preamplifiers. Next, the signal is relayed to a bandpass filter for elimination of low frequencies (common to background noise) and high frequencies. Following completion of this process, the signal travels to the acoustic system mainframe and eventually to a computer or similar device for analysis and storage. Depending on noise conditions, further filtering or amplification at the mainframe may still be necessary.



Schematic Diagram of a Basic Four-channel Acoustic Emission Testing System

After passing the AE system mainframe, the signal comes to a detection/measurement circuit as shown in the figure directly above. Note that multiple-measurement circuits can be used in multiple sensor/channel systems for source location purposes (to be described later). At the measurement circuitry, the shape of the conditioned signal is compared with a threshold voltage value that has been programmed by the operator. Signals are either continuous (analogous to Gaussian, random noise with amplitudes varying according to the magnitude of the AE events) or burst-type. Each time the threshold voltage is exceeded, the measurement circuit releases a digital pulse. The first pulse is used to signify the beginning of a hit. (A hit is used to describe the AE event that is detected by a particular sensor. One AE event can cause a system with numerous channels to record multiple hits.) Pulses will continue to be generated while the signal exceeds the threshold voltage. Once this process has stopped for a predetermined amount of time, the hit is finished (as far as the circuitry is concerned). The data from the hit is then read into a microcomputer and the measurement circuit is reset.

Hit Driven AE Systems and Measurement of Signal Features:



Although several AE system designs are available (combining various options, sensitivity, and cost), most AE systems use a hit-driven architecture. The hit-driven design is able to efficiently measure all detected signals and record digital descriptions for each individual feature (detailed later in this section). During periods of inactivity, the system lies dormant. Once a new signal is detected, the system records the hit or hits, and the data is logged for present and/or future display.

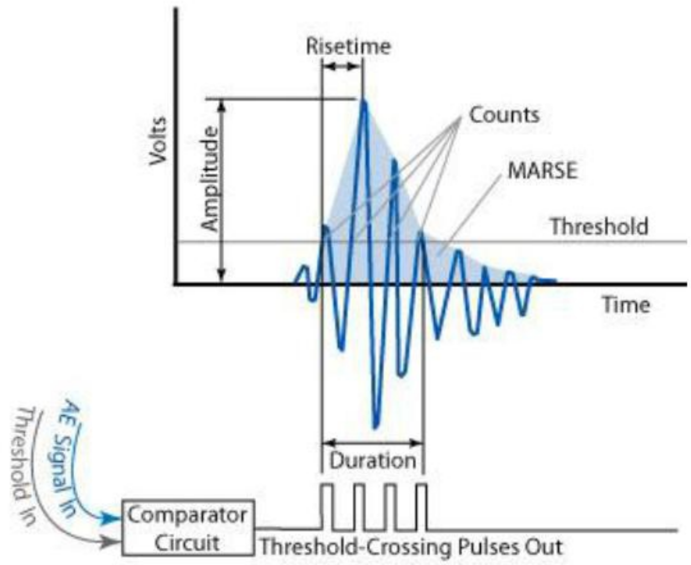
Also common to most AE systems is the ability to perform routine tasks that are valuable for AE inspection. These tasks include quantitative signal measurements with corresponding time and/or load readings, discrimination between real and false signals (noise), and the collection of statistical information about the parameters of each signal.

AE Signal Features

With the equipment configured and setup complete, AE testing may begin. The sensor is coupled to the test surface and held in place with tape or adhesive. An operator then monitors the signals which are excited by the induced stresses in the object. When a useful transient, or burst signal is correctly obtained, parameters like amplitude, counts, measured area under the rectified signal envelope (MARSE), duration, and rise time can be gathered. Each of the AE signal feature shown in the image is described below.

Amplitude, A, is the greatest measured voltage in a waveform and is measured in decibels (dB). This is an important parameter in acoustic emission inspection because it determines the detectability of the signal. Signals with amplitudes below the operator-defined, minimum threshold will not be recorded.

Rise time, R, is the time interval between the first threshold crossing and the signal peak. This parameter is related to the propagation of the wave between the source of the acoustic emission event and the sensor. Therefore, rise time is used for qualification of signals and as a criterion for noise filter.



Duration, D, is the time difference between the first and last threshold crossings. Duration can be used to identify different types of sources and to filter out noise. Like counts (N), this parameter relies upon the magnitude of the signal and the acoustics of the material.

MARSE, E, sometimes referred to as energy counts, is the measure of the area under the envelope of the rectified linear voltage time signal from the transducer. This can be thought of as the relative signal amplitude and is useful because the energy of the emission can be determined. MARSE is also sensitive to the duration and amplitude of the signal, but does not use counts or user defined thresholds and operating frequencies. MARSE is regularly used in the measurements of acoustic emissions.

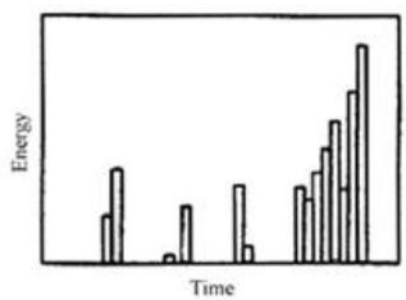
Counts, N, refers to the number of pulses emitted by the measurement circuitry if the signal amplitude is greater than the threshold. Depending on the magnitude of the AE event and the characteristics of the material, one hit may produce one or many counts. While this is a relatively simple parameter to collect, it usually needs to be combined with amplitude and/or duration measurements to provide quality information about the shape of a signal.

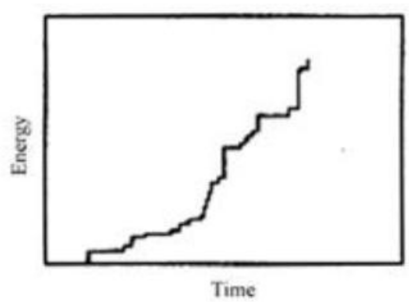
Data Display

Software-based AE systems are able to generate graphical displays for analysis of the signals recorded during AE inspection. These displays provide valuable information about the detected events and can be classified into four categories: location, activity, intensity, and data quality (crossplots).

Location displays identify the origin of the detected AE events. These can be graphed by X coordinates, X-Y coordinates, or by channel for linear computed-source location, planar computed-source location, and zone location techniques. Examples of each graph are shown to the right.

Activity displays show AE activity as a function of time on an X-Y plot (figure below left). Each bar on the graphs represents a specified amount of time. For example, a one-hour test could be divided into 100 time increments. All activity measured within a given 36 second interval would be displayed in a given histogram bar. Either axis may be displayed logarithmically in the event of high AE activity or long testing periods. In addition to showing measured activity over a single time period, cumulative activity displays (figure below right) can be created to show the total amount of activity detected during a test. This display is valuable for measuring the total emission quantity and the average rate of emission.) can be created to show the total amount of activity detected during a test. This display is valuable for measuring the total emission quantity and the average rate of emission.





Intensity displays are used to give statistical information concerning the magnitude of the detected signals. As can be seen in the amplitude distribution graph to the near right, the number of hits is plotted at each amplitude increment (expressed in dB's) beyond the user-defined threshold. These graphs can be used to determine whether a few large signals or many small ones created the detected AE signal energy. In addition, if the Y-axis is plotted logarithmically, the shape of the amplitude distribution can be interpreted to determine the activity of a crack (e.g. a linear distribution indicates growth).

The fourth category of AE displays, crossplots, is used for evaluating the quality of the data collected. Counts versus amplitude, duration versus amplitude, and counts versus duration are frequently used crossplots. As shown in the final figure, each hit is marked as a single point, indicating the correlation between the two signal features. The recognized signals from AE events typically form a diagonal band since larger signals usually generate higher counts. Because noise signals caused by electromagnetic interference do not have as many threshold-crossing pulses as typical AE source events, the hits are located below the main band. Conversely, signals caused by friction or leaks have more threshold-crossing pulses than typical AE source events and are subsequently located above the main band. In the case of ambiguous data, expertise is necessary in separating desirable and unwanted hits.

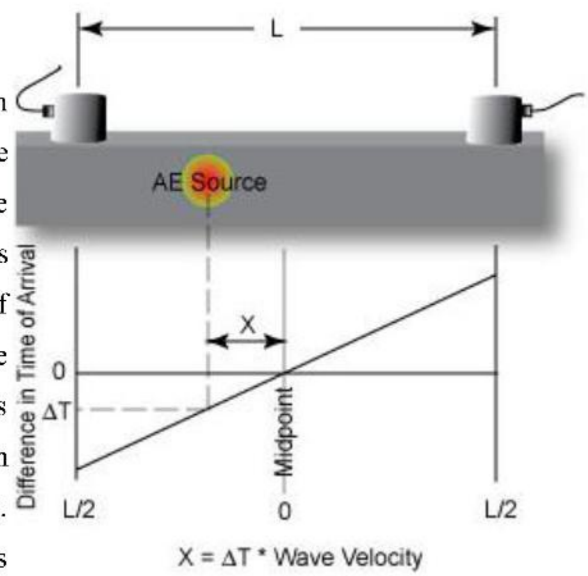
AE Source Location Techniques:

Multi-Channel Source Location Techniques:

Locating the source of significant acoustic emissions is often the main goal of an inspection. Although the magnitude of the damage may be unknown after AE analysis, follow up testing at source locations can provide these answers. As previously mentioned, many AE systems are capable of using multiple sensors/channels during testing, allowing them to record a hit from a single AE event. These AE systems can be used to determine the location of an event source. As hits are recorded by each sensor/channel, the source can be located by knowing the velocity of the wave in the material and the difference in hit arrival times among the sensors, as measured by hardware circuitry or computer software. By properly spacing the sensors in this manner, it is possible to inspect an entire structure with relatively few sensors.

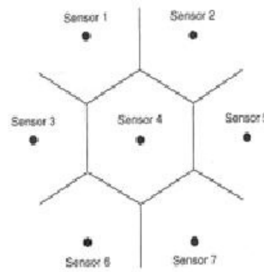
Source location techniques assume that AE waves travel at a constant velocity in a material. However, various effects may alter the expected velocity of the AE waves (e.g. reflections and multiple wave modes) and can affect the accuracy of this technique. Therefore, the geometric effects of the structure being tested and the operating frequency of the AE system must be considered when determining whether a particular source location technique is feasible for a given test structure.

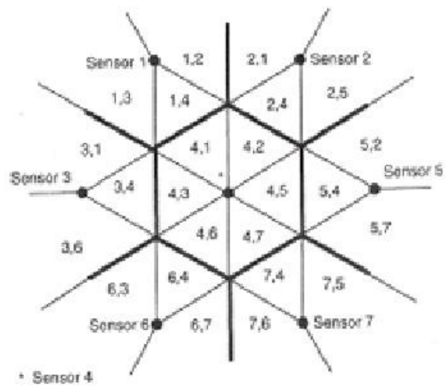
Linear Location Technique`



Several source location techniques have been developed based on this method. One of the commonly used computed-source location techniques is the linear location principle shown to the right. Linear location is often used to evaluate struts on truss bridges. When the source is located at the midpoint, the time of arrival difference for the wave at the two sensors is zero. If the source is closer to one of the sensors, a difference in arrival times is measured. To calculate the distance of the source location from the midpoint, the arrival time is multiplied by the wave velocity. Whether the location lies to the right or left of the midpoint is determined by which sensor first records the hit. This is a linear relationship and applies to any event sources between the sensors.

Because the above scenario implicitly assumes that the source is on a line passing through the two sensors, it is only valid for a linear problem. When using AE to identify a source location in a planar material, three or more sensors are used, and the optimal position of the source is between the sensors. Two categories of source location analysis are used for this situation: zonal location and point location.





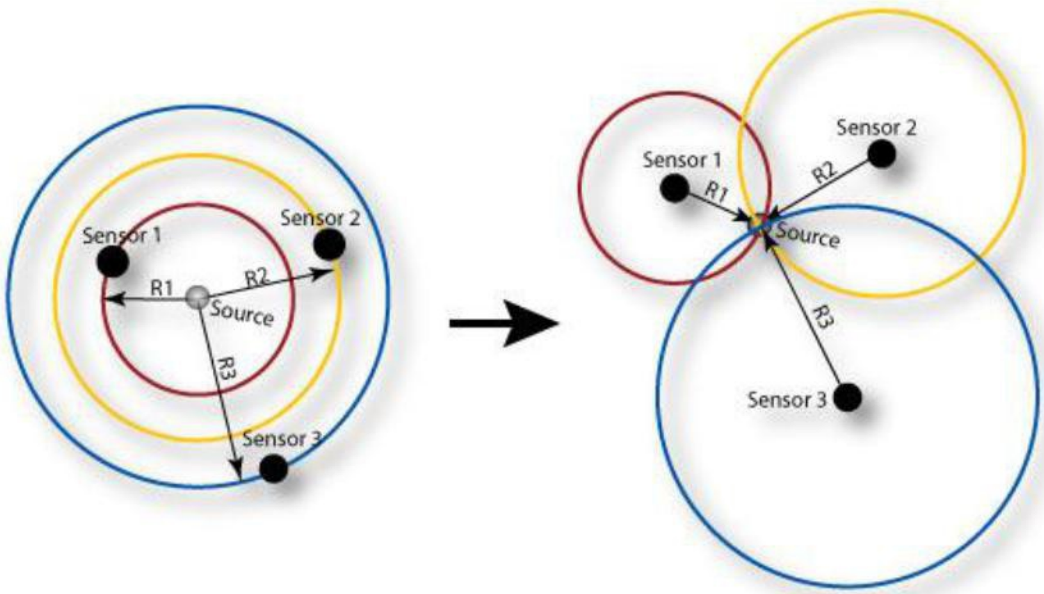
Zonal Location Technique

As the name implies, zonal location aims to trace the waves to a specific zone or region around a sensor. This method is used in anisotropic materials or in other structures where sensors are spaced relatively far apart or when high material attenuation affects the quality of signals at multiple sensors. Zones can be lengths, areas or volumes depending on the dimensions of the array. A planar sensor array with detection by one sensor is shown in the upper right figure. The source can be assumed to be within the region and less than halfway between sensors.

When additional sensors are applied, arrival times and amplitudes help pinpoint the source zone. The ordered pair in lower right figure represents the two sensors detecting the signal in the zone and the order of signal arrival at each sensor. When relating signal strength to peak amplitude, the largest peak amplitude is assumed to come from the nearest sensor, second largest from the next closest sensor and so forth.

Point Location

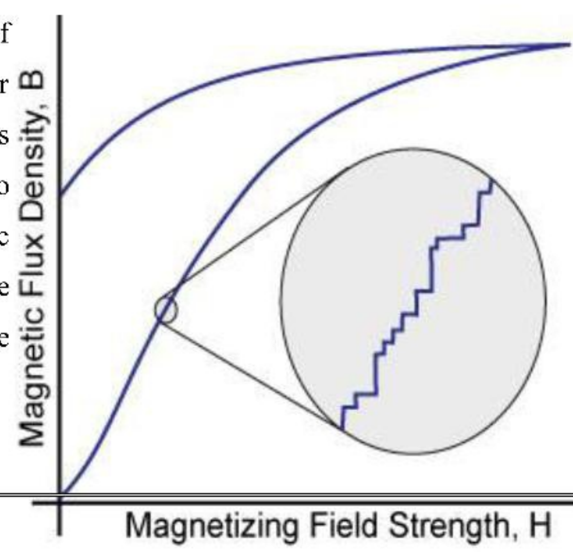
In order for point location to be justified, signals must be detected in a minimum number of sensors: two for linear, three for planar, four for volumetric. Accurate arrival times must also be available. Arrival times are often found by using peak amplitude or the first threshold crossing. The velocity of wave propagation and exact position of the sensors are necessary criteria as well. Equations can then be derived using sensor array geometry or more complex algebra to locate more specific points of interest.



AE Barkhausen Techniques:

Barkhausen Effect

The Barkhausen effect refers to the sudden change in size of ferromagnetic domains that occur during magnetization or demagnetization. During magnetization, favorably oriented domains develop at the cost of less favorably oriented domains. These two factors result in minute jumps of magnetization when a ferromagnetic sample (e.g. iron) is exposed to an increasing magnetic field (see figure). Domain wall motion itself is determined by many factors like



microstructure, grain boundaries, inclusions, and stress and strain. By the same token, the Barkhausen effect is too a function of stress and strain.

Barkhausen Noise

Barkhausen noise can be heard if a coil of wire is wrapped around the sample undergoing magnetization. Abrupt movements in the magnetic field produce spiking current pulses in the coil. When amplified, the clicks can be compared to Rice Krispies or the crumbling a candy wrapper. The amount of Barkhausen noise is influenced by material imperfections and dislocations and is likewise dependent on the mechanical properties of a material. Currently, materials exposed to high energy particles (nuclear reactors) or cyclic mechanical stresses (pipelines) are available for nondestructive evaluation using Barkhausen noise, one of the many branches of AE testing.

Applications

Acoustic emission is a very versatile, non-invasive way to gather information about a material or structure. Acoustic Emission testing (AET) is be applied to inspect and monitor pipelines, pressure vessels, storage tanks, bridges, aircraft, and bucket trucks, and a variety of composite and ceramic components. It is also used in process control applications such as monitoring welding processes. A few examples of AET applications follow.

Weld Monitoring

During the welding process, temperature changes induce stresses between the weld and the base metal. These stresses are often relieved by heat treating the weld. However, in some cases tempering the weld is not possible and minor cracking occurs. Amazingly, cracking can continue for up to 10 days after the weld has been completed. Using stainless steel welds with known inclusions and accelerometers for detection purposes and background noise monitoring, it was found by W. D. Jolly (1969) that low level signals and more sizeable bursts were related to the growth of microfissures and larger cracks respectively. ASTM E 749-96 is a standard practice of AE monitoring of continuous welding.

Bucket Truck (Cherry Pickers) Integrity Evaluation

Accidents, overloads and fatigue can all occur when operating bucket trucks or other aerial equipment. If a mechanical or structural defect is ignored, serious injury or fatality can result. In 1976, the Georgia Power Company pioneered the aerial manlift device inspection. Testing by independent labs and electrical utilities followed. Although originally intended to examine only the boom sections, the method is now used for inspecting the pedestal, pins, and various other components. Normally, the AE tests are second in a chain of inspections which start with visual checks. If necessary, follow-up tests take the form of magnetic particle, dye penetrant, or ultrasonic inspections. Experienced personnel can perform five to ten tests per day, saving valuable time and money along the way. ASTM F914 governs the procedures for examining insulated aerial personnel devices.

Gas Trailer Tubes

Acoustic emission testing on pressurized jumbo tube trailers was authorized by the Department of Transportation in 1983. Instead of using hydrostatic retesting, where tubes must be removed from service and disassembled, AET allows for in situ testing. A 10% over-pressurization is performed at a normal filling station with AE sensors attached to the tubes at each end. A multichannel acoustic system is used to detection and mapped source locations. Suspect locations are further evaluated using ultrasonic inspection, and when defects are confirmed the tube is removed from use. AET can detect subcritical flaws whereas hydrostatic testing cannot detect cracks until they cause rupture of the tube. Because of the high stresses in the circumferential direction of the tubes, tests are geared toward finding longitudinal fatigue cracks.

Bridges

Bridges contain many welds, joints and connections, and a combination of load and environmental factors heavily influence damage mechanisms such as fatigue cracking and metal thinning due to corrosion. Bridges receive a visual inspection about every two years and when damage is detected, the bridge is either shut down, its weight capacity is lowered, or it is singled out for more frequent monitoring. Acoustic Emission is increasingly being used for bridge monitoring applications because it can continuously gather data and detect changes that may be due to damage without requiring lane closures or bridge shutdown. In fact, traffic flow is commonly used to load or stress the bridge for the AE testing.

Aerospace Structures

Most aerospace structures consist of complex assemblies of components that have been design to carry significant loads while being as light as possible. This combination of requirements leads to many parts that can tolerate only a minor amount of damage before failing. This fact makes detection of damage extremely important but components are often packed tightly together making access for inspections difficult. AET has found applications in monitoring the health of aerospace structures because sensors can be attached in easily accessed areas that are remotely located from damage prone sites. AET has been used in laboratory structural tests, as well as in flight test applications. NASA's Wing Leading Edge Impact Detection System is partially based on AE technology. The image to the right shows a technician applying AE transducers on the inside of the Space Shuttle Discovery wing structure. The impact detection system was developed to alert NASA officials to events such as the sprayed-on-foam insulation impact that damaged the Space Shuttle Columbia's wing leading edge during launch and lead to its breakup on reentry to the Earth's atmosphere.

Others

- Fiber-reinforced polymer-matrix composites, in particular glass-fiber reinforced parts or structures (e.g. fan blades)
- Material research (e.g. investigation of material properties, breakdown mechanisms, and damage behavior)
- Inspection and quality assurance, (e.g. wood drying processes, scratch tests)
- Real-time leakage test and location within various components (small valves, steam lines, tank bottoms)
- Detection and location of high-voltage partial discharges in transformers
- Railroad tank car and rocket motor testing

There are a number of standards and guidelines that describe AE testing and application procedures as supplied by the American Society for Testing and Materials (ASTM). Examples are ASTM E 1932 for the AE examination of small parts and ASTM E1419-00 for the method of examining seamless, gas-filled, pressure vessels.

Leak testing:

It is conventional to use the term "leak" to refer to an actual discontinuity or passage through which a fluid flows or permeates. "Leakage" refers to the fluid that has flown through a leak. "Leak rate" refers to the rate of fluid per unit of time under a given set of conditions, and is properly expressed in units of mass per unit time. Modern leak testing is thus based on the notion that all containment systems leak, the only rational requirement that can be imposed is that such systems leak at a rate no greater than some finite maximum allowable rate, however small that may be as long as it is within the range of sensitivity of a measuring system.

There are two basic types of leaks : one is an essentially localized i.e., a discrete passage through which fluid may flow (crudely, a hole). Such a leak may take the from of a tube, crack, orifice, or the like. A system may also leak through permeation of a somewhat extended barrier; such a leak is called a distributed leak. Gases may flow through solids having no holes large enough to permit more than a small fraction of the gas to flow through any one hole. This process involves diffusion through the solid and may involve various surface phenomena such as absorption, dissociation, migration, and desorption of gas molecules.

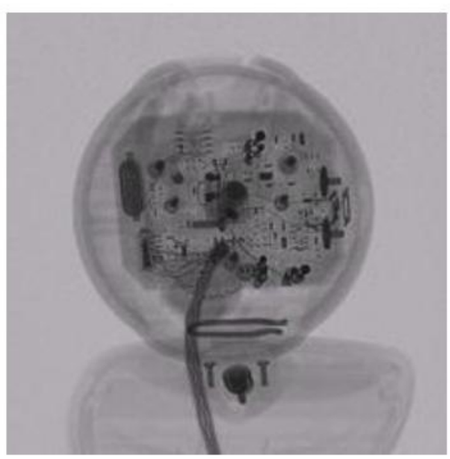
A distinction may be drawn between "real" and "virtual" leaks. Real leaks are the type described above, "virtual leak" refers to gradual desorption of gases from surfaces or components within a vacuum system. It is not uncommon for a vacuum system to have real and virtual leaks simultaneously.

It is convenient to categorize leak-testing methods according to whether the method is primarily applicable to the testing of internally pressurized systems or to vacuum systems. There are two basic ways to detect leaks in internally pressurized gas systems: (1) any reduction in the total quantity of gas contained within the system may be detected and (2) the escaping gas may itself be detected. For small leaks in pressurized gas systems, some method of directly sensing the escaping gas is usually necessary, especially when it is essential to locate the leak. Some of the methods used for this purpose are described here. The sound produced by the escaping gas may be listened to. The pressurized test system may be submerged in a liquid bath and visually observed. A soap solution may be applied on the outer surface of a pressurized system and bubbles formed due to escaping gas be observed. Detectors which are sensitive to specific gases may be used such as mass spectrometers as helium leak detectors and the radiation detectors for detection of leaking radioactive krypton-85 gas. The leak testing of vacuum systems also makes use of several specially adopted versions of specific gas detectors.

Typical applications of leak testing include testing of metals and non-porous materials, enclosures and seals, vacuum leak test of experimental and operating equipment, testing of welds, testing of brazing and adhesive bonds, testing of vacuum chambers and metal gasket seals, reactor fuel element inspection and testing of liquid-metal containers and components.

The application of leak testing techniques is, however, limited because direct access is required to at least one side of the test system and special type of sniffer or probe is required. Smeared metal or containments may plug the leak passage. Radiation and other residual gas hazards are possible.

Computed Tomography:



Industrial computed tomography (CT) scanning is any computer-aided tomographic process; usually X-ray computed tomography, that uses irradiation to produce three-dimensional internal and external representations of a scanned object. Industrial CT scanning has been used in many areas of industry for internal inspection of components. Some of the key uses for industrial CT scanning have been flaw detection, failure analysis, metrology, assembly analysis and reverse engineering applications.[1][2] Just as in medical imaging, industrial imaging includes both nontomographic radiography (industrial radiography) and computed tomographic radiography (computed tomography).

Types of scanners:

Line beam scanning is the traditional process of industrial CT scanning. X-rays are produced and the beam is collimated to create a line. The X-ray line beam is then translated across the part and data is collected by the detector. The data is then reconstructed to create a 3-D volume rendering of the part.

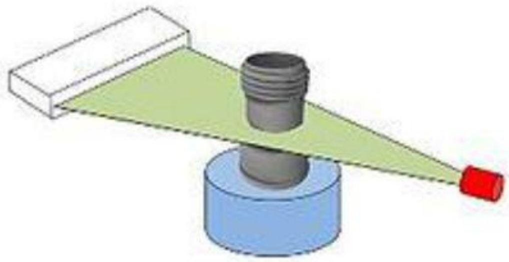


Fig: Line beam scanning

In *cone beam scanning*, the part to be scanned is placed on a rotary table. As the part rotates, the cone of X-rays produce a large number of 2D images that are collected by the detector. The 2D images are then processed to create a 3D volume rendering of the external and internal geometries of the part.

Fig: Cone beam scanner

Analysis and inspection techniques:

Various inspection uses and techniques include part-to-CAD comparisons, part-to-part comparisons, assembly and defect analysis, void analysis, wall thickness analysis, and generation of CAD data. The CAD data can be used for reverse engineering, geometric dimensioning and tolerance analysis, and production part approval

Assembly:

One of the most recognized forms of analysis using CT is for assembly, or visual analysis. CT scanning provides views inside components in their functioning position, without disassembly. Some software programs for industrial CT scanning allow for measurements to be taken from the CT dataset volume rendering. These measurements are useful for determining the clearances between assembled parts or the dimension of an individual feature.

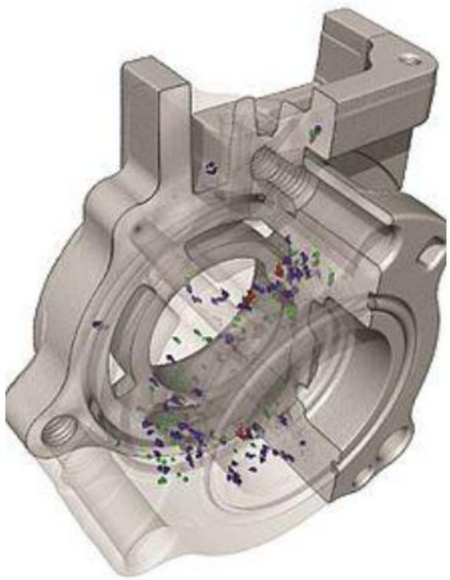


Fig: An industrial computed tomography (CT) scan conducted on an aluminum casting to identify internal failures such as voids. All color coordinated particles within casting are voids/porosity/air pockets, which can additionally be measured and are color coordinated according to size.

Void, crack and defect detection:

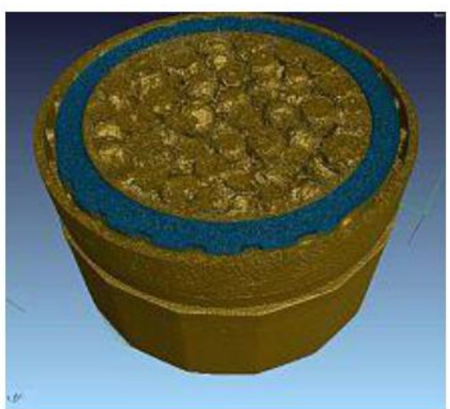


Fig: Flight through a 3D reconstruction of a disposable pepper grinder. Glass in blue.

Traditionally, determining defects, voids and cracks within an object would require destructive testing. CT scanning

can detect internal features and flaws displaying this information in 3D without destroying the part. Industrial CT scanning (3D X-ray) is used to detect flaws inside a part such as porosity,[7] an inclusion, or a crack.
Metal casting and moulded plastic components are typically prone to porosity because of cooling processes, transitions between thick and thin walls, and material properties. Void analysis can be used to locate, measure, and analyze voids inside plastic or metal components.

Geometric dimensioning and tolerancing analysis:

Traditionally, without destructive testing, full metrology has only been performed on the exterior dimensions of components, such as with a coordinate-measuring machine (CMM) or with a vision system to map exterior surfaces. Internal inspection methods would require using a 2D X-ray of the component or the use of destructive testing. Industrial CT scanning allows for full non-destructive metrology. With unlimited geometrical complexity, 3D printing allows for complex internal features to be created with no impact on cost, such features are not accessible using traditional CMM. The first 3D printed artefact that is optimised for characterisation of form using computed tomography CT

Image-based finite element methods

Image-based finite element method converts the 3D image data from X-ray computed tomography directly into meshes for finite element analysis. Benefits of this method include modelling complex geometries (e.g. composite materials) or accurately modelling "as manufactured" components at the micro-scale.

Aapplications of Computed Tomography (CT):

The number of industrial applications of Computed Tomography (CT) is large and rapidly increasing. After a brief market overview, the paper gives a survey of state of the art and upcoming CT technologies, covering types of CT systems, scanning capabilities, and technological advances. The paper contains a survey of application examples from the manufacturing industry as well as from other industries, e.g., electrical and electronic devices, inhomogeneous materials, and from the food industry. Challenges as well as major national and international coordinated activities in the field of industrial CT are also presented.