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# Unconventional Method of Non-Destructive Tests Part 1

**Abstract:** The article presents methods which can be used when conventional non-destructive tests are unable to detect discontinuities. Non-destructive testing methods are based on physical phenomena enabling the obtainment of diagnostic information. Diagnostic information can be obtained using commonly applied methods as well as less popular techniques of specific nature.

**Keywords:** acoustic emission tests, infrared thermal imaging, Metal Magnetic Memory Method

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**Non-destructive tests** (NDTs) constitute a key element ensuring the failure-free operation of equipment and machinery. Non-destructive tests make it possible to detect discontinuities formed both at the manufacturing stage and during operation. However, NDTs as such also have their limitations. Non-destructive tests are mostly indirect methods, where conclusions about the presence of discontinuities are based on the course of specific physical phenomena. Non-destructive tests provide information about properties of a given object. They aim to detect discontinuities and identify their nature. The primary non-destructive tests are as follows [1]:

- visual tests (VT),
- penetrant tests (PT),
- magnetic particle tests (MT),
- radiographic tests (RT),
- ultrasonic tests (UT),
- eddy current tests (ET).

**Visual tests** (VT) are used to initially assess surface discontinuities. The tests involve eyesight aided by optical geometry instruments including magnifying glasses, sets of mirrors, endoscopes etc. Among other things, visual tests enable the detection of undercuts, lacks of penetration, cracks, discontinuities of shape (e.g. corrosion pits), angular distortions or linear misalignment. Endoscopic techniques entail the use of equipment supplying light and optical systems, including optical fibres (fiberscopes) and systems of lenses (borescopes). The above-named testing systems make it possible to detect discontinuities located in hard-to-reach areas within girth welds (e.g. of heat exchangers). Visual tests are also very useful in the detection of operation-related discontinuities [2].

**Penetrant tests** (PT) use of the phenomenon of capillarity to detect discontinuities open on the surface e.g. cracks and surface gas pores. Penetrant tests include dye penetrant tests, fluorescent penetrant tests and dye-fluorescent penetrant tests. A surface to be examined must be cleaned before the test. Once cleaned, the

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surface is provided with penetrant entering discontinuities open on the surface. Finally, the penetrant is removed. The subsequent stage involves the application of developer (on the surface being tested) "highlighting" the penetrant present (left over) on the surface in the form of linear or round indications. Penetrant tests are used in the examination of ferromagnetic and non-ferromagnetic materials (steel, iron, aluminium and copper) as well as non-metallic materials (ceramics). Significant advantages of penetrant tests include simplicity, immediacy and low costs. Disadvantages of penetrant tests include the limited detectability of surface discontinuities, the significant toxicity of substances used in tests as well as the need for degreasing and cleaning a surface to be examined [3].

**Magnetic particle tests** are used exclusively when examining ferromagnetic materials. These tests involve the use of a magnetic field, which, by means of various coils and inductors and changes in stray fields indicate the location of discontinuities. Magnetic particle tests are based on the dye technique performed in the visible light and the fluorescent technique performed in the UV-A light. The tests are used in the examination of welded joints, forgings, casts and ropes. Advantages of magnetic article tests include fast performance and the immediate obtainment of a test result [3].

**Radiographic tests** enable the detection of both internal and external discontinuities. The tests involve the exposure of objects to ionising radiation (x and γ) followed by the recording of images on x-ray films. The method is used when testing welded joints, casts, forgings and tubes [1].

**Ultrasonic tests** involve the use of waves, the frequency of which is restricted within the range of approximately 50 kHz to several MHz (in some cases even up to 1 GHz). Welded joints are tested using waves having frequency restricted within the range of 0.5 MHz to 10 MHz (usually between 2 MHz and 5 MHz) [3].

**The pitch/catch technique** involves the use of two transducers characterised by the same parameters, where one of the transducers is the transmitter and the other is the receiver. If the transducers are located opposite each other, a signal provided to a material by the transmitting transducer should reach the transducer acting as the receiver [2].

**The echo technique** involves the use of a single transducer initially acting as the transmitter of impulses and next, after "switching over", acting as the receiver. Signals transmitted by the transducers are reflected against discontinuities or the opposite surface and return to the transducer. Time passing between the emission of an impulse to the moment of its return and reception by the transducer can be identified knowing the velocity of the ultrasonic wave in the material and the distance between the transducer and the "obstacle". The height of the echo of a given imperfection on the defectoscope screen enables the identification of the approximate size of the imperfection [2].

**The resonance technique** is used in thickness measurements and involves the excitation of the standing wave in the material and the going of the wave into resonance with the wavelength. The above-named situation is possible if the thickness of the material constitutes the multiplicity of the half of the wavelength. Usually, the resonance technique involves the emission of continuous waves [2].

**Eddy current tests** belong to surface methods. The tests involve the generation of a variable magnetic field in a given material and the reception of signals by a transducer and an eddy-current defectoscope. Recorded changes in the intensity of the electromagnetic field, the phase shift of voltage and current as well as amplitude enable the assessment of the state of a material being tested. Eddy current tests are used to detect discontinuities in the form of corrosion defects and cracks. Apart from detection, the tests also enable the identification of the size and the depth of discontinuities. The method is used in the petrochemical, chemical, aviation and the machine-building industry. Eddy current tests are also used to examine tubes of heat exchangers in conventional and nuclear power plants [3].

Other non-destructive testing methods include:
- acoustic emission,
- infrared thermal imaging,
- metal magnetic memory method.

## Acoustic emission

Acoustic emission-based tests consist in the reception and the analysis of acoustic signals generated in an object subjected to tests. The term of acoustic emission (AE) includes phenomena involving the generation of elastic waves inside or on the surface of a medium during deformation processes, i.e. the generation of elastic waves as a result of local and dynamic changes in the material structure. Signals are generated as a result of changes in mechanical loads, pressure, temperature, structural transformations or chemical processes. Sources of acoustic signals are formed as a result of the development of cracks, plastic strains, friction, intense corrosion and the flow of liquids and gases (leaks). Acoustic emission is also used in measurement methods involving the use of elastic waves, methods of data analysis and measurement systems [4]. The acoustic emission method is used when testing pressure components of pressure vessels (Fig. 1), technological pipelines or reactors. The method enables the detection of discontinuities and active damage such as:
- cracks and their propagation as well as other discontinuities in the structure of metals,
- local plastic deformations,
- corrosion-induced material degradation resulting in the weakening of device material structure, local plastic deformations and the degradation of materials leading to the local weakening of device material structure [4].

Figure 2 presents exemplary equipment used in acoustic emission tests.

Fig. 1. Exemplary tests of a pressure vessel based on the acoustic emission method involving the use of sensors

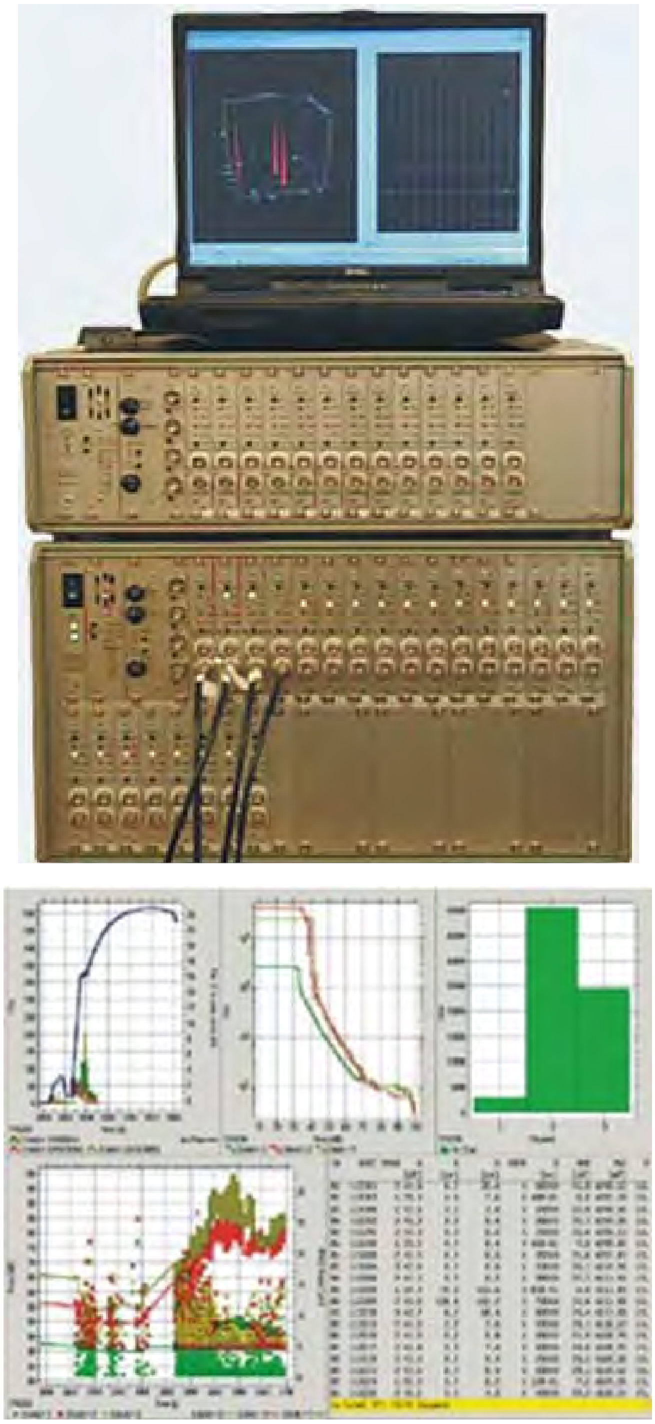

Fig. 2. Exemplary equipment used in multiparametric analysis in acoustic emission method-based tests

Acoustic emission collects signals from the entire volume of a material being tested. Acoustic emission-related problems include false signals and their separation from noise. The assessment of discontinuities is difficult and requires the use of a special echogram (Fig. 3).

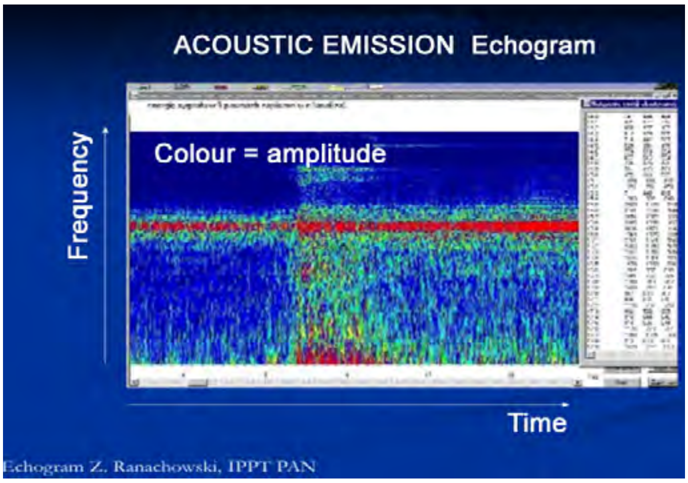


Fig. 3. Exemplary echogram used in acoustic emission tests

## Heat flow method – infrared thermal imaging

Infrared thermal imaging is a method enabling the acquisition and analysis of thermal information using non-contact thermographic equipment. Personnel performing measurements are safely distant from the hazard, do not disturb tests and do not affect an object subjected to examination. Measurements are performed on a real-time basis, which makes it possible to capture fast moving objects and quickly changing thermal patterns. The method enables the fast scanning of stationary objects as well as the overview and comparison of various areas. The flow of heat can be visualised for analysis. Infrared thermal imaging finds applications in medicine and veterinary medicine, quality and process control as well as non-destructive tests and maintenance. Among other things, the technique is used in inspections of electric wiring, buildings, furnaces, boilers, tanks and containers as well as in relation to such issues as mechanical friction and problems accompanying the flow of liquids [4–5].

Passive infrared thermal imaging uses the flow of heat in a given element. The method is used when examining the thermal insulating power of buildings (see Fig. 4) and detecting areas characterised by elevated temperature triggered by friction in bearings or sparking. The technique uses heat generated by discontinuities (as is the case with galled bearings) or the flow of heat in a given system. Discontinuities or the reduction of thickness in a given material impedes or alters the flow of heat and the distribution of temperature [6].


Fig. 4. Passive infrared thermal imaging used in the examination of the thermal insulating power of buildings

In turn, active infrared thermal imaging requires the heating of an element (which is connected with the gradient of temperature). The method makes it possible to identify the gradual change of temperature along a specific distance and show the direction of heat flow. The technique detects the transfer of heat through conduction [4]. Testing methods are based on the analysis of temperature (in time) of a heated surface. The technique sensitivity enables the detection of discontinuities. Elements to be tested are heated using media (hot water or air), surface equipment (lamps or heating blankets) and linear devices (laser). Heat is recorded using heat-sensitive paints, liquid cholesterol crystals and infrared cameras (tests of aircraft and integrated circuit). The advantages of the method include the possibility of testing a large area at a time or one-sided access. For instance, the method can be used in tests of laminated materials. The disadvantages of the technique include the detection of "shallow" discontinuities (i.e. located near the surface) and low resolution. The successful identification of discontinuities also requires the knowledge of the structure of an element being tested [5].

Thermal imaging tests can also be divided into qualitative and quantitative methods. The qualitative thermographic method involves the analysis of thermal patterns to detect, locate and assess existing defects. In turn, the quantitative method is used in temperature measurements, the results of which are based on specific imperfection criteria and constitute the basis for identifying the course and manner of repair (if any).

The infrared camera transforms invisible infrared radiation into a visible image. An example of an infrared image is presented in Figure 5. The camera is equipped with a lens, which, however, is not made of glass as is the case with systems used in the optical spectrum. The camera is mounted in a leak-tight housing provided with a transmission window within the range of infrared radiation. Measurements are sometimes performed in a chamber provided with transparent windows. The lenses and cameras are made of materials characterised by a high infrared transmission coefficient. Temperatures exceeding 300°C are sometimes measured using CCD cameras, operated within the near infrared spectrum. One of the advantages of the cameras is the easy adjustment of the camera range, whereas one of the disadvantages is the necessity of performing precise calibration within the range of near infrared. The cameras are small, lightweight and equipped with the matrix featuring a large number of point sensors [5].

Fig. 5. Exemplary thermogram of a steam engine performed using the high-resolution camera

Thermographic tests can be used in the analysis of fusion and pressure welding processes, where information concerning temperature in individual zones of joints enables the identification of the properties of such joints. However, a significant limitation is the high costs of thermal imaging equipment [2].

**The Metal Magnetic Memory Method** (MMM method) makes it possible to perform tests of technical objects during their operation. The method consists in the demonstration of irreversible changes in magnetisation, triggered by stresses exceeding the mean level of internal stresses generated in an object being tested. The technique is based on the object's own magnetic field. The effect of the magnetic field generated on the surface of the object results in generation of the magnetic gradient of the stray field, recorded by means of magnetometers [8]. The flow of the magnetic field vector though discontinuities is presented in Figure 6.

The lines of magnetic field forces are disturbed in the area of a material discontinuity [7]. The significant number of magnetic field

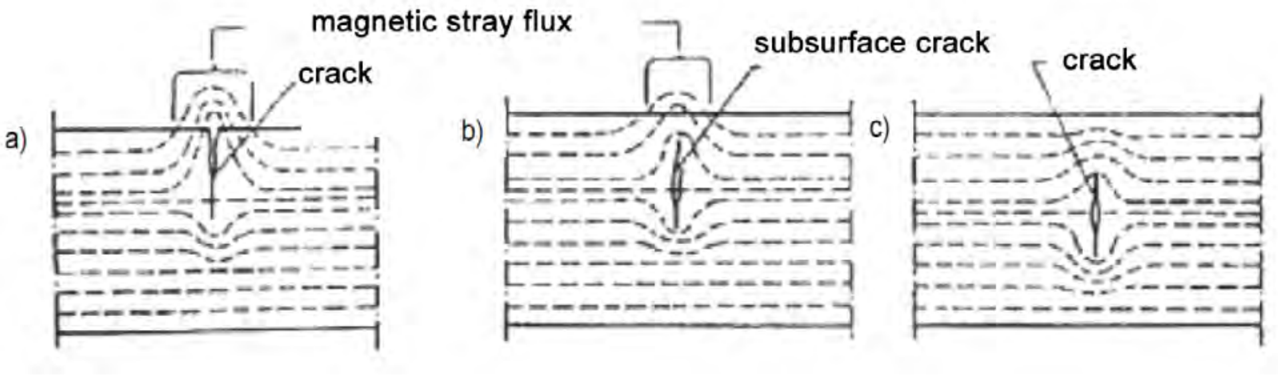


Fig. 6. Flow of the magnetic field vector though discontinuities

lines is concentrated in the material; some of them penetrate the air gap, whereas the remaining lines close over the material surface. The lines of magnetic field forces are inclined at an angle of approximately 90°. The phenomenon is referred to as the magnetic stray field [2]. The highest intensity of the above-named phenomenon is directly related to surface discontinuities perpendicular in relation to the lines of magnetic field forces. The intensity of the stray field induced by subsurface discontinuities tends to be lower. The greater the distance to the surface and the smaller the dimensions, the lower the values of the stray field. When moving over the area of a discontinuity, the magnetometer detects changes in the component of magnetic field intensity (signalled by an increase in the gradient of magnetic field intensity). Usually, the value of gradient indicates the area of stress concentration or the location of a discontinuity. The analysis is usually based on the gradient of measured magnetic field intensity in relation to a specific object (see Fig. 7). Low values of the gradient correspond to areas free from discontinuities and stress concentration zones. If the cross-section of a given area is uniform and so are magnetic properties, the magnetic field intensity is close to zero (which does not lead to an increase in the gradient) [8].

The analysis based on the Metal Magnetic Memory (MMM) method involves the interpretation of the local disturbance of the magnetic field triggered by a local stress in the material, the local plastic strain of the material or the presence of mechanically (cracks) or structurally (delamination) induced material discontinuities. The method is based on the phenomenon of "memorising" the results of cyclic and ultimate loads [8]. The primary criterion adopted in the MMM method-based diagnostics involves the identification (on the basis of the distribution of magnetic stray field Hp) of local areas of concentrated stresses KN, where the phenomena of corrosion, fatigue, creep and cracking of the material are usually initiated and develop. The MMM method can be used in tests of elements made of ferromagnetic and paramagnetic materials (e.g. austenitic steels). The MMM method-based tests make it possible to evaluate the technical condition of elements, assess their operation time and forecast the areas of future damage (by locating

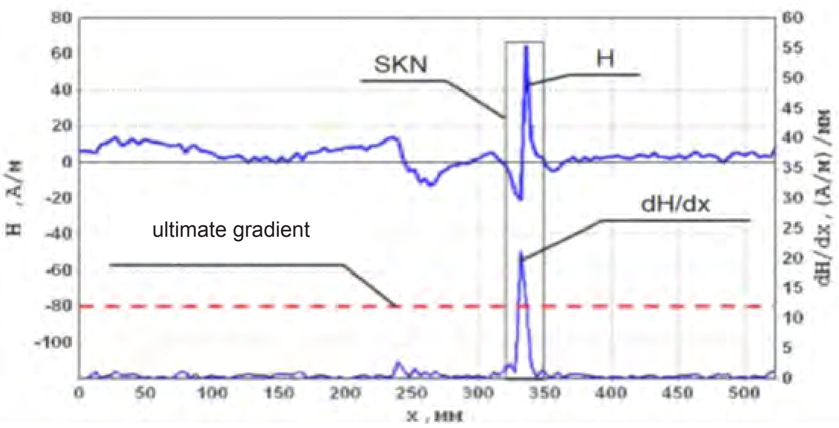


Fig. 7. Exemplary stress concentration zone in the material tested using the MMM method

stress concentration zones). The method enables the detection of material discontinuities and areas of stress concentration as early as during their initiation and early development. The method does not require the special preparation of a surface to be tested and time of testing is relatively short. The method used residual magnetism generated during the operation of equipment [7–8].

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