NON-DESTRUCTIVE TESTING

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Contents

Summary

This section contains a review of physical fundamentals and results of practical implementation of methods of nondestructive testing (NDT) and evaluation. It also presents relevant information on magnetic, electrical, eddy current, HF electromagnetic, infrared, optical, acoustic, radiographic, penetrant and other (such as vibration, leakage testing and integrated) methods of NDT and evaluation of products manufactured by the machine building industry.

1. Classification of NDT Methods

Nondestructive testing (NDT) is based on physical processes of interrelation between a physical field or a substance and a tested object (TO). Nine types of NDT are generally distinguished. They are: electric, magnetic, eddy-current, high-frequency, electromagnetic, infrared, optical, radiographic, acoustic and penetrant. In addition, some other types of NDT have gained acceptance, such as vibration analysis, leak testing and integrated ones.

In all the NDT methods, the nature of interrelationships between a field or substance and a TO should provide that a tested characteristic (defect) of that object would bring about measurable changes in the field or state of the substance. Sometimes, a physical field used for testing originates under the impact of other physical effects associated with the characteristic tested. For example, the electromotive force that emerges due to the thermocouple effect when heterogeneous materials are heated makes it possible to test the chemical composition of such materials (i.e. here we have a thermoelectric effect).

2. Magnetic NDT Methods

Magnetic NDT methods are used for items of ferro-magnetic materials capable of substantially changing their magnetic characteristics when exposed to an external (magnetizing) magnetic field. The magnetizing procedure (i.e. placing an item in the magnetic field) is mandatory under this type of testing.

Here are the basic informative parameters: coercive force, magnetization, induction (residual induction), magnetic permeability, intensity, Barkhausen effect (magnetic noise).

By method of receiving initial information, the following subtypes of magnetic NDT are distinguished: magnetic particle (MP), magnetographic (MG), ferro-sounding (FS), Hall effect (HE), induction (I), ponderomotive (PM) and magnetoresistor (MR).

These magnetic NDT methods make it possible to test items for: continuity (flaw detection) [MP, MG, FS, HE, I], dimensions [FS, HE, I, PM] and structure and mechanical properties [FS, HE, I].

The magnetic flaw detection method is based on exploring of the distortion of a magnetic field that appears at defective points of items made of ferro-magnetic materials.

The sensitivity of magnetic flaw detection depends upon magnetic characteristics of materials, indicators, probes, magnetizing modes, etc.

Magnetic flaw detection can detect macro-defects, i.e. cracks, blowholes, incomplete fusion areas, and delaminations at a depth of 10 mm with a minimal depth size of more than 0.1 mm.

The structure and mechanical properties of items are tested by identifying correlation relationships between the parameter tested (hardening and tempering temperature, hardness, etc.) and a certain magnetic characteristic (or characteristics). It has been an effective practice to test the condition of surface layers, quality of surface hardening, nitration and so on, as well as the presence of an α–phase.

To determine the presence of the ferrite phase, instruments capable of measuring magnetic permeability are used. Other testing techniques to identify the ferrite phase (α–phase) are:

- ponderomotive testing based on measuring the force or the moment of force acting on the sample in a constant magnetic field, or the force pull of a permanent magnet or electromagnet from the item to be tested, or the torque of the sample;

- magnetostatic testing based on measuring magnetic permeability of the tested material;
- induction testing based on measuring of a combined resistance or inductance of the measuring coil, etc.

The form and size of the magnetic hysteresis loop (their family) depend upon the chemical composition of the material which is responsible for the specificity of spin-spin interactions and exchange energy; crystallographic anisotropy; the presence and place of impurities and atoms of alloy components; micro- and macrostress and heterogeneity; the presence and place of dislocations, grain size, etc.

It is for this reason that magnetic coercive force meters with attachable electromagnets have gained wide application. They are used for gradual magnetizing and demagnetizing of a tested area up to a point when the magnetic flux is no longer present in the metal.

Magnetic techniques very often use geometrical parameters to determine thickness of nonmagnetic coatings applied on a magnetic base, and width of the walls of items made of magnetic and nonmagnetic materials.

Ponderomotive thickness gauges make up a large group of test instruments.

The operation of magnetostatic-type instruments is based on identifying the variation of the field intensity by Hall generators, ferroprobes, current-carrying loop, magnetic needle and so forth incorporated in the electromagnet or permanent magnet circuit that occurs when the distance between it and the ferro-magnetic item is changed because of the nonmagnetic coat thereon.

Induction thickness gauges are widely used today to measure thickness of nonmagnetic coatings on a ferro-magnetic base. They are based on identifying changes in magnetic resistance (conductivity) of a magnetic circuit.

The magnetic techniques are widely used nowadays for making metal detectors in use with the Customs as well as mine detectors.

3. Electric NDT methods

Electric NDT consists in creating an electric field in the tested object by a direct action of electric disturbance (e.g. electrostatic field, constant AC or DC field) aimed at that object, or an indirect action of non-electric disturbance (e.g. infrared, mechanical, etc.). The tested object's electrical characteristics are used as initial informative parameter.

Electric capacitance testing (ECT) method consists of placing a tested object or its portion to be tested into an electrostatic field and finding the desired characteristics of the material by the response it induces in the source of that field. An electric capacitor is used as a field source and simultaneously as a primary electric capacitance converter (ECC) for it converts physical and geometric characteristics of a tested object into an electrical parameter. The ECC response shows as a change in its integral parameters one of which characterizes the "capacitive" properties of the ECC and the other – dielectric losses (such as capacity and loss angle tangent; integrated conductivity components).

According to their purpose, the ECT methods can be divided into three groups: methods based on measuring parameters of the composition and structure of a material, those based on finding geometrical dimensions of a tested object and those based on finding moisture level.

If water is a free (hygroscopic) part of a material, its relative dielectric permittivity ε = 80 while for water absorbed as a monolayer, ε = 2.5.

To remove the influence of a contact or that of other impeding factors with respect to tested object geometry, a multi-parameter testing technique is used in which a signal is formed by way of variable topography of an electric field (due to a change in the field intensity distribution within a tested space).

The gauges with dielectric characteristics (i.e. dielectric permittivity and the loss angle tangent) operate on the basis of changing parameters of the remote resonance circuit which incorporates the ECC. The oscillation frequency and voltages in the circuit are automatically maintained at the same constant level. A change in the capacity of the circuit after a tested object is placed in the ECC electric field is compensated by a varicap and a tunnel diode.

Instruments to test non-metallic coatings (e.g. varnish, plastic, etc.) over a conducting base measure the distance between the attachable ECC and the conducting surface irrespective of the electric properties of the coating and base material. There are instruments in which ECC electrodes that are made as a parallel plate capacitor are permanently fixed. So, the change in thickness of a tested plate or a band in between the ECC electrodes bring a change in the distribution of the thickness of the components of the two-layer flat capacitor, and, therefore, a change in the ECC capacity.

The operation of electric potential instruments is based on direct passage of current through the tested area and measuring the potential difference of a certain portion or recording distortion of the electromagnetic field caused by current by-passing the defect.

The potential difference depends upon three factors, namely: the specific electric conductivity σ, geometric dimensions (e.g. thickness) and the presence of surface cracks. If AC is applied to the conductor, the potential difference will also depend on magnetic permeability μ.

There are four electrodes in instruments designed to measure the depth of cracks. Two of them (that are conductors) supply current to a tested area. The other two are measuring. They are used to measure potential difference at a certain distance (normally no more than 2 mm), which makes it possible to judge about the depth of a detected crack.

The electric potential instruments are used to measure the thickness of items' walls, study the anisotropy of electric and magnetic properties that occurs because of mechanical stresses applied to a tested object.

The NDT practices also use instruments that put to record the distortions of lines of force of the current density vector due to a defect. These instruments record the lateral component of the current density vector that is absent in a defect-free portion of an item.

This method makes a functional basis for flaw detectors designed for detecting fatigue cracks in complex-profile items, such as threaded joints, gear transmissions, transition surfaces (fillets).

Single ferro-elements are used to indicate dispersed fields against defects emerging on account of the lateral tangent component.

The NDT instruments designed to employ a thermoelectric technique are gaining application in rating items by mark of steel, steel and pig iron express-analysis directly during smelting and in ingots, determining thickness of electroplated coatings, measuring the depth of a hardened layer, a study of metal fatigue processes.

The source of information on the physical condition of a material in thermoelectric NDT method is the thermal EMF that appears in the circuit consisting of a pair of electrodes (hot and cold) and a tested metal.

To test dielectric coatings (enamel, glass, epoxy compounds) on uniformity and continuity, electric-spark instruments are employed. Their operation is based on spark-over defect spots in a dielectric coating with high voltage applied.

To test dielectric materials and compounds based on them, pulse high-frequency flaw detectors are used that create high-intensity electromagnetic fields (Kyrlian effect) that allow quantitative analysis of a high-frequency discharge occurring between the surface of the tested object and the electrode of the discharge converter.

The electrostatic technique is based on the use of electrostatic field in which an item is placed. To detect cracks on the surface of non-current-conducting materials (porcelain, glass, plastics) and metals coated with the same materials, the tested surface is powdered with fine chalk. Chalk particles applied thereon receive a positive charge and by virtue of the heterogeneity of the electrostatic field group close to crack edges.

Instruments designed to measure the intensity of electrostatic charges that occur in the process of electrization of fast moving dielectric materials (such as textile, paper and so on) have been finding utility in textile, paper-making, petrochemical and other industries.

The role of a measuring converter is played by a dynamic capacitor incorporating a fixed measuring electrode and a movable grounded electrode made in the shape of a blade wheel which screens periodically the measuring electrode against the electrostatic field. The electrostatic charge induced across the measuring electrode is then converted into an alternating voltage whose amplitude and phase carry the information about the intensity of that electrostatic field and the sign of the charge.

4. Eddy-Current NDT methods

The basis for eddy current NDT methods is the analysis of the interaction between an external electromagnetic field and the electromagnetic field of eddy currents induced by an excitation coil in a current-conducting test object. The density of eddy currents in the object depends upon its geometrical and electromagnetic parameters as well as on the relative positions of the eddy-current measuring transducer and the object. For an eddy-current measuring transducer (one or several) induction coils are used. Keeping record of the voltage or resistance across the coil terminals is way for obtaining information on the properties of the tested object and the position of the transducer with reference to it.
By working position with reference to the tested object, measuring eddy current transducers are divided into transfer, surface, forked and combined.

Testing may be conducted without contact of the eddy-current transducer and the tested object at distances large enough to allow free movement of the transducer with reference to the object (from a fraction of a millimeter to several millimeters). This gives reliable test results at the object's speeds up to 50 m/s.

Automated, high-speed and non-contact quality control techniques provide for the use of flaw detectors fitted with transfer eddy-current transducers that allow testing a wide size and type assortment of pipes, rods, wire with a section from 0.5 to 135 mm and small items as bearings' balls and rollers, needles, metalware and so forth. The operating efficiency of that control can amount to tens of meters per second or several thousand small items per hour.

Flaw detectors fitted with surface eddy-current transducers revolving around the object are used for testing rods and pipes made of ferro-magnetic and low-magnetic types of steel as well as of non-ferrous metals and alloys.

The eddy-current structural flaw detectors make it possible to evaluate the degree of chemical purity of electric conductors, sort out semi-finished items and items by mark (chemical composition), rigidity, hardness, strength and so forth. They can also be used to determine the degree of mechanical stress, reveal fatigue zones, monitor the quality of surface layers, the presence of α-phase and so on.

The eddy-current structural flaw detectors for testing ferromagnetic objects are generally divided into instruments designed for testing objects in low-frequency high-intensity fields and in high-frequency low-intensity fields as well as in two- and multi-frequency fields.

High-frequency structural flaw detectors are used to test surface reinforcement (cold-work, cold hardening), rigidity of ferromagnetic plates, surface high-frequency hardening and chemical-thermal treatment consisting in the saturation of the surface layer with carbon (carburization), nitrogen (nitration) and with both nitrogen and carbon (cyanidation).

The basis of eddy-current flaw detection in items of non-ferromagnetic electric conductors consists in measuring and evaluating changes in the specific electric conductivity with prior delineation of the margins for the dispersion of its values with due provision for a possible technical stepback.

The eddy-current testing techniques allow testing item dimensions, measuring the diameter of wire, rods and pipes, thickness of metal plates and that of pipe walls with a one-way only access to the tested object, the thickness of electric conducting (e.g. electroplated) and dielectric (e.g. varnished and painted) coats applied onto electric conducting bases, layer thickness of multi-layer structures incorporating electric conducting layers. The thicknesses measured may vary from microns to tens of millimeters. For most instruments the relative measurement error is 2-5 percent. The eddy-current testing technique is also used for measuring clearance, shifts and vibrations of machines and mechanisms.

When template specimens, albums, graduation diagrams, nomograms or changeable scales (for needle-type indicators) are employed, one and the same eddy-current thickness meter can be used to measure the thickness of electric conducting coatings over electric conducting bases in different combinations.

Eddy-current thickness meters can effectively be used for testing electric conducting layers no more than 5-10 mm thick.

To measure the thickness of plates, tapes, bands of non-ferro- and ferromagnetic metals and alloys within a thickness range from 0.005060 mm, surface eddy-current transducers are placed on both sides of the tested object and thus measure the clearance magnitude.

Universal eddy-current instruments and devices make it possible to resolve a wide spectrum of problems of flaw detection, thickness measurements and structural flaw detection. Instruments and devices of that kind are normally referred to as multi-parameter units that allow separate testing of several parameters of an object or one parameter with the suppression of several impeding factors.

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Biographical Sketch

Klyuev Vladimir V. was born on January 2, 1937, Moscow, Russia. He graduated from the Moscow State Technical University named after Bauman in 1960 and Received the Degree of Candidate of Technical Sciences in 1964 and the Degree of Doctor of Technical Sciences in 1973.

Professional Employment: 1960-1964, engineer of the Moscow State Technical University named after Bauman; 1964-1970, Senior Researcher, Head of Laboratory, Head of Department at the Institute of Introscopy; 1970 – present, General Director of the Moscow Scientific Industrial Association "Spectrum".

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President of the Scientific Council on Automated Systems of Diagnostics of the Russian Academy of Sciences, President of the Russian Society for Non-Destructive Testing and Technical Diagnostics, Member of Editorial Board of journal "Defectoscopiya", Editor-in-chief of Journal "Testing. Diagnostics."

Elected Corresponding Member of the USSR/Russian Academy of Sciences, Member of Academia Europaea, Member of the Board of Directors of the European Federation for Non-Destructive Testing.

Prize of the Council of Ministers of the USSR, State Prize of the Russian Federation in the field of science and technology.