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The application of Magnetic Particle Inspection (MPI), Eddy Current (ECT) and Alternating Current Field Measurement (ACFM) Non-Destructive Testing (NDT) techniques to the inspection of amusement devices

Following the letter issued by the Health and Safety Executive (HSE) and the Amusement Device Inspection Procedures Scheme (ADIPS) on the 25/9/19, in regards to Inspection Bodies' (IBs) application of BS EN ISO 9934-1 and the issue of carrying out MPI through more than 50 microns of paint, NAFLIC would like to make the following observations and comments.

Below we describe the three methods of NDT referenced within the above letter.

Magnetic Particle Inspection (MPI)

This method is employed for the detection of surface and near-surface flaws in ferromagnetic materials and is primarily used for surface breaking defect/crack detection. The specimen is magnetised either locally or overall and if the material is sound the magnetic flux is predominantly inside the material. If, however, there is a surface-breaking flaw, the magnetic field is distorted, causing local magnetic flux leakage around the flaw. This flux leakage is displayed by covering the surface with very fine iron particles applied either dry or suspended in a liquid. The particles accumulate at the regions of flux leakage, producing a build-up which can be seen visually even when the defect/crack opening is very narrow. Thus, a defect/crack is indicated as a line of iron powder particles on the surface.

The MPI method is applicable to all metals which can be strongly magnetised – ferritic steels and irons, but not generally austenitic steels.

The method of magnetisation must produce a magnetic field with lines of force at a large angle to the expected direction of the defects to be detected. As such it is usual to apply the magnetisation more than once in different directions, for example in two directions mutually at right-angles. However, methods of swinging the field direction during magnetisation are also available.

The magnetisation may be produced by any of the following methods:

- a) Applying a permanent or electro-magnet to the surface (magnetic flow).
- b) Passing a large current through the specimen, or locally by means of current prods (current flow).
- c) Putting the specimen inside a current-carrying coil, or forming a coil around the specimen;
- d) Making the specimen the secondary loop of a transformer – (induced current) – suitable for ring-shaped specimens.
- e) Placing a current-carrying coil or loop close to the specimen surface.
- f) Threading a current-carrying bar through a hollow specimen.

The electric current used may be DC or AC of any waveform, but the current required to produce adequate magnetisation depends on the waveform of the supply, the magnetisation method used and the material of the specimen. It is most important to ensure that the current used is correct for the specimen size and shape and also that the direction of the magnetic flux produced is suitable for the defects or flaw expected. By using a combination of two magnetic fields, a swinging or rotating magnetic flux can be produced, which will detect a defect or flaw in any orientation.

Usually the iron particles – dry powder or suspended in a liquid (magnetic ink) – are applied while the magnetising current is still flowing, but residual magnetisation is sometimes used, when the particles are applied after magnetisation. Some steels retain sufficient magnetisation for this method to be satisfactory and in this case smaller, more portable, magnetising equipment can be used.

Magnetic inks (particles suspended in a liquid) are used more widely than dry powders. They are applied by low-pressure spray, dipping or brushing; it is important to use plenty of ink and to allow time for the particles to flow over the surface and migrate to any defects. A very thin layer of white paint is often applied to give a higher contrast indication.

Fluorescent particles, which require UV-A illumination, are widely used and coloured particles are also available. The indications of cracks can be preserved by photography or by the use of peel-off transparent adhesive film. MPI methods can be applied to relatively rough and dirty surfaces, but the flaw sensitivity may be impaired. Magnetic methods for underwater applications have been developed. Only under very special conditions can sub-surface flaws be detected by MPI.

Alternating Current Field Measurement (ACFM)

Alternating Current Field Measurement (ACFM) is an electromagnetic technique used for the detection and sizing of surface breaking cracks in metallic components and welds. It combines the advantages of the Alternating Current Potential Drop (ACPD) technique and Eddy Current Testing (ECT) in terms of defect sizing without calibration and ability to work without electrical contact respectively.

The ACFM probe introduces an electric current locally into the part and measures the associated electromagnetic fields close to the surface. The presence of a defect disturbs the associated fields and the information is graphically presented to the system operator. The ends of a defect are easily identified to provide information on defect location and length.

Through wall extent of the flaw plays an important role in determining structural integrity and the same is calculated using mathematical computation, thus allowing an immediate evaluation of the implication of the indication. ACFM inspection can be performed through paint and coatings, hence it is considered to be a faster and more economic technique than others, e.g. Magnetic Particle Inspection (MPI).

The ACFM technique is a non-contact electromagnetic technique capable of both detecting and sizing (length and depth) defects in metals. The basis of the technique is that an alternating current flow in a thin skin near the surface of any conductor. By introducing a remote uniform current into an area of the component under test, when there are no defects present, the electrical current will be undisturbed. If a defect/crack is present the current flows around the ends and down the faces of the defect/crack.

The current flowing in the surface has an associated magnetic field above the surface and this magnetic field will also be disturbed if the current is disturbed by a defect. The ACFM method involves the measurement of this magnetic field. The magnitude of any disturbances in the field can then be related back to the size of defect causing them by the use of mathematical models. In its simplest form, ACFM involves the use of a single hand-held probe which contains the field induction and the field measurement sensors. This is then connected to an ACFM instrument which is, in turn, controlled by a PC which provides data displays and recordings.

As the technique requires no electrical contact with the surface, it can be used to inspect through paint and coatings. The technique is widely used for weld and thread inspection and for sub-sea inspection of offshore platforms. It can also be used on both magnetic and non-magnetic components and at elevated temperatures in excess of 600 °C.

Array probes containing large numbers of sensors can be deployed either manually or robotically, typically in situations where larger areas need to be inspected or where 'pick and place' deployment is preferable to probe scanning. ACFM array systems have been incorporated into automated inspection systems to give simple PASS/FAIL reporting, thus avoiding the need for skilled operators.

The ACFM method should only be applied to surface-breaking defects when used on carbon steels but is suitable for sub-surface flaws in some non-magnetic materials.

Eddy Current Testing (ECT)

In Eddy Current Testing (ECT), a coil carrying an AC current is placed close to the specimen surface, or around the specimen. The current in the coil generates circulating eddy currents in the specimen close to the surface and these in turn affect the current in the coil by mutual induction. Flaws and material variations in the specimen affect the strength of the eddy currents.

The presence of flaws, etc., is therefore measured by electrical changes in the exciting coil. Both voltage and phase changes can be measured, but some simpler instruments measure only the voltage changes.

The strength of the eddy currents produced depends on the:

- a) Electrical conductivity of the specimen.
- b) Magnetic permeability (for a ferromagnetic specimen).
- c) Stand-off distance between the specimen and coil.
- d) AC frequency used in the exciting coil.
- e) Dimensions of the coil and specimen.

It also depends on the presence of flaws and much of the success of Eddy Current Testing depends on separating the effects of these variables. Most eddy current instruments require calibration on a set of test specimens and the flaw sensitivity can be very high.

Equipment varies from simple portable meter read-out instruments to more complex oscilloscope read-out instruments displaying both phase and voltage; recently the outputs have been digitised to produce fully automated computer-programmed equipment with monitored outputs for high-speed testing.

Applications vary from crack detection to the rapid sorting of small components for either flaws, size variations or material variation. Many applications are to bar, tube and wire testing. Metal sorting is also a common application of Eddy Current Testing.

In specific regards to the above techniques and their use in the amusement industry, NAFLIC would like to make the following comments and observations.

Magnetic Particle Inspection (MPI)

MPI is a well-established, tried and tested technique used for many years in the leisure industry for identifying surface breaking defects. If used correctly, it will identify all surface breaking defects in the welds tested. It can be used on welds of any quality, orientation and size. To identify defects to BS EN 5817 (the quality standard referenced for welds in BS EN 13814) it should be carried out on welds with the paint removed. However, depending on the acceptance criteria detailed in the relevant NDT schedule, i.e. the identification of in-service defects such as fatigue cracks, then it may be that the inspection can be completed through a surface coating. However, it should always be carried out in accordance with BS EN ISO 9934-1.

In regard to testing through a galvanised or metal sprayed coating, whilst MPI on these types of coatings is not ideal, depending on the thickness of the coating, it is feasible. However, it should be noted and considered that it can restrict the inspection and the findings. It is unlikely to be able to identify defects to BS EN 5817 with this type of coating, but it should be possible to identify in-service defects such as fatigue cracks. It must be remembered that the item will have been galvanised for a reason and removal of the coating would potentially be more harmful to the item than a reduced-sensitivity MPI test.

Alternating Current Field Measurement (ACFM)

The Alternating Current Field Measurement (ACFM) non-destructive testing technique was developed in the 80s to detect and estimate the penetration depth of fatigue cracks in underwater welded tubular intersections on off-shore oil platforms. Prior to the advent of ACFM, these defects were generally detected and their length measured with magnetic particle inspection.

The severity of fatigue cracks (directly related to the remaining life of structures or components) is commensurate with how deep they are. At the time, conventional eddy current testing systems were not well suited for use underwater or for welds in ferritic steel. They were unable to accurately measure defects deeper than 5mm (0.2 in). Alternating Current Potential Drop (ACPD) was the technique used to measure depth, but it was slow and very difficult to use underwater because of the need to maintain very good electrical contact between the voltage probe and the steel surface.

Addressing this problem required a non-contact equivalent to ACPD. A group of United Kingdom oil companies approached the University College London to develop the new technique – ACFM.

ACFM limitations:

- Not recommended for short sections or small items.
- Locations of weld repairs and localised grinding can cause spurious indications.
- Multiple defects reduce the ability to estimate defect depth.
- Equipment more bulky than for MT and indications may be more difficult to interpret.

ACFM is less sensitive than MPI and capable of detecting defects as small as 0.5mm deep and 5-10mm length under favourable conditions.

The probability of detection and false detection rate is generally good, but it is application dependent.

The ACFM method does not have available performance demonstration initiative results. Based upon hundreds of performance demonstration initiatives for MPI, ECT and ACFM, the probability of detection for ACFM is given below.

In refereed PDI's based on fit-for-purpose in-service, the Oil and Gas and Drilling Contractors use 6mm length and .5mm depth and non-visual for width. Using MPI based on API RP 2X, ET BSI 1711 and ACFM ASTM-A36 MT the probability of detection for MPI and ET were 90%, while ACFM was 76%.

It is recommended that if this technique is used, it is thoroughly researched and tested prior to use on in-service amusement rides. Test pieces containing the type and size of defects that require to be identified can be used to verify the sensitivity and accuracy of the equipment. It should be noted that two NAFLIC members have trialled the ACFM technique and in both instances found that defects were not identified correctly.

Eddy Current Testing (ECT)

ECT is also a well-established NDT technique. However, it has not generally been widely used within the amusement inspection industry to date. It can be used through paint and other surface coatings. The advantages and disadvantages are detailed below. ECT is less sensitive than MPI and capable of detecting defects as small as 0.5mm deep and 5mm length under favourable conditions.

Advantages of ECT:

- i) Can detect through several layers – the ability to detect defects in multi-layer structures (up to about 14 layers), without interference from the planar interfaces.
- ii) Can detect through surface coatings – able to detect defects through non-conductive surface coatings in excess of 5mm thickness.
- iii) Accurate conductivity measurements – dedicated conductivity measurement instruments operate using eddy currents.
- iv) Can be automated – relatively uniform parts can be inspected quickly and reliably using automated or semi-automated equipment, e.g. wheels, boiler tubes and aero-engine disks.
- v) Little pre-cleaning required – only major soils and loose or uneven surface coatings need to be removed, reducing preparation time.
- vi) Portability – portable test equipment is very small and light, some of the latest equipment being as small as a video cassette box and weighing less than 2kg.

In regard to the above advantages, it is noted that the weld quality on many amusement rides, especially those in the travelling industry, is such that it would significantly limit the sensitivity of this inspection technique and as such it would not be recommended in those instances.

Disadvantages of ECT:

- i) Very susceptible to magnetic permeability changes – small changes in permeability have a pronounced effect on the eddy currents, especially in ferromagnetic materials. This makes the testing of welds and other ferromagnetic materials difficult but, with modern digital flaw detectors and probe design, not impossible.
- ii) Only effective on conductive materials – the material must be able to support a flow of electrical current. This makes the testing of fibre reinforced plastics unfeasible.
- iii) Will not detect defects parallel to surface – the flow of eddy currents is always parallel to the surface. If a planar defect does not cross or interfere with the current, then the defect will not be detected.
- iv) Not suitable for large areas and/or complex geometries – large area scanning can be accomplished, but needs the aid of some type of area scanning device, usually supported by a computer, both of which are not inexpensive. The more complex the geometry becomes, the more difficult it is to differentiate defect signals from geometry effect signals.
- v) Signal interpretation required – due to the many factors which affect eddy currents, careful interpretation of signals is needed to distinguish between relevant and non-relevant indications.

With regards to point v) of the disadvantages, test pieces containing the type and size of defects that require identification can be used to calibrate the equipment.

Summary

If ECT or ACFM techniques are used for the inspection of surface breaking defects on an amusement device then it should be clearly established that the technique used will effectively distinguish between relevant and non-relevant indications and is also suitable for the fabrication quality and the acceptance criteria specified, in relation to the components or welds being tested.

It is also advised that if defects are identified using either of these techniques, MPI should then be carried out to confirm the size (length) and type of defect. ACFM may be useful in establishing the depth of the defect. MPI does not have the same limitations as either ACFM or ECT and is able to identify surface breaking defects in most instances and where the weld quality may not be of the highest standard. It is generally a more sensitive technique, especially when fluorescent MPI is used.

References:

- <https://www.bindt.org/>
- <https://www.twi-global.com/>
- <https://en.wikipedia.org/>