Detection of surface breaking discontinuities on steel structures above non-conductive coating

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ABSTRACT

Many applications of non-destructive testing in the industry and especially in metallic structures refer to surface discontinuities of the metal. Conventional methods for detecting such discontinuities with Magnetic (MT) and / or Penetrating Fluids (PT) both require paint removal and thorough cleaning of the surface. On the other hand, both methods are based on visual detection of discontinuities and, hence, to the human factor, lighting conditions and surface quality.

Electromagnetic methods such as Eddy Currents and ACFMT allow rapid control of surface discontinuities without paint removal and minimal surface preparation, and without the use of chemicals, offering better POD probability and reducing maintenance time and costs. Main applications for these techniques include in-service quality control of welds above paint in tanks, vessels, reactors, platforms, cranes, etc. but also in the food industry where the use of chemicals in containers is not allowed.

This paper presents briefly these techniques as well as typical applications. Reference is also made to other methods, such as XRF, for determining the composition of the metallic

material, and the application of advanced Phased Array ultrasonic techniques to detect and size internal discontinuities.

1. INTRODUCTION

Many applications of non-destructive testing (NDT) in the industry and especially in metallic structures refer to surface discontinuities of the metal, either due to the codes involved, where they exist, or because the expected failures are expected on the surface (e.g. surface breaking cracks) due to the operating conditions and the nature of the structure. Conventional methods for detecting such discontinuities with Magnetic (MT) and / or Penetrating Fluids (PT) both require paint or coating removal and thorough cleaning of the surface, as well as re-coating of the surface upon finishing of the inspection. On the other hand, both methods are based on visual detection of discontinuities and, hence, to the human factor, lighting conditions and surface quality.

Electromagnetic methods such as Eddy Currents and ACFM allow rapid control of surface discontinuities without paint removal or other surface preparation, and without the use of chemicals, offering better POD probability and reducing maintenance time and costs. Main applications for these techniques include in-service quality control of welds above paint in tanks, vessels, reactors, platforms, cranes, etc. but also in the food industry where the use of chemicals in containers is not allowed.

This paper presents briefly these techniques as well as typical applications. Reference is also made to other methods, such as XRF, for determining the composition of the metallic material, and the application of advanced Phased Array ultrasonic techniques to detect and size internal discontinuities.

2. CONVENTIONAL NDT TECHNIQUES

2.1. Penetrant Testing

Dye or Liquid penetrant testing (PT) is one of the most popular NDT methods used to locate surface breaking discontinuities in all non-porous materials. Generally, liquid penetrant is applied uniformly over the surface of the test specimen and is allowed for a sufficient time to penetrate into the open surface discontinuities. After a sufficient dwell time, the redundant penetrant is removed with special cleaners or water from the surface of specimen and the latter is dried. Then a specialist developer is applied, which allows the liquid penetrant to surface out of the trace making the discontinuity visible. The object throughout the development process is examined visually to assess the presence or absence of indications (Fig.1).

The technique requires removal of paint or coating and meticulous cleaning of the surface to remove dirt, paint, loose scale, oil, grease and any contaminant that would prevent the penetrant from entering in the discontinuity. In addition, the surface should be as smooth as possible, otherwise false indications can occur from penetrant trapped in the rough surface of the specimen and not removed during excessive penetrant cleaning. Furthermore, in case of fluorescent penetrant testing, darkness conditions should be ensured and the inspection should be carried out using a special UV light source.

Fig. 1. Two linear indications detected by dye penetrant testing.

2.2. Magnetic Testing

Magnetic Testing (MT) or Magnetic Particles Inspection (MPI) is the second most popular NDT method used to locate surface or slightly subsurface discontinuities in ferromagnetic materials up to a depth of 2 mm. The technique refers to the creation of a magnetic field on the surface of the component under inspection using alternating current electromagnet and the simultaneous injection of liquid solvent with metal particles (size 8 to 10 micro), which, under the influence of the magnetic field, are concentrated in the discontinuity forming an indication on the edges of the discontinuity (Fig 2). The test is performed using a white sub layer which makes it possible to spot the concentration of black magnetized particles on the edges of the crack, or using a UV light source in case of fluorescent magnetized particles.

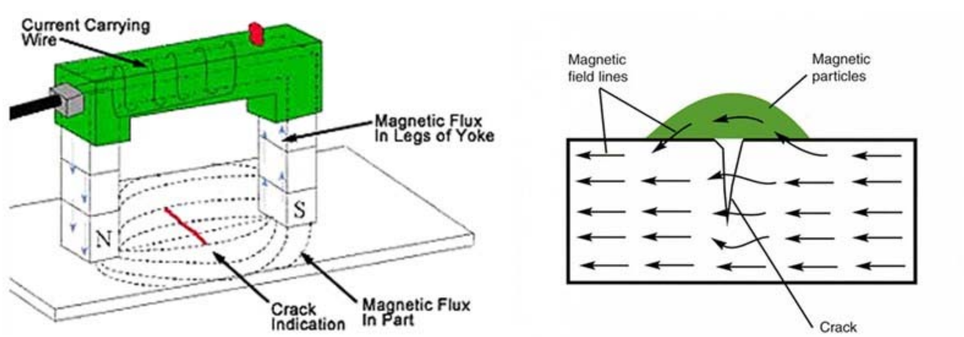


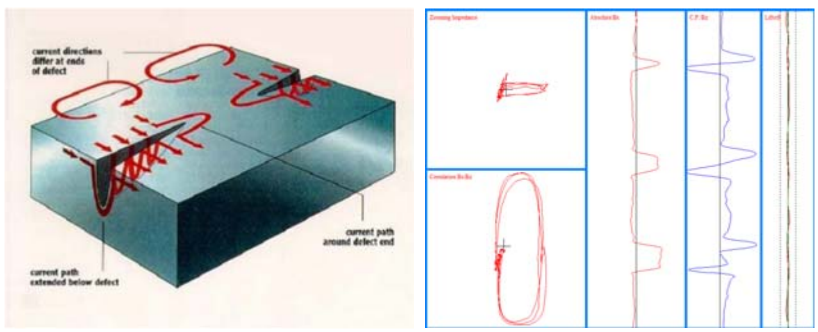
Fig. 2. Magnetic Testing working principle

Discontinuities oriented parallel to the magnetic field lines cannot be detected. For this reason the inspection is carried out in two directions almost perpendicular to each other. Furthermore, for a successful Magnetic Particle Inspection, removal of coating (if any) is required, otherwise the sensitivity of the method is reduced. In case of Fluorescence Magnetic Particle Testing, darkness conditions should be ensured and the inspection should be carried out using a special UV light source. Finally, adequate space is required for applying the magnetic poles from both sides of the inspected part (e.g. weld). Upon finishing of inspection demagnetization of the inspected parts should follow, as well as cleaning of the surface to remove the white sub-layer sprayed over the surface of the part.

3. ELECTROMAGNETIC NDT TECHNIQUES

3.1. ACFMT

Alternating Current Field Measurement Technique (ACFMT) is a non-contact electromagnetic inspection technique that relies on the principle that an alternating current flowing in a component will be disturbed by the presence of a discontinuity (crack) (Fig.3a). An ACFMT probe induces an electric current locally into the structure and measures the associated electromagnetic fields close to the surface. The presence of a discontinuity (crack) disturbs the associated fields and the recorded information is then converted to a graphical display on a computer for the system operator to analyze. The ends of the defect are easily identified to provide information on defect location and length. Furthermore, using mathematical modeling, the system also provides an estimation of the through wall depth of the defect, thus allowing an immediate evaluation of the significance of individual indications. This is a major advantage in comparison to other techniques utilized for the detection of surface breaking indications that are only capable of detection or at best, length information.



(a) *(b)*

Fig. 3. (a) ACFMT working principle, ACFMT signals acquired by three surface breaking discontinuities.

ACFMT systems have been used for a range of applications where rugged inspection systems are needed. The speed of scanning provides a rapid cost-effective means of inspecting welded connections with reduced cleaning requirements compared to conventional techniques. The probes have been developed to minimize signals from features that are not cracks, i.e. Corrosion, undercut; HAZ and material property changes, thus overcoming the problems often associated with other electromagnetic systems false calls. In addition, ACFMT systems provide the ability of storing the complete inspection data or selected parts of it (e.g. only the defects data) in a computer for further analyses and reporting purposes (Fig. 3b).

The ACFMT technique was initially developed to examine offshore structures below sea level and through thick paint to minimize costs associated with weld inspection (Fig. 4a). Other typical applications include inspection of coated or uncoated welds of metallic constructions such us pressure vessels (Fig. 4b), tanks, cranes, platforms, metallic bridges and many other applications where removal of coating is difficult and costly, such as in cases where thick non-conductive coating is present (paint, glass fibre, epoxy, bitumen, etc.).

Furthermore, as no application of any kind of liquid or other material, couplant, contrast paint, etc. is required, the technique is suitable for use in confined spaces and sensitive environments (food industry, pharmaceutical industry etc.).

Currently the technique has been acknowledged and supported by international standards [1, 2] and has been approved for weld examination by distinguished authorities around the world, including Lloyds; Bureau Veritas; ABS; DNV and OCB Germanischer Lloyd.

(a) (b)

Fig. 4. (a) Underwater weld inspection with ACFMT, (b) Weld inspection above paint with ACMFT

Comparison of ACFM to Magnetic Particle and Liquid Penetrant

	ACFM	Magnetic Particle Testing	Liquid Penetrant Testing
Depth information	Yes	No	No
Storage of data	Yes	No	No
Works through paint / coatings	Yes	Yes*	No
Detects scratches & undercuts	Yes	Yes	Yes
Produces waste chemicals	No	Yes	Yes

* There are some magnetic particle techniques that can penetrate paint and coatings, such as the AC yoke or coil.

Fig. 5. Comparison of ACFMT against MT and PT.

3.2 Eddy Current

Eddy current testing (ECT) is an excellent non-contact electromagnetic technique for detection of surface breaking and near surface planar imperfections when the probable defect location and orientation is known in conductive materials. The technique relies on the principle that a coil carrying an alternating current creates an alternating magnetic field which induces eddy currents in any conductive material which oppose the primary magnetic field. Variations in the electrical conductivity and magnetic permeability of the specimen under inspection, as well as the presence of surface discontinuities (e.g. cracks), disturb the flow of eddy currents on the surface of the specimen and cause a corresponding change in phase and amplitude of the primary magnetic field sensed by a coil and displayed on the screen of an electronic system (Fig. 6). This way the presence of material variations or the presence of discontinuities on the surface of the specimen are detected and recorded.

Eddy currents depth penetration is limited by a physics law called the “skin effect”, which imposes that eddy current distribution decreases exponentially from the surface of the specimen to 1/e (37%) of the surface current within a skin depth. That effect makes eddy currents very sensitive in typical surface breaking discontinuities, but also insensitive to subsurface defects. Typical skin depth at a frequency of 100 kHz for steel is below 0.1 mm.

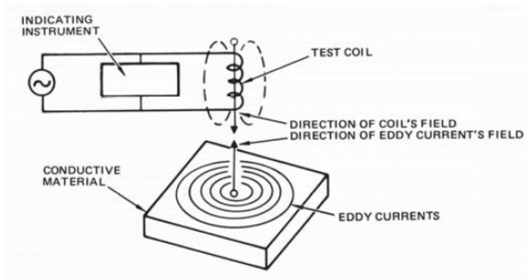


Fig. 6. Schematic diagram showing a standard eddy current test coil and the eddy current field induced in the conductive material.

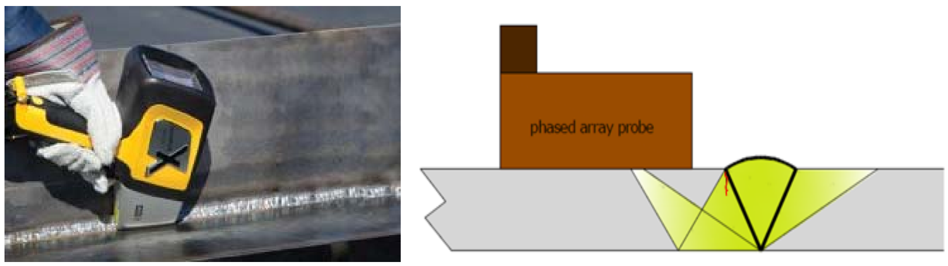
ECT is used extensively in the aerospace industry for the inspection of the aircraft frames and their components for corrosion and cracking, but is also extensively used in the petrochemical industry as the technique is very sensitive and can detect tight cracks. Surface inspection can be performed both on ferromagnetic and non-ferromagnetic materials and can also be applied to coated and non-coated objects during fabrication and for in-service inspection. Such typical applications consist the inspection of welds for detection of surface breaking cracks mainly in ferritic materials (Fig. 7), where due to the operating conditions and the nature of the structure surface, cracking may be expected either on the weld metal, the heat affected zones or the parent material of the weld. The same technique can also be applied to other metallic construction materials (e.g. stainless steels), if required by the design specification.

Fig. 7. Portable ECT system and typical eddy current weld probe.

Depending on the sensitivity requirements, the eddy current method is able to indicate surface cracks through non-metallic coatings up to 2 mm thickness. However, thicker coatings may be considered if the relevant sensitivity can be demonstrated. Finally, in contrast to PT/MT there is no use of contrast paint or any liquid or any material that would contaminate the inspected material. The technique provides an approximate depth of the detected discontinuity based on phase and/or amplitude information. Similar to ACFMT the ECT weld inspection is being supported by international ISO standard [3] and approved for weld examination by distinguished authorities around the world.

4. COMPLIMENTARY NDT TECHNIQUES

Both ACFMT and ECT weld inspection techniques require knowledge of the metallic material under inspection as, in most cases, inspection code or standard require a calibration block with artificial notches from same material and heat treatment as the tested material in order to set properly or verify the sensitivity of the instrument [1-3]. Usually that kind of information is available from the manufacturer or plant operator. However, there are cases that such information is not available or provided information is incorrect. In such cases handheld XRF analyzers can be used to provide fast, non-destructive elemental analysis of the composition of the tested material and accurately identify alloy grades and pure metals within seconds (Fig. 8a).



(a) (b)

Fig. 8. Inspection of weldment with (a) XRF, (b) Phased Array

Finally, when surface breaking cracks are detected and accurate knowledge of their depth is required then the application of an advanced Phased Array ultrasonic technique can be used to detect and size the depth of the detected discontinuities (Fig. 8b). The technique gives many benefits in the examination of the welds improving the probability of surface and internal discontinuities detection and sizing. The technique is capable of testing the whole weld rapidly through linear scans and / or sectorial scans providing additional information about the internal condition of weldments.

5. CONCLUSIONS

In this paper electromagnetic non-destructive methods such as Eddy Currents and ACFMT, which allow rapid control of surface discontinuities without coating removal, and minimal surface preparation, have been discussed. Their advantages over the conventional NDT techniques such as penetrant liquids and magnetic testing have been presented and typical applications have also been discussed. Finally, a reference to complimentary NDT techniques such as XRF used to evaluate the exact material under inspection and Phased Array Ultrasonic used for surface discontinuities sizing and internal defects evaluation was performed.

6. REFERENCES

[1] ASME SECTION V, Article 15, “Alternating Current Field Measurement Technique (ACFMT)”.
[2] ASTM E2261-07, “Standard Practice for Examination of Welds Using the Alternating

Current Field Measurement Technique”.
[3] ISO 17643, “Non-destructive testing of welds - Eddy current testing of welds by complex-plane analysis”.

Εντοπισμός επιφανειακών ασυνεχειών σε μεταλλικές κατασκευές πάνω από μη αγώγιμη επικάλυψη

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ΠΕΡΙΛΗΨΗ

Πολλές εφαρμογές μη-καταστροφικών επιθεωρήσεων στη βιομηχανία και γενικότερα σε μεταλλικές κατασκευές αναφέρονται σε επιφανειακές ασυνέχειες, είτε διότι το απαιτούν οι σχετικοί κώδικες, όπου υπάρχουν, είτε διότι οι αναμενόμενες αστοχίες λόγω των συνθηκών λειτουργίας και της φύσης της κατασκευής αναμένονται στην επιφάνεια (π.χ. επιφανειακές ρηγματώσεις). Οι συμβατικές μέθοδοι ανίχνευσης με μαγνητικά (MT) ή/και διεισδυτικά υγρά (PT) αφενός απαιτούν αφαίρεση χρώματος και επαναβαφή, αφετέρου βασίζονται στην οπτική ανίχνευση των ασυνεχειών και, άρα, στον ανθρώπινο παράγοντα, συνθήκες φωτισμού, ποιότητα επιφανείας κλπ.

Ηλεκτρομαγνητικές μέθοδοι όπως δινορρεύματα (Eddy Currents) και ACFM επιτρέπουν ταχύτατο έλεγχο χωρίς απαίτηση για αφαίρεση χρώματος ή άλλης προετοιμασίας της επιφάνειας και χωρίς χρήση χημικών, προσφέροντας καλύτερη πιθανότητα ανίχνευσης με μείωση χρόνου και κόστους συντήρησης. Κύρια εφαρμογή τους είναι ο έλεγχος συγκολλήσεων πάνω από βαφή και όπου δεν επιτρέπεται η χρήση χημικών ουσιών.