DC or AC Magnetising Waveforms in Magnetic Particle Inspection

A Paper By

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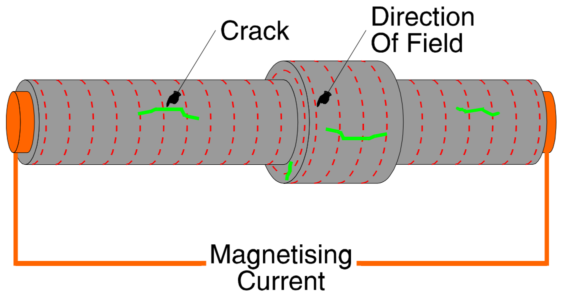
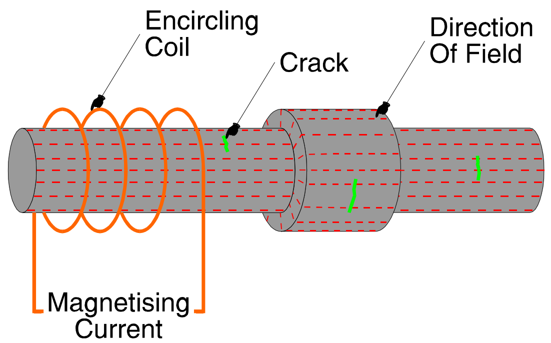
1 Introduction

We maintain that the purpose of NDT is not necessarily to identify defective pieces, but to be sure, with the highest degree of confidence, that the supposed flawless piece is indeed without deleterious defect. Thus NDT is a positive acceptance procedure rather than a rejection procedure. The detection of a defect is not necessarily a verification of the efficiency of a particular technique.

Magnetic Particle Inspection is a reasonably forgiving technique of crack detection, in that the latitude permissible in test parameters is quite liberal without great affect on the sensitivity.



Schematic arrangement for detecting longitudinal defects using current flow through the subject. The source of the current can be a portable / mobile power pack or, in the case of a bench unit, from the built-in power pack.



Schematic arrangement of an encircling coil for the detection of circumferential and transverse defects. The coil may be cable wrapped round loosely or wound on a former, as in a bench unit.

Figure 1 - The Principle of Magnetic Particle Inspection

The principles of the method are illustrated in Figure 1. For the detection of generally longitudinal defects current flow is normally used and for circumferential or transverse defects an encircling coil is used. Note that the direction of the defects detected is the same as the direction of the current. There are many variations on these techniques.

However, notwithstanding the above, M.P.I. is a fail to danger method in that, if after submitting a component to an M.P.I. test there are no indications of discontinuities one of two conclusions may be drawn a) there are no defects in the piece or b) there are defects but the correct technique has not been carried out. On the assumption that the majority of work is defect free, it is essential that techniques are very carefully drafted.

The range of variables in M.P.I. is limited compared to other NDT techniques and they are:

- Direction of magnetic flux.
- Method of inducing flux into the piece under test.
- Magnitude of the flux and thus the amplitude of the imposed field.
- Duration of application of the imposed field.
- Defect indicating materials, and mode of application.
- Waveform of current which energises the magnetising mode.

In the paper we will discuss current waveform in more detail.

The two basic waveforms used in M.P.I. are A.C. in which the current is bi-directional and varies in amplitude with time and D.C. which is uni-directional, and remains at near constant amplitude. A form of D.C. is that in which the system of rectification of the input A.C. causes variations of amplitude with time. The current, though remains unidirectional.

2 A.C. Waveform Magnetising

A.C. magnetising possesses the phenomenon of the skin effect, in which the magnetic flux stays preferentially close to the surface following the contours.

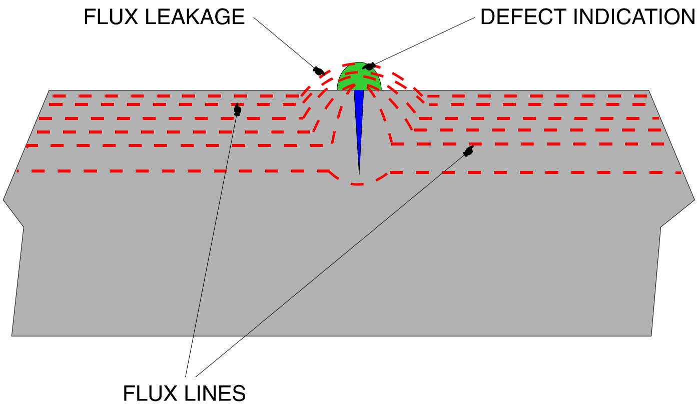


Figure 2 - A.C. Flux Showing Skin Effect

Figure 2, shows the use of A.C. flux on a surface breaking defect. Because the flux is concentrated near the surface there is a significant amount of flux leakage around the crack to form the necessary attractive poles to which the indicated particles will migrate. Thus bold indications are obtained.

The depth *d* if the penetration can be calculated as follows: $d = 500\,[f.c.u]^{-1/2}$

When f = frequency, c = conductivity and u = relative permeability. In most common steels at 50/60Hz the penetration of A.C. induced fields is less than 2mm (0.080”).

The skin effect is absent in D.C. magnetising. With this waveform, the entire cross section of the piece being magnetised is filled with the magnetic flux. D.C. flux tends to cut corners at section changes because of this characteristic lack of skin effect. This accounts for the less defined indications of surface breaking cracks compared to A.C.

Measurements of field density around a square section being magnetised by current flow shows that there is a considerable reduction in the circumferential field at the corners compared to the centre of the face; a difference of 40%.

With A.C. magnetising, provided the correct technique has been employed, it is possible to state with high degree of confidence that indications will have been formed from defects which break the surface. No indications - No defects.

3 D.C. Waveform Magnetising

The limitation of A.C. flux is its inability to detect subsurface defects. This is a completely recognised aspect and it is never advocated to be anything other than for the detection of surface breaking or very near surface defects.

Whether or not indications are seen is an entirely different matter, and the subject of much work with good papers published by Hagemaier and others. It is without doubt easier to see defect indications having used A.C. magnetising than the diffuse defect indications when using D.C.

It is worth noting that in current flow magnetising, the centre of the piece is flux free. With D.C. the density increases linearly toward the surface and with A.C. the decrease is exponential.

The lack of skin effect is often quoted as an argument that, since D.C. penetrates to a greater depth, it must be suitable for the detection of sub-surface defects. The above though shows that the flux density reduces with increasing distance from the surface. The often quoted advantage of the use of D.C. magnetising is its ability to detect sub-surface defects. Whilst there is no doubt that the deeper penetration of the field might reveal conditions below the surface, in the light of the confidence philosophy and criteria above this requires consideration - in depth you might say.

It is necessary to make a more quantitative evaluation of the depth effect with D.C. That is, at what depth can discontinuities of different size, shape and condition be indicated? The flux leakage on the surface depends not only on the depth below the surface to the discontinuity, but also on the size and shape of the flaw, its direction, the thickness of the material section and the surface texture.

The direction of the crack is very relevant. A crack which is perpendicular to, but beneath the surface will obviously provide greater flux leakage than a crack of the same size and shape which is parallel to the surface.

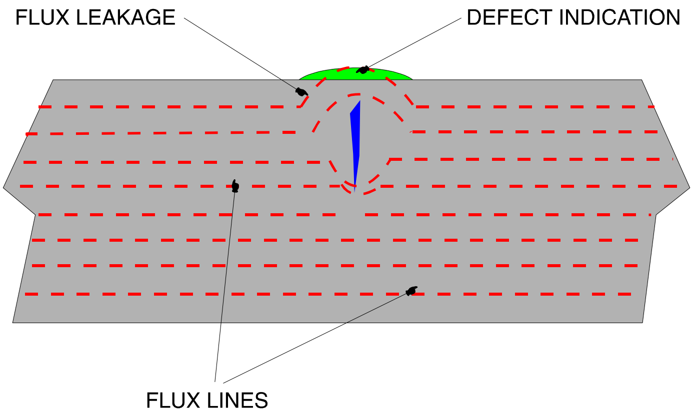


Figure 3 - Full Wave D.C. Flux Around Near Surface Defect

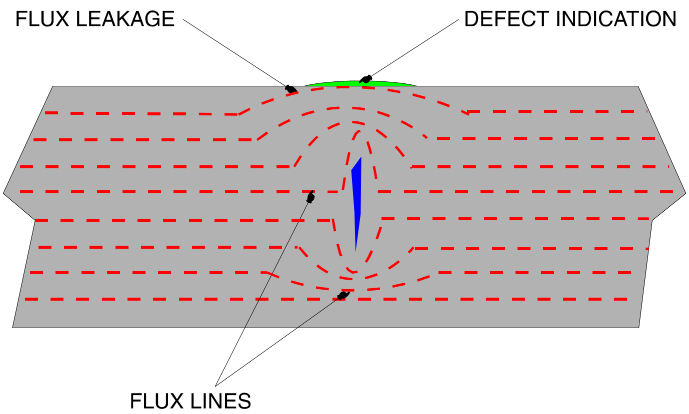


Figure 4 - Full Wave D.C. Flux Around Internal Flaw

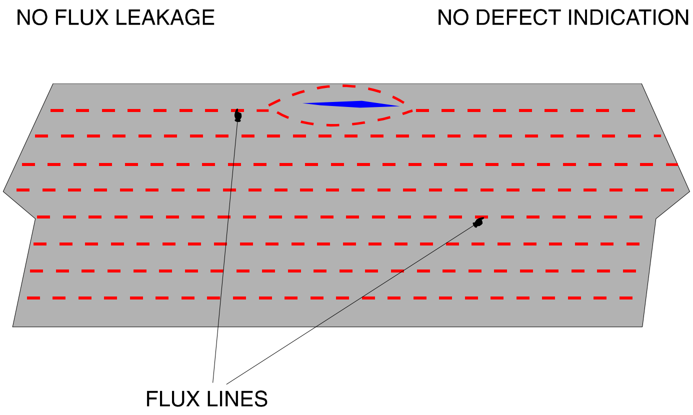


Figure 5 - Full Wave D.C. Flux Around Near Surface Flaw With Major Dimension Parallel to the Surface

Figure 3 shows what might be expected with the application of D.C. flux to a piece bearing a slightly subsurface defect. There will be a degree of flux leakage at the surface but since the flux lines are not so concentrated as in A.C. the indication for a similar size defect as in Figure 2 would not be nearly so pronounced. It follows in Figure 4 that as the defect increases in distance from the surface there will be even less flux leakage and what there is will be over a wider area leading to diffuse particle distribution on the surface and therefore an indistinct indication. Figure 5 shows the same size of defect but which is parallel to the surface. This type of defect will not cause the flux lines to break the surface and thus no indication would be formed.

Further, a crack 2mm beneath the surface will provide more flux leakage than one of the same size 4mm below the surface. In addition to this a two dimensional defect the same distance below the surface as a three dimensional defect will provide different indication than will the latter.

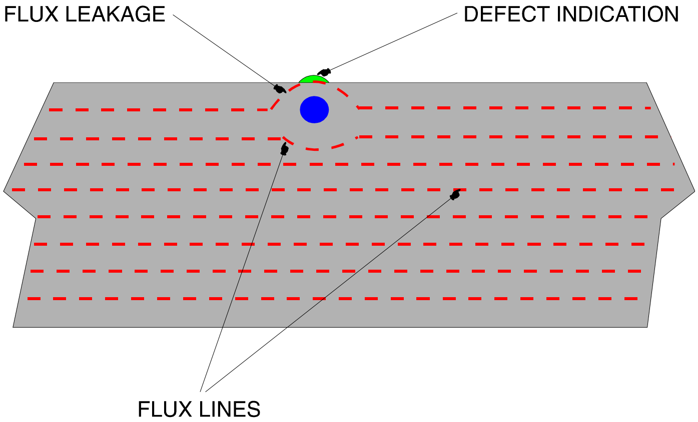


Figure 6 - Full Wave D.C. Flux Around A Near Surface Spherical Defect

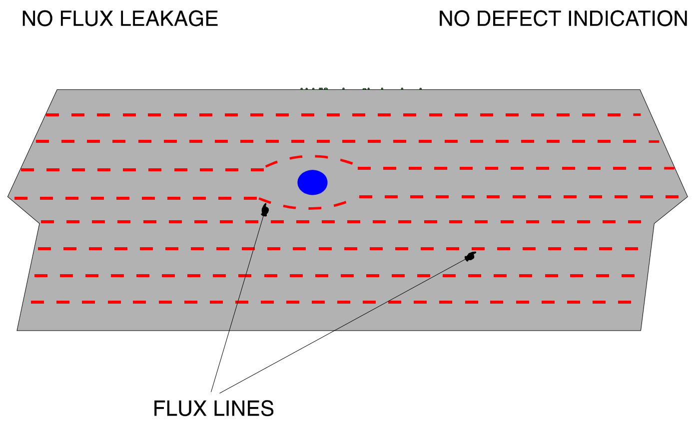


Figure 7 - Full Wave D.C. Flux With A Internal Spherical Flaw

Figures 6 and 7 show the effect of increasing depth from the surface of a circular cross section defect. For the same size of flaw at two different depths there is the difference between an indication, albeit diffuse on the near surface defect and no indication whatsoever in one slightly deeper.

The possible permutation of defect type, size, and depth below the surface and their effect on the flux leakage does not permit the formulation of any rule which would allow accurate diagnosis of a subcutaneous condition.

4 Conclusions

Therefore whilst it may be possible to establish the presence of defects using D.C. it is not possible to conclude that a part is free from sub-surface defects because of the absence of indications.

Test pieces, such as the Ketos Ring, which have drilled holes of various depths from a machined surface may be useful for evaluating any change of performance of crack detection facility with time, they should not be use to determine the depth capability of a system. The smooth drilled holes parallel to a smooth surface, at optimum angle to the flux and the locations of which are known, bears little resemblance to, say, internal shrinkage cracks in steel castings with an as cast surface.

It should always be borne in mind that defects arising from fatigue, in service invariably propagate from a surface, which is where the stress is the greatest, and therefore there is no advantage to the use of D.C. in this application of in service testing.

D.C. has not the vibratory effect of A.C. in which the indicating particles are assisted in their migration to the crack edges.

A further disadvantage to D.C. magnetism is the difficulties encountered with demagnetising. As the D.C. field penetrates deeply the use of a reducing 50/60Hz field will not be effective because of its skin effect. It is necessary to resort to low frequency reversing polarity, reducing pulses of D.C. which is an expensive and time consuming operation.

Thus the only advantage of D.C. is that it ***may*** be possible to detect sub-surface defects but there is no sure way to establish a technique guaranteed to form indications of any such discontinuity. If the objective is to detect sub-surface faults, then I suggest, there are many better ways than MPI. A.C. does not pretend to detect sub-surface defects but, with the correct technique, is guaranteed to reveal surface breaking defects. Better the devil you know, than the devil you don't.

There are however many other advantages with A.C. including the relatively lower capital costs. Apart from the improved management of the M.P.I. techniques and results, the main ones are the transformer effect and the swinging field multi-directional magnetising.

4.1 Use of AC Magnetising of Circular Components

For circular components with a central hole, normally circumferential defects can only be detected by current flow around the ring. At least two shots are necessary, the second after rotating the part through 90^o. This is required because the direction of the flux at the contact points is not assured. Not only is there a danger of arcing with this technique but care has to be taken that with thin wall components to avoid distortion when clamping.

A.C. offers a non-contact method. A split laminated iron yoke with an energising winding is set up so that one limb of the yoke passes through the central hole. On being energised, the yoke acts as a transformer primary circuit, the secondary circuit being the component itself. Thus a high current circulates round the single shorted turn. This current generates a toroidal magnetic field to display circumferential defects.

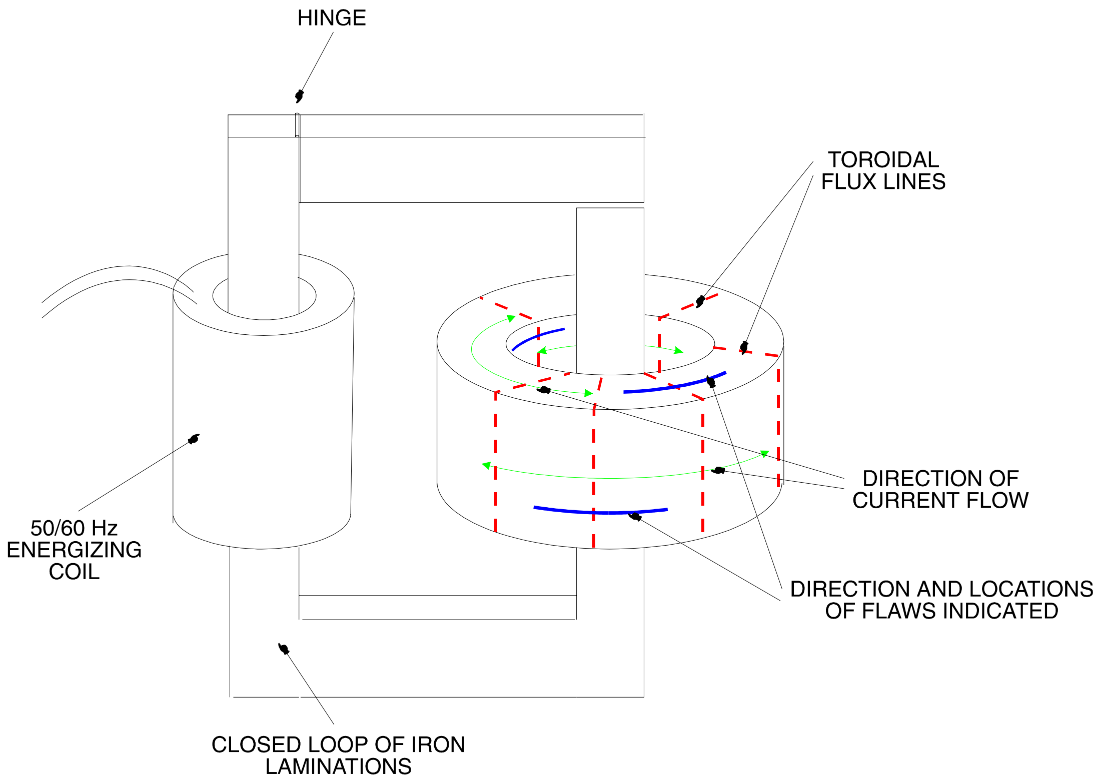


Figure 8 - Non-Contact Magnetising of Hollow Pieces Using The Induced Current (Transformer) Method

The principle is shown in Figure 8. This is a particularly good technique in parts which might be distorted by the pressure of contact pads when using current flow which is the only alternative to indicating defects on the noted surfaces and direction.

4.2 Use of AC Multi-Directional Magnetising

The second important benefit of the use of A.C. magnetising is its application to Swinging Field multi-directional magnetising, that is a method capable of indicating in a single procedure all cracks regardless of their direction in the work piece. (See paper 'Faster Magnetic Crack Detection Using the Multi-directional Swinging Field Method' The use of two phase shifted A.C. currents - one derived from one phase of the line input for say longitudinal magnetising and one from another phase with 120^{o} shift for, say, circumferential magnetising will in combination perform a dynamic vector of flux in the work piece which will rotate through 360^{o}.

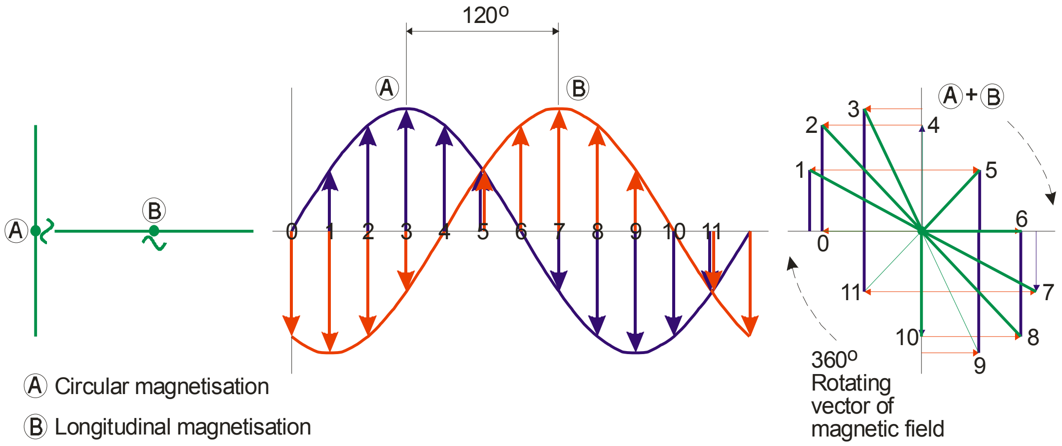


Figure 9 - Principle of A.C. Multi-Directional Magnetising

Figure 9 shows the principle of multidirectional magnetising using the A.C. rotating vector system. It will be noted that the flux is always present and rotates through 360° crossing any direction of defect many times during a magnetising shot. Timing of the application of the indicating fluid is important in that it must cease to flow over the area before the end of the magnetising shot. (This should be the case in all forms of ink application except where the remnant technique is being used). Application of the ink after the completion of the shot will disturb the formed indication and the corollary is that as the shot is continued beyond the application of the fluid the particles will remain in situ after the fluid has drained from the area depriving the indicating particles of their mobility.

The advantage of this dynamic vector system is that its sensitivity is practically even throughout the 360°.

The advantage of A.C. multi-directional fields is not only the time saved in magnetising and therefore viewing of tested components, but also in the even sensitivity throughout the arc of detection, and perhaps of considerable importance in mass testing of components, the obviating of adjustment of parameters between each shot.

The major application of rotating vector multidirectional magnetising is in automatic systems and there is a wealth of possibilities available to magnetise components in a minimum number of shots to allow them to advance through a process at the end of which only one visual examination for defect indications is necessary. An example is the testing of hollow subjects which uses a combination of current carrying threader bar to indicate radial defects and the induced current method described above to indicate circumferential defects. The hardware is quite simple in that the copper conductor is integral with but insulated from the laminated threader bar and is fed from a different phase of the A.C. supply. This will reveal all surface defects regardless of their orientation.

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