Western Instruments
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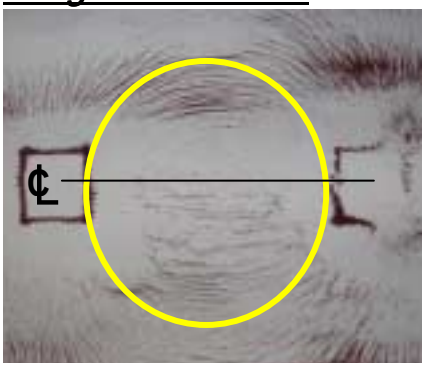
Magnetic Particle Inspection with Yokes

The use of Yokes, as a magnetic source, for Magnetic Particle Inspection is the most common method of MPI in the 21st century. Unfortunately most training and reference material consider the use of Wet Horizontal Benches or High Amperage Power Supplies (Cable Wraps) as the magnetic source. This guide will help the reader in the use of MPI Yokes, as well as their selection.

Magnetic Field



Yokes produce a magnetic field that flows from one leg (Positive Pole) to the other (Negative Pole), thus they are sensitive to cracks that are perpendicular to the centerline of the Yoke's Body. Furthermore, cracks that are orientated up to 45º to this centerline are also detected. As the magnetic field flows outward and from one leg to the other, defects within about 1 ½" (40mm), on either side of this centerline, will be detected. The picture to the right illustrates the lines of flux traveling from one Pole to the other (the pole pieces are 1" or 25mm square). The British Specification BS 6072 (15.6), describes the sensitive area as a circle, the same diameter as the leg spacing extending out from the centerline by the radius. This may be a little over optimistic, so as a Manufacturer we will stand by the 1 ½" or 40mm.

Revealing Cracks

Normally, the magnetic field flows along the surface of the workpiece, from one pole (+) to the other (-). However when the magnetic field encounters an interruption, like a crack, it flows above/below and on either side of the indication, like water over a rock in a stream. Conversely, if a weld or a fastener is between the poles, the magnetic field will also flow around it so the operator must be sure about what is actually a defect and what might just be a change in the surface of the workpiece, such as a weld undercut.

When these interruptions in the Field Flow occur, and the Magnetic Media is applied, it attempts to fill in the interruptions, to allow the field to move smoothly over the surface. However, the media continues to congregate at the interruption thus highlighting it very clearly. The type of inspection media to select (Dry or Wet Method) is outlined below.

Types of Yokes

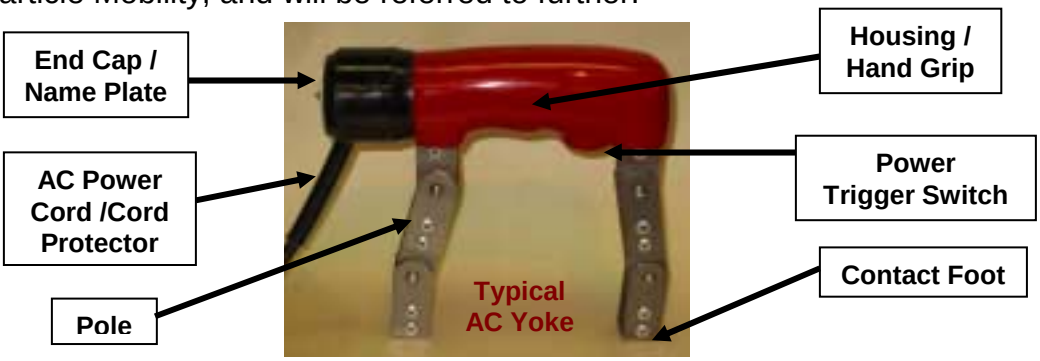
There are 3 basic forms of Yokes; AC, DC, and AC/DC. The most common type of Yoke is an AC unit as it is the simplest and fastest one to use, as indications form very

quickly. DC Yokes take several forms; Electrical (rectified AC), Battery Powered, and Permanent Magnets. Electrical or AC/DC Yokes operate from AC Power and give the operator the ability to use either an AC or a DC Field, however they require careful operation, as the controls are easily damaged.

AC Yokes make fast work of large areas, and require less skill to apply the inspection media. DC Yokes give some subsurface sensitivity, however operators must be careful to apply particle correctly, and to give time for indications to form.

AC Yokes

AC (Alternating Current) Yokes are so successful because the poles change from positive to negative 50 or 60 times per second, depending on the frequency of the power. This alternating field causes the magnetic particles to vibrate on the surface of the workpiece, thus they quickly congregate at cracks. This vibration is referred to as Particle Mobility, and will be referred to further.



AC Yokes must lift a minimum of 10 Pounds or 4.6kg, which requires the Feet to be placed squarely on a Pull Test Bar (W-PT), thus permitting as much magnetic field as possible to flow thought the bar. Thus when the Yoke is place on a curved surface the operator must ensure that as much of the foot as possible is contacting the workpiece. A properly maintained AC Yoke, with the feet ground flat, will lift the Pull Test Bar if the feet are at their maximum or minimum distance.

DC Yokes

A Direct Current (DC) Field can be produced by applying a DC voltage, such as a battery, to the internal coil of a Yoke. A DC field can also be produced by a Permanent Magnet, such as a fixture made with Rare Earth Magnets. Unfortunately, there is no Particle Mobility with a DC field, so the operator must introduce the Particles perpendicular to the centerline between the poles.

Depending on the specification being recognized, a DC Yoke must lift between 40 to 50 pounds (18 to 23kg), on a pull test bar. The operator must recognize similar precautions as an AC Yoke, with respect to the contact area of the feet. However, Reference Specifications limit the spacing of the feet to a maximum of 6” or 150mm, as a greater distance stops the field flow between the positive and negative poles.

DC Current Yokes

To produce a DC Field from a 12 Volt Battery, we condition the voltage to Conserve battery power. This is done by Chopping (or interrupting) the current to the internal wire core approximately 125 times per second. Unfortunately, due

to the inductance of the wire core, and the Iron Laminations of the frame, the field produced provides no greater Particle Mobility. However, the Chopping does conserve battery life and limits the lift to 50 pounds.

A 12 Volt Battery can be used on an AC Yoke, but it will overheat very quickly while lifting 100 pounds! When a conventional AC Yoke is connected to a 6 Volt Battery, it will not heat as fast and will still lift 50 pounds.

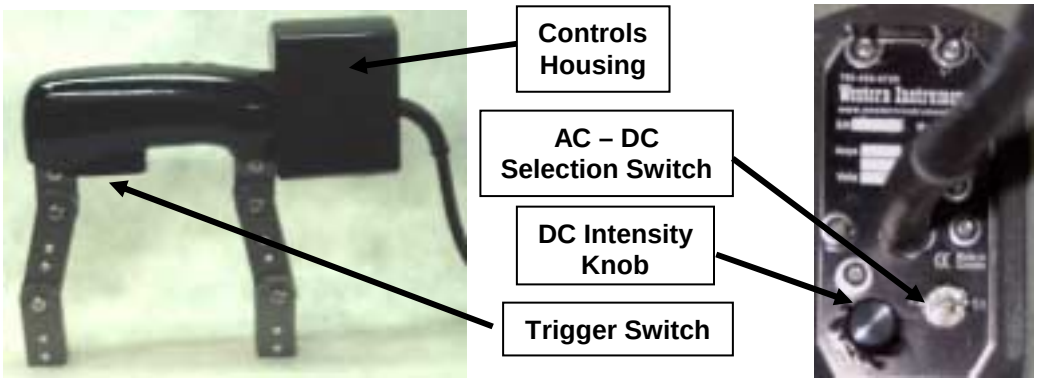
Permanent Magnet

These Yokes are available in two basic configurations; Hinged Frames, or Cable Type. Both perform identically, and it is really a matter of operator preference as to which on is used. Those unfamiliar with Permanent Magnet Yokes refer to the

difficulty in removing or placing the contact feet to and from the workpiece, however the poles are simply moved to minimize there contact and they are easily removed. Enough can not be said about the benefits of a Permanent Magnet Yokes, but bias writers of specifications have limited their use.

AC/DC Yokes

As their name implies, these Yokes have a selector switch that permits the operator to induce an AC Field or a DC Field. In AC Mode, the Yoke is just the same as any



other AC Yoke. When the DC Field is selected, the line voltage is reduced (in the form of heat) and rectified to produce a DC wave, often referred to as Half Wave DC, or Pulsed DC. This form of DC provides the best Particle Mobility of any type of DC magnetization, but it is still not as good as AC. Here again DC will find slightly subsurface defects while AC only works on surface breaking defects, which in essence is the befit of an AC/DC Yoke.

The same requisite Pull Test applies to either field with an AC/DC Yoke, 10 Pounds/4.6kg for AC, and 50 pounds/23kg for DC. Some Reference Specifications, for DC mode, call for a lift of 30 Pounds (13.6kg) on a pole spacing under 4" (100mm), so the DC mode in these Yokes is equipped with an Intensity Potentiometer to control the lifting power. However, this is typically ignored by many inspectors as it requires one to carry multiple Pull Test Bars to every site!

Selection of Media

There are 3 basic forms of Magnetic Particles; Dry, Wet Visible, and Wet Fluorescent. This guide only discusses Dry and Wet Visible as they are the simplest to use. Wet Fluorescent is the most sensitive, but requires the us of a Long Wave UV Lamp (Black Light).

Dry Method

Dry Method Media is simply referred to as *Dry Powder*. The mean particle size of Dry Particles is 180 microns, which is like a very fine sand. Dry Powder is available in 3 basic forms; Natural (Dark Grey), Colored, and Fluorescent, all of which perform equally well. The various colors are used to increase the contrast to the workpiece, therefore it isn't practical to use a Natural Powder on a Sand Blasted surface. The most common type is Colored Powder which is normally available in White (light gray), Yellow, Red, and Blue/Black.

Dry Powder performs well when looking for large cracks that are immediately injurious. In actual fact, Dry Method is basically an Aid to Visual Inspection. If one were to remove the powder from around an indication, and look very closely chances are better than even that the indication would be visible. That being said, an operator can very easily inspect a large area quickly and reliably…without using a magnifying glass.

Fluorescent Dry Powder is not commonly used, as it is quite expensive. Inspection Media with a mean particle size close to that of Dry Particle is available for underwater use as well.

Wet Method

Wet Visible Method particles have a mean particle size of 10 to 20 microns, so it is particularly good at detecting small cracks. This Wet Method Particle is most commonly Black, however it is available in Red. In order to highlight the very fine Black Particles, a White Lacquer Paint is used. We commonly refer to this method as *Black on White*.

The workpiece must be clean and dry to allow the inspector to apply the White *Contrast Paint*. The Contrast Paint simply allows the operator to see the very fine Black Particles which are suspended in either an Oil or Water Base Bath. Contrast

Paint is typically applied by Aerosol Can, which slightly adds to the expense and time required for this method. However, it is widely accepted that *Black on White* is almost as sensitive as Wet Fluorescent.
White Contrast Paint is available in 5 gallon (*Bulk*) pails, however application becomes an issue so Aerosols dominate industry. However if large areas are being inspected, such as Stress Corrosion Cracking Investigations (*Digs*) on Large Diameter Pipelines, the application of Bulk White Contrast Paint is well worth the trouble. Here, industrial spraying systems are easily employed (pneumatic or airless), and quickly pay for themselves.

The picture to the right shows an inspector applying White Contrast Paint to a Boiler Fire Tube in the field (note surface finish). A specialized crew would use bulk application system, due to the area needed to be covered, however this application is by more expensive aerosol cans.

Black Particles are commonly used in Aerosols, however it is readily available as a powder that can be mixed with water (and a wetting agent) or oil (Mineral Spirits/Stoddard Solvent). Premixed water base slurry is also readily available and makes mixing very fast and simple. Mixing one's own bath, no matter the carrier, is very economical.

Wet Fluorescent MPI Inspection is very popular, however operators must have a UV Lamp (Black Light) in order to see the indications. Wet Fluorescent is a bit more sensitive than Wet Visible, but typically is slightly more involved and will be covered in a supplementary insert to this guide.

Surface Preparation

This section outlines what the operator should do to ensure his Magnetic Particle Inspection is as successful as possible. The larger the particle, the less sensitive surface preparation is. Therefore, with Dry Powder, a hot rolled finish can be left alone, but corrosion, due to weathering should be removed. When a wet method is used, with it's smaller particles, the smoother the better. If the surface is rough, a lot of White Contrast Paint is required, which may affect the sensitivity of the inspection (see *Through Coating* supplement).

All of Western Instruments' Inspection Kits are equipped with a W-FI Field Indicator. These instruments provide a measure of residual magnetism in the workpiece. Operators should check the workpiece, before inspection, to see how much field (if any) is present.

Cleanliness

Dry Powder is the least sensitive to surface cleanliness, however one should avoid Inspection with any oils, grease, or moisture on the surface. Loose Scale should be removed however tightly it is adhered to the surface, however hard carbon scale (hot rolled steel) is acceptable. If there are ledges of heavy scale, they can inhibit particle

mobility with particle collecting at the this point, producing a false indication.

Wet Method is far more susceptible to any type of surface contamination. One must remember that White Contrast Paint is only as good as the surface it is applied to. Placing to much on the surface will constitute a coating and should be dealt with accordingly (see *AC Fields for Through Coatings*), not to mention the added cost in time and Contrast Paint.

Many consumable manufacturers recommend Aerosol Solvent Based Cleaners prior to any inspection, leading one to believe that no 'elbow grease' is required. With today's limited use of harsh chemicals this is not the case. For heavy grease one should use Mineral Spirits, and if time is short or only light oil remains Isopropyl Alcohol is an excellent, extremely low residue cleaner. Both of these cleaners are fairly benign and safe to use. On the other hand one can use soap and water, with a fresh water rinse but get out the cloths and dry the workpiece as quickly as possible.

Surface Finish

As implied above, a smoother surface is beneficial to Particle Mobility, or lack there of, when using a DC Field. However, attempts to grind a surface smooth should be avoided as metal can smear over surface cracks. The same can occur with sand blasting as the peening action can again mask surface cracks. Wire brushes make an excellent surface for any type of MPI Inspection.

Welders will often grind a weld to remove weld slag, however heavy grinding may mimic toe cracking. If a welder is removing slag from hot rolled material, impregnated wire brushes have the necessary rigidity to remove slag, with this type of brush being common while cleaning the root on multiple pass welds.

Surface corrosion on Weathered Steel, such as the1018 grades seen on bridges and structures, must be removed prior to Dry or Wet Method Inspection. Conversely, the surface bloom we see forming hours or days after sandblasting has little effect on the surface profile and can be left alone prior to inspection.

While no cost effective business wants to spend money unnecessarily, however the use of an orbital sander makes a perfect surface. The better the surface condition the better the inspection.

Residual Magnetism

No matter the type of Yoke or Media the inspector will use, it is a good practice to measure the workpiece for a Residual Magnetic Field. A Magnetic Field Indicator, like the W-FI-10 illustrated to the left, provides a measure up +/-10 Gauss. The earth's magnetic field is approximately 0.5 Gauss. Any Residual Field will of course be DC, in that the workpiece could be like a weak or strong magnet with a positive and negative pole. A residual field of +/-3 Gauss is considered demagnetized. The operator should check several points (if possible), as a single point could be zero, while the opposite ends could be very strong. Some inspectors, such as Oilwell Drill Collars (Pipe), can be inspected by just using the residual field, as the workpiece is highly magnetized when it comes out of the well!

The rule of thumb for testing with a residual field is 18 to 24 Gauss. Such a residual field can be positive or negative. However, it would not be unusual to see residual fields, on a component that is prone to being magnetized, of over 50 Gauss.

If an AC Yoke is being used, and there is a strong residual field, there may be little to no Particle Mobility. Conversely if a DC Yoke is being used and the workpiece is highly magnetized, particle will simply be attracted to the surface, not congregating at a crack. In the case of highly magnetized workpieces it may be necessary to reduce the field (demagnetization) before applying a desired field. Only experience operators should attempt an inspection using a Residual Field.

Any Yoke can induce a magnetic field into a workpiece, especially any of the DC Yokes. The only practical unit to demagnetize with is an AC Yoke. To demagnetize, place the AC Yoke on the workpiece, activate it and pull it off the surface. The Yoke should remain activated until it is at least 6" (150mm) off the workpiece. This will demagnetize the surface, but if the field extends into the workpiece, it will *creep* back to the surface in time. Full demagnetization is beyond the scope of this guide, but requires a *Reducing and Reversing DC Field*.

System Verification

Like any type of equipment, an operator must be sure his tools are working correctly. Magnetism can't be seen, so specifications call for various forms of testing. With MPI, the operator must be sure his Yoke is working, his Particle is at a correct concentration (Wet Method), and that he can detect a certain orientation of crack. The following are a list of tools to check your 'system'.

Pull Test

4 x10 Pound Pull Test Bars bolted together

The Pull Test is referred to above under *Types of Yokes*, however it is worth repeating. AC Yokes must lift a minimum of 10 Pounds or 4.6kg. DC Yokes, no matter the type, must lift a minimum of 40 Pounds (18kg), however if they are being used on any type of Process Equipment (Liquid or Gas) the inspector must ensure a 50 Pound (23kg) lift to comply with ASME specifications. Such inspections may be beyond the scope of one reviewing this or similar guides for the first time. Pole spacing on DC Yokes, during a Pull Test or while being used for an inspection, can not exceed 6" or 150mm.

If one were to follow specifications to the letter, regarding the frequency of performing the pull test, they won't get any inspections done. However, from a practical standpoint, Yokes should be tested with a Pull Test annually, or when the contact feed appear to be worn or damaged.

Particle Tests

No matter the Particle Type (Dry Powder or Wet Bath) the inspector must determine if it is up to the job. The following are methods to test powder.

Dry Particles

Sensitivity Tests for Dry Powder are limited, and the most basic is for the operator to determine the contrast between his Powder Color and the color of the workpiece. It goes without saying that there must be a significant contrast (color difference between the two items.

The only tool to evaluate the characteristics of Dry Powder is a Type A, Magnetic Stripe Card. This evaluation tool looks like Credit Card, complete with a magnetically coded Stripe. Dry Powder is 'dusted' onto the stripe, and it forms into evenly space stripes. If the Stripes are not uniform, the particle may be unsuitable or contaminated.

Wet Method

Wet Method particles are tested for concentration and contamination. Contamination is either foreign material in the carrier (Oil or Water) or an excessive amount of black dye in the carrier. Carrier fluids should be relatively clear as to not mask indications on the workpiece.

The most consistent and reliable method of testing concentration is with a Centrifuge Tube (W-CT). 100ml of a well mixed bath is dispensed into the Pear Shaped Tube, and left for approximately 1 hour. The settled particles should displace 1.2 to 2.4ml in the capillary section of the tube. After settling, the bath is also checked for contamination. A Type A or the newer Type 2000 Magnetic Stripe Card is also available however can be difficult to read with visible baths.

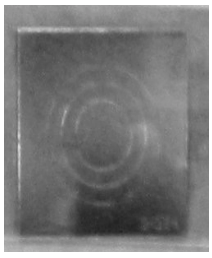
If an operator wants to impress auditors, a Number 3, MTU Block can be used. These Blocks have accurate recordings of inductions with reproducible parameters (Field Strength, Bath, etc.). A bath can be tested by reapplying it to the Block, and comparing to a Digital photograph originally supplied with the block. Like snow flakes, the indications on 2 MTU Blocks are not the same.

Artificial Indications

In a perfect world, prior to testing and to verify the Magnetic Field and Particles, an operator would have a similar part with an actual defect. Unfortunately this type of workpiece is either repaired or disposed of as scrap. There are tools available with Artificial Indications that mimic defects. The most popular of these is a Castrol Strip

Package of Castrol Stripes

Typical QQI's



(Flexible Magnetic Flux Indicators), or the more delicate QQI's (Quantitative Quality Indicators). These tools are placed on the workpiece, at different orientations, to

ensure a crack of a given size and angle is detectable.

A W-PT-DB, is a 10 Pound (4.5kg) Pull test Bar with artificial indications, that can be used for either Wet or Dry media, makes an excellent tool to verify the system, demonstrating ability to lift and sensitivity to known defects. A very popular (and very old) accessory is a Pie Gauge (P-PG), which is placed on a workpiece to verify the magnetic field is sensitive to a given orientation of crack. Some mistake a Pie Gauge as a sensitivity test, however Castrol Strips and QQI's are far superior. Pie Gauges are expensive and easily damaged.

Pie Gauge

Indications on W-PT-DB

Application of Particle

The application of Inspection Media is the only item that can sometimes make MPI a bit tricky. Due to the Particle Mobility with AC, it virtually doesn't matter how it is applied. However DC requires more care and attention.

Dry Method Powder

Dry Magnetic Powder is applied with a Powder Bulb (illustrated to the right), which are available in several sizes and configurations. Electrical Dry Powder Applicators, with integral air compressors, are available and can save a high percentage of particle due to a more accurate dispersion pattern. However, Wet Visible method is coming to dominate industry due to its greater sensitivity in detecting small cracks.

When applying Dry Powder, the Powder Bulb should only be filled about half way with powder. The residual volume of air allows the bulb to be rapidly squeezed, so the rush of air carries the desired amount of powder toward the workpiece. The stream of powder is directed perpendicular to the Yoke centerline, virtually parallel to the surface of the workpiece. The technique is illustrated in the picture to the left on the Cylinder Head Inspection. This dusting technique is very affective on AC Yokes, and is a necessary skill for DC Yokes. As there is no particle mobility with DC, this shearing technique moves the powder, so if a crack is within the Shearing the application target area, the stray magnetic field will tend to grab it. permits more powder to pass the crack compared to simply allowing it to fall vertically to the surface.

Wet Method Bath

In portable use, Wet Baths are applied with an Aerosol Can, or a manual Spray Bottle. As mentioned previously, mixing one's own bath, and using a Spray Bottle, is far more economical. Similar to Dry Powder, wet method bath is directed with a shearing motion, perpendicular to the centerline of the Yoke.

Prior to applying Wet Bath, the workpiece must be sprayed with White Contrast Paint as illustrated on Page 5. Again, a minimum amount of Contrast Paint is better that to much.

How an Indication Forms

Dry method MPI inspection is basically an aid to visual inspection, as the iron particles are very large. With a close up view from the Cylinder Head inspection from the previous page, we can see a crack that was found. This indication was unseen visually by a seasoned inspector, but was later found with MPI. After a quick buff of the area, this same inspector was able to visually see the lower portion of the crack. However, visual inspection will seldom detect the initiation point or overall length of such cracks.

Wet method inspection will highlight indications that are not visible to the naked eye or even with the use of basic magnification, as the coated iron oxide particles are very small. No matter the inspection media, indication are formed in the same manner, but the iron particles attempting to fill (or bridge) cracks.

When a magnetic field is formed with any Yoke, particles are introduced to the workpiece perpendicular to the centerline. If there is an 'anomaly' within the target area, particles are attracted to the interruption in the field. The particles will attempt to fill this 'magnetic interruption' (the crack). The larger the crack, the more particles will be necessary to fill it. As Dry Method particles are so large, they will quickly fill large cracks, however Wet Method particles will take many times more particles to fill the same crack Therefore, Wet Method inspection is considered far more sensitive than the dry counterpart.

Does this mean that one should apply great quantities of Wet Method Particles onto a workpiece to find all cracks? In short. the answer is no, as an inspector should know the general size of particles he is to use on a workpiece. Experience will tell the inspector what inspection method he should use, but it the answer isn't know, then it should be found.

How to Magnetize

As described above under *Magnetic Field*, Yokes are sensitive to cracks that are perpendicular (+/-45º) to the centerline of the Yoke, and outside the centerline by about 1 ½" (40mm), on either side. Therefore, if the inspector doesn't already know the orientation of cracks, he must test with the Yoke in two positions, 90º apart.

As an example, while testing the Head of an Engine, the Yoke must be positioned on either side of a Cylinder and lengthwise to the cylinder. These two testing positions will make sure that a crack extending radially from a Valve Seat will be detected. When testing a Weld, the Yoke should be placed 45º to the centerline of the weld to test the for one geometry of crack. The Yoke is then repositioned by 90º to retesting the same area for a different orientation of crack.

If the operator is doing maintenance or inspecting a part during a rebuilding process, he will probably know the orientation of cracks. In this case, he doesn't need to test in two separate directs, but just places the Yoke 90º to the typical crack orientation. Shafts are a perfect example of this, as typically they crack transversely, thus the operator positions the Yoke longitudinally to the axis.

Often we don't have the luxury of testing flat workpieces, as uneven surfaces are sometimes the norm. When testing curved surfaces, for surface fatigue cracks, the contact feet will not sit flat on the surface. The first thing that comes to mind is that the Yoke will not comply with a Pull Test, thus how does one verify that a test is actually being done? Whenever in question, in a situation like this, the operator should use a Castrol Strip or some other Artificial Indicator.

When testing Welds, there are changes in surface geometry that can fool the inspector. The most common is the Toe area of the weld, as the change between the surface and the weld cap or reinforcement causes a large interruption of the magnetic field, which causes particle to collect. Therefore it is very difficult to detect a Toe Crack, which is a very common weld crack. The weld cap, on manual welding, has many transverse irregularities cause by welding speed and filling. As the inspector must test in two directions (45º to the weld and 90º apart), these irregularities may produce an indication that can mimic porosity or even a transverse crack. Therefore, unless a weld is extremely smooth or has been ground flat there are difficulties for inexperienced inspectors.

Mobile equipment (Backhoes, Graders, Cranes, Draglines, etc.) have many stress points in there steel frames and structures. These components are subject to cracking that can be detected by MPI. This equipment is normally painted for corrosion protection, however this paint is not a flexible as steel, so paint will tend to crack or become disbanded for the surface. An example is the lattice structure of a crane boom. Areas with good paint adhesion can be inspected using practices outline in *AC Fields for Through Coatings*, however if there is paint adhesion issues it should be removed and then tested. Weld areas on this mobile equipment is often ground smooth to aid in MPI.

Post Inspection

Demagnetization

Small Parts may be demagnetized by positioning the contact surfaces of the Pole Pieces together, activating an AC Field and pass the part through the opening formed between the Legs and Yoke Housing. Larger Work Pieces can be demagnetized by placing the Yoke on the surface, in a similar manner as used during inspection, activating an AC Field and pull the Yoke off the surface. The work piece can be tested with a Magnetic Field Indicator, such as the W-Series W-PT®, to ensure it is fully demagnetized

Clean-up

In some cases no clean-up of wet or dry media is required, such as when the workpiece is to be sand blasted prior to coating. Conversely, after testing a gear box

casing prior to reassembly the inspector will want to work with the mechanic to ensure all of the Iron Particles are removed.

When a Yoke is being switched between either Wet and Dry inspection media, the inspector should fully clean the Articulating Hinge points on the Yoke Legs to ensure they move easily, This will ensure that the contact feet can be conveniently positioned on the work piece.

* Reference Specifications are referred to in this document, unless specifically mentioned in this texted, they are either ASTM E709, E1444, or ASME Section V.

* Other Western Instruments' guides are referred to in this document, and must be requested separately.

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WE-3HD AC Yoke

WC-6 AC Yoke