GOOD PRACTICE GUIDE FOR MAGNETIC PARTICLE TESTING
A help to choose the most suitable technique

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1- INTRODUCTION

Magnetic Particle Testing (MT) is a non-destructive testing (NDT) method used to detect surface-breaking or just-below-surface (generally down to some mm deep) discontinuities, only on ferromagnetic materials. This method requires following the rules to get the best results.

You will find in this paper some useful advice. In no way, this paper can be considered as a standard or as a specification.

This paper is far from exhaustive. We only want to draw your attention to issues we feel as important. That is why we recommend that you read the documents we have referenced, as well as the relevant and applicable standards, specifications and procedures issued, or accepted, by your primes.

Feel free to send us your comments and remarks.

We thank you in advance.

2- CHOOSE YOUR SUPPLIER/MANUFACTURER

There are a large number of suppliers and manufacturers. Better to choose among those with the highest standards.

The criteria to choose a supplier/manufacturer are:

- Its range of products shall be wide.

- The supplier shall be able to supply products that meet all, or almost all the requirements of the relevant European, ISO standards and codes, and products that are also approved by many primes.
  Indeed, a user may work for different primes. Therefore, it is important that the materials that he is to use be approved by ALL the primes he works for.
  You know for sure that it is not that easy to use two magnetic inks in the same magnetic bench.

- The supplier shall be able to supply complete systems, i.e. both equipment and products/accessories/meters/reference test blocks.

- It shall have a Research and Development (R and D) Department.

- It shall have an efficient technical support and assistance to customers.
- It shall have a Quality Assurance System certified to ISO 9001.

- It shall have an environmental management system and take advantage of certification, valid, in accordance with ISO 14001.

- It shall have an HSE (Health, Safety, Environment) Manager and a REACH (REACH stands for: Registration, Evaluation and Authorisation of Chemicals Substances) coordinator.

- Etc.

Of course, this does not come for free.

Make provision to audit your MT materials supplier every year.

3- QUALIFICATION AND CERTIFICATION OF PERSONNEL

To carry out reliable inspections, the personnel (operators, inspectors, etc.) shall gain the necessary skills.

An in-house training, plus training in renowned training centres is essential. In France, it is anticipated that the training centres will have to be approved by the French Confederation for Non-Destructive Testing, (COFREND).

In most countries, training centres are approved by certification bodies, and they provide theoretical training and practical training.

Note that the system of qualification is quite different in the USA and in Europe. Large areas and industrial sectors in the world work after the US system, in which Level Is and Level IIs are certified by their employers, while the European system certifies even Level Is through a third body. Obviously, this leads to some differences in the training process. We describe here the way it is done currently in Europe.

Several criteria are a basis for choosing a training centre.

- First, the industrial sector in which the trainees work: aerospace, foundry, railways maintenance, etc.

- Further, while the theoretical training provided by the training centres is somewhat on a par, the song may be different when dealing with the practical side of the training. This depends on the skills and industrial experience of trainers, but also on the quality and quantity of the available equipment, accessories, artificial parts or real parts, etc. Some training centres invest heavily every year in recent equipment that helps to assure of a relevant and high-quality training. Others recover equipment from industrial companies, which either replace or no longer need it. This may include, for example, MT equipment that, after overhaul, may be convenient, as a teaching tool for training.
In most cases, the training personnel is certified in accordance with the ISO 9712 standard or according to standards recognized as equivalent. Nevertheless, some individual contractors, though not certified, but with a good expertise, may also be valuable trainers.

4- SURFACE PREPARATION AND PRECLEANING

Contaminants may affect the sensitivity of detection of discontinuities, such as:
   - Organic contaminants: oil, grease, etc.
   - Inorganic contaminants: carbonaceous deposits, rust, oxidation, heat scale, etc.

Therefore, it is mandatory to remove these contaminants from the surface before an MT process without altering the mechanical characteristics and the fatigue limit of the parent metal.

Note that if the surface of the parts is not thoroughly degreased, the magnetic ink will poorly wet the surface under inspection, which may lead to the non-detection of defects.

If the surface to be inspected is coated with contrast aid paint and/or any other non-ferromagnetic coating such as paint and/or metal (e.g. zinc), the total non-ferrous coating thickness shall not exceed 50 μm to carry out a reliable inspection. Indeed, the sensitivity of detection dramatically decreases with the non-ferrous coating thickness.

The thickness measurement is very easy and very fast to perform using a calibrated digital thickness gauge fitted with an integrated or separate ferrous probe, for ferromagnetic alloys, in accordance with ISO 2808 standard.

5- MAGNETIZING TECHNIQUES

MT requires that parts under inspection be magnetized. Several techniques of magnetization are available, some of them using different electric wave forms.

5.1- TRADITIONAL TECHNIQUES

- Transverse magnetization by the current flow technique

To produce a transverse magnetization, the current flow technique is generally used. It gives rise to a circular magnetic field that circles the part.

Transverse magnetization allows for the longitudinal discontinuities detection.
• Longitudinal magnetization through either magnetic heads or coil

To produce the longitudinal magnetization, either two magnetic heads, each set at one end of the part, or a coil circling the part, is generally used.

Longitudinal magnetization allows for the transverse discontinuities detection.

5.2- OTHER TECHNIQUES

There are many other techniques to magnetize parts. They are preferably used when the electric arc produced during the current flow may be detrimental to the part. Then, non-contact magnetization techniques are performed. They may be used also when the need is to lower the time-for-inspection when using a swinging field process. Two examples are described underneath:

• Magnetization using a threaded bar and the magnetic core of the induced current transformer.

This technique, processed with sinusoidal AC allows for both the transverse and longitudinal magnetizations of the part, while there is no contact between the part and the magnetization equipment. Thanks to out-of-phase electric currents, the transverse and longitudinal magnetizations can be simultaneously applied and produce a swinging field in the part.
- Swinging field magnetization in a chamber \(^{(2)}\)\(^{(3)}\)\(^{(4)}\).

The swinging field magnetization produces on the entire surface of the part under inspection a magnetic field whose direction is constantly changing, without any contact with the part. This technique shall use only sinusoidal AC and has some limits that shall be thoroughly known.

When sinusoidal AC is not allowed, it is still possible to use a threaded bar or a coil to magnetize a part without contact. Nevertheless, no swinging field can then be produced.

Other less common techniques, such as the residual magnetization or permanent magnets \(^{(1)}\), may also be useful in specific applications. However, these techniques are not described in the ISO standards.

### 5.3- ELECTRIC CURRENT MAIN WAVE FORMS

Almost all magnetizations are produced by an electric current. There are several current wave forms, each with its own advantages or limits:

- Sinusoidal alternating current (AC).

- Half wave rectified direct current (HWDC) (single phase) or pulsating direct current.
- Full wave rectified direct current (FWDC) (single phase).
- Three phase half-wave rectified current (HWDC) (three phases).
- Full wave rectified direct current (FWDC) (three phases).
- Direct current (DC).

The sinusoidal alternating current is suitable for the detecting open-to-surface discontinuities. DC and rectified currents allow for the detecting sub-surface discontinuities, with some limits. The higher the DC component of a rectified current, the easier the detection of discontinuities deep inside the part. With some limits, too: it is impossible to determine accurately the detection depth because it also greatly depends on the defect size and on the magnetic-field strength in the part.

Rectified currents are generally produced by using more or less complex electronic circuits that include diodes, depending on the type of the target current:

- **Half wave rectified direct current (HWDC) (single phase)**

![Half wave rectified direct current (HWDC) (single phase)](image)

- **Full wave rectified direct current (FWDC) (single phase)**

![Full wave rectified direct current (FWDC) (single phase)](image)
• Full wave rectified direct current (FWDC) (three phases)

It is important to note that the actual current wave form is highly dependent on the load induction. In MT, the load may be weakly inductive when using direct current flow in a part or when using a threaded bar. However, the load is far more inductive when using a coil, which has the effect of averaging the current (see the above diagrams). The more turns the coil has or the better it is coupled with the part under test, the more inductive the load will be and the more averaged the current will be.

Maybe the most extreme example deals with the DC magnetic heads: these magnetic heads comprise a very high number of turns directly wound on a magnetic core. Thus, in this situation, the load is so inductive that it is possible to get a DC-like current, with almost no fluctuation, using a very simple full-wave rectifier.

The form of the magnetic field is directly linked to the current wave form. It is then possible to use a tangential magnetic field strength meter that displays the field form to know the current wave form.

6- CHECKING MAGNETIZATION TECHNIQUES

The magnetization check is performed by measuring the tangential magnetic field strength.

Relevant specifications state the required values. This may be peak values, as often in the aerospace industries, or RMS (root mean square) values, as may be the case for the automotive industries, the nuclear industry, etc.

Hence, the need to use calibrated digital strength meters the RMS (Root Mean Square) values (see the calibrated digital strength meters the RMS (Root Mean Square) values (see the photographs below).
Digital tangential magnetic field strength meter displaying simultaneously the mean, TP and TRMS values

Furthermore, when using thyristor-control currents which generate waveforms far away from the sinusoidal form, meters displaying "TRMS" (True Root Mean Square) and "TP" (True Peak) values shall be absolutely used. Similarly, using conversion tables such as the one displayed in Table 1 of ISO 9934-1 should be avoided because the factors led to huge errors, as can be seen in the following example where the coefficient between $\pi$ and $H_{\text{peak}}$ and $H_{\text{mean}}$ can only apply when the thyristors are fully open (full wave).
To check the magnetization conditions qualitatively only, flux indicators\(^1\) (artificial flaw shim standards) are used. The foil-type magnetic flux strips (slotted strips) give some pieces of information about the magnetizing conditions. These flux strips are still marketed, though with other trademark names or as the “foil type magnetic flux indicators”\(^1\).

When using the residual magnetization technique, the magnetic field cannot be measured using a tangential magnetic field meter. Indeed the magnetic field which goes out from the part is an “axial” field perpendicular to the surface, and not tangent to the surface\(^1\).

Residual magnetic flux/field strength digital meters (see the photograph below) have been available for some time. They allow for the checking of the apparent residual magnetic flux density in the part (which dramatically depends on the shape and on the part’s length/diameter ratio)\(^1\).

![Residual magnetization, or residual magnetic field digital meter](image)

7- MATERIALS

They must be reliable. Their quality and performance shall be stable over time and batch after batch. This assumes that the manufacturer is able to detect any drift.

For its part, the user shall also be able to detect such problems, to finger out a possible failure of his supplier.

7.1- MATERIALS MANAGEMENT

Some points deserve a special attention. In particular, check that:

- The certificates of conformity of the materials contain at least the product name, the batch number, the “use before” date\(^5\), the reference to relevant standards/codes/specifications, possibly the date of manufacture, etc.

- The laboratory Test Reports include at least:
- The product name.
- The batch number.
- The “use before” date.
- The reference to relevant standards/codes/specifications.
- The descriptions of tests and their relevant standardized test methods.
- The acceptable upper and lower limit values.
- The test results.
- etc.

- When applicable, the analysis certificates for halogens, sulphur, etc.

Batch management of materials is important and shall take into account the “use before” dates. This requires carefully storing materials in the warehouse and taking out the materials “use before” dates of which are the closest. Some people think the rule is "first in, first out." This implies that the delivered materials have a “use before” date that is not earlier than the same previously delivered materials. However, it already occurred that some suppliers, whose warehouses were mismanaged, did not follow this rule of thumb.

Therefore, when receiving a shipment, the user shall thoroughly check:

- That the packaging is in good condition.

- That data match (labels, certificates, test reports).

- That the materials are not out-of-date, as already seen.

In our opinion, the residual life of a material when delivered, as required by some primes, shall be at least six months before its “use before” date.

The expiry date, set by the manufacturer, assumes that the material is kept as per the storage conditions stated by the manufacturer as mentioned in paragraph 7.2. Storage, of the material safety data sheet filled in in accordance with the Annex II Guide to the compilation of safety data sheets of the Regulation (EC) No 1907/2006 (6).

As a safety rule, the quantities of materials taken from the warehouse shall be used within the same day.

7.2- MT PRODUCTS COMPATIBILITY WITH MATERIALS

MT being a non-destructive testing method (7), it is implied that MT products shall have no adverse effect on the materials on which they are applied.

The ISO 9934-2 standard states testing of corrosion induced, on steel and copper, by the detection media.
If using a water-based magnetic ink, the user will check the pertaining data in the technical data sheet. Quite often, manufacturers have products with different corrosion-preventive performances. The most protective ones shall be used on finished parts, when less powerful corrosion-preventive systems may be acceptable on parts that will be machined in a further step. Nevertheless, think not only “parts”, but also “equipment”: water-based products shall, in no way, corrode the equipment!

7.3— SELECTION CRITERIA OF DETECTION MEDIA

There are several criteria to select the suitable detection media and we already published several papers dealing with this topic, giving many examples (8)(9)(10).

7.4— USING THE MATERIALS

The user shall comply with the MT processes stated in the relevant standards and specifications.

MT requires working in a clean and neat environment.

Clean and neat means:

- The surface of parts under inspection shall be rid of foreign matters.

- The workstation shall be clean.

- The operator’s/inspector’s hands shall be clean. Do not eat food of any kind while performing an MT inspection.

Materials shall be used according to the instructions stated in paragraph 7.1. Handling and, as appropriate, in paragraph 7.3. Specific use(s) of the material safety data sheet filled in in accordance with Annex II Guide to the compilation of safety data sheets of the Regulation (EC) N° 1907/2006(6).

Storing spray cans (11) requires some rules are followed.

To do a neat job is, for instance, to apply the products only on the areas under inspection, as far as possible, and to apply the smallest possible quantity.

Applying the materials requires some precautions.

- The contrast aid paint shall be vigorously shaken before use and applied as a thin, uniform and continuous coating. Avoid any running-down and extra thickness.

- The magnetic ink also shall be vigorously shaken before use.

- The user shall comply with the recommended concentration for use: magnetic powder in suspension in an organic carrier liquid, oil-based concentrate in an organic carrier liquid, water-based concentrate diluted in water, etc.
Using a detection medium in a wrong concentration may lead to significant drop of the sensitivity of the detection medium.

Generally, the detection medium is applied just before or during magnetization (continuous magnetization technique). The application of the detection medium shall be stopped BEFORE the end of magnetization; otherwise, the magnetic particles retained by the magnetic flux leakages may be washed-off by the carrier liquid in excess.

The magnetic ink shall be let drain to enhance the detectability of the indications.

8- LIGHTING AND VIEWING CONDITIONS

Viewing conditions are stated in the relevant specifications. If not, it is possible to refer to the ISO 3059 standard, which details the viewing conditions. In general, when using non-fluorescent detection media, the illuminance on the surface under inspection shall be higher than or equal to 500 lx. When using fluorescent detection media, the UV-A irradiance shall be higher than 10 W/m² with an ambient visible light illuminance less than 20 lx. Viewing conditions shall be periodically checked with a calibrated digital radiometer/luxmeter.

Digital radiometer/luxmeter simultaneously displaying illuminance and (UV-A) irradiance figures.

The part inspection is a critical step. Indeed, the inspector shall focus on parts under inspection, interpret the indications, then, accept or reject the parts.

A reliable inspection requires that:

- The inspector has room enough to perform his (her) duty.

- The inspector’s vision examination is periodically performed. As an example, the EN 4179 standard states: every year for near vision and at least every five years for colour perception.
He or she shall pay attention to the work, which requires to have had a restful sleep or not to be bothered by personal or occupational worries.

- No glare shall impair his (her) vision, with fluorescent or non-fluorescent detection media.

- If in a UV-A inspection booth, the inspector shall wait for dark adaptation of the eyes before beginning the inspection. UV-blocking goggles are recommended, while photochromic spectacles are forbidden.

- In a UV-A inspection booth, there shall be no fluorescent or reflective surfaces.

- The inspection area shall be clean. In particular, no fluorescent spot is accepted, as detrimental to the inspector’s ability to perform a suitable work.

- Do not wear clothes and gloves that fluoresce under UV-A radiation.

9- GLOBAL SYSTEM PERFORMANCE

The global system performance test is carried out using reference test blocks with known defects (natural or artificial).

As an example of artificial Known Defect Standard, we may quote the KETOS RING \(^{(12)}\) \(^{(13)}\) or similar disk when using half wave (HWDC) or full wave rectified direct current (FWDC) (three phases).

In the absence of Known Defect Standard, it is possible to use flux indicators (artificial flaw shim standards), such as the Berthold penetrator, the ASME indicator (pie gage), foil-type magnetic flux strips (slotted strips), etc.
The global system performance is assessed by performing comparative tests between in-use materials and the same new and unused materials, by following exactly the same MT process parameters, every day with the first parts, and at the end of each shift or of each day to make operators sure that all the parts were processed in accordance with the specified criteria.

To ensure that the results are reproducible, the reference test blocks shall be demagnetized and cleaned immediately after each test. This cleaning should not modify the cracks.

Note that in the automotive industry, so-called “ghost parts” (10) are used along the parts under inspection. These ghost parts have peculiar discontinuities. The inspector shall detect ALL the parts. If not, the inspection is deemed as non-reliable.

10- IN-USE MATERIALS CHECK

A periodic check of in-use materials is required to ensure their conformity to the relevant standards and specifications and to ensure the reliability of discontinuities detection. These checks deal mainly with in-use materials used in manual, semi-automatic and automatic process plants. However, they generally do not apply to "single-use" materials, such as those in spray cans.

This check is generally performed using Type 1 and Type 2 reference test blocks of the ISO 9934-2 standard (14). Regarding Type 1 reference test block, we recommend you to read the paper (15).

Some specifications require, especially for the products used in a magnetic bench, that the settlement volume or the magnetic particles content be checked. This check is performed in a centrifuge tube, often pear-shaped. However, keep in mind that the solids that settle comprise magnetic particles, but also many other solid particles, wiped off from the parts, for instance, dust, etc. A figure of the settlement volume in the right range does not mean that there is the requested quantity of magnetic particles, or that these particles have not been damaged by the pumps, taking the fluorescent pigment from the particles.
Refer to the relevant standards and specifications for further tests

Note that some manufacturers may agree to extend the shelf life (5) of a product. Nothing prevents a user to ask the manufacturer. This process is applicable only to never-used materials, kept in sealed containers and in suitable storage conditions. Before going this way, better to be sure that the product seems to be in good condition. For instance, check a spray can for a continuous-without-surge spray, no clogging of the spray nozzle or of the valve. A liquid material shall be checked for an unusual smell, separation, turbidity, etc. Otherwise, going on is useless. Nevertheless, keep in mind that the fluorescent pigment (bonded with heat cured epoxy resin) glued on the magnetic particles is slowly solubilized by any carrier (organic, or water). This prevents the user to keep a product, even unused, for too long.

11- EFFLUENT TREATMENT

MT produces gaseous, liquid or solid wastes, and their treatment is not counterproductive to the method. In fact, treatment processes have been used for decades and give suitable results.

Indeed, Council Directive 1999/13/EC (16), amended by Council Directive 2004/42/EC, aims to reduce emissions of volatile organic compounds (17) due to the use of organic solvents in certain activities and installations. MT materials manufacturers have made serious efforts in this way, for example, by replacing, liquefied petroleum gas (LPG) used as propellants by carbon dioxide (CO₂) (18) (19) in spray aerosols.
Several techniques are used for wastewater treatment (20) (21).

Solid wastes do not raise problems. The preferred techniques are:

- The incineration of rags and papers.
- The disposal of solid wastes in approved landfill sites.

12-COMPLIANCE WITH PROCESS PARAMETERS

MT requires checking some parameters to ensure a reliable detection of discontinuities.

It is a true delight for auditors, and a kind of sword of Damocles hanging over the auditees’ heads, who always worry about getting one or more non-compliance reports (NCR).

We do not want to give figures, as per the periodicity or the acceptable limits: users shall comply with the relevant standards and specifications, as every prime (or so) has its own requirements.

These parameters may be:

- The intensity (I) and the magnetomotive force (N.I) of magnetization/demagnetization.
- The lighting conditions in the workstation.
- The accuracy of timers (a NADCAP requirement).
- A leakage current test, the push-button in the “ON” position, without any part clamped between heads. Then, same test when a part made of a non-conductive material (wood) is clamped between the heads (Boeing BSS7040 requirement).
- Quick-break feature (when applicable), (a NADCAP requirement.)
- An oversight of the various functional aspects of the magnetic bench and of their automatic functioning (spray time and pressure, ejection of defective parts, safety devices).

13-DEMAGNETIZATION

After MT inspection, parts keep a more or less important residual magnetization according to the current waveform that has been used, its intensity, the parts shape, the alloy that part is made of, etc.

Sometimes, this residual magnetization may be a problem, and a demagnetization may be necessary, depending on the further processing/manufacturing steps performed on the part or on its use. Underneath, the generally allowed values.

<table>
<thead>
<tr>
<th>Process</th>
<th>Residual magnetization (mT)</th>
<th>Residual field (A/m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Precision</td>
<td>0.8</td>
<td>600</td>
</tr>
<tr>
<td></td>
<td>Machining</td>
<td>Standard Machining</td>
</tr>
<tr>
<td>----------------</td>
<td>-----------</td>
<td>--------------------</td>
</tr>
<tr>
<td>Standard Machining</td>
<td>1.2</td>
<td></td>
</tr>
</tbody>
</table>

The values shown above are given for information only and are especially useful for users who need to de-magnetize the parts but who do not know the value to be met (this is not a specification).

The statement of a very low residual magnetization value shall take into account the presence of the magnetic field and the ability of some part geometries to channel and amplify it.

### 13.1- MACROSCOPIC MAGNETIC PHENOMENA

Ferromagnetic materials that have never been in a strong magnetic field comprise myriads of tiny magnetic domains, which are similar to small magnets, North-South or South-North oriented. All these magnetic moments are distributed at random, and the resultant is null.

When the ferromagnetic material is in a magnetic field, all the magnetic domains are parallel to the direction of the magnetic field.

When the magnetic field is switched off, the magnetic domains never go back to their original situation. An impossible task! The resultant is then higher than zero. A North pole and a South pole appear at the ends of the part. This is the residual magnetization\(^{(24)}\).

The residual magnetization figure depends on the alloy.

### 13.2- HYSTERESIS LOOP

The hysteresis loop allows for the knowing of all the magnetic characteristics of a ferromagnetic material. The magnetic flux density (B) inside the material comes as a function of the outside magnetic field (H) applied to it.
Every ferromagnetic material has its own hysteresis loop. Soft iron hysteresis loop is very narrow. Carbon steel’s is much wider.

When the field $H$ decreases, the magnetic flux density $B$ decreases more rapidly in soft iron than in carbon steel. The $Br$ value is the retentivity or residual magnetization figure.
13.3- DEMAGNETIZATION PRINCIPLE

To demagnetize a part, it is recommended to apply a decreasing alternating magnetic field, the strength of which is at least equal to or greater than that of the magnetizing field. This last point is extremely important if the demagnetization is performed on the magnetic bench itself. In fact, if the magnetic bench has been used at its maximum power to magnetize the part, it is likely it will be unable to demagnetize it.

When the magnetic field strength is gradually lowered, the surface of the hysteresis loops decreases and circles the “zero” point. Therefore, the value of the residual magnetization $Br$ will be lower and lower, without never being zero. The magnetic field strength being proportional to the intensity of the current that generated it, it is then possible to gradually lower the intensity of a current sent directly through the part, or in a coil.

This is a bit more complex, as the magnetic field goes also in the air: its strength decreases proportionally to the distance. Therefore, when the part goes through the coil, it “sees” a decreasing alternating magnetic field as it goes farther from the centre of the coil. The movement shall be regular, and the current in the coil shall not be switched off before the part is at least one meter apart from the coil; even more for large diameter coils. This is the so-called the demagnetization “tunnel” technique It is the most widely used demagnetization technique.
Important remarks

When using a 50 Hz tunnel, the magnetic field produced by an alternating current stays in the outer area of the part: this is the “skin effect”, due to Eddy currents. The demagnetization is a magnetic balance in the very first millimetres of the material. Any machining or dismantling (if a part assembly has been inspected and demagnetized) destroys this balance. Another residual magnetic field appears, more or less strong, depending on the kind of magnetic field used for inspection. If a HWDC magnetic field has been used, for instance, it has magnetized the part far deeper than the AC demagnetization field has gone down. Therefore, a second demagnetization may be required. The parts magnetized by a DC or rectified magnetic field are even more difficult to demagnetize and require specific techniques (low-frequency current, reversing DC current, etc.)

For parts with a low length/diameter ratio, putting them along an East-West axis, and/or using magnetic extenders make it easier to demagnetize them.

When users have trouble to demagnetize their parts the right way, some MT equipment manufacturers may do it, as a paid-for service, in their own facilities.

A successful demagnetization depends on the material, the shape and dimensions of parts. Some troubles may be due to high amperage conductors close to the area where parts are stored, for instance. A service company or a supplier cannot commit itself on the results without preliminary tests.

Residual magnetic field measurement is checked using a residual magnetic flux digital meter (teslamer, improperly called gaussmeter) or a magnetic field strength digital meter, such as the one previously displayed in the Chapter 6 of this paper, and in the Chapter 3 of another paper (1).

14- INSPECTION EQUIPMENT AND ACCESSORIES PERIODIC CHECK

At least once a year, a periodic check shall be performed for:
- Permanent magnet yokes: lift test using a steel plate of 18 kg corresponding to a lift force of 176 N, the magnet poles set at their recommended spacing.

- Hand-held electromagnets:
  o Magnetic field strength at the centre of a line joining the centre of the pole faces, the magnet poles set at their recommended spacing, using a steel plate.
  o Lift test, poles set at their recommended spacing, using a steel plate or parallelepiped bar weighing:
    ▪ 4.5 kg, corresponding to a lift force of 44 N when using AC current.
    ▪ 18 kg, corresponding to a lift force of 176 N when using DC or rectified current.

- Current generators, magnetic benches, specialized testing systems: full functional check, including the following control tests:
  o Ammeter accuracy check.
  o Timer control check.
  o Magnetic field quick break check (1) (where appropriate).
  o Equipment current output check.
  o Internal short circuit check.
  o Etc.

The above checks are usually performed every 6 months or every year.

- The entire MT equipment cleanliness shall be maintained for better working conditions.

- UV-A filter integrity shall be checked. Any cracked or broken filter shall be replaced immediately.

- UV-A radiometer, luxmeter, tangential (and axial if any) magnetic field meters, residual magnetic field meters, reference test blocks shall, etc. be calibrated or verified, and the pertaining certificates shall be kept available to the auditors.

- When using the current flow technique, copper contact pads shall be regularly checked and replaced, if necessary.

Let us remind you of an important point: a measuring equipment defined as an “indicator” does not require any calibration. Typically, this concerns the residual magnetic induction (or the residual magnetic field) indicators, used to check demagnetization. It is up to the Level III responsible for the installation to define which meters are indicators. Obviously, they shall be stated in the applicable procedure. They may even be labelled as such, to prevent any misunderstanding by an auditor.
15- CLEANING AFTER INSPECTION – RESTORING THE INITIAL CLEANLINESS

Generally, parts’ cleaning is not required after inspection.

However, for some specific applications, it is necessary to restore the initial cleanliness of the part, removing, if necessary, the contrast aid paint and magnetic particles remaining on the parts surface.

Quite often, when a dry magnetic powder has been applied, the powder shall be blown-off by a dry and oil-free air flow.

16- CORROSION PROTECTION AFTER INSPECTION

Some ferromagnetic alloys are subject to corrosion.

Therefore, the metallic surfaces shall be protected against corrosion before receiving their final protection, such as painting.

There are mainly two kinds of corrosion preventives:
   - Temporary corrosion protection for indoor storage using a water-displacing corrosion preventive.
   - Long-term corrosion protection for outdoor storage using a film-forming corrosion preventive.

All these materials shall be silicone-free (especially if the parts are to be painted later) and easily solvent-removable.

17- OPPORTUNITIES TO MAKE THESE TECHNIQUES GREENER

What can be done?

17.1- REDUCING THE MT MATERIALS CONSUMPTION

For the “on-the-spot” inspection, spray cans are the most convenient means.

Though materials in spray cans are more expensive than the same products in bulk, spray cans for such an application are cheaper when considering material losses and man-power costs(8). It is also the best way to prevent any accidental contamination of the MT materials by chlorine, fluorine or sulphur containing materials (8) where applicable. Therefore, using spray cans reduces the waste of materials as well the volume of effluents to be treated.

When materials are used on magnetic bench, the drag-out losses of materials shall be minimized for at least two main reasons:
- To reduce the waste of materials.
- To reduce the effluent treatment cost.

For this the right positioning of the parts: the recessed surfaces, blind holes, etc. shall be facing down. When impossible, it will be necessary to turn the part upside down so as the retained material goes back to the reservoir of the magnetic bench.

Many users try to use their magnetic water-based detection media longer than their given life expectancy, to save on products. The user performs a performance test with the Type 2 reference test block of the ISO 9934-2 standard, or with a real part, at the beginning of every shift (every eight hours) to check the product complies with the applicable requirements. Indeed, it is impossible to guarantee the lifetime of an MT detection medium. The lifetime depends upon several parameters:

- The more or less fast contamination of the MT medium by contaminants brought by the parts, such as cutting oils, sand, shavings, dust, etc.
- The number of hours the magnetic bench is running,
- The particles drag-out by the part, which leads to a lower concentration in the MT detection medium.

If the product is reliable, the fluorescent particles of the MT detection medium may overcome the agitation due to the circulation pump for a week, without any “breaking” of the particles. This “breaking,” in fact, is due to the breaking of the link between the organic bonding agent and the fluorescent pigments attached to the magnetic particles.

As a general rule, one shall:

- Empty the reservoir at least once or twice a week, AS A MINIMUM,
- Check the performance of the product at the beginning of every shift, using the Type 2 reference test block described in the ISO 9934-2 standard,
- Add brand new product, so that the pump is always immersed.

**17.2— REDUCING QUANTITIES AND GLOBAL VOLUME OF PACKAGING AND OVERWRAP**

Be they made of cardboard, plastic, metal (steel, tinplate, etc.) or wood, packaging and overwrap are recyclable.

Year after year, the volume of our packaging, be they domestic or industrial, tends to increase, although some manufacturers undertake some efforts to reduce them.
Although essential, packages are an additional cost, which we would like to reduce.

Hence, a question: what can we do to reduce their quantities and their overall volume?

Generally, chemical waste and used packaging are charged per kilogramme, though transport is charged according to the number of pallets. Therefore, the higher the volume, the higher the transport cost.

One way is, where technically possible, to order materials as concentrates, such as magnetic powder or magnetic ink concentrate magnetic to be put in suspension into a carrier liquid. For example, a 10 kg can of a magnetic ink concentrate for aqueous dispersion, used at a concentration of 2 %, is equivalent to 500 litres of ready-to-use material.

Using 500 mL spray cans, instead of 300 or 400 mL ones, may seem the right way, but it is not that simple (22). Where technically possible, using 500 mL spray cans is a real source of savings.

Reducing the number and overall volume of packaging would lead to switch to 200-litre drums. However, MT materials, such as magnetic inks, contrast aid paints, containing solids in suspension in a carrier liquid need to be vigorously shaken before use. This is the reason why they are packaged in 5 litre-, and less frequently, 25 litre-containers.

Note also that MT materials are supplied in brand new packaging to prevent any risk of accidental contamination.

17.3— REDUCING THE QUANTITY OF HYDROCARBONS

Reducing the quantity of hydrocarbons is a concern that has been there for a while. This was done in some industries such as automotive, railways, etc. by replacing oil-based magnetic inks by water-based magnetic inks (10).

17.4— REDUCING ENERGY CONSUMPTION

The Directive 2005/32/EC (23) of July 6, 2005, states among others:

“Article 1: Subject matter and scope
1. This Directive establishes a framework for the setting of Community ecodesign requirements for energy-using products with the aim of ensuring the free movement of those products within the internal market.

2. This Directive provides for the setting of requirements which the energy-using products covered by implementing measures must fulfil in order for them to be placed on the market and/or put into service. It contributes to sustainable development by increasing energy efficiency and the level of protection of the environment, while at the same time increasing the security of the energy supply.”
This Directive does not apply and will not apply to MT equipment because it states that “the EuP (Energy-using product) shall represent a significant volume of sales and trade, indicatively more than of 200,000 units a year within the Community according to most recently available figures.” It deals more with consumer products (television sets, refrigerators, etc.).

However, we quote this Directive as an example, as it encourages the voluntary and preventive initiatives.

The relevant specifications state the parameters of magnetization to comply with. Obviously, the most energy-thirsty step is magnetization. However, some technical means may be implemented, such as:

- To improve efficiency by ensuring a good magnetic coupling between the part under inspection and the magnetization or demagnetization system. This can be done by choosing a coil with a diameter that matches the part size. As an example, let us consider the three-turn coil as seen in the picture, underneath:

![Image of a three-turn coil](image)

If one wishes to get a 10 kA/m magnetic field at the centre of the coil, the apparent power ($U \times I$) will increase very quickly along with the diameter of the coil.

<table>
<thead>
<tr>
<th>Coil diameter (mm)</th>
<th>Apparent power required for a magnetic field of 10 kA/m (V.A)</th>
<th>Power coefficient in relation with the coil of 200 mm diameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>200</td>
<td>460</td>
<td>x1</td>
</tr>
<tr>
<td>300</td>
<td>1400</td>
<td>x3</td>
</tr>
<tr>
<td>400</td>
<td>3500</td>
<td>x7.6</td>
</tr>
<tr>
<td>500</td>
<td>7000</td>
<td>x15.2</td>
</tr>
<tr>
<td>1000</td>
<td>63,000</td>
<td>X136</td>
</tr>
</tbody>
</table>

The consumed power increases very quickly as the coil diameter is larger. To get a 10 kA/m magnetic field at the centre of a one-metre diameter coil powered under 400 V$_{\text{rms}}$ AC current using a transformer, a current of more than 150 A$_{\text{rms}}$ will be required. Furthermore, it should be noted that the tangential magnetic field obtained on a part placed in this coil will necessarily be less than 10 kA/m, due to the presence of a
demagnetizing field, depending on the part shape. For a large-diameter short part, the risk is high to get a magnetic field as low as 1-2 kA/m.

- To use any means of compensation of the reactive energy. Most of the energy consumed by MT equipment is reactive energy.

\[ P_{\text{apparent}} = P_{\text{active}} + P_{\text{reactive}} \]

\[ P_{\text{active}} = R \cdot I^2 / U \]

\[ U: \text{ supply voltage of the load} \]

\[ I: \text{ current in the load} \]

This lost energy cannot be compensated for by the equipment, and it is necessarily drawn from the electrical network. It will be consumed as Joule effect (heat) in the magnetization windings.

\[ P_{\text{reactive}} = (2 \cdot \pi \cdot f \cdot L) \cdot I^2 / U^2 \]

\[ U: \text{ supply voltage of the load} \]

\[ I: \text{ current in the load} \]

\[ L: \text{ inductance of the load} \]

\[ f: \text{ frequency of the current supplied to the load (usually 50 Hz)} \]

This power, normally drawn from the electric network, can be compensated for by sets of capacitors.

Should the compensation be perfect, only the power needed for the active power would be drawn from the electrical network. When the load is highly reactive, the compensation may dramatically lower the consumption. Let us consider a rectangular, 500 mm x 200 mm aperture, magnetizing coil, such as the one on the picture, underneath:
Without an equipment of reactive energy compensation, the current drawn from the network is 190 A. With reactive energy compensation equipment, the current needs go down to 30 A only.

Nevertheless, reactive energy compensation equipment cannot be the right answer to all cases.

In fact, this technique is much more efficient when using a magnetizing/demagnetization coil than when using current flow, due to the higher consumption of reactive power. Furthermore, this equipment comes at a cost that could be partially recovered, thanks to a reduced energy invoice.

- To lower the number of connections when using very high amperage currents. Indeed, the resistance of every connection is about 50 μΩ. For example, when using a 3,000 A (RMS) current from a mobile MT equipment, if four 2-meter long cables are used to “manufacture” an 8-meter long cable, instead of an 8-meter long cable alone, there are three additional connections. This would lead to a useless additional consumption of 1,350 VA (3*50 μΩ * 3000 A²).

- A poorly crimped cable increases the contact resistance and lowers the capabilities of the equipment. Though this kind of trouble is more likely to be settled during the yearly equipment check, its influence on consumption is far from negligible.
Using energy-efficient lighting is another way to reduce energy consumption.

Thanks to the development of LEDs and their diminishing prices, a good question is: would it not be possible to replace the overhead sources comprising several mercury vapour-bulbs with 365 nm LED overhead sources? This would significantly reduce energy consumption, reduce the amount of heat wasted in the inspection booths (i.e. lower the cost of ventilation or air conditioning), reduce maintenance costs (less shutdowns to replace bulbs), stocks of spare parts, etc.

17.5—GREENER MATERIALS: REDUCING THE VOLATILE COMPOUNDS (COV)

Manufacturers are continuing their efforts to reduce volatile organic compounds (VOC) in their detection media according to the Council Directive 1999/13/EC, which was amended by the Council Directive 2004/42/EC (16).

For example: replacing a petroleum-based carrier liquid with a PMMC (Pensky-Martens closed cup) flash point of 60 °C (140 °F), which is a VOC, by another one with a flash point of 100 °C (212 °F), which is not a VOC.

We recommend you read the article we published on volatile organic compounds (17).

18-CONCLUSION

We hope this paper provided you with additional information to increase your MT knowledge and to get even better and more reliable results.

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