MAGNETIZING CURRENT DETERMINATION

By Arthur R. Lindgren

Many times the inspector must decide how much current to use on a part when there is no sample available containing minimum size flaws to be detected. Guideline **formulas** are available for selected sizes and shapes of parts, but many times, they can be rather difficult to interpret. I suggest the following procedure to determine an amount of current to start with for a given part.

Please note, if there is a customer specification indicating the amount of current to use, use the following procedures only to confirm that the amount specified is adequate, not to lower it.

Before reviewing the many factors involved in this very important subject, the inspector should keep in mind the words of Carl Betz, a founding father of Magnaflux Corporation and author of Principles of Magnetic Particle Testing.

> **"The purpose of using MPI is not to find cracks in ferromagnetic parts. Its purpose is to assure the user that a given part is defect-free. The method should detect small, as well as large, defects on all surfaces of the part."**

Let us consider the traditional (formula) rules of current determination for a head shot, a coil shot, and a prod contact shot. We will review the use of many inspection aids now being used.

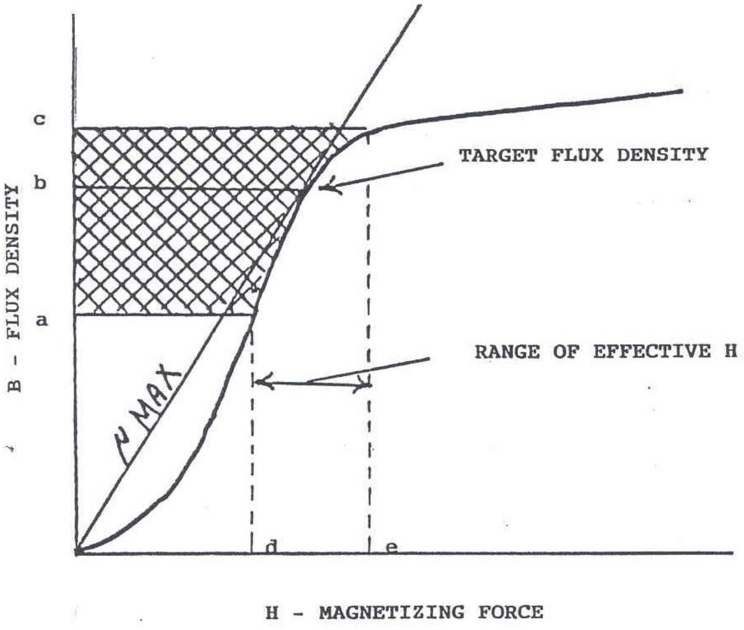
Since a very large portion of all MPI inspection is conducted using a wet horizontal unit and black light, we will review single shot magnetizing first, using either a head shot or coil shot or both. The factors involved in determining current will also apply to semi-production inspection (same person processes part and inspects it) and production inspection (processing and inspection separate). In this category, think of a five pound or less casting, forging or fabrication used in the aerospace, automotive, or nuclear industry. The amount of current to use on prod contact applications will be discussed separately.

Current selection for both the head shot and coil shot must take into consideration that other factors, which affect locating defects, may have deteriorated from their normal condition, namely:

1. ***Proper bath concentration with no contamination.***
2. ***Adequate black light intensity with minimal visible (white) light.***
3. ***"Continuous Method" being used.***
4. ***Maintaining "balanced fields" when using multi-directional magnetizing.***

3.1 HEAD SHOT (CIRCULAR FIELD)

(Fig. 3.1) For the head shot, theory indicates that the target amount of current to use should place the flux density at the knee of the magnetizing curve. This is the highest point of effective permeability for any given part. The current to attain this value of flux density is “1000 amperes” for each one inch (2.5 cm) of outside diameter or diagonal of the part. The same rule applies if a central conductor is used to magnetize the part. Note that the effective range of H (magnetizing force) from d to e is quite wide. Values of B (flux density) vary from one-half the target amount to well over it, from a to c. The use of inspection aids dropped this “1000 ampere” target, starting in the 1970’s. Many of the more popular specifications now call for 300 to 500 amperes per inch (2.5 cm).



(Fig 3.1) How Much Current for a Circular Field

Knee of Magnetizing Curve Suggested as Target Flux Density in Selecting Current for Circular Shot

3.2 COIL SHOT (LONGITUDINAL FIELD)

The formula used by most inspectors for determining the approximate amount of current to use when magnetizing a part positioned on the I.D. surface of a magnetizing coil is:

$$I = \frac{K}{L/D \times N}$$

Where:

I = current in amperes
D = part diameter and
K = 45,000
N = number of turns in coil

L = part length

This formula is valid only for parts with an L/D ratio of 2 to 15 and is independent of coil diameter provided the part's cross section area is not greater than 1/10 that of the coil. For parts exceeding this limit, the "constant" changes and the coil diameter is included in the revised formula.

The formula indicates that the amount of current to use depends entirely on the part's L/D ratio. For example, if a part's length is doubled, the amount of current to use to produce those same indications would be cut in half. To check this theory, a new inspector could take two bolts having the same diameter, six inches (15 cm) long, and hold them end-to-end in the center of the coil. When coil is energized, use the **Hall Effect Meter** to measure B_T. If one of the bolts is then removed and the coil re-energized, B_T. on the remaining bolt should drop by 50%.

Note, the formula tells us that short parts require more force to magnetize them than longer ones. When magnetizing a part in a coil, magnetic poles appear at the ends of the part. These poles are formed as such that they decrease the magnetizing field within the part. This effect is called "self-demagnetization." Since the poles are localized to the ends of the part, their effect on magnetizing the part decreases as the part length increases.

Finally, keep in mind that should the length of a part exceed the coils inside diameter by more than 50%, the part must be processed more than once to attain best inspection sensitivity. (In examples using a 12 inch (30 cm) diameter coil to magnetize a 60 inch (1.5 m) long shaft, the shaft should be processed four times. A quick check, using a **QQI,** would most likely reduce the number of processings to two.

3.3 MULTIPLE PASS WELDS AND STEEL CASTINGS

Where subsurface sensitivity is required, HWDC current must be used along with contact prods. Lack of penetration at the root of the weld, lack of fusion where the filler metal fails to coalesce with the base metal, subsurface shrink and inclusions can all be detected within limits. Surface flaws, such as undercut and overlap, surface shrink, and crater cracks, can be detected with either AC or HWDC. MPI cannot detect porosity.

To attain subsurface sensitivity, use the **RULE OF EIGHT**. At prod spacing of eight inches (20.3 cm), use 800 ampere HWDC to locate a flaw one-eighth of an inch (3.17 mm) below the surface. To increase sensitivity and locate flaws one-quarter inch (6.35 mm) below the surface, either go to six inch (15.2 cm) spacing and 1200 amperes or eight inch (20.3 cm) spacing and 1600 amperes. Do not apply the powder; blow off any excess amount and then turn off the current. Performing the inspection as the powder is applied attains best sensitivity.

At high values of current, there exists a dead zone of about one-half inch (12.7 mm) around each prod as current enters or leaves the weld. The excessive powder built up around the prods makes less than six inch (15.2 cm) spacing non-productive. This is the primary reason the inspector must overlap the prod about one inch (25.4 mm) as he proceeds to inspect long welds.

Prod must be placed on the weld, never on the base metal being joined. Burn spots on a cast product, such as the welds, are not acceptable if they can be avoided; but on a wrought product, they are much more likely to be a starting point for metal fatigue. Prod tips must be dressed frequently to avoid arcing.

Except for crater cracks, all multipass weld defects run with the weld so inspection is required in only one direction.

If for some reason only surface defects in the weld are to be located, AC magnetizing may be used. Perhaps the inspector is looking only for fatigue cracks. If this is the case, 12 inch (30.5 cm) to 18 inches (45.7 cm) prod spacing may be used. A **Pie Gauge** can verify sensitivity.

3.4 INSPECTION AIDS TO DETERMINE CURRENT TO USE

Pie Gauge. A typical gauge is made of eight, highly permeable, low retentivity steel segments, brazed together in the shape of a pie. When held against the surface of the part while magnetizing it, the magnetic force generates a flux field across one or more of the four simulated cracks in the pie.

The pie gauge finds its primary use on applications where large parts are being magnetized using clamps and coil wraps with the dry method. Dry magnetic particle indications do stay in place after the force is removed.

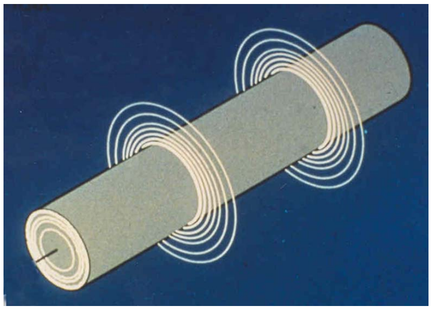
Inspectors on wet applications also use the pie gauge. When a bath containing magnetic particles is flowed over the gauge, good indications form. The indications will stay in place as long as the flux field exists. However, these indications melt away quickly when the current goes off. The indications on the gauge must be viewed under black light while the current is flowing. On complex shaped parts, processing the part and gauge at the same time is not always easy. When possible, it will furnish reliable information on the direction of flux flow.

Hall Effect Meter

With the introduction of the Hall Effect Probe, the 1000-ampere figure for a head shot dropped to 500 amperes and in some applications as low as 300 amperes. The inspector could now measure the exact amount of B_T at any point on the part considered critical. Many companies conducted tests on their products. Most agree that Hall Effect readings of 30 to 60 gauss in air on the surface of the part were high enough to disclose defects they considered critical. Inspection supervisors knew these values were conservative and modified them downward for production inspection only when a group of sample test parts containing known typical defects in all critical locations was available. Determining B_T at some locations on a part when magnetizing with a coil can sometimes be difficult. The Hall Effect Meter probe coil must be held normal (at an angle of 90°) to the surface, fixtured if necessary. Readings taken near the ends of a part can include values of flux density normal to the surface (B_N) since it increases rapidly at these locations. For this reason, some firms still do not rely on B_T readings taken while magnetizing with a coil.

Readings of gauss taken by the Hall Effect Meter are a compromise. There is no convenient way to measure the actual amount of flux passing through the defect near the surface of the part, causing a leakage field. We therefore measure the value of B_T in the air as close to the part surface as convenient.

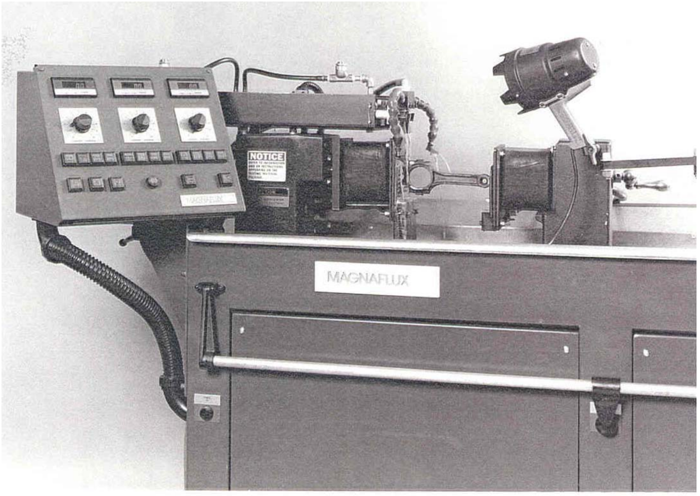
Even this reading is a compromise since we are taking our reading at the centerline of the Hall Effect Probe's coil. For a part circularly magnetized, B_T in air drops slightly as distance from the part increases **(Fig. 3.2)**. Conversely, for parts longitudinally magnetized, B_T in air increases slightly as distance from the part increases since the "self demagnetizing effect" decreases.



(Fig. 3.2).
Magnetic Field During Current Flow Through A Part

When the use of the Hall Effect Meter was first introduced for estimating inspection sensitivity, some firms felt there were too many variables involved, particularly when a coil was being used for magnetizing. Since the advent of the calibrated Paste On defect, the two "inspection aids" working jointly have proven useful in all industries.

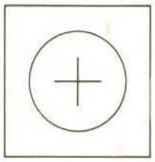
(Fig. 3.3) On this unit, the single magnetizing coil has been replaced by two coils, wound around pole pieces located in back of the headstock and tailstock contact plates. These pole pieces effectively increase the L/D ratio of the part, requiring less current for magnetizing. (More about these pole pieces when Multi-Directional Magnetizing)

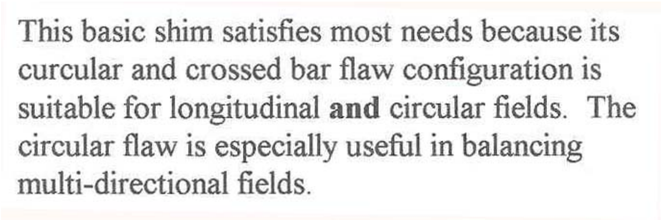


Single Magnetizing Coil is replaced by
two coils wound around pole pieces
to increase L/D ratio of part

(Fig. 3.3) Pole Pieces Increase L/D Ratio

Paste on Defects - QQIs. For many years, a paste on defect that worked, one with accurate, reproducible values, was a dream. The QQI introduced in the 1980's was an answer to that dream. **(Fig. 3.4)** It is a small steel shim, .750 inches (1.9 cm) square, .002 inches (50 microns) thick containing a precision etched simulated defect, a circle and cross. It is made of highly permeable, low retentivity steel. When used, it is held against or glued on a part, with the simulated defect face down.





This basic shim satisfies most needs because its curcular and crossed bar flaw configuration is suitable for longitudinal **and** circular fields. The circular flaw is especially useful in balancing multi-directional fields.

(Fig. 3.4) QQI Field Indicator

QQI's are not the least bit retentive. If they were, they could not be used in multi-directional magnetizing operations. However, at times a given QQI glued to a part may appear to be retentive by retaining an indication after the magnetizing force has been removed. This happens when the test part is very retentive and contains a longitudinal field. The part itself is magnetizing the QQI. This phenomenon will not occur should the retained field be circular since a circular field has no poles and is entirely contained within the part.

Sharp cracks, open to the surface, require only one or two gauss of B_T, as measured with a Hall Effect Meter. Forging laps, which are neither open to the surface nor normal to it, are harder to indicate. They require five or more gauss to provide an indication that may be easily viewed.

Many inspectors use these QQI shims, much like a pie gauge is used. One of them is glued, face down on the end of a thin, flat piece of stiff plastic about .750 inches (19 mm) wide, 5 inches (13 cm) long. When held against and processed with the part, the shim indicates the direction and amount of flux flow. Unlike the pie gauge, the particles hold their position after processing. Indications may be viewed any time after processing.

Now take a closer look at the design of the QQI. **(Fig 3.5)** The defect depth of .0006 inches (15 microns) is the <u>height</u> of the artificial flaw. The defect's depth below the surface is .0014 inches (35 microns). The value of the leakage field, which controls the brightness of the indication, will increase the deeper the cut is made in the QQI. There are two reasons for this. First, the number of flux lines intercepted by the artificial flaw increases as the <u>height</u> of the flaw increases. In addition, the number of those flux lines that reach the surface of the QQI increases as the depth of the flaw beneath the surface <u>decreases</u>. The QQI shows a reasonable indication at 5 gauss and a very bright indication at 15 gauss.

Most aerospace and automotive firms, after using QQI's for several years, rely on them. The 5 to 15 gauss range is considered both safe and conservative. They realize that there are other operating variables involved in MPI processing that may deteriorate, such as bath quality and lighting. Flaws a little bit harder to find are therefore a plus.

Other uses of QQI's will be reviewed later under headings of Multidirectional and Induced Current Magnetizing.

(Fig. 3.5) QQI Cross Section
(not to scale)