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Understanding Test Ring Specimens

History:

The term “Ketos” is actually Crucible Steel’s registered trade name for the industry standard oil-hardening tool steel (AISI – 01). The term “Ketos” ring has been used in our industry so long that it has become synonymous for the “test ring specimen” that we currently use today as an overall system performance indicator in the magnetic particle inspection process.

Most people who are familiar with the MPI process are already aware of the current usage of this ring, however not all parties are aware that this ring actually started life as a gauge intended to be used for quantifying the sensitivity of magnetic particles.

William E. Hoke has been credited with being the first to understand and describe magnetic particle testing some time after WW-I. Later Alfred V. de Forest made a review of Hoke’s work and became the first to use high current electric fields to develop the required magnetic fields necessary in the magnetic particle inspection process. On July 5th, 1929 the patent for this work was applied for. Between the years of 1934 and 1935 de Forest applied for patents covering the particles used in the magnetic particle inspection process. In 1935 C.E. Betz began improving upon the particles and pastes used in the wet method. Soon a methodology was needed to be able grade the overall sensitivity of the magnetic particles used in the MPI process and the Ketos Ring was born, first known as the “Betz Ring”.

As time moved forward, the ring moved out of the lab and onto the production room floor where is was then used as a comparative reference standard. With this development, the demand for the rings went up and as the demand went up, so did the number of different ring suppliers.

This is where some of the problems started, not all of the suppliers produced the rings in exactly the same way and the results turned out to be much like having multiple suppliers all producing micrometers with randomly oriented numbering on the thimbles.

As one might expect, when used as a gauge for grading the sensitivity of magnetic particles, it is highly critical that all of these rings perform in exactly the same way, otherwise there would be no perceived consistency in the particle performance even if there was.

Ring Differences:

There still continues to be a lot of confusion regarding the differences between these two rings, so let’s start by discussing exactly what these differences are.

The image shows a 1928 Electyro-Magnetic Steel Testing Device (MPI) made by the Equipment and Engineering Company Ltd. (ECO) of Strand, England. Photo Courtesy of NDT-ed.org

Both the original “Ketos” Ring and the “AS5282” Ring are actually rings manufactured out of the same AISI-01 tool steel and they are dimensionally equivalent, with the exception of the *optional* removal of deepest few holes in the AS5282 version, the ASME version and the GE version specified in P3TF48.

The *intended* heat treatment *is the same for both specimens*, however SAE AS5282 does goes on to further clarify the details of the heat treatment methodology in a manner much better than most of the other previous documents.

The tool steel that these rings are made from is generally supplied in the annealed state (technically, a normalized state) when it is sold; otherwise the end users would not be able to machine it. It is important to remember it is not the steel produces goal to put the steel in a magnetically homogeneous state, only to make it easy and uniform for the customer to machine. This as-supplied hardness generally runs approximately 91-92 RHB. The goal of first step in the heat treat cycle as specified in SAE AS 5282 - section 3.3, is to put the steel in a machinable state. This is almost always performed by the steel supplier prior to shipment of the product; if it is not, this step must first be performed by the OEM and is spelled out here. After receipt of the normalized bar stock from the steel house, the first step is to saw cut the material into rings blanks; then all of the other secondary machining operations are performed on the ring. After completion of all the secondary operations, the ring goes through the *final* heat treatment operation which *is intended* to put the ring into a magnetically homogeneous state. The RHB hardness number generally does not vary more than about one point from the time the steel is delivered from the supplier in the normalized state, to the final fully-annealing state, post machining. Other than dimensional gauging, the hardness check was the *only* required NDT test of the first generation of the test

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rings (Ketos Rings). Since the hardness value does not change much (generally <1 point), the customer can not easily detect if this *required* final annealing operation had ever been performed.

This *final* full-anneal operation is detailed in SAE AS 5282 section 3.4. This portion of the required heat treatment is essentially no different than it was approximately 60 years ago; the verbiage has just been clarified a bit in the AS spec so as to eliminate as much confusion as possible. The time and temperature requirements are actually based off of the steel manufacturer's recommendations for this alloy; **this is true for both versions of rings.** Slight variations in the time and temperature values can be seen between Crucible Steel's recommendations for annealing and the listed NDT specs below, however these differences are no more than what can be found between the different brands of O-1 tool steel manufacturers. The requirements listed in the NDT specs do tend to be a bit more conservative comparatively.

Specification Differences:

Now the "reasons for being" on the "new" 13-year old AS spec:

SAE AS-5282 came into existence as a corrective action to combat the tremendous variations in the performance of rings being produced and sold over the past 60 years or so. Unfortunately, these variations were further amplified when ASTM E1444-94a changed the requirement for the *most critical final heat treatment* from a *shall* , to a *may* condition. The next revision which was ASTM E1444-01, *actually eliminated the final heat treat requirement altogether.* Elimination of that step did save the ring manufacturers money……however, the final result of this action spoke for itself.

Previous to the introduction of AS5282 there was no "magnetic" qualification test requirement on *any ring* to insure that it was in fact produced in a magnetically homogeneous state. Two of the main goals of AS5282 were, 1. introduce a methodology to magnetically qualify and quantify the test ring and, 2. make the ring individually traceable to the plotted results. The shortcomings in ASTM E1444 were never addressed by SAE.

In any magnetically homogeneous material one should expect to see a direct relationship between the field strength and the measurement distance; in this case it would be the increasing distance from the outer periphery to the holes. The inverse square would result in air when doubling the distance and in any magnetically homogeneous material, one should expect something approaching this same relationship. On a good ring, *regardless of the version*, the results should show this type relationship when mapped. For examples of this see illustrations 1 & 2.

With a qualified magnetizing power supply (not an MPI machine) and proper magnetic data logging equipment an individualized field leakage plot of the ring may be obtained in order to quantify and qualify this variable for the finished ring.

Usage Notes:

Oddly enough, people still get confused over the proper use of the Ketos test ring, so the next few paragraphs have been added to help add clarification.

In short, this ring is generally considered a quick and easy "gauge" to determine the machine's overall system condition prior to inspection of parts. This is to be used as one of the daily systems tests which are to be logged for each machine in use. So with this being said, one is using the ring to check the system, *not the system to check the ring*. "Certifying" the test ring with a mag machine is working backwards and although this may seem obvious, it is still done.

As most people are already aware, either version of the test ring is intended to be used on machines with a **DC** output waveform. That could be either HWDC or FWDC, in a single-phase configuration, or in a three-phase configuration. Any one of these DC waveforms should give similar, but not exactly the same results on the test ring, assuming the ammeters are properly scaled and calibrated. Due to the pulsating nature of the HWDC waveform, HW generally has a tendency to show more lines that FW does at a particular given amperage. It is also interesting to note that not all ammeters which claim to be scaled to properly read HWDC actually are; this can be another major source of consternation when using the test ring.

With all of this being said, the number of lines you get on a *qualified* AS5282 Ring, or Ketos ring should not be a variable of the ring itself, but some other combination of the variables of the entire inspection system. If one has a good ring and they are having problems developing an adequate number of lines at a given amperage, it would indicate some type of problem within the system which would need to be corrected prior to performing any actual inspection work. However, when problems do come up, it is always good practice to look at the ring's pedigree; any ring without an individual serialized field plot should be suspect right away. Make sure you have a gauge prior to trying to perform a measurement, without one it simply cannot be done.

There are many system variables which can affect how many lines one might see on the ring, but once you have a known good standard, you can then make meaningful tests.

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General Notes on Annealing and Normalizing:

The main difference between full annealing and normalizing is that fully annealed parts are uniform in softness (and machinablilty) throughout the entire part; since the entire part is exposed to the controlled furnace cooling. In the case of the normalized part, depending on the part geometry, the cooling is non-uniform resulting in non-uniform material properties across the part. This may not be desirable if further machining is desired, since it makes the machining job somewhat unpredictable. In such a case it is better to do full annealing.

Read more: http://wiki.answers.com/Q/What_is_difference_between_annealing_and_normalizing#ixzz1HSWRoS18

NOTE: Some of the NDT documents reviewed use the word *may* and *should* instead of the correct word *shall* for the final annealing cycle. SHALL was the intended operation to have been performed on *all* of these rings.

This deviation from the original intent of the documents *could* have been a typo in E1444-94a which then was copied from document-to-document, just like the words "*ANSI* 0-I Tool Steel", instead of the correct *AISI* O-1 Tool Steel, but reviewing the history of changes, it appears that this was an intended change at the time, probably because of the lack of understanding for the reason behind the final annealing step.

It is interesting to note that the GE document did maintain the correct word *shall*, however the typo of "ANSI" was not corrected; this typo is the same as in ASTM E1444-91 through E1444-05 and ASME Sec V. Additionally, ASME listed two different annealing methods within the same document without the accompanying reasoning for the discrepancy.

Annealing Verbiage Contained within the Steel Makers Specifications

Verbiage from Crucible Steel's Tool-Steel Handbook

KETOS® Steel (AISI O1 Steel)
Annealing

*Full Anneal
1. Heat to 1400/1440° F. hold for 2 hours.
2. Cool slowly at a maximum rate of 50° F per hour to below 1200° F.
3. Air Cool

Verbiage from Cincinnati Tool Steel Company

AISI O1 Steel
Annealing

The recommended annealing practice is to use controlled-atmosphere furnaces. If these are not available, pack-anneal in an inert material. For a quick annealing cycle to develop fair machining properties, heat slowly to 1375 to 1425°F. and cool slowly in the furnace. *To develop the lowest hardness and best spheroidization for optimum machinability, heat slowly to 1450°F. and furnace cool at 20 degrees per hour to 900°F. The piece may then be removed from the furnace and cooled in air. Hardness after this cycle will be Brinell 202 max.

*Full Anneal
1. Heat to 1450° F. (no mention of soak time)
2. Cool slowly at a maximum rate of 20° F per hour to below 900° F.
3. Air Cool

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Chronology of Related Specifications:

Changes in MIL Documents over the decades:

MIL-M-11472 – 24 Nov 1952, makes no mention of test rings specimens at all.

MIL-M-6867C – 27 Jan 1969, makes no mention of test rings specimens at all.

MIL-I-6868E – 8 March 1976, references the "Ring Specimen" however gives no data for heat treat or alloy.

MIL-STD 1949 – 1 Aug 1985, uses the *correct* acronym for the steel alloy and uses the word *shall* in the annealing requirements, however it *does not* go on further to state the specific annealing methodology within the document.

Changes in ASTM E1444 over the decades:

ASTM E1444-91 – 15 Nov 1991, uses the *incorrect* acronym for the steel alloy and uses the word *shall* in the annealing requirements, and it *does* go on further to state the specific annealing methodology within the document.

ASTM E1444-94a – 15 Nov 1994, uses the *incorrect* acronym for the steel alloy and uses the word *may* in the heat treat section. No reference to AS5282 Ring introduced yet.

ASTM E1444-01 – 10 Feb 2001, uses the *incorrect* acronym for the steel and the ***heat treat section has now been completely eliminated*** for the original "Ketos" ring. Reference table inserted for AS5282 Ring.

ASTM E1444-05 – 1 Mar 2005, uses the *incorrect* acronym for the steel and the heat treat section continues to be eliminated on the original "Ketos" ring. Reference table included for AS5282 Ring.

ASTM E1444M-11 – Sept 26, 2011, no change in the -05 verbiage used.

Note:
This document was passed out for review at the June 2011 ASTM meeting to be used as the basis for future corrections to be inserted into the next E1444 document revision. A new ASTM Work Item (WK35427) for E1444 was created and went out for subcommittee voting on November 28 2011. The necessary corrections to restore the original -91 verbiage (with corrected typos) were added to this work item as ballot items 7 and 8. The ballot was voted on and the various negatives were then reviewed at the January 2011 meeting in Plantation Florida. Several members voted negative on the ballot line items 7 and 8. The basis of these negatives can be paraphrased as essentially this: "There is approximately 20 years worth of rings out in the field which would all have questionable compliance to the proposed newly restored -91 version of the verbiage and we (these voting members) feel that there is no value added to compel our vendors to have this compliance". The subcommittee member group upheld the negatives using the following rational; " the current document does not force the user to utilize the "Ketos Ring" as their overall system check, and it does allow other alternatives to be used". However, nothing was mentioned about the companies which *had, and will continue to be using this particular ring* (one which lacks an adequate pedigree to be considered a gauge) as the basis for their system performance test. This means that the 20 years worth of confusion over this correctable issue will not be corrected at this time. Expect audit issues to continue for the users of this ring.

As an additional side note: For those who are unfamiliar with the way ASTM operates, it is an organization made up of committees and subcommittees composed of volunteer members who write *consensus documents*. This means whether right, wrong, or indifferent, whatever ends up in the documents has agreed to by the *majority* of the voting members.

Changes in SAE AS5282 to date:

SAE AS5282 – Mar 1998, uses the SAE J438 (or equiv) description for the steel and an independently defined section detailing the annealing and normalizing of the ring (section 3.3 and 3.4).

Annealing Specification Verbiage:

Annealing Verbiage from ASTM E1444 -91

The ring **shall** be heat treated as follows:
1. Heat to 1400/1450° F. (760° to 790°C) – hold for 1 hour.
2. Cool to a maximum rate of 40°F/hr (22°C/hr) to below 1000°F (540°C).
3. Furnace or air cool to room temperature.

Annealing Verbiage from ASTM E1444 -94a (Same as E-1444-91 except for the substitution of **shall,** for **may**)

The ring **may** be heat treated as follows:
1. Heat to 1400/1450° F. (760° to 790°C) – hold for 1 hour.
2. Cool to a maximum rate of 40°F/hr (22°C/hr) to below 1000°F (540°C).
3. Furnace or air cool to room temperature.

Annealing Verbiage from SAE AS5282

The ring **shall** be heat treated as follows:
1. Heat to 1400/1440° F. (760° to 782°C) – hold for 3 hours minimum.
2. Cool to a maximum rate of 50°F/hr ± 5°F (28°C/hr ± 3°C) to below 1200°F (649°C).
3. Furnace or air cool to room temperature.

Verbiage from GE P3TF48

The ring **shall** be heat treated as follows:
1. Heat to 1400/1450° F. (760° to 790°C) – hold for 1 hour.
2. Cool to a maximum rate of 40°F/hr (22°C/hr) to below 1000°F (540°C).
3. Furnace or air cool to room temperature.

Verbiage from ASME Sec V Article 7 July 1 2008

Note: The body of text in T-766 does not match the verbiage in the illustration T-766.1; both are shown below.

[1]Heat Treat verbiage under **Illustration** T-766.1
The ring **may** be heat treated as follows:
1. Heat to 1400/1500° F. (760° to 790°C) – hold for 1 hour.
2. Cool to a maximum rate of 40°F/hr (22°C/hr) to below 1000°F (540°C).
3. Furnace or air cool to room temperature.

[1]Heat Treat verbiage in **text body** T-766.1
The ring **should** be heat treated as follows:
1. Either the ring, or the steel blank **should** be annealed at 1650° F. (900°C).
2. Cool to a maximum rate of 50°F/hr (28°C/hr) to below 1000°F (540°C).
3. Furnace or air cool to room temperature.

There is an added reference note which states “Material and heat treatment are important variables. Experience indicates controlling the softness of the ring by hardness (90 to 95HRB) alone is insufficient.”

[1]The intent of both portions of the document seems to address the *final* heat treatment portion of the product rather than the pre-delivery normalizing portion of the steel and since one section says “may” and the other says “should”, it would *seem to indicate* that the “should” portion would be their preferred method. (The higher annealing temperature of 1650° F will generally result in a slightly softer material hardness value.)

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Some Industry Specific Document Verbiage Regarding Test Rings:

GE P3TF48:

P3TF48 - 14 Feb 2000, uses the *incorrect* acronym for the steel, however does use the correct word *shall* in the heat treat section and unlike the later "Ketos" standards documents, GE's document has an extra note under the illustration, which allows for holes 8 through 12 being optional.

ASME Section V Article 7:

2008a Addenda - 1 July 2008, uses the *incorrect* acronym for the steel, and has *two different methods* spelled out for annealing, one uses the word *may* in the heat treat section and the other section uses the word "should" in the second annealing reference. Like GE's document, ASME has an extra note under the illustration, which allows for holes 8 through 12 being optional.

2010 - 1 July 2010, no change from 2008a version.

Bell Helicopter BHT-ALL-SPM:

BHT-ALL-SPM - 16 Feb 2007, MPI process control allows usage of both rings, but no mention is made regarding heat treatment of either.

Bell Helicopter BPS 4075 Rev K:

BPS 4075 Rev K - 21 Sept 2004, Only states the following regarding the usage of a test ring – "2.7 Test Sensitivity Ring. A test sensitivity ring in accordance with ASTM-E1444 shall be available."

Boeing DPS 4 704 Rev AP:

DPS 4 407 - 02 Nov 2008, MPI process control allows usage of both rings, but no mention is made regarding heat treatment of either. "The ring shall be fabricated from AISI 01 tool steel *cut from annealed round stock*. *Its Rockwell - B hardness shall be a maximum of 95."* This seems to imply that no final anneal cycle is required and there is no mention of anything further in the body of the text or the notes section of the illustration.

Boeing BSS 7040 Rev A:

BSS 7040 - 20 Feb 2009, MPI process control allows usage of the AS5282 ring, but no mention is made regarding heat treatment in the main body for the text and there is no illustration in the main document.

Rolls Royce EIS 901:

EIS 901 - 18 Jan 2008, MPI process control allows usage of the AS5282 ring, but no mention is made regarding heat treatment. The verbiage in the notes section of the illustration states "Hole numbers 10–12 are optional. Material shall be AISI 01 tool steel from annealed round stock. Hardness shall be 90–95 HRB." This seems to imply that no final anneal cycle is required and there is no mention of anything further in the body of the text or notes section of the illustration. This also seems to state that there is a *minimum hardness* of 90HRB. AS5282 allows a maximum of 95HRB with no minimum hardness tolerance being stated.

Airbus A310 Part 8 51-80-00 & A318/A319/A320/A321 Nondestructive Testing Manual 51-70-00-PB1 Feb 01/11:

A310 Part 8 51-80-00 - 01 June 1991, MPI process control allows usage of the Ketos rings, the heat treatment verbiage is stated in note 5 under the illustration as follows: "The ring **may** be heat treated as follows: HEAT TO 1400° TO 1450°F, (760° to 790°C) Hold at this temperature for 1 hour. Cool to a maximum rate of 40°F/hr (22°C/hr) to below 1000°F (540°C). Furnace or air cool to room temperature." Note 4 states: "Material is **ANSI** O1 Tool Steel from annealed round stock." This is the same verbiage as in ASTM E1444-94a which also uses *may* in the heat treat section and the incorrect acronym for the steel alloy.

ISO 9934-1, 2, & 3:

ISO 9934-1:2001(E) - 1 Dec 2001, MPI General Principles - no mention is made regarding either style O1 alloy test ring.
ISO 9934-2:2002 (E) - 1 Dec 2002, MPI Detection Media - no mention is made regarding either style O1 alloy test ring.
ISO 9934-3:2002(E) - 15 July 2002, MPI Equipment - no mention is made regarding either style O1 alloy test ring.

ASTM E709-08:

E709-08 - 15 Feb 2008, 20.8.4 *Test Ring Specimen*—A verification (Ketos) ring specimen may also be used in evaluating and comparing the overall performance and sensitivity of both dry and wet, fluorescent and non-fluorescent magnetic particle techniques using a central conductor magnetization technique. Refer to Practice E 1444, Appendix X1.

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Sample Ring Plots

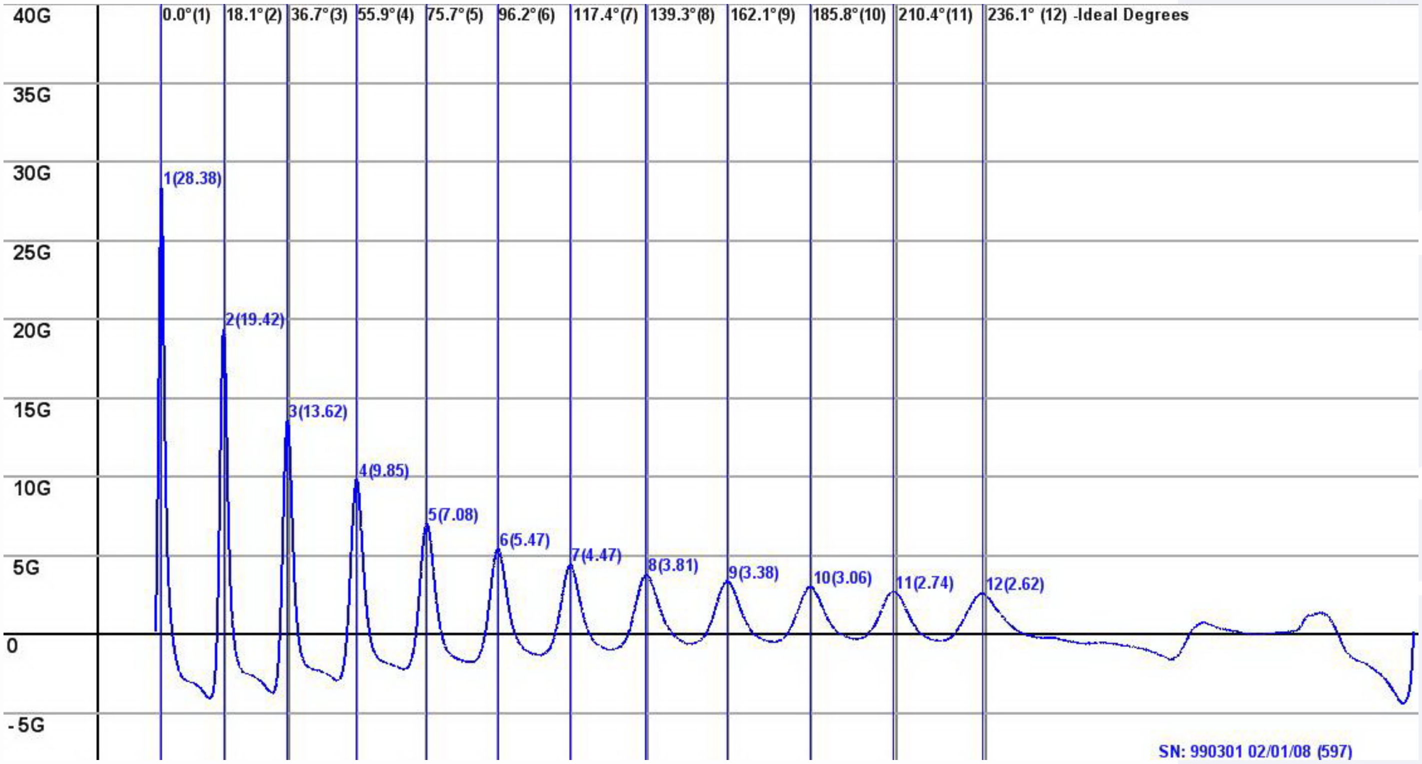

Illustration 1: Typical Good Magnetic Field Leakage Plot.
(Note: the two indications seen on the tail end of this plot are from a milled pocket which contains the name and serial number and is not relevant).

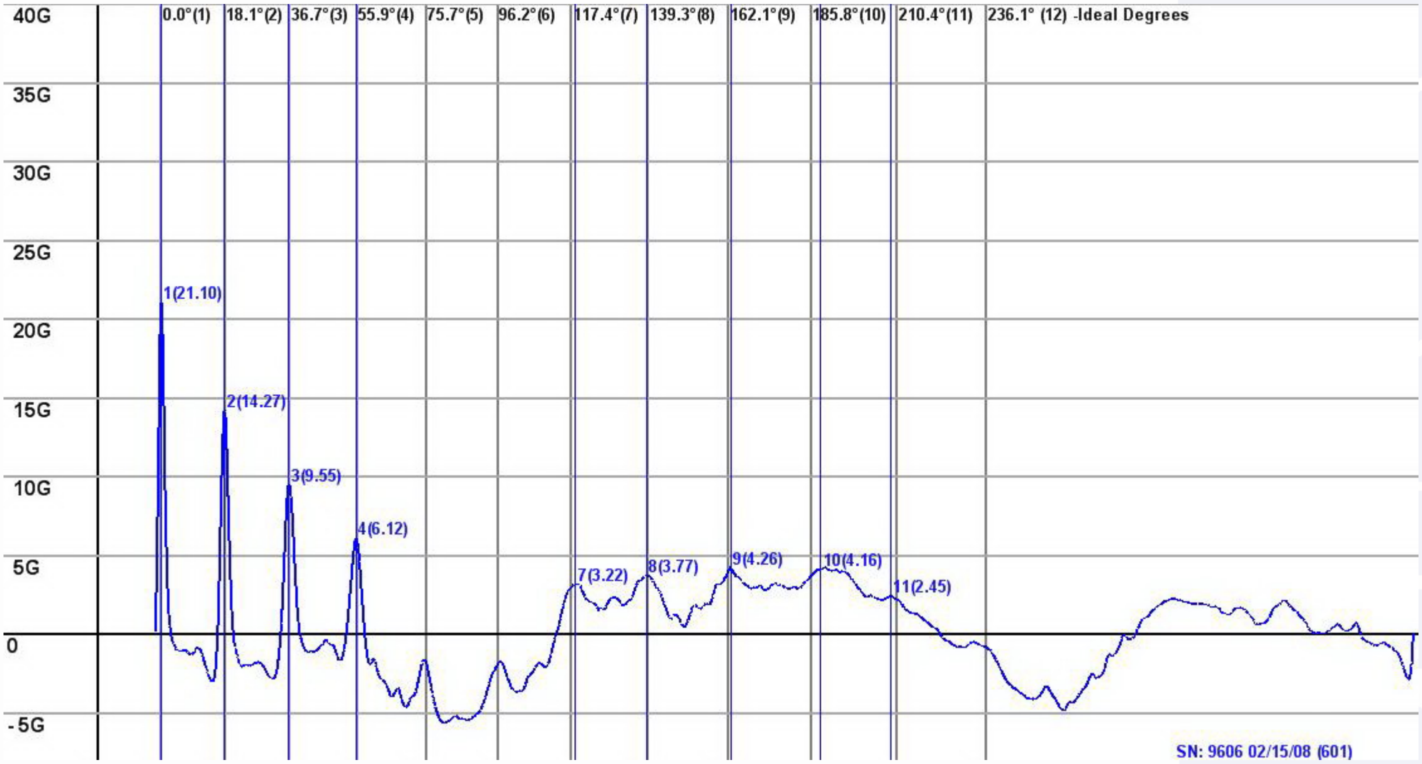

Illustration 2. Typical Failure of Magnetic Field Leakage Plot.

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Sample Ring Plots Cont.

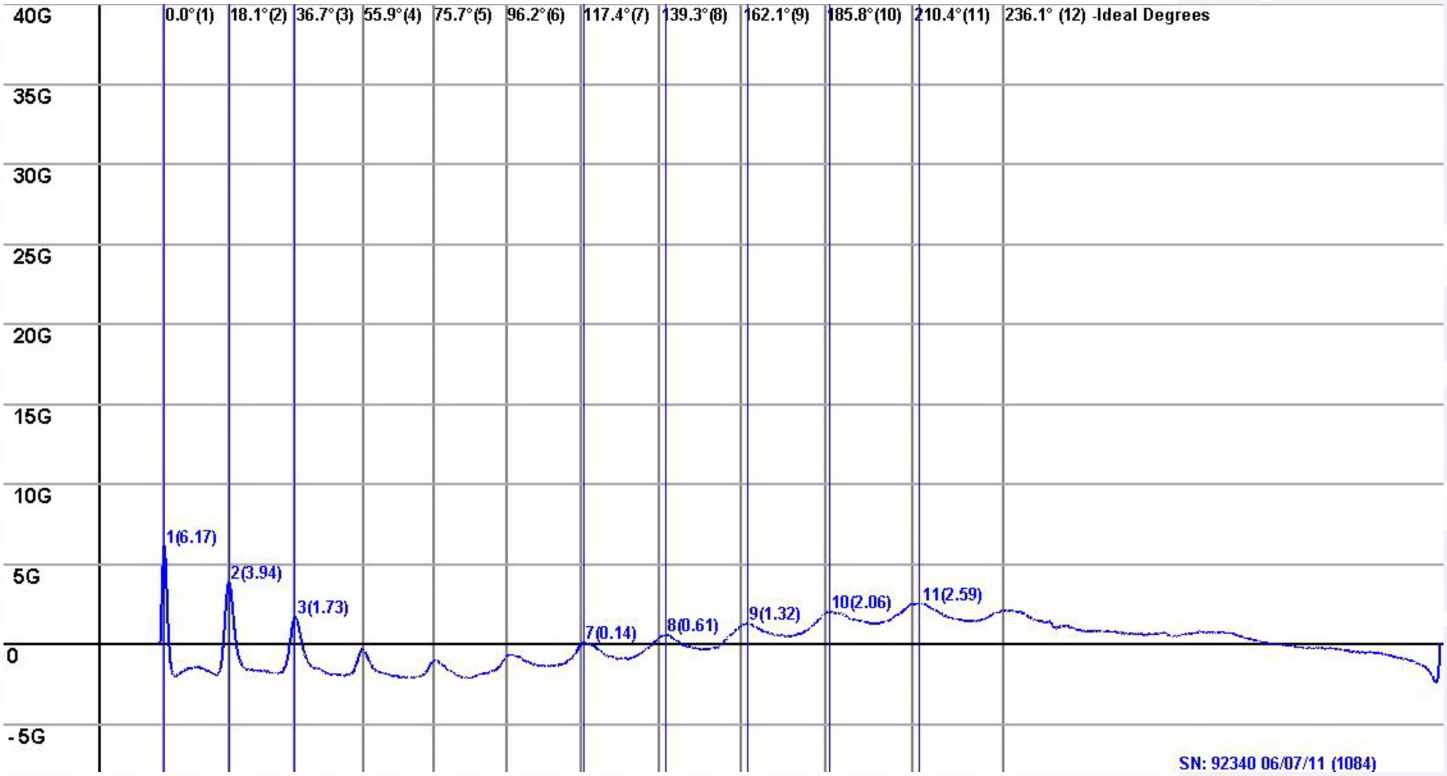

Illustration 3. Typical Failure of Magnetic Field Leakage Plot.

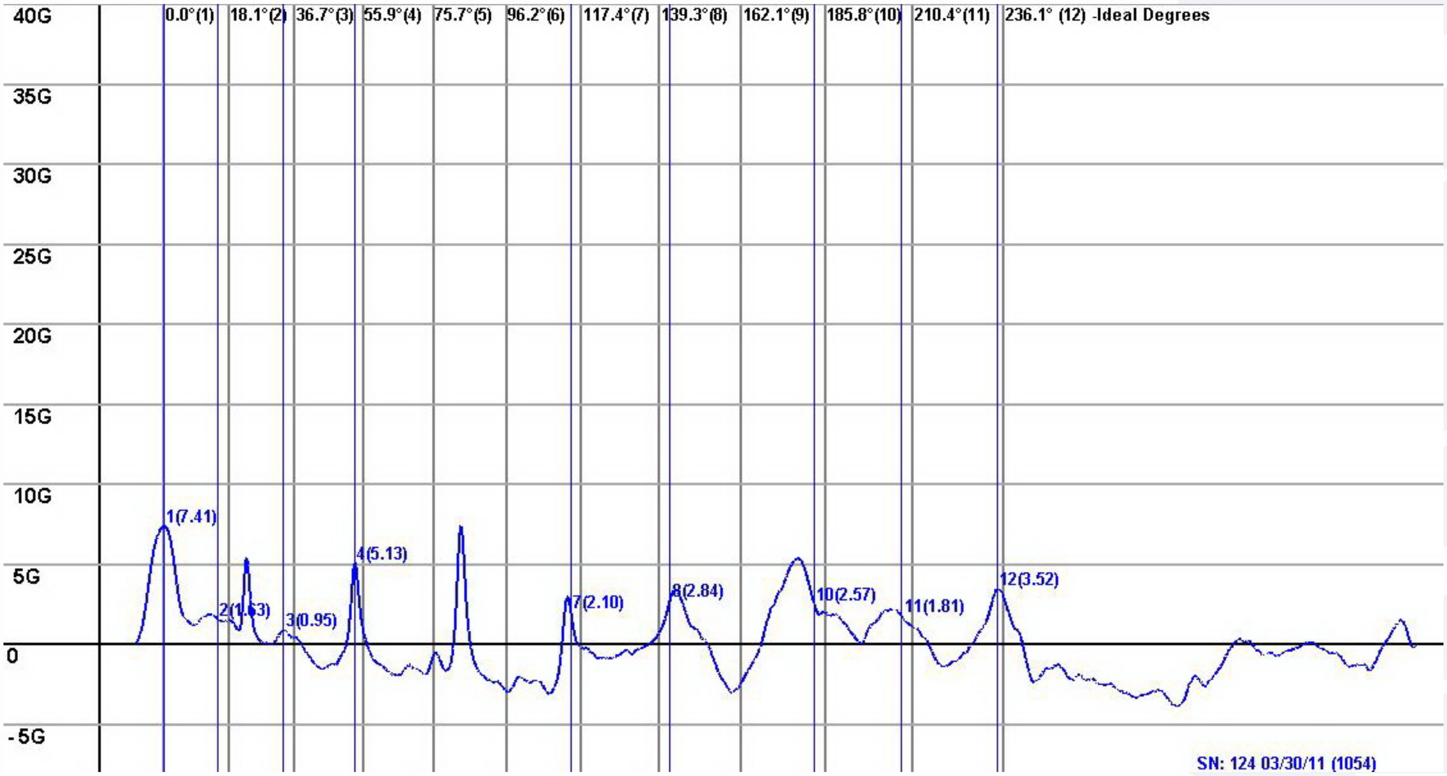

Illustration 4. Atypical Failure of Magnetic Field Leakage Plot.
(This plot from NIST ring SN124 is so bad that it actually broke the peak counting and identifying algorithm in the software.

**The relevant question at this point should be; do you want to be using rings that were manufactured with a *may,* or a *should,* instead of a *shall* and then trying to achieve comparative test results, and furthermore, do you want *your AS/SAE particle supplier* grading his particles using a ring that was manufactured with a *may,* or a *should,* instead of a *shall?*

Magwerks has hundreds and hundreds of sample plots on file and other examples are available upon request. Specific questions may be addressed to Patrick Jenkins at pjenkins@magwerks.com regarding this article.