Agilent AN 1319

Compliance Testing to IEC/EN 61000-4-8

Application Note

Compliance Testing to the IEC/EN 61000-4-8 Standard

"The magnetic fields to which equipment is subjected may influence the reliable operation of equipment and systems."

The statement above is taken directly from the IEC/EN 61000-4-8 standard, and is the premise upon which the standard is based. Electronic equipment can encounter magnetic fields at power line frequencies in a variety of places. As such, it is wise to ensure that the equipment will operate reliably when exposed to these power line frequency magnetic fields. The IEC/EN 61000-4-8 standard describes how equipment should be tested for immunity to power line frequency magnetic fields. This application note provides a discussion of the standard, including interpretation of the requirements, and suggestions for equipment selection.

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Agilent Technologies

Introduction

Magnetic fields generated at power line frequencies are all around us. The electronic equipment we use is subjected to these fields in a variety of places: residential and commercial locations, industrial installations and power plants, and medium and high voltage sub-stations. The source of the magnetic fields is typically the power line current flowing in conductors, or occasionally, transformers in nearby equipment. As such, it is wise to ensure that electronic equipment will operate reliably when exposed to these power line frequency magnetic fields, namely, 50Hz or 60Hz, depending on the country. The fields may be present continuously, or for short duration, so equipment may have to be tested by being exposed to either type of field. The proximity of the equipment to the source of the magnetic disturbance will also significantly affect the equipment's behavior within the magnetic field since the field strength is dependent on the distance from the magnetic disturbance.

The IEC/EN 61000-4-8 standard addresses these phenomena. Part 4 of the 61000 series refers to "Testing and measurement techniques," while Section 8 addresses the "Power frequency magnetic field immunity test." This standard describes an immunity test. It specifies the magnetic fields to which electronic equipment is subjected to ensure the equipment continues to operate reliably. Stated another way, it ensures that electronic equipment is immune to certain commonly occurring magnetic fields, fields that the equipment is likely to encounter during operation. The specific fields are those occurring at the power line frequencies. Although immunity limits are not specified in this standard, generic immunity standards or product standards state specific limits. The standard also does not address fields produced at frequencies other than 50Hz and 60Hz, nor does it address magnetic fields resulting from dc current flow. Although it is recognized that the current producing the power line frequency magnetic fields contains harmonics of the line frequency, the resultant harmonic magnetic fields are thought to be negligible and are therefore not considered in the present revision of the standard.

Under normal operating conditions, power line frequency current flows continuously in conductors, producing continuous or steady power line frequency magnetic fields. When some type of fault occurs, the fault condition can cause comparatively high current to flow in the conductor. This high current may exist for only a short duration if a protection device like a fuse, circuit breaker, or other protection circuitry interrupts the flow. High current can also temporarily exist during initial power turn-on of some electronic equipment. A comparatively high magnetic field will result while the current is flowing, but again, for only a short duration. The standard addresses both types of fields (continuous and short duration) by specifying field strengths for continuously applied fields and even higher field strengths for short periods of time that could occur under fault or ac turn-on conditions.

The method for testing equipment for immunity to magnetic fields is to produce a controlled magnetic field of known field strength by driving a large coil with a test generator, and placing the equipment in the center of the coil, thereby subjecting the equipment to the magnetic field. Proper operation of the equipment is evaluated during the application of the field. For equipment that will be tested, the IEC/EN 61000-4-8 standard provides guidelines for selecting a magnetic field strength test level, test generator specifications, induction coil specifications, as well as test set-up, procedure, and reporting information.

Selecting a test level

The IEC/EN 61000-4-8 standard specifies five test levels for testing products as shown in Table 1. The level labeled "X" is an open level that can be called out in the product specification.

Table 1. Test levels for continuous and short duration (pulsed) fields

Level	Continuous field strength	Pulsed (1 to 3 sec.) field strength
1	1 A/m	Not applicable
2	3 A/m	Not applicable
3	10 A/m	Not applicable
4	30 A/m	300 A/m
5	100 A/m	1000 A/m
X	Special	Special

Selection of a test level depends on the expected operating environment of the equipment under test (EUT). An appropriate test level for an EUT should be chosen based upon the magnetic field strengths the EUT is likely to encounter in its typical operating environment. In choosing a test level, it is useful to note some commonly occurring magnetic field strengths for various environments as reported in Annex D of the standard, and as described in the following four paragraphs. Note that the field strength decreases as the distance from the source of the field increases; the amount by which it decreases depends upon the configuration of the source of the magnetic field and the proximity to the source.

Most household appliances generate magnetic field strengths in the range of 0.03 A/m to 10 A/m, with a maximum of around 20 A/m, all at a distance of 0.3 m from the surface of the appliance. At a distance of 1.5 m from the appliance surface, the field strengths are typically below 0.1 A/m, with a maximum of 0.4 A/m.

Directly under high voltage lines, field strengths in the range of 10 to 16 A/m for every 1000 A flowing in the lines are encountered. At a lateral distance of 30 m from the lines, the field strength range is reduced to 3 to 5 A/m for every 1000 A flowing in the line.

High voltage sub-stations (220 and 400 kV) can produce field strengths of 9 to 14 A/m near a line carrying 500 A. In the relay room, 1 to 7 A/m field strengths are encountered, while in the equipment room, 0.7 A/m can be found.

In power/industrial plants, bus-bars carrying 2200 A produce field strengths of 6 to 85 A/m, depending on the distance from the bus-bar (roughly 0.3 m to 1.5 m, with the higher field strength encountered closer to the bus-bar). Other magnetic field sources in this environment produce field strengths from 4 to 30 A/m, depending on the source.

Taking these commonly occurring field strengths for various operating environments into consideration, Annex C of IEC/EN 61000-4-8 provides guidance for selecting an appropriate test level. Equipment is classified based upon the environment in which it will be operating, and the corresponding test level is then selected. The environments in which equipment can operate are as follows:

Class 1:
Environment where a device using an electron beam is used. Examples include environments containing CRT monitors or an electron microscope.

Class 2:
Well protected environment. Examples include household, office, and hospitals.

Class 3:
Protected environment. Examples include commercial areas, small industrial plants, or a computer room of a high voltage sub-station.

Class 4:
Industrial environment. Examples include heavy industrial plants, power plants, or the control room of a high voltage sub-station.

Class 5:
Severe industrial environment. Examples include the switchyard of heavy industrial plants, or medium voltage and high voltage power stations.

Note that the information presented from both Annex C and Annex D of the standard is labeled as "informative" information in the standard. As such, it is considered to be useful in applying the standard, but not a compliance requirement. Information labeled "normative" would include requirements that must be met for compliance. The techniques, procedures, and instrumentation characteristics specified in IEC/EN 61000-4-8 are considered normative. Specific limits would be determined by product committees and specified in the corresponding product standard. Additional immunity test information is contained in EN 50082-1 (1997), "Generic immunity standard for residential, commercial, and light industry environments," and in EN 50082-2 (1995), "Generic immunity standard for industrial enviroments."

As an example, consider testing an appliance such as a digital alarm clock. Since the environment in which this piece of equipment will typically operate is "household", the environment would be a Class 2 environment. Corresponding to this class, a Level 2 field strength from Table 1 is shown as 3 A/m continuous, while a short duration, pulsed test is not required. This is assuming that the product is not covered by a more specific product standard that specifies different test criteria.

Once the required field strength to which the EUT must be subjected is selected, it is necessary to generate this field according to the standard. For the alarm clock example, proper operation of the clock would have to be verified with the clock immersed in a 3 A/m magnetic field.

Generating a test field

The overall purpose of the IEC/EN 61000-4-8 standard is to describe a method for generating a power line frequency magnetic field in which an EUT may be placed for testing its immunity to the field. In order to generate a magnetic field, some type of induction coil is used, driven by a power line frequency current flowing in the coil from a test generator like an ac source. The field strength is controlled by controlling the magnitude of the current flowing in the coil. There is a direct relationship between the magnitude of the coil current and the strength of the magnetic field that depends on the coil configuration. (Refer to the appendix for simple examples.)

The induction coil

Annex B of the standard (a normative Annex, which requires compliance) specifies:

"The requirement of the induction coil is 3 dB tolerance of the test field in the volume of the EUT."

Magnetic field homogeneity over a given volume is dependent on the physical configuration of the induction coil. Various configurations are discussed in Annex B of the standard, including square, rectangular, and double square induction coils. For each of these configurations, profiles are shown of the area surrounding the center of the coil for which the field strength varies by no more than ± 3 dB (either higher or lower) from the value at the center of the coil. The profiles are shown for areas in both the plane of the coil, and the mean orthogonal plane. From these areas, conclusions can be drawn regarding the volume over which a magnetic field is developed that varies by no more than ± 3 dB from the value at its center. This volume then determines the maximum sized EUT that can be tested with the given coil configuration in order to meet the ± 3 dB field uniformity requirement throughout the volume of the EUT. The field strength at the center of the volume is the test level selected from Table 1 according to the EUT's expected operating environment.

For example, consider a square coil, 1 m on each side. This coil will produce a magnetic field strength that varies by no more than ± 3 dB from the value at its center in a volume within the coil that is 0.6 m by 0.6 m by 0.5 m high. (The volume extends 0.25 m above and 0.25 m below the plane of the coil, accounting for the total 0.5 m height, and is centered about the center of the coil.) This type of coil is appropriate for testing EUTs that will fit within this testing volume.

Larger testing volumes are possible by increasing the size of the coil, however, larger coils will require greater drive current to produce the same magnitude magnetic field at the coil's center, increasing the current requirements for the test generator that is driving the coil. Using a multi-turn coil will reduce the current requirements of the test generator, since a coil having N turns will increase the effective current by N, thereby increasing the magnitude of the magnetic field by N. Another alternative for increasing testing volume is to use a double coil (Helmholtz coil). For example, using double square coils, each having 1 m sides and spaced 0.6 m apart, the testing volume is increased to 0.6 m by 0.6 m by 1.0 m high.

The types of coils discussed so far are appropriate for testing table-top equipment. Larger floor-standing equipment may make it impractical to develop a magnetic field with the required homogeneity and of sufficient volume to envelop the entire EUT all at once. The standard recognizes this possibility and makes allowances for these situations. A coil may be used to surround a portion of a larger piece of equipment, and the test can be performed repeatedly, moving the coil along the EUT between tests, until the entire volume of the EUT is eventually tested.
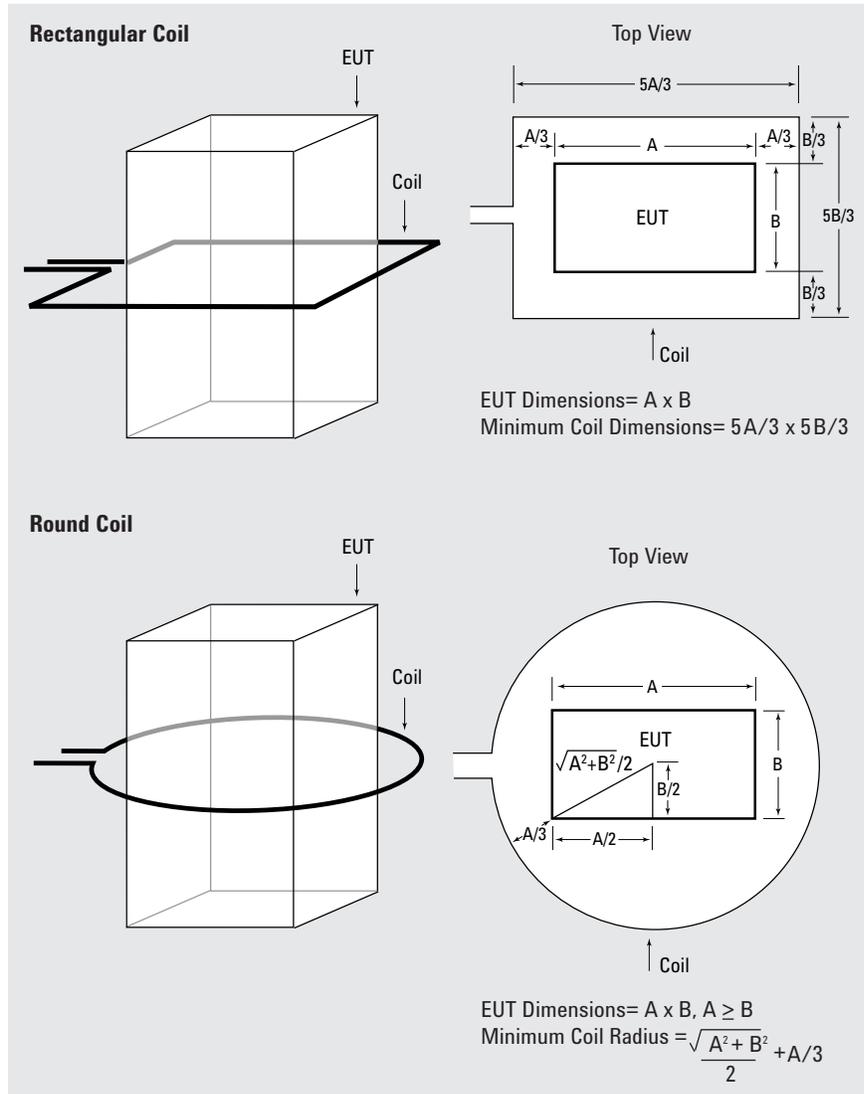

Rectangular Coil

EUT Dimensions= A x B
Minimum Coil Dimensions= 5A/3 x 5B/3

Round Coil

EUT Dimensions= A x B, A $\geq$ B
Minimum Coil Radius = $\sqrt{\dfrac{A^2 + B^2}{2}}$ +A/3

Figure 1: Minimum distance between floor standing EUT and coil

Specific requirements for the induction coil are as follows:

1. Connected to the test generator, it shall generate the field strength corresponding to the selected test level and defined homogeneity (coil must result in a ± 3 dB tolerance of the test field in the volume of the EUT)

2. Material shall be copper, aluminum, or any conductive non-magnetic material

3. Cross section and mechanical arrangement shall facilitate stable positioning

4. Single turn, multi-turn, or double (Helmholtz) coils with suitable current carrying capability are acceptable

5. Coil conductors shall be of relatively small cross section

6. Coil must surround the EUT. To accommodate 3 orthogonal positions and different sized EUTs, different sized coils may be used

7. Constancy of field is limited to a single direction, orthogonal to the coil plane

8. Fields in different directions are obtained by rotating the coil or by rotating the EUT

9. For floor-standing equipment, the minimum distance between the coil and EUT walls must be 1/3 the dimension of the EUT (EUT with dimension A by B requires a coil of dimension 5/3*A by 5/3*B if the coil is rectangular—see Figure 1)

Calibration of the induction coil is required and the calibration procedure must meet the following requirements:

1. Calibrate in a free space condition with no EUT present

2. At least 1 m distance must separate the coil from any wall or magnetic material

3. The coil shall be connected to the test generator with twisted conductors no more than 3 m in length

4. An appropriate magnetic field sensor must be located at the coil center, oriented to detect the maximum field strength. The sensor dimension must be no greater than 1/10 the coil dimension and must use a power frequency narrow band measurement instrument (note that the standard makes no specific reference to the accuracy of the sensor)

5. With the test generator providing the current, the current to produce the desired test level field is noted at the power line frequency. This determines the coil factor, which is a scaling factor expressed as the field strength per unit of current from the test generator (units are Amps per meter/amp = A/m/A =1/m)

6. Test instrumentation to verify coil current shall be accurate to ± 2 %

There are some "off-the-shelf" coils available from some manufacturers. For example, the EMCO 6404 is a Helmholtz type coil consisting of two 1.22 m (4 feet) diameter coils. The coil impedance is roughly 1.5 ohms in series with 19 mH. The configuration results in a coil factor of 65.73 A/m/A. Therefore, as an example, if an EUT is expected to operate in a Class 3 environment, it would need to be tested with a Level 3 field, or 10 A/m. With the EMCO 6404 coil, a drive current of (10 A/m)/(65.73 A/m/A) = 0.152 A would be required.

The test generator

The test generator is used to produce the current required to drive the coil, thereby creating the required magnetic field. Several different configurations of test generators have been used in the past. For example, function generators with small signal outputs driving audio power amplifiers have been used, or motor-controlled variacs, to produce the required drive currents. However, there are drawbacks to each of these configurations.

For example, audio amplifiers are not designed to drive a wide range of load impedances, or highly inductive loads. These amplifier outputs also do not have any specified amplitude accuracy, nor do they have any robust protection against short circuits. Variacs also have poor accuracy and regulation, in addition to unpredictable distortion and no frequency adjustment since the output voltage is dependent on the ac mains line voltage. Another possibility to drive the coil that does not have these drawbacks is to use a typical ac source product. These versatile products can cover a wide range of the required field strengths, and with the addition of a transformer on the output, any of the required field strengths mentioned in the standard can be produced. The transformer is used to scale the output of the ac source to the appropriate range for producing the required magnetic field strength with a given coil factor. In this case, the combination of the ac source and the transformer would comprise the test generator.
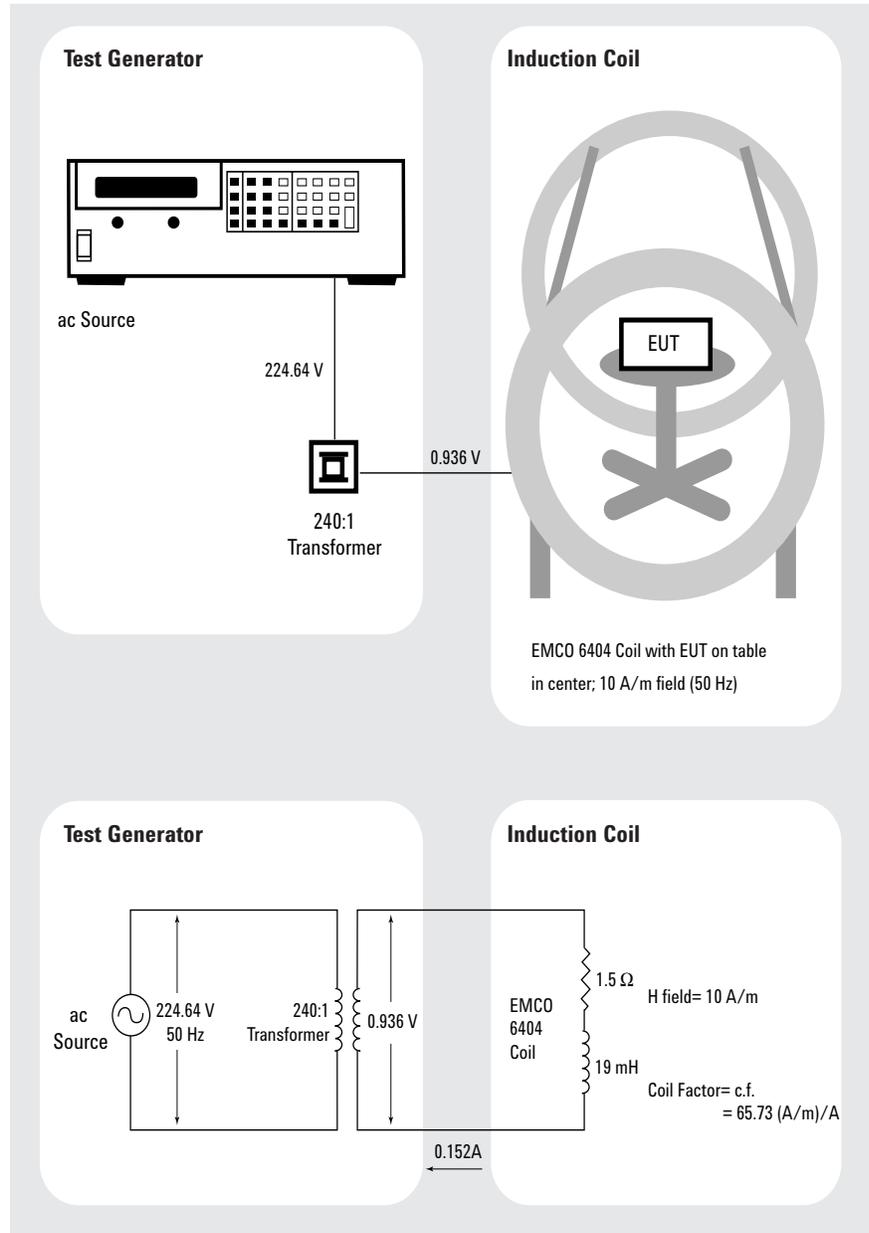
Test Generator

ac Source

224.64 V

240:1
Transformer

0.936 V

Induction Coil

EUT

EMCO 6404 Coil with EUT on table
in center; 10 A/m field (50 Hz)

Test Generator

ac Source — 224.64 V 50 Hz — 240:1 Transformer — 0.936 V

0.152A

Induction Coil

EMCO 6404 Coil

1.5 Ω   H field= 10 A/m

19 mH

Coil Factor= c.f.
= 65.73 (A/m)/A

Figure 2: Example test set-up showing source, transformer, and coil

For example, using the EMCO 6404 coil again, and building on the example above for a product requiring a Level 3 field strength (10 A/m), 0.152 A from the source was required. The voltage needed to produce this current can be calculated given the impedance of the coil. This impedance consists of the series resistance and inductance of the coil, and is therefore frequency dependent.

The standard requires the frequency of the test magnetic field to match the power line frequency of the environment in which the EUT will operate. Assuming the EUT is to operate in a 50 Hz environment, the 1.5 ohms and 19 mH result in a total impedance of 6.15 ohms, which means that with 0.152 A flowing, the resultant voltage is 0.936 V. Since many typical ac source products are rated for much higher voltages and regulate their output voltage rather than their output current, it makes sense to use a step-down transformer on the output of the ac source so that the ac source voltage may be much higher than the required 0.936 V. Note that the output of a digitally controlled source is quantized, meaning it can be set to discrete values only, determined by the output resolution specification of the source. The resolution must be sufficiently small to produce a voltage of sufficient accuracy to properly control the coil current, and the resultant magnetic field. Using a transformer to step the output voltage down improves the effective resolution at the output of the transformer by the transformer turns-ratio.

In this case, a transformer with a turns-ratio of 240:1 could be used, enabling the ac source output to be set to 224.64 V to produce the required 0.152 A of current on the secondary of the transformer, flowing in the induction coil. See Figure 2.

Note that the standard specifies the requirements for the accuracy of the magnetic field: ± 3dB in the volume of the EUT. The ± 3dB volume is determined by the geometry of the coil and the accuracy of the coil current, which generates the magnetic field. Therefore, in order to maintain the appropriate magnetic field within the volume of the EUT, it is important to accurately control the coil current. The coil current accuracy itself is not specified by the standard. Instead, the standard specifies the requirements for the accuracy of the instrumentation (± 2%) used to measure the coil current. It is clear that if the instrumentation specified to measure the current is accurate to ± 2%, then the current itself can be no more accurate than ± 2%. In fact, it could be much worse. (Note that it is possible to use measurement instrumentation that is accurate to 2% to measure and control current to within 5%, or 10%, or any accuracy that is greater than the 2% accuracy of the measurement instrumentation.) A reasonable

interpretation here for the current accuracy requirement is to assume that it must be controlled to the best that the measurement instrumentation can do, namely ± 2% accuracy. Better current measurement accuracy, which is easy to obtain, will only improve the overall accuracy of the current setting, to the point where it will become a negligible factor.

The magnetic field accuracy of ± 3 dB allows for roughly +40% and -30% of variation in its magnitude throughout the volume of the EUT. Since the magnetic field magnitude is directly proportional to the coil current magnitude, as stated above, the accuracy of the current directly influences the accuracy of the magnetic field strength. As a result, the above interpretation of the current accuracy requirement (± 2%) would be consistent with the magnetic field accuracy since it is much lower than the magnetic field accuracy requirement (+40%, -30%).

Specific requirements for the test generator are as follows:

1. Sinusoidal output current with total distortion factor <8% (Note that the standard does not define "total distortion factor." Therefore, the assumption here is that it is equivalent to total harmonic distortion.)

2. Ability to drive the induction coil

3. Ability to operate in either continuous or pulsed (short duration) mode

4. Current capability is determinedby the test level and coil factor. Current range is 1 A to 100 A divided by the coil factor for continuous mode and 300 A to 1000 A divided by the coil factor for pulsed mode (set time for pulsed mode is 1 s to 3 s)

5. Ability to operate into a short circuit condition (Note that all induction coils will have resistance and inductance, meaning the generator will actually never be required to operate into a true "short circuit condition," the definition of which is unspecified.)

6. Ability to have the low output terminal connected to earth ground

7. Prevents large disturbances in the power line (Note that "large disturbances" are unspecified.)

Verification of the test generator is required and must include the following:

1. Test generator must be connected to the induction coil with twisted conductors no longer than 3 m

2. Verify output current value

3. Verify current distortion factor

4. Verify emissions of disturbances by the generator (Note that there are no specific numbers associatedwith this requirement; only the statement "precautions to prevent the emission of large disturbances that may be injected in the power supply network or may influence the test results" is made.)

5. Verification instrumentation (current probe, etc.) needs ± 2 % accuracy

As an example of an "off-the-shelf" test generator, consider the Agilent Technologies 6813B ac power source/analyzer. This instrument has the capability of producing output voltages up to 300 Vrms and output currents up to 13 Arms, with a maximum output rating of 1750 VA. The low distortion output voltage can be used to drive an induction coil directly, or through a transformer, depending on the coil factor and required magnetic field strength. With the output set to produce a sine wave, the highly regulated output has no more than 0.25% total harmonic distortion (at 50 Hz or 60 Hz).

Some other features of the 6813B ac source that enable it to help do magnetic immunity testing according to the standard include its ability to produce either continuous or pulsed (short duration) output waveforms. The 1 s to 3 s pulse duration mentioned in the standard is easily covered by the 6813B's ability to produce pulses as short as 0.2 ms to as long as multiple hours in 0.2 ms increments. This ac source can drive loads of any power factor (0 to 1), has programmable current limit, and can operate with its output shorted. The output frequency can be set in the range of DC to 1000 Hz, enabling it to drive coils to produce either 50 Hz or 60 Hz magnetic fields. Both output terminals are isolated from ground making it possible to connect either output terminal to ground, a test generator requirement also mentioned later concerning the ground reference plane. Additionally, disturbances on the ac mains from operating this instrument are minimized due to an internal design utilizing multi-stage power conversion with extensive filtering. Figure 3 shows a simplified internal block diagram.

Note that the induction coil current is the important parameter to control when producing the required magnetic field. An ac source typically regulates the voltage on its output, as does the 6813B. Therefore, the accuracy with which the ac source produces the output voltage directly affects the accuracy of the coil current, which is simply the ac source output voltage divided by the coil impedance, if no transformer is used in between. When a transformer is used, the ac source output voltage gets scaled down by the turns-ratio of the transformer. Since the requirement for current accuracy was assumed to be ± 2% as discussed earlier, the ac source voltage accuracy should be at least as good. In the example of Figure 2, the required voltage across the coil to produce the 10 A/m field was 0.936 V, which translated back through the 240:1 transformer into 224.64 V on the output of the ac source. The 6813B output voltage accuracy specification is ± (0.15% + 0.3 V), which results in ± 0.637 V of inaccuracy on the 224.64 V. This is 0.28% of the required 224.64 V, well within the 2%

requirement. Note that if the transformer was not used, the output voltage accuracy specification applied directly to the required 0.936 V results in ± 0.301 V of inaccuracy, which is more that 32% of the required 0.936 V! Clearly, a transformer is required to obtain sufficient accuracy.

It is important to consider the VA requirements for the ac source when attempting to produce a particular field strength using a particular coil. Following the earlier example using the EMCO 6404 coil (1.5 ohms, 19 mH, 65.73 A/m/A coil factor) operating at 50 Hz, the required coil current to produce a 10 A/m field was calculated to be 0.152 A, requiring a coil voltage of 0.936 V across the resultant 6.15 ohms of total coil impedance. In this case, the VA requirement is small, namely, 0.152 A x 0.936 V = 0.142 VA. However, to produce higher field strengths, higher coil drive currents are required, increasing the requirements for VA. In fact, the VA requirements increase with the square of the current increase (or, equivalently, with the square of the

field strength increase), so if the required field strength goes up by a factor of 10, the ac source VA requirements increase by 100. For example, recalculating the coil current and voltage for a 100 A/m field strength yields 1.521 A and 9.363 V for a requirement of 14.245 VA, which is 100 times the 10 A/m VA requirement. Taking a look at the pulsed field strengths of 300 A/m and 1000 A/m yields VA requirements of 128.2 VA and 1424.5 VA respectively. As can be seen here, generating large field strengths results in sizeable VA requirements, even if the fields are to be present for only a short duration.
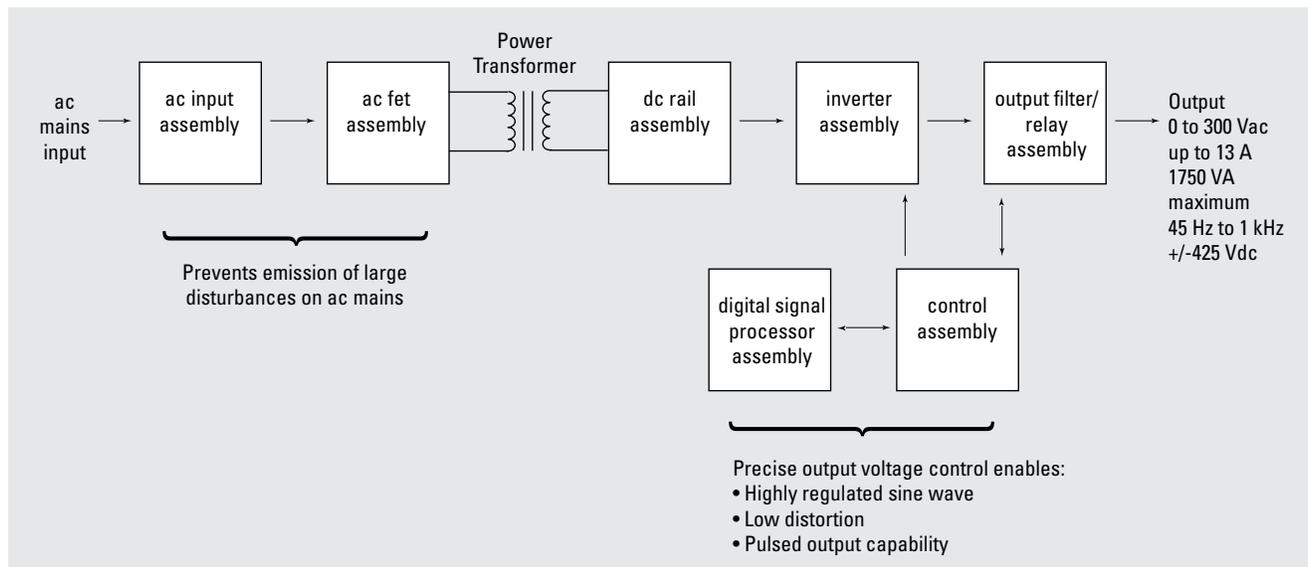

Figure 3: Simplified internal block diagram of Agilent 6813B and advantages for magnetic immunity testing

Agilent ac sources are available in maximum VA ratings from 375 VA to 4800 VA as shown in Table 2. The table lists the maximum output voltage, maximum output current, and maximum VA capabilities of each of the ac source models. It also shows the calculated maximum field strength (Hmax) that can be produced by each of the ac sources based upon the VA rating of the source and the EMCO 6404 induction coil being used at 50 Hz (coil factor is 65.73, and impedance is 6.15 ohms). Note that the maximum output VA of each ac source does not equal the maximum voltage times the maximum current. This is due to the fact that the three lower power models of sources listed here have auto-ranging output capabilities, while the two highest power models have dual output ranges. Each of these features extends the output capabilities of the ac sources beyond those obtained with an equivalently sized ac source with a single rectangular shaped output characteristic. The output capabilities are extended by providing high output voltages at lower currents, and high output currents at lower voltages, but not maximum voltage and maximum current at the same time, which would require a larger sized ac source.

Note also that selection of a coil with a lower coil factor increases the VA requirement for the source, while a higher coil factor results in a lower VA requirement.

As mentioned earlier, using a coil like the EMCO 6404 at 50 Hz to produce a field strength of 300 A/m required an ac source capable of 128.2 VA. Table 2 shows that any of the Agilent ac sources can produce 128.2 VA or more. Therefore, any of them can be used to produce the field strengths mentioned in the standard up to and including 300 A/m.

Table 2: Agilent ac source ratings and maximum field strength (Hmax) that can be produced by each ac source based on only maximum VA rating, using EMCO 6404 induction coil at 50 Hz. (In each case, a transformer would be required to scale the voltage and current to produce the listed Hmax.)

ac source model number	Maximum output voltage	Maximum output current	Maximum output VA	Hmax based on VA alone*
6811B	300 V	3.25 A	375 VA	513 A/m
6812B	300 V	6.5 A	750 VA	726 A/m
6813B	300 V	13 A	1750 VA	1108 A/m
6814B**	300 V	20 A	3000 VA	1451 A/m
6834B**	300 V	30 A	4500 VA	1777 A/m
6843A**	300 V	32 A	4800 VA	1836 A/m

* VA = $(H/cf)^2$ x Z (H = field strength, cf = coil factor, Z = coil impedance)
** Obsolete products

Table 3: Agilent ac source ability to produce field strengths using EMCO 6404 induction coil at 50 Hz based on VA rating.

Can this ac source produce this field strength using EMCO 6404 coil?	6811B (375 VA max)	6812B (750 VA max)	6813B (1750 VA max)	6814B* (3000 VA max)	6834B* (4500 VA max)	6843A* (4800 VA max)
1 A/m	Yes	Yes	Yes	Yes	Yes	Yes
3 A/m	Yes	Yes	Yes	Yes	Yes	Yes
10 A/m	Yes	Yes	Yes	Yes	Yes	Yes
30 A/m	Yes	Yes	Yes	Yes	Yes	Yes
100 A/m	Yes	Yes	Yes	Yes	Yes	Yes
300 A/m	Yes	Yes	Yes	Yes	Yes	Yes
1000 A/m	No	No	Yes	Yes	Yes	Yes

* Obsolete products

The Hmax column in Table 2 supports this conclusion as well. The 1000 A/m field strength requirement in the standard necessitates the use of one of the larger ac sources. This information is summarized in Table 3 above. The table shows which of the ac source models can produce the various field strengths mentioned in the standard using the EMCO 6404 induction coil at 50 Hz.

Current measurement

Since calibration of the induction coil requires that the coil current be measured, a current probe or current shunt in series with the coil and connected to a voltmeter may be used. The type of probe or shunt used will depend upon the expected drive current for the coil, which is determined by the coil factor and the required magnetic field strength.

When an ac source (or any constant voltage regulating test generator) is used to drive the coil, the series impedance of the current measuring device, although low, needs to be considered since it adds to the coil impedance, and the current is the ac source output voltage divided by the total impedance. There are many readily available shunts that can be chosen along with an appropriate voltmeter to produce the required 2% current measurement accuracy specification. The ac source output voltage will be set to produce the required current through the total impedance comprised of the shunt and induction coil series combination.

Another factor to consider concerning current measurement when using a constant voltage test generator to drive the coil is the effect of the presence of the EUT on the coil impedance. The coil calibration procedure specifies that the coil factor be determined "without the EUT" which is appropriate for determining the coil factor. However, when the EUT is placed inside the coil, the coil "core" material changes, possibly affecting the impedance (but not the coil factor, which is field strength per unit of current).
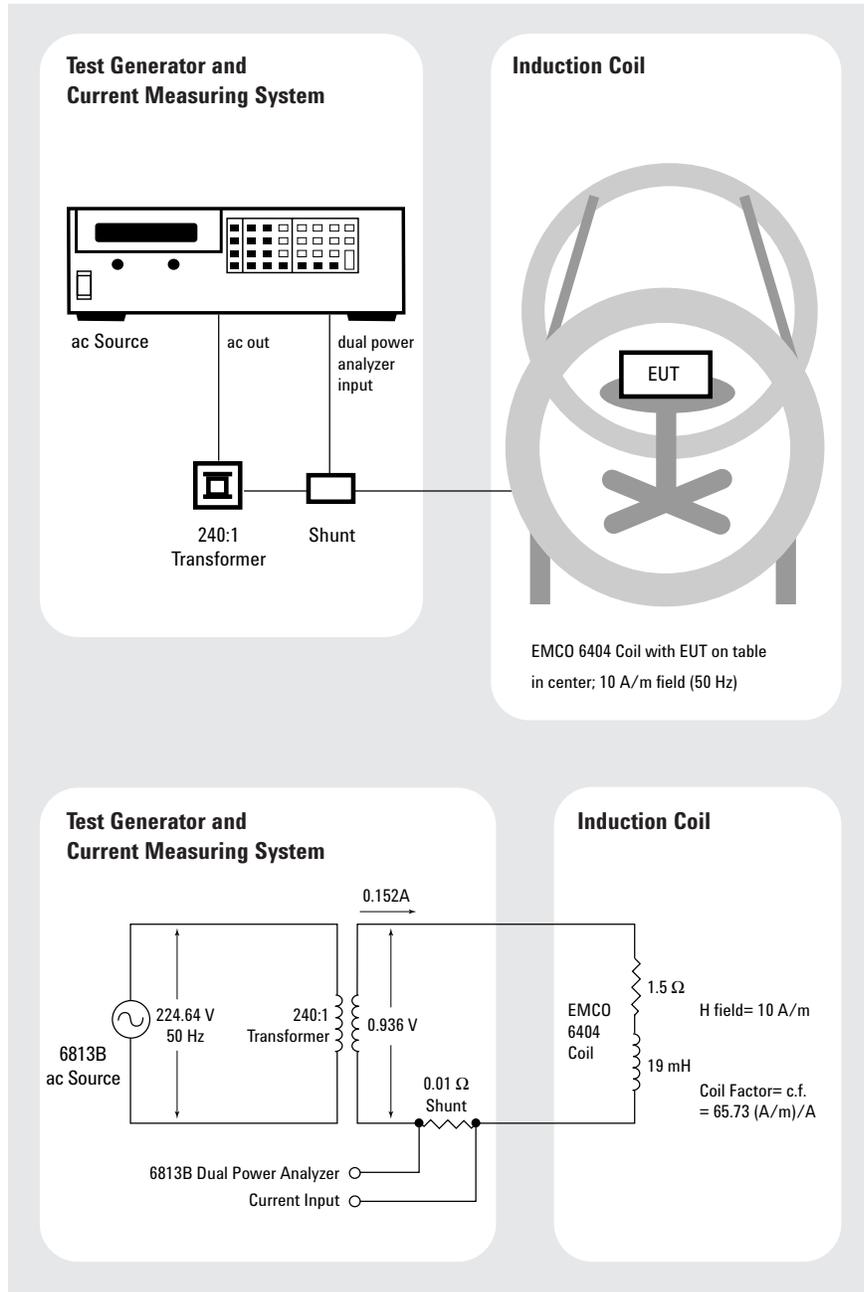
Test Generator and Current Measuring System

ac Source   ac out   dual power analyzer input

240:1 Transformer   Shunt

Induction Coil

EUT

EMCO 6404 Coil with EUT on table in center; 10 A/m field (50 Hz)

Test Generator and Current Measuring System

0.152A

6813B ac Source   224.64 V 50 Hz   240:1 Transformer   0.936 V

0.01 Ω Shunt

6813B Dual Power Analyzer
Current Input

Induction Coil

EMCO 6404 Coil   1.5 Ω   H field= 10 A/m

19 mH

Coil Factor= c.f. = 65.73 (A/m)/A

Figure 4: Setup showing Agilent 6813B with Dual Power Analyzer option, transformer, and coil. The current shunt is included with the option.

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If the voltage needed to produce the coil current is noted without the EUT, and used later with the EUT in the coil, it is possible that a slightly different coil current will result, and consequently, a slightly different field strength will result. This is due to the fact that the presence of the EUT in the center of the coil can change the coil's impedance, changing the current flowing in it for a given voltage. When depending solely on a constant voltage to regulate the coil current, it is therefore important to determine that voltage with the EUT present, so that this voltage can be used during the actual test. Alternately, if the coil current is monitored during the test, the test generator voltage can be adjusted to produce the correct current, compensating for this effect.

Note that if an ac source that has built-in output current measurement capability (readback) is used, and the source is driving the coil directly without a transformer, the source's output current readback can be used to verify the current, eliminating the need for an external shunt and voltmeter. The 6813B can measure its output current with an accuracy of ± (0.05 % + 1.5 mA) for peak currents up to ± 8.08 A (sinusoidal rms currents up to 5.71 A), and an accuracy of ± (0.05% + 10 mA) at higher currents.

When a step-down transformer is used to allow the ac source output voltage to be a higher value relative to the coil voltage, the ac source output current is reduced by the transformer turns-ratio as compared to the coil current. Depending on the required field strength, coil, and transformer used, the ac source current may be very low (< 1 mA). In these cases, it is necessary to measure the transformer secondary current (the coil input current) instead of the ac source output current. The 6813B ac source is available with a

Dual Power Analyzer option providing the ability to measure an external voltage and an external current using a current shunt that could be used to measure the current on the secondary side of the transformer. This setup is shown in Figure 4, which builds upon the example shown earlier in Figure 2. The shunt, included with the Dual Power Analyzer option, has resistance that is low enough to avoid adding any significant voltage drop. The current measurement specifications of the Dual Power Analyzer current input are the same as those for the ac source output current mentioned earlier. The low range current measurement accuracy specification results in 1% of inaccuracy on the 0.152 A of coil drive current required in the example, well within the standard's 2% measurement instrumentation requirement. Additionally, the 6813B ac source can directly measure the current total harmonic distortion, either on its output current or on the Dual Power Measurement current input, verifying that it is less than 8% as required by the standard. Alternately, a shunt and voltmeter could be used to measure the current, and an instrument such as a power meter to measure the distortion.

Transformers

Coil current and coil voltage are directly proportional to field strength, and the field strength test levels in the standard vary from 1 A/m to 1000 A/m (including the pulsed tests). In order to cover the full test level range, the test generator would be required to produce currents and voltages throughout the 1000:1 range of values. The use of transformers with various turns-ratios makes this possible. A single transformer can be used to test to several test levels covered by the standard. Generating field strengths within about a 10:1 range is possible with a single transformer, given a particular configuration

including an ac source and induction coil. Given that the test level range of values is 1000:1, three transformers can be used to cover all of the levels in the standard.

For example, using the EMCO 6404 coil (1.5 ohms, 19 mH, 65.73 A/m/A coil factor) operating at 50 Hz and an 6813B ac source, transformers with turns-ratios of 240, 8, and 2.5 could be used to produce all of the magnetic field strengths in the standard. Table 4 shows the resultant current and voltage for the coil and the ac source output.

The coil current and voltage are simply determined by the required field strength, the coil factor, and the coil impedance. The ac source current and voltage are derived from the coil current and voltage, and the transformer turns-ratio. The ac source and transformer must each be capable of handling the resultant VA. As can be seen in the table, the VA requirements become large as the field strength increases. As was mentioned earlier, the 6813B is a 1750VA product, so it can produce any of the field strengths in the standard. Since it is the regulated output voltage of the ac source that is controlling the coil current, it is important to make sure the ac source output voltage is a reasonable value with respect to its maximum output capability (300 Vac) to ensure adequate voltage resolution and accuracy. A product capable of 300 Vac should not be used to directly produce voltages like those required across the coil at low field strengths (0.094 Vac, 0.281 Vac, etc.). The transformer turns-ratio values in the table are chosen to ensure that the ac source voltage is well within the ac source's operating capabilities.

A simple model for a transformer and its effect on current generation and current measurement is shown in Figure 5. The objective is to control the magnetic field by controlling the coil current, which is the transformer secondary current. As mentioned earlier, one way in which to verify the coil current is to measure the primary current and use the turns-ratio to calculate the secondary current (coil current).

However, as can be seen from the figure, the magnetizing inductance, Lm, shunts some of the ac source current away from the transformer primary windings, thereby introducing an error. Additionally, the primary and secondary resistances introduce some voltage drop. Of course, if the ac source current needed to produce a particular field strength is measured, these errors would be calibrated out when performing the coil calibration procedure. However, since the primary current is reduced by the turns-ratio of the transformer compared to the secondary current, its magnitude could become very small which may present some measurement challenges. These factors make it necessary to measure the secondary current in order to ensure the accuracy of the resultant magnetic field.
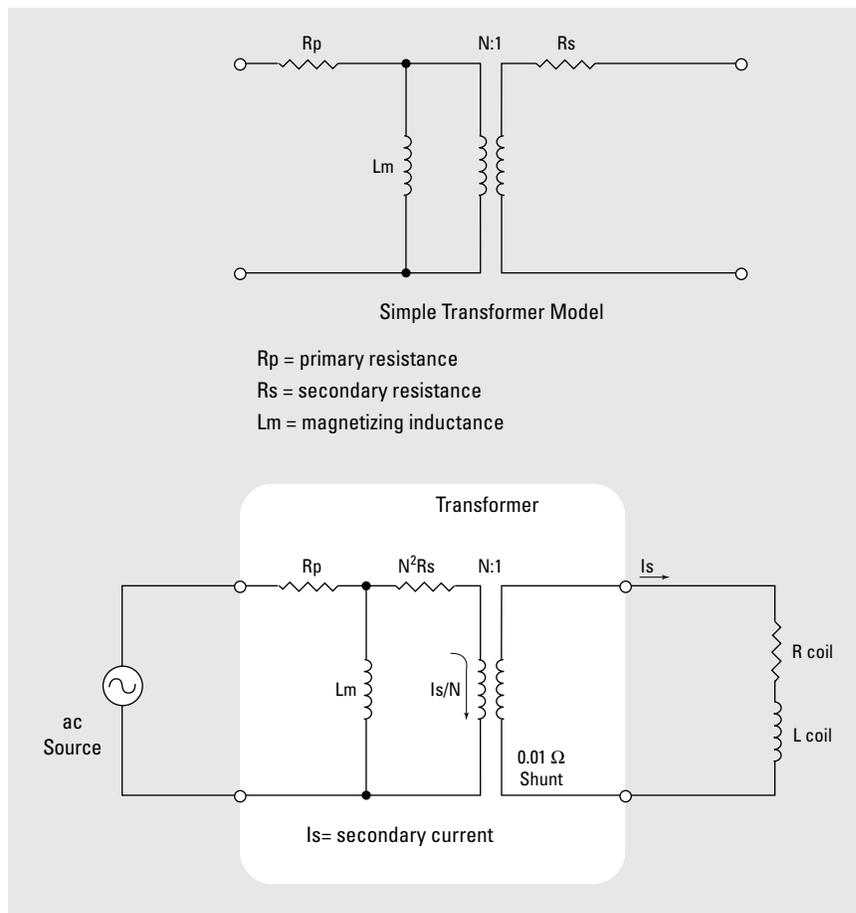

Figure 5: Transformer parameters affect generation of current and current measurement

Table 4. Coil and ac source (ACS) I and V for transformers of various turns-ratios using EMCO 6404 coil at 50 Hz

H (A/m)	Coil I (A)	Coil V (V)	N:1	ACS I (A)	ACS V (V)	ACS VA
1	0.015	0.094	240	6.34E-05	22.5	0.001
3	0.046	0.281	240	1.90E-04	67.4	0.013
10	0.152	0.936	240	6.34E-04	224.7	0.142
30	0.456	2.809	8	0.057	22.5	1.282
100	1.521	9.363	8	0.190	74.9	14.245
300	4.564	28.090	8	0.571	224.7	128.208
1000	15.214	93.635	2.5	6.086	234.1	1424.533

Performing a test

In addition to the test generator and induction coil, the other components necessary to test to the IEC/EN 61000-4-8 standard include a ground plane, equipment to operate the EUT, equipment to test (verify) the EUT, and, of course, the EUT itself.

The ground (reference) plane (GRP) requirements are as follows:

1. The standard specifies that "the EUT and auxiliary test equipment shall be placed on" the GRP. Auxiliary instrumentation is defined by the standard as "…any other instrument necessary for the operation and verification of the EUT functional specifications." Certainly, the EUT should be placed on the GRP. Since the auxiliary test equipment is comprised of equipment to both operate the EUT and verify the EUT functionality, it is reasonable to include on the GRP, at most, some equipment necessary to operate the EUT. For example, this might include equipment to simulate EUT operating signals. However, it is not reasonable to include on the GRP some other types of equipment necessary to operate the EUT. For example, if a regulated source is used to provide power to the EUT, it should not be on the GRP. It also does not seem reasonable to include on the GRP the equipment necessary to verify the EUT, like an oscilloscope or voltmeter, since the magnetic immunity of this verification equipment may be unknown. Figures 3 and 4 in the standard support the interpretation that no auxiliary test equipment is placed on the GRP. Instead, cabling is run to this equipment. The standard should allow for auxiliary test equipment to be both on and/or off the GRP.

2. Made of non-magnetic metal sheet (copper or aluminum), 0.25 mm thick. If a different metal is used, thickness must be 0.65 mm minimum

3. Minimum dimensions: 1 m by 1 m (final size depends on EUT size)

4. Must be connected to safety earth ground

The EUT is to be placed on the GRP on a 0.1 m insulating support (e.g., dry wood) with the EUT earth terminal connected to the safety earth of the GRP. The GRP can be used to complete the return current path for the induction coil. However, the standard does not make any provisions for utilizing the GRP with either multiple turn coils, or double coils, either of which can be used to produce the required magnetic field. In fact, the GRP is conspicuously absent from Figure 6 in the standard that shows an illustration of a Helmholtz coil. The entire purpose of the GRP with respect to testing magnetic immunity is not clear.

The induction coil must enclose the EUT, with the EUT at its center, in order to allow the EUT to be immersed in the magnetic field produced by the coil. Supplied or recommended cabling is to be used, exposing the cables to the magnetic field for 1 m of their length. This requirement could be problematic if the EUT is small enough to allow for a coil of such dimensions as to produce a magnetic field smaller than the 1 m cable length.

The test generator must be located less than 3 m from the induction coil, with one terminal connected to the GRP.

After the induction coil has been calibrated and the test generator verified according to the procedures discussed earlier, the actual test procedure then consists of the following:

1. Verify the laboratory environmental conditions. The required temperature, relative humidity, and atmospheric pressure are described in the standard. Note also that the ambient magnetic field in the laboratory must be 20 dB lower than the selected test level. Otherwise, a Faraday cage should be used.

2. Verify that the EUT is operating properly without the magnetic field present

3. Select the appropriate test level, apply the test field, and examine the operation of the EUT

4. Evaluate the results

Although the test section (8.2 a) of the standard specifically calls out the use of an "induction coil of standard dimensions (1 m x 1 m)" for testing table-top equipment, the more detailed coil characteristics section (6.2.1) states that, "depending on the size of the EUT, induction coils of different dimensions may be used." (Note that "different" here means "various.") Since the spirit of the standard is to subject an EUT to a particular magnetic field strength of known magnitude and homogeneity, it would seem reasonable to assume that the method by which that field is produced is less important than the characteristics of the field itself. Therefore, use of a coil with "non-standard" dimensions would then be acceptable, as long as the field produced meets the requirements. Of course, use of the recommended dimensions lessens the need for confirmation of the resultant field characteristics.

The test section of the standard calls for rotating the coil 90 degrees in order to expose the EUT to fields of different orientations. The EUT should be tested in a field oriented in each of 3 orthogonal positions (left to right, front to back, and top to bottom), requiring the test to be repeated 3 times. Although the standard specifically mentions rotating the coil to produce the different orientations, rotating the EUT instead is an acceptable way to produce the exact same result.

Floor-standing equipment is typically larger than table-top equipment necessitating the use of coils of suitable dimensions. The coil must still surround the EUT, but may be moved along the EUT and the test repeated in order to cover the entire volume of the EUT, for each of the 3 orthogonal orientations. When moving the coil, (or, likewise, the EUT within the coil), the distance moved shall be 50% of the shortest side of the coil.

Evaluating test results

During the application of the test field, the operation of the EUT is examined and compared against expected performance. The results can be classified into one of the following four categories:

1. Normal performance within the specification limits

2. Temporary degradation or loss of function or performance which is self-recoverable

3. Temporary degradation or loss of function or performance which requires operator intervention or system reset

4. Degradation or loss of function which is not recoverable due to damage of equipment (components) or software, or loss of data.

Of course, the EUT shall not become dangerous or unsafe as a result of being exposed to the test field.

Clearly, the EUT passes the test if number 1 above is the result since the equipment has demonstrated its immunity to the applied field. The other levels of immunity can also be considered acceptable (except becoming dangerous) if the manufacturer clearly states that the observed EUT behavior is expected. However, products with low immunity relative to competitive products will compare unfavorably. Also, generic immunity or product standards may include specific requirements necessitating a particular degree of immunity.

Finally, test conditions and test results should be summarized in a test report.

Appendix

Useful reference material related to magnetic field immunity testing

Magnetic flux: 1 weber = 10^8 maxwell

Magnetic flux density = magnetic induction = B = μH: 1 weber/m^2 = 1 tesla = 10^4 gauss

Magnetic field intensity = H: 1 amp-turn/m = 1 A/m = $4\pi \times 10^{-3}$ oersted
(1 A-turn = 1.257 gilberts)

Permeability of free space = μ0 = $4\pi \times 10^{-7}$ Wb/A-m = 1 gauss/oersted
Note that in free space, B = μ_0H
With H = 1 A/m, B = $4\pi \times 10^{-3}$ gauss = 1/79.577 gauss
Therefore, roughly 80 A/m = 1 gauss in free space

For a long straight wire, B = μH = $\mu/4\pi \times 2i/r$
i = current in wire in amps
r = perpendicular distance from wire in meters
μ = magnetic permeability in webers/(amp-meter)

For a segment of straight wire, B = $\mu/4\pi \times id/(r \times \sqrt{r^2 + d^2/4}\,)$
i = current in wire segment in amps
d = length of wire segment in meters
r = perpendicular distance from mid-point of segment in meters
μ = magnetic permeability in webers/(amp-meter)

At the center of a square loop of wire, B = $\mu/4\pi \times 8 \times \sqrt{2}\ i/d = (2 \times \sqrt{2}\ /\pi) \times \mu i/d$
i = current in wire in amps
d = length of one side of square in meters
μ = magnetic permeability in webers/(amp-meter)

At the center of a circular loop of wire, B = $\mu/4\pi \times 2\pi i/r = \mu/4\pi \times 4\pi i/d = \mu i/d = \mu i/2r$
i = current in wire in amps
r = radius of loop in meters
d = diameter of loop in meters
μ = magnetic permeability in webers/(amp-meter)

Abbreviations:

Wb = weber	T = tesla
G = gauss	m = meter
A = amp	

Magnetic field of the earth is roughly 0.5 G
Magnetic field of a typical, small permanent magnet is roughly 100 G
Magnetic field of a large electromagnet can be roughly 20 kG = 2 Wb/m2

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