Magnetic Shielding

TESTING CAPABILITY ASSURES MEASUREMENT CONSISTENCY IN SHIELDING ENCLOSURES

Uniform field testing is widely regarded as one of the most consistent, simple and effective methods of testing magnetic shielding materials and enclosures at audio and power frequencies. Its value is in good measurement repeatability and excellent field uniformity.

EQUIPMENT AND OPERATION

1. Souce of Uniform Field: (a) Two 30″ ID coils spaced at 18″ apart. Each coil contains 120 turns of #12 ga. solid, insulated wire. The coils are driven with approx. 57VAC to achieve a 5 Gauss field when using a variac-power supply. (b) Regulated power supplies0-300VAC, 0-250VDC (two, including current and voltage metering). (c) Construction: entirely wood, including wooden dowels. No ferromagnetic materials are used.
2. Small Detector Probes (placed inside the enclosure under test with accurate position control): (a) Small diameter calibrated multi-turn copper wire coils enclosed in slotted copper cans for shielding out electric field component. Ballantine VTVMs Model 310A, including 0.10 Ohm current sampling resistor. (b) Hall Effect AC/DC Gauss meter Dyna-Empire Model 800.
3. Measurement Standards: (a) Two standard magnets for calibrating Hall Effect probes—90 Gauss and 1K. Gauss. (b) Classical Flux Calibrator (provides a known change of flux linkage). (c) Skin-effect magnetometer, using one of the Ballantine 310A's as a detector. (d) A set of calibrated attenuators.

HELMHOLTZ TESTING AND THEORY

The two equal Helmholtz coils are placed with coinciding axes at a distance from each other equal to their common radius to provide a homogeneous magnetic field extending to approx. 1/10th the radius around the center point. To illustrate this theory quantatively, plot on graph paper the field intensity values due to each coil at various points along the axis:

For one coil, $H = \dfrac{2\pi a^2 cm}{(a^2 + x^2)^{3/2}}$, where a = mean radius radius (cm) of Helmholtz coil, x = axial distance from center (cm), I = current (C.G.S. unit), n = number of turns, H = field intensity (Oerstad or Gauss).

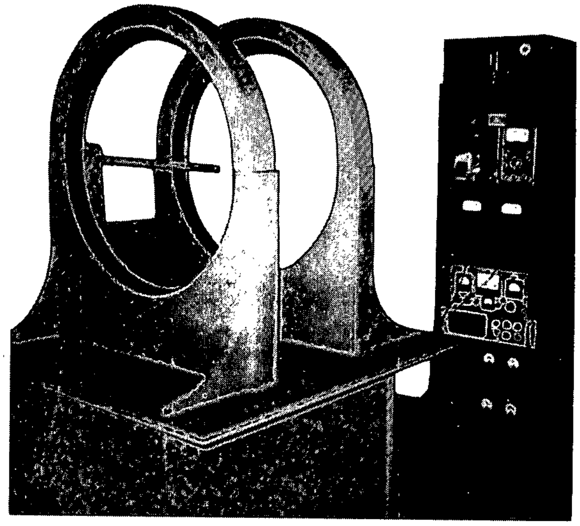
Adding together the intensities due to the two separate coils provides the resultant intensity: H =

$$\frac{4\pi a^2 n}{a^2 + \frac{a^2}{4}^{3/2}} = \frac{4\pi n}{\frac{5}{4}^{3/2} \times a} = \frac{4\pi n \times 4^{3/2}}{5^{3/2} \times a} = \frac{6.4\pi n}{a\sqrt{5}}$$

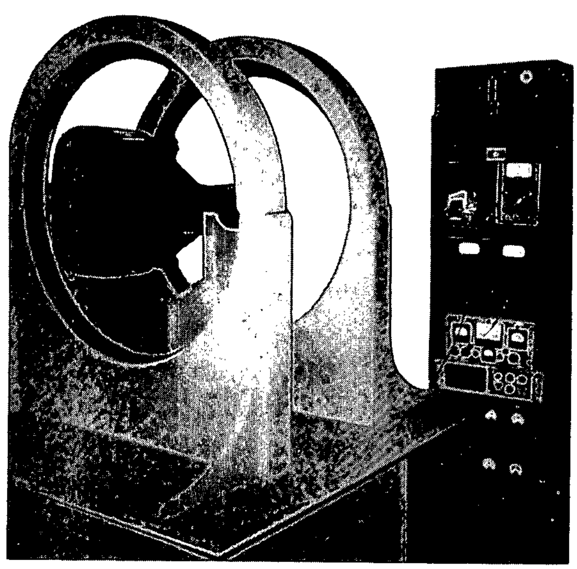
(at the center). (Two coils with currents in the same directions.)

Dynamic range is good because the generated field's intensity is reasonably strong. Larger shields, relative to the Helmholtz coil diameter than 1/5th diameter may be subjected to uniform field test if nearly symmetrical; e.g., cube shaped boxes, cylinders, or other shapes that are very rough approximations to the sphere.

Possible shield abnormalities or shielding deviations caused by seams, discontinuities, etc. are indicated by variations in shield attenuation (at a constant distance from the Helmholtz source). With short measurement times and low costs facilitating production testing and locating possible faults, rejects are prevented.



For optimum operation, Magnetics' in-house Helmholtz testing equipment should be built entirely with wood. Even the dowels should be wood. There should be no metal in the frame to distort test results.



CRT shield testing: The shielding enclosure being tested is entirely contained within the two Helmholtz coils.

CAUTION: YOU MAY NEED MORE THAN JUST FIGURES TO DESIGN MAGNETIC SHIELDS

It is difficult to predict exactly how a magnetic field goes to work on a given piece of ferro magnetic alloy even though all the formulas for calculations are perfectly correct. That's why more than figures alone may be needed to design the optimum shield.

Certain assumptions must be made in initial calculations of shielding performance expected in a magnetic shielding structure. A number must be established to express the anticipated flux density "H" to which the shield will be exposed. Then an additional assumption must be made that this flux exposure will result in a line density "B" in the shielding material derived from the BH curve for the specific alloy used. It appears that the material may not actually develop this density.

For example, a simple cylindrical shield can be placed for test purposes in an "H" field generated by a single plane Helmholtz system. If this "H" field has been measured by introducing a probe in the geometric system's center and the cylindrical shield then inserted into the Helmholtz system, with the same probe measuring the field within the shield, the resultant attenuation may not correlate with the calculated value by a factor of 2 or 3.

This factor may vary depending on the shield's orientation within the Helmholtz system. For example, the shield's axis may be aligned in the direction of the Helmholtz system's lines for one measurement. In another measurement, the cylindrical system may be normal to the lines in the Helmholtz system. In all instances, let us assume that the shield's length to diameter ratio is at least 4:1. This latter qualification is set up to minimize the shield's open end effect.

In the initial experiments, the Helmholtz system's "H" flux density was introduced into the calculations and the resultant numbers of actual measurements versus calculations would not correlate satisfactorily. Further experiments indicated that correlation was generally acceptable if a factor of "3H" were used. No detailed investigation to explain this was conducted. It was arbitrarily assumed that the initial flux density "H" measured within the Helmholtz was correct. However, introducing the ferro magnetic shield within this field generated a significant anomaly which could explain the necessity for the correction factor of 3. We would appreciate being informed of your observations on this matter.

STANDARD INSPECTION PROCEDURE

A good inspection set-up permits continuous monitoring of the attenuation capabilities of a strip of foil. It consists of a table and adjustable guides on the table's surface to direct the foil to travel properly past the test probe area. A controllable magnetic field radiator can be constructed as follows:

Basically, two solenoid type coils wound on bobbins having a central hole large enough to accommodate a 3/8″ dia. soft iron pole piece should be used. These coils should be two standard windings removed from commercial 110 AC solenoids—each coil of approximately 6000 turns of #36 enameled wire. A soft iron pole piece 3/8″ OD and approximately 3¼″ long should be positioned in the assembly, and the two coils connected series aiding. The outside terminations should be brought out to a standard AC plug. At the top end of the pole piece, a "flux sensor" made by winding a single layer coil consisting of ten turns of #20 enameled wire should be brought out in a twisted pair.

The assembly can then be mounted below the table, with the top end of the pole piece approximately 1″ below the table's surface. A yoke shaped aluminum frame locates the magnetic field generator assembly below the table. The top portion of this assembly, holding the calibrated magnetic field probe, should then be adjustable vertically. A slot in the table should be cut normal to the direction of the foil's travel. This slot should be wide enough to allow entry of the field test probe. The twisted pair on the flux intensity sensor should be brought out and connected to a Hewlett-Packard VTVM (#1), Model 400B or equivalent. The shielded plug on the calibrated magnetic field probe should be connected to another VTVM (#2) of the same type. The AC plug from the solenoid winding should be connected to a Variac. The calibrated magnetic field probe can then be lowered into position with its field reference plane parallel and in line with the table's surface. The voltage on the Variac should be adjusted until the output voltage on the VTVM (#2) indicates 5 oersteds. (In this case the calibrated magnetic field probe had a sensitivity of 20 mv per gauss at 60Hz.) The output of the flux sensor coil should then be noted on the VTVM (#1). The sole purpose of the flux sensor is to have a reference to re-establish the flux density appearing at the surface of the table at any time simply by adjusting the Variac for the required voltage.

The calibrated probe should then be positioned slightly above the table and locked into position. This position would not be critical and would only require that a reasonable mechanical clearance be maintained between it and the foil. Always maintaining VTVM (#1) at its original setting, the VTVM (#2) reading should be noted and designated E1. The foil would then be slid under the field probe and across the table. A second voltage, designated E2, should be read from VTVM (#2).

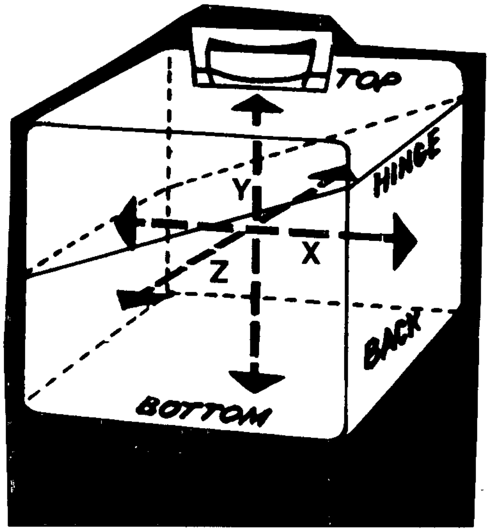
Using the voltage noted:

$$dB = 20 \log_{10} \frac{V1}{V2}$$

The entire order of the 15″ foil should be passed through the probe area noting the dB level. All of the material must display a minimum of 18 dB attenuation.

TWO ENGINEERING REPORTS ON SHIELDING EFFECTIVENESS

TEST DATA DERIVED BY EXPOSING TAPE DATA PROTECTOR TO A CONSTANT MAGNETIC FIELD IN 3 AXES



SETTING UP THE TEST

The test probe was positioned on the plane generated by the X and Y axes, which was at the approximate geometric center of the Tape Data Protector being tested. This location was chosen to provide measurements in what could be termed a "worst case area."

The leads from the high sensitivity probe consisted of a pair of fine insulated twisted wires. These were brought out from the case by simply passing them through the overlapping clearance of the seams. When the cover was closed, a situation identical to that of a normal closed cover was obtained.

To provide a means of generating a field controlling both the direction and magnitude of the field, a multi-turn heavy wire hoop coil was made up with a diameter adequate to encompass the Tape Data Protector in all axes.

TESTING PROCEDURE

First, the current required to generate a field of 20 oersteds at the center of the hoop coil was determined. Maintaining this current constant during measurements made certain the Tape Data Protector under evaulation was being subjected to an even 20 oersteds excitation.

The probe used displayed a voltage output at 60 Hz of 1.8 volts when immersed in a field of 1 oersted. With this information, it then became a matter of noting the voltage output of the probe and its axes of alignment with respect to the position of the external hoop coil.

Three measurements were made with the probe in each axis. Notation was made of the placement of the hoop coil with reference to the previously defined axis of the Tape Data Protector. The resultant data is tabulated as follows:

TABULATION OF TEST RESULTS

PROBE LOCATION	HOOP COIL LOCATION	PROBE OUTPUT	EFFECTIVE ATTENUATION
On X Axis Alignment	Parallel to X Axis	3.85 volts RMS	Approx. 9 times
On X Axis Alignment	Parallel to Y Axis	0.13 volts RMS	Approx. 276 times
On X Axis Alignment	Parallel to Z Axis	0.3 volts RMS	Approx. 120 times
On Z Axis Alignment	Parallel to X Axis	0.43 volts RMS	Approx. 84 times
On Z Axis Alignment	Parallel to Y Axis	0.28 volts RMS	Approx. 128 times
On Z Axis Alignment	Parallel to Z Axis	4.4 volts RMS	Approx. 8 times
On Y Axis Alignment	Parallel to X Axis	0.78 volts RMS	Approx. 46 times
On Y Axis Alignment	Parallel to Y Axis	4.3 volts RMS	Approx. 8 times
On Y Axis Alignment	Parallel to Z Axis	0.52 volts RMS	Approx. 68 times

WHAT WAS TESTED

Tape Data Protector made of .049 alloy. After fabrication, including heliarc welding of all seams, the Protector was properly heat treated, phosphatized, zinc chromatized and a final finish of baked blue gray textured enamel applied. Piano type hinges are on non-magnetic stainless steel. Other hardware is heavy nickel plated steel.

TEST EQUIPMENT USED

Industrial type demagnetizer was used as a field generator with a maximum current rating of approximately 5 amps, 110 volts, 60 hertz. The pole structure of this device consisted of E laminations stacked to form a 1.75″ square on the center pole surface.

Ballantine AC Voltmeter Model 410 with a calibrated pickup probe.

A commercial tape recorder.

An audio oscillator.

THE MAJOR PROBLEMS ENCOUNTERED AND THEIR SOLUTION

Variables in magnetic field characteristics a tape might be exposed to are multitudinous. Some of them are field intensity, duration of exposure, field dimension and wave shape. For these reasons it is impractical to simulate all conditions to which the recorded tape under test might be exposed. For simplicity in evaluation, the test was limited to one type of field only.

The above article was prepared by Richard D. Vance, President, Ad-Vance Magnetics, Inc., Rochester, Ind.

TEST SETUP CONSIDERATIONS

The voltmeter and probe were used to determine relative voltage levels developed by the magnetic field as a function of distance from the demagnetizer's center pole. (Please refer to the Tabulation given at the end of this Report for distance vs. voltages.) The distances measured were from the end of the probe shield to the pole piece. Field intensity at the point of contact with the probe's shield enclosure is not indicated by the dimensions because the probe's electric field shield is separated from the pickup coil by a finite distance. However, the comparative ratios arrived at are relevant due to the fact that this same technique was used in all measurement.

DESCRIPTION OF TESTS MADE

A signal of about 1,000 hertz was recorded on tape with the aid of an audio oscillator. After playing back and observing the output level on the voltmeter, the tape was positioned at a fixed distance from and parallel to the face of the center pole piece of the demagnetizer and exposed for one minute. Then the tape was played back and the level observed.

With the tape approximately 1.5″ from the pole piece, a slight signal degradation (about 1 dB) was observed. At a 1″ distance, the signal level showed a very decided reduction. Conservatively it was assumed that the field intensity was strong enough to affect the unshielded tape at a distance of about 1.5″. The probe was positioned with its calibrated reference band at 1.5″ from the pole structure and a voltage of approximately 4 volts RMS was measured.

Having determined that this arbitrary level affected the tape, the probe was located inside the protected enclosure. Then, by varying the distance of the enclosure from the plane of the demagnetizer's pole piece, it was determined that the Tape Data Protector could be brought to within .250″ of the pole piece before the internal field approached the predetermined degrading level. As a matter of reference, probe sensitivity was 20.0 mv per gauss RMS.

TABULATION

Distance	Reference Probe Voltage Without Shielding	Voltage with Probe Positioned Inside Tape Data Protectors
2.5″ or 63.5mm.	1.9	0.052
1.5″ or 38.1mm.	4.0	0.07
1.0″ or 25.4mm.	8.0	0.1
0.6875″ or 17.27mm.	10.0	0.5
0.25″ or 6.35mm.	15.0	3.8

PERTINENT ELECTRICAL PROPERTIES OF SHIELDING MATERIALS

TABLE I

PERTINENT ELECTRICAL PROPERTIES OF SHIELDING MATERIALS

Material	G	Frequency(Hz)	u	G/u	u/G	uG
Aluminum	0.61	all	1.0	0.61	1.64	0.61
Beryllium	0.1	all	1.0	0.10	10.0	0.10
Brass	0.26	all	1.0	0.26	3.85	0.26
Cadmium	0.235	all	1.0	0.235	4.26	0.235
Conetic*	0.0304	up to 1k	25115	1.3×10^{-6}	760×10^{3}	820
Copper (annealed)	1.0	all	1.0	1.0	1.0	1.0
Copper (hard drawn)	0.96	all	1.0	0.96	1.04	0.96
Gold	0.7	all	1.0	0.7	1.43	0.7
Hypernick	0.035	up to 1k	4529	7.8×10^{-6}	128205	160
Hypernom		up to 1k				
Iron (commercial)	0.0444	up to 150k	54.1	8.2×10^{-4}	1220	2.4
Iron (purified)	0.17	up to 150k	1000	1.7×10^{-4}	5882	170
	0.17	1M	700	2.4×10^{-4}	4118	119
	0.17	3M	600	2.8×10^{-4}	3529	102
	0.17	10M	500	3.4×10^{-4}	2941	85
	0.17	15M	400	4.2×10^{-4}	2353	68
	0.17	100M	100	1.7×10^{-3}	588	17
	0.17	1G	50	3.4×10^{-3}	294	8.5
	0.17	1.5G	10	1.7×10^{-2}	59	1.7
	0.17	10G	1.0	1.7×10^{-1}	1.0	0.17
Lead	0.08	all	1.0	0.08	12.50	0.08
Magnesium	0.378	all	1.0	0.378	2.66	0.378
Monel	0.04	all	1.0	0.04	25.0	0.04
Mumetal	0.03	up to 1k	19833	1.5×10^{-6}	667×10^{3}	590
NI-FE 50	0.12	up to 1k	3162	3.9×10^{-5}	25641	390
Netic (Blue)	0.1116	up to 1k	570	1.9×10^{-4}	5108	63.6
Netic (Special)	0.1263	up to 1k	440	2.8×10^{-4}	3484	55.6
Netic S3-6	0.1263	up to 1k	1000	1.26×10^{-4}	7918	126.3
Nichrome	0.02	up to 1k	18.2	1.1×10^{-3}	910	0.36
Nickel	0.2	up to 1k	100	$2. \times 10^{-3}$	500	20.0
Permalloy 4/79	0.03	up to 1k	20667	1.45×10^{-6}	68890	620
Permalloy 45	0.04	up to 1k	2450	1.6×10^{-5}	62500	96
Permalloy 78	0.035	up to 1k	2692	1.3×10^{-5}	76923	94.23
Phosphor-Bronze	0.18	all	1.0	0.18	5.56	0.18
Platinum	0.17	all	1.0	0.17	5.88	0.17
Primag 40*	0.0116	up to 1k	1700	6.8×10^{-6}	146551	19.72
Primag 90*	0.33	up to 1k	780	4.2×10^{-4}	2364	257.4
SI-FE 4%	0.0247	up to 1k	425	5.8×10^{-5}	17240	10.5
SI-FE 4% (Oriented)	0.11	up to 1k	4787	2.4×10^{-5}	41667	550
Silver	1.06	all	1.0	1.06	0.94	1.06
Steel (cold rolled)	0.17	up to 200	224	7.59×10^{-4}	1318	38.0
	0.17	1k	212	8.02×10^{-4}	1247	36.0
	0.17	6k	153	1.11×10^{-3}	900	26.0
	0.17	8k	147	1.16×10^{-3}	865	25.0
	0.17	10k	135	1.26×10^{-3}	794	23.0
	0.17	15k	97	1.75×10^{-3}	571	16.5
	0.17	20k	86	1.98×10^{-3}	506	14.5
	0.17	30k	59	2.88×10^{-3}	347	10.0
	0.17	40k	49	3.47×10^{-3}	288	8.3
Steel (Galvanized)	0.1766	up to 1k	227	7.78×10^{-4}	1285	40.9
Steel (hot rolled)	0.1603	up to 1k	160	10^{-3}	998	25.65
Steel (stainless)	0.0284	all	1.0	0.0284	35.2	0.0284
Steel (Terne)	0.1517	up to 1k	157	9.6×10^{-4}	1035	23.8
Supermalloy	0.03	up to 1k	100000	2.9×10^{-7}	345×10^{4}	2900
Tin	0.15	all	1.0	0.15	6.67	0.15
Zinc	0.29	all	1.0	0.29	3.45	0.29

*values given hold for magnetic induction between 3.2 and 159.2 A/m, above 318.4 A/m the permeabilities at 1kHz are as follows:
Primag 40 : 48 000
Primag 90 : 60 000

NOTE: INQUIRE AT THE MANUFACTURERS OF MAGNETIC MATERIALS FOR PERMEABILITIES AND OTHER MAGNETIC PROPERTIES (SATURATION, ETC) IF USED ABOVE 1kHz! Permeabilities generally decrease with increasing frequencies. The minimum permeabilities of some materials at undefined frequencies are:

Conetic	3000
Netic (Blue)	240
Netic (Special)	125
Netic (S3-6)	220
Primag 40	1300, above 318.4 A/m : 1500
Primag 90	560, above 318.4 A/m : 3000

For shielding effectiveness calculations, usually the following mathematical expressions are used:

$$S = R + A + B$$

where S = shielding effectiveness (dB)
R = refelction losses (dB)*
A = absorption losses (dB)
B = corrections factor (dB)**

*R is *either* R_E or R_H or R_P referring to electric (E), magnetic (H) or plane wave (P) reflection losses

**B correction factor should be added whenever the absorption losses (A) turn out to be 10 dB or less

The individual terms of the shielding effectiveness equation above can be calculated as follows:

$$R_E = 10 \log (G/u \times 1/f^3r^2) + 353.6$$

$$R_H = 20 \log [0.462/r\,(u/G \times 1/f)^{0.5} + 0.136r\,(u/G \times 1/f)^{-0.5} + 0.354]$$

$$R_P = 10 \log (G/u \times 1/f) + 168.2$$

$$A = t(uGf)^{0.5} \times 3.38 \times 10^{-3}$$

where R_E, R_H, R_P and A are in dB and were explained above,
G = relative conductivity of material (compared to copper)
u = relative permeability of material (related to free space)
f = frequency of the field (Hz)
r = source-to-shield distance (inches: 1 inch = 25.4 mm)

As it can be seen, each of the expressions are a function of some relations between the quantities of G and u, which are given electrical properties of the materials used for shielding. TABLE 1 presents the magnitudes of G, u, Gu.G/u and u/G ready to use in the individual shielding equations. The values of "B" (the correction factor) can be calculated either for electric or for magnetic fields and are tabulated in most of the literature discussing the shielding effectiveness. Just for completeness, the equations are repeated here:

$$B_{(dB)} = 20 \log \left[1 - \left(\frac{Z_s - Z_w}{Z_s + Z_w}\right)^2 \left(\frac{1}{10^{0.1A}}\right) \left(\cos 7.68 \times 10^{-4}\right. \right.$$
$$\left.\left. \left(t\sqrt{\mu G f}\right) - j \sin 7.68 \times 10^{-4} \left(t\sqrt{\mu G f}\right)\right) \right]$$

where $Z_s = (1 + j)\,(f/2)\,(u/G)\,(3.69 \times 10^{-7}$ ohms

$Z_{w(E)} = -j(0.71)\,(10^{12})\,/fr$ ohms

$Z_{w(H)} = j(0.2)\,(10^{-6})\,(fr)$ ohms

$Z_{w(P)} = 377$ ohms

For magnetic fields only there is a simpler formula:

$$B_{(dB)} = 20 \log \left| 1 - \frac{(K-1)^2}{(K+1)^2} \right|$$

where $K = 1.3\,(u/G)\,(1/fr^2)$

The above article was prepared by Dr. Leslie Radnay, Sr. Consultant, R. & B. Enterprises.