BROOKHAVEN NATIONAL LABORATORY Safety & Health Services Division INDUSTRIAL HYGIENE GROUP Standard Operating Procedure	NUMBER IH99110 REVISION FINAL rev 3
SUBJECT: Static Magnetic Fields Measurement Principles	DATE 04/25/08 PAGE 1 OF 14

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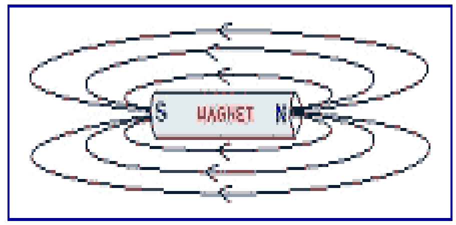


1.0 Purpose/Scope

This procedure provides a standardized method for conducting area surveys with direct reading meters. It should be used in conjunction with the SBMS Subject Area Static Magnetic Fields (SMF) and an *Instrument Operation* procedure in the series as IH SOP IH99240 Instrument Operation: F.W. Bell Gauss Meter, IH99380 and IH99400 THM 7025 3-Axis Hall Magnetometer.

An area survey meter should be used to determine baseline static magnetic field area levels and the need for further dosimetry. Survey meters are designed for conducting static magnetic field surveys to determine the need for area warning posting, locate problem-static magnetic field sources, and measuring the effectiveness of engineering controls. It can be used as a screening tool to determine the need for personal monitoring and to sketch isometric lines for control area delineation.

Generally, employee exposure assessments should be made with a static magnetic field dosimeter when the levels indicate that the exposure will exceed exposure guidelines. However an area survey meter can be used as a screening tool to identify those areas that may need further employee assessment or for operations that are of short duration (15 to 30 minutes) and that involve limited employee movement so that the meter can measure the actual employee exposure. In these cases, the meter reading must be observed and recorded over the entire time of exposure. It can also be used to map the area so as to determine posting levels and zones that may require additional precautions (e.g., special tool handling; limitation of personnel; training; barriers, etc).

2.0 Responsibilities

2.1 **Program Administration:** This procedure is administered through the SHSD Industrial Hygiene Group. Members of the SHSD Industrial Hygiene Group are required to follow this procedure.

2.2 Other BNL organizations that provide BNL with field monitoring or other hazard assessment services are required to follow this SOP or an equivalent document that ensures an equal or superior method of assessment documentation and recordkeeping.

2.3 ***Industrial Hygiene Professional:*** The *Industrial Hygiene Professional* of SHSD and other BNL organizations using this procedure are to be qualified by the SHSD IH Group. These individuals will conduct or supervise industrial hygiene hazard assessments and personal exposure monitoring using this procedure. These *IH Professionals* are responsible for:

- Interpreting, reporting, and documenting personal exposure monitoring in accordance with the requirements of this procedure, other appropriate SOPs, and generally accepted professional standards and practices.
- Ensuring a quality report is prepared that documents the exposure, evaluates the relevance to exposure standards, and recommends protective and corrective actions.
- Ensuring the final report is provided in a timely manner to all appropriate parties.
- Ensuring that the appropriate data is correctly and completely entered into the BNL IH exposure monitoring database (i.e. *Compliance Suite*®).
- Ensuring that original records of sampling and analysis enter the SHSD *Record Custodian* filing system.

2.4 ***Industrial Hygiene Technician (Sampler)*****:** The industrial hygiene technician using this procedure is to be qualified by SHSD to conduct industrial hygiene personal exposure monitoring under the direction of his/her organization's *IH Professional*. The sampler is responsible for collecting personal exposure monitoring samples in accordance with the guidance of the *IH Professional* and the requirements of all SOP's pertinent to the particular monitoring requirements (i.e. Chain of custody, equipment check in/out, equipment operation, recordkeeping, etc.).

2.5 ***Compliance Suite*® *data entry:*** The management of the person conducting the sampling is responsible for entering complete and correct data into the BNL IH exposure monitoring database (i.e. *Compliance Suite*). This task may be assigned to one or more individuals who act as the data entry person for an organization, however, it remains the responsibility of the line management of the *Sampler* to ensure this task is fulfilled within 21 calendar days of the end of the sampling event.

3.0 <u>Definitions</u>

Gauss (G) – in the CGS system, this the unit for one flux line passing through one square centimeter.

Magnetic Field – for static magnetic fields and extremely low frequencies, this is generally used for the magnetic flux density. When referring to RF and microwaves, the term usually means magnetic field strength (H field).

Table 1. Static Magnetic Field Units

INTEGRATED SYSTEM (SI UNITS)		CENTIMETER-GRAM-SECOND UNIT SYSTEM (CGS)	
Tesla (T)	**MilliTesla (mT)**	**Gauss (G)**	**Milligauss (mG)**
1	1000	10,000	10,000,000
0.1	100	1000	1,000,000
0.01	10	100	100,000
0.001	1	10	10,000
0.0001	0.1	1	1000

Magnetic field strength –(H) vector field () with units of amps per meter.

Magnetic Flux Density (B) Gauss: The number of magnetic flux lines per area that is induced by an applied magnetic field intensity H. The B results from an applied H is given by B = μH, where μ is the permeability (sometimes referred to as the *absolute permeability)* of the magnetic material in which the flux is contained. Where U is zero then B=H.

Magnetic Field Strength or magnetizing force (H) - The force within the magnet that produces the flux lines. It must be understood that flux density and magnetic field strength are related but not equal. The intrinsic characteristics of the magnetic material must be considered. Only in free space (air) are flux density and field strength considered equal.

Occupational Exposure Limit: The maximum time weighted average (TWA) or ceiling value exposure permitted for employee exposure, based on the less of the OSHA Permissible Exposure Limits (PEL) or ACGIH Threshold Limit Value (TLV). OSHA does not have a static magnetic field standard. BNL has adopted the following found in the Static Magnetic Field subject area.

BNL Exposure Limits for Static Magnetic Fields		
Areas of Concern	***8-hour Time-Weighted Average (TWA)***	***Ceiling***
Medical Electronic Device Wearers *(e.g., cardiac pacemakers, electronic inner ear prostheses, insulin pumps)*	--	.5 mT (5 G)
Ferromagnetic Objects *(includes tools and medical implants/prostheses)*	--	60 mT (600 G)*****

Whole Body	60 mT (600 G)	2 T (20,000 G)
Limbs	600 mT (6,000 G)	5 T (50,000 G)

Tesla (T)- In the SI system this is 10,000 lines per square centimeter. Unit of magnetic induction or magnetic flux density (B field) in the meter-kilogram-second system (SI) of physical units. One Tesla equals one weber per square meter (or magnetic flux per unit area), corresponding to 10^4 gauss

4.0 Prerequisites

4.1 **Training prior to using this instrument:**

4.1.1 Demonstration of proper operation of the procedure to the satisfaction of the SHSD IH Program Administrator. See Section 7 for qualification requirements.

4.1.2 Other appropriate training for the area to be entered (check with ESH coordinator or FS Representative for the facility).

4.2 **Area Access**:

4.2.1 Contact the appropriate Facility Support Representative or Technician to obtain approval to enter radiological areas.

4.2.2 Verify with the appropriate Facility Support Representative or Technician if a Work Permit or Radiological Work Permit is needed or is in effect. If so, review and sign the permit.

4.2.3 Use appropriate PPE for area.

5.0 Precautions

5.1 Hazard Determination:

5.1.1 The operation of an area survey meter or use of this procedure does not cause exposure to any chemical, physical, or radiological hazards. The meters do not generate Hazardous Waste.

5.1.2 The operation an area survey meter or use of this procedure does not cause exposure to any chemical, physical, or radiological hazards, except the potential for SMF exposure.

5.1.2.1 By its very nature, a SMF survey meter may be used in areas where excessive SMF levels exist or are suspected to be present. Check the instrument procedures to determine if there are limitations on the strength of field that the instrument can be introduced. The user must take into consideration the effects of such strong magnetic fields.

5.1.2.2 If individuals using a meter wear pacemakers, or other medical electronic devices, they may not be exposed to fields greater than or equal to 0.5 mT (5 Gauss) without consultation with the Occupational Medicine Clinic. Also, individuals with ferromagnetic implants should not be exposed to levels greater than or equal to 60 mT (600 G) without clearance from the Occupational Medicine Clinic.

5.1.3 In areas where the field strength may potentially exceed 10 mT (100G), exposure levels as low as 1 mT (10 Gauss) have been reported to cause deletion of information on magnetic memory materials, such as found on credit cards, identification badges, computer disks, and video tapes. Watches may be stopped.

5.2 Personal Protective Equipment:

5.2.1 Use nonmagnetic objects or tools when working with or around magnetic fields above 60 mT. These objects may be drawn into the magnet and pose a flying object hazard. Metal-toed safety shoes may also be affected.

5.2.2 Additional PPE: Other appropriate PPE for hands, feet, skin, head, or eyes may be needed for the area being entered because of other hazards. Check with your ES&H representative.

5.2.3 SMF protective clothing is not available. Rely on engineering and administrative controls such as remaining a safe distance from the source as indicated by the direct reading meter.

5.3 **Job Risk Assessment:** Consult the *Job Risk Assessment* SHSD-JRA-05 for the risk analysis of this operation based on the hazards and controls of this SOP.

5.4 **Work Planning:** All requirements of work permits and work planning system reviews must be met in performing this procedure.

5.5 **Environmental Impact and Waste Disposal:** This sampling does not have adverse impact on the environment or create waste for disposal.

6.0 Procedure

6.1 **Select the appropriate piece of equipment.**

6.1.1 Determine if the field strength is within the range of the equipment.

6.1.2 Operate the meter as per the BNL Instrument Operation SOP.

6.2 **Calibrate** the meter as per the Instrument Operation SOP.

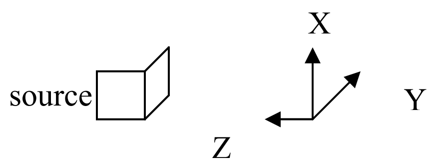
6.3 **Zero Check:** Check if the instrument reads zero. Indicate this on the sheet. If the instrument does not read zero, then the probe must be placed in the zero field chamber. This must be done in an area without a magnetic field. Record results on survey sheet.

6.4 **Measuring the Field Strength:** Approach source, taking reading from further away.

6.4.1 For meters that provide the route-mean-square (rms) value of all the fields at that position (triaxial response), skip to step 6.4.3.

6.4.2 For meters that do not provide integrated rms readings, the users must take the rms values of the three orthogonal measurements (Bx, By and Bz).

6.4.2.1 For a transverse probe, the flat surface is rotated through the axis,



Bx = perpendicular to the source
By = parallel to the source
Bz = vertical to the source, or

The user should peak the probe, a process in which the probe is rotated and tilted in several planes to obtain the highest possible output for a given field. At each axis (x,y,z), rotate the probe till you find the highest value. Without changing the base location, then rotate the probe to the next axis and find the highest value again. Do this for each axis and take the highest reading.

6.4.3 Take measurements at the following locations:

Take at least 5 measurements along the vertical plane from floor to about 6.5 feet high. Measurements should be at a max of 20 cm (~8 inches) apart. Determine point of highest reading.

Take at least 4 additional measurements on a horizontal line from the centerline. Ideal locations for measurements are:

- 0.5 mT line/perimeter
- 10 mT
- 60 mT line/perimeter
- Maximum whole body exposure
- Maximum extremity exposure
- Typical operating positions
- Surface levels.

If fields are about 60 mT take a string with a paperclip to visually identify gradients and to make sure that surrounding structures and equipment are not affecting the fields.

6.5 **Calculations**

6.5.1 For meters that do not provide integrated RMS readings (such as the Bell Gauss meter), calculate the static magnitude by taking the resultant of the x, y, and z components (square root of the sum of $x^2 + y^2 + z^2$).

6.5.2 For all instruments, spatially average the values across the vertical range or visually identify the highest value as the worst-case incident.

6.6 **Recording readings:**

6.6.1 Use a BNL Static Magnetic Fields Forms (found in SBMS subject area) to record readings and additional required information.

6.6.2 Return meter and original sampling form to the SHSD IH Laboratory. Copy goes to the ESH Coordinator.

6.6.3 If levels are greater than 0.5 mT (5 Gauss) and employees with medical electronic devices are exposed, send a copy to the Occupational Medicine Clinic.

6.6.4 Plan and conduct hazard assessments and exposure monitoring using the procedure outlined in I*H 60500 Reporting Personnel Exposure Monitoring Results* for:

- Exposure Assessment Sampling Strategy,
- Initial Notification of Employee Monitoring Results, and
- Preparation of a formal report on the exposure monitoring or hazard assessment.

6.6.5 Ensure that a copy of any hazard evaluation report written by a competent person on the survey is sent to the IH Laboratory and the Occupational

Medicine Clinic, the department ESH coordinator, and the individuals surveyed.

7.0 Implementation and Training

Prior to using this procedure, the user:

7.1 Demonstrates proper operation of this procedure and the corresponding instruments to the satisfaction of the SHSD IH Program Administrator.

7.2 Completes other appropriate training for the area to be entered (check with ESH coordinator or FS representative for the facility).

7.3 Completes OT&Q Training and a medical surveillance required for any PPE used on the job or for other hazards encountered in the work area.

7.4 Completes qualification on this procedure on at least a 3 year basis. Provide documentation of the use the procedure and equipment several times per year using the Annual Skills Qualification form.

7.5 Personnel are to document their training using the Qualification Criteria listed in Attachment 9.3 Job Performance Measure.

8.0 References

8.1 SBMS subject area *Static Magnetic Fields.*

8.2 *Manual for Measuring Occupational Electric and Magnetic Field Exposures*. US Department of Heath and Human Services, Public Health Service, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, Division of Biomedical and Behavioral Services, October, 1998.

8.3 ACGIH American Conference of Governmental Industrial Hygienists Threshold Limit Values for Chemical Substances and Physical Agents and Biological Exposure Indices (most recent).

9.0 Attachments

9.1 Flowchart of Magnetic Field Measurements
9.2 Theory of Magnetic Field Measurements
9.3 Job Performance Measure

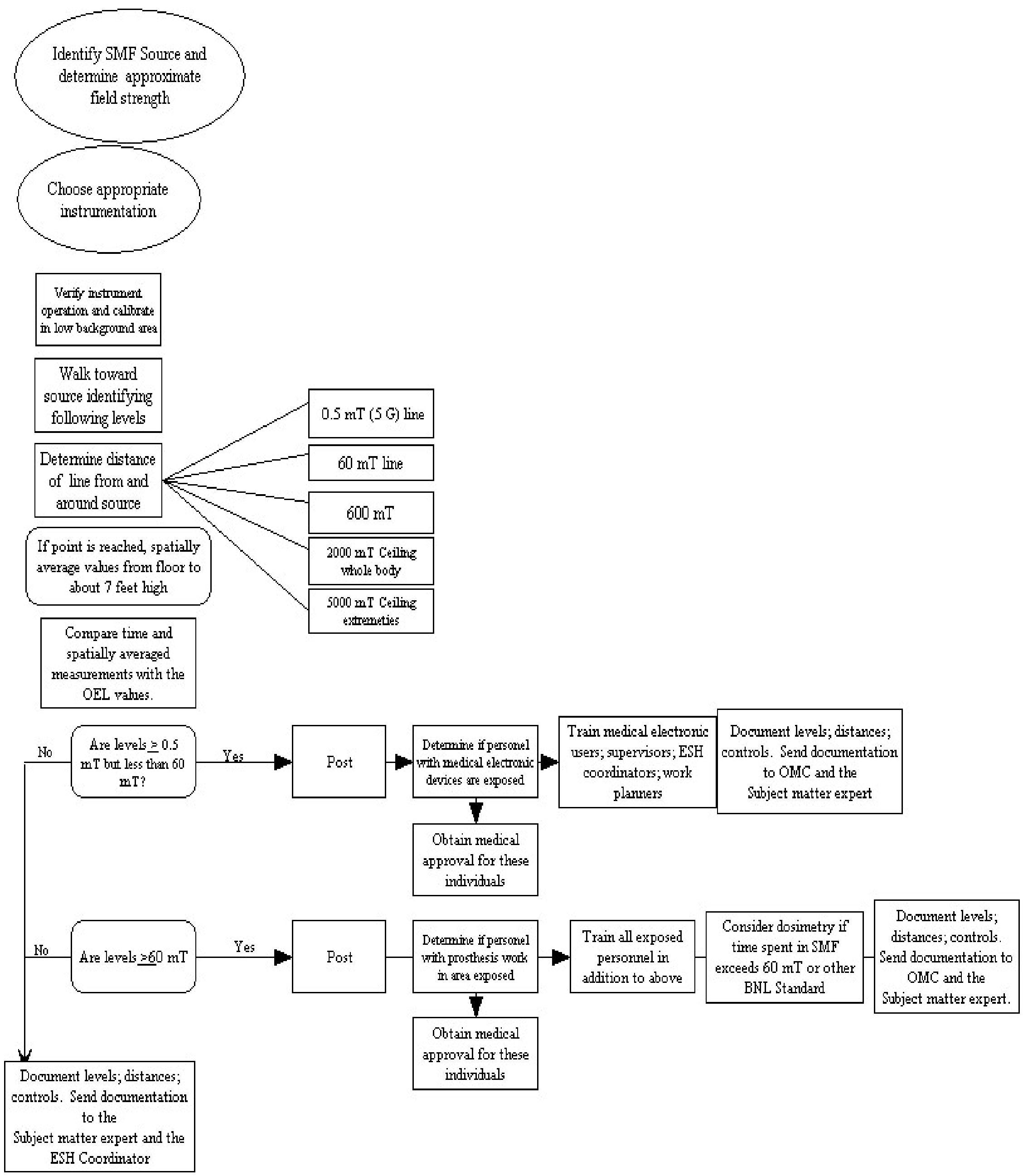
10.0 Documentation

Document Development		
PREPARED BY: *(Signature and date on file)* N. M. Bernholc, CIH Date 07/02/01	REVIEWED BY: *(Signature and date on file)* J. Peters, CIH Date 07/02/01	APPROVED BY: *(Signature and date on file)* R. Selvey, CIH SHSD IH Group Leader Date 07/05/01
ESH Coordinator/ Date: *none*	Work Coordinator/ Date: *none*	SHSD Manager / Date *none*
QA Representative / Date: *none*	Training Coordinator / Date: *none*	Filing Code: **IH52**
Facility Support Rep. / Date: *none*	Environ. Compliance Rep. / Date: *none*	Effective Date: **07/06/01**
ISM Review - Hazard Categorization ☐ High ☒ Moderate ☐ Low/Skill of the craft	Validation: ☐ Formal Walkthrough ☐ Desk Top Review ☒ SME Review Name / Date: 04/22/08	Implementation: Training Completed: Tracked in BTMS Procedure posted on Web: 04/25/08 Hard Copy files updated: 04/25/08 Document Control: no changes in forms

Revision Log
Purpose: ☐ Temporary Change ☐ Change in Scope ☐ Periodic review ☐ Clarify/enhance procedural controls Changed resulting from: ☐ Environmental impacts ☐ Federal, State and/or Local requirements ☐ Corrective/preventive actions to non-conformances ☒ none of the above Revision 1: Section/page and Description of change: Revised to include Section 7 Implementation and Training. Text added to Section 2, 4,5, 6, and 7. JRA added to Section 5. Deleted Attachment 9.3 which are now in SBMS Subject Area *SMF.* SME Reviewer/Date: R. Selvey 03/29/05*(Signature and date on file)*
Purpose: ☐ Temporary Change ☐ Change in Scope ☒ Periodic review ☒ Clarify/enhance procedural controls Changed resulting from: ☐ Environmental impacts ☐ Federal, State and/or Local requirements ☒ Corrective/preventive actions to non-conformances ☐ none of the above Revision 2: Section/page and Description of change: Modified Section 2.1-3.2 and 4.1 to contain correct wording on the Qualification Policy. Added 5.2.3, 5.4 and 5.5 in hazard assessment section. Changed 5.3 to link to current JRA. Made text changes in Section 6 for clarity and revised policy on calibration. Modified Section 7 to refer to JPM. Added Attachment 9.3 JPM. [Changes are significant enough that all personnel qualified prior to 2007 need re-qualification on this revision.] SME Reviewer/Date: R. Selvey 01/02/07 *(Signature & date on file)*
Purpose: ☐ Temporary Change ☐ Change in Scope ☐ Periodic review ☒ Clarify/enhance procedural controls Changed resulting from: ☐ Environmental impacts ☐ Federal, State and/or Local requirements ☐ Corrective/preventive actions to non-conformances ☒ none of the above Revision 3: Section/page and Description of change: Modified Section 4 to remove mention of ozone meter. Changed 5 mT to the correct 0.5 mT in Step 6.4. SME Reviewer/Date: N. Bernholc 4/25/08 *(Signature & date on file)*

Attachment 9.1

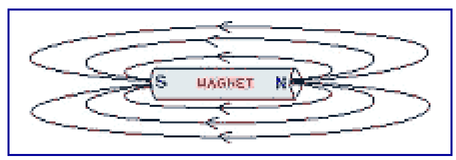
Flowchart of Field Measurement Process



Attachment 9.2
Theory of Magnetic Field Measurements

Magnetic fields are well defined in theory but do not behave predictably in real life. Often the root cause for the failure of a design involving magnetic fields is the designer's inability to understand how the lines of force, or flux lines, are generated or affected by the surrounding environment. Magnetic fields are perhaps more easily understood in terms of magnetic field lines. *Field lines*, also known as *lines of force*, define the direction and strength of the magnetic field at any local in space. Magnetic fields have both a direction and strength (or "magnitude"). The direction of the field lines indicates the direction of the field, while the *density* of the field lines indicates the magnitude of the field. Thus at points where the field lines are closer together, the field is stronger. Field lines are described mathematically with a quantity known as *flux*.

Magnetic fields are commonly a result of *magnetic dipoles*. A simple example of a magnetic dipole is the bar magnet. The magnetic field lines always begin on the *north* pole of a magnet, and end on the *south* pole. Magnetic dipoles always like to align themselves parallel to an external magnetic field, so the dipole's field matches the one applied to it. This is why bar magnets line up north-to-south.



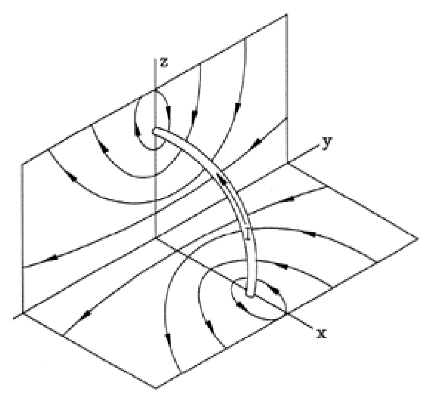
How strong is the magnetic field at a given distance from the magnet?

Elementary physics states that the magnetic field of a magnetic dipole is approximately proportional to the inverse cube of the distance from the dipole. Therefore, if you double the distance from the magnet, the magnetic field strength will be reduced (roughly) by a factor of 8.

The strength of a magnetic field is measured in units of *Gauss (G)*, or alternatively, in *Tesla (T)*. In the MKS (metric) system of units, 1 T = 1 kilogram*ampere/second^2 = 10^4 G.

For comparison, the magnetic field of the earth at the surface is on the order of 1 Gauss, where that of a Neodymium magnet is on the order of 10^4 Gauss. This means that Neodymium magnets produce magnetic fields *tens of thousands* of times stronger than those of the earth!

Technically, Gauss and Tesla are units of *magnetic induction*, also known as *magnetic flux density*. Quantitatively, the force on a charged particle q moving with velocity **v** is given by the vector equation **F** = q**v** x **B**, where **B** is the magnetic induction.

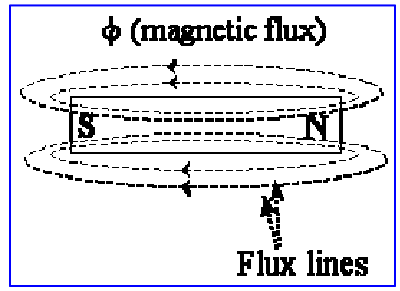


The magnetic field has vector components – x, y, and z. If the sensor uses a three-axis sensor – it will simultaneously read the fields three spatial components by aligning the three probes orthogonally. The THM meter is such a probe and does not require probe orientation. If the instrument does not do this (e.g., the Bell Gauss Meter), then the surveyor must take the vector components and take the root mean square average as follows:

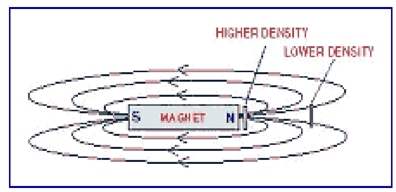
$$B = \sqrt{}B_x^2 + B_y^2 + B_z^2$$

or the user should peak the probe, a process in which the probe is rotated and tilted in several planes to obtain the highest possible output for a given field.

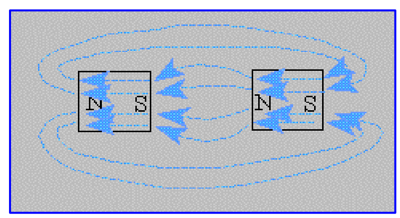
In physics, magnetic flux is the term used to describe the total amount of magnetic field in a given region. The term *flux* was chosen because the power of a magnet seems to "flow" out of the magnet at one pole and return at the other pole in a circulating pattern, as suggested by the patterns formed by iron filings sprinkled on a paper placed over a magnet or a conductor carrying an electric current. These patterns are called lines of induction. Although there is no actual physical flow, the lines of induction suggest the correct mathematical description of magnetism in terms of a field of force. The lines of induction originate on the north pole of the magnet and end on the south pole; their direction at any point is the direction of the magnetic field, and their density (the number of lines passing through a unit area) gives the strength of the field. Near the poles where the lines converge, the field and the force it produces are large; away from the poles where the lines diverge, the field and force are progressively weaker.



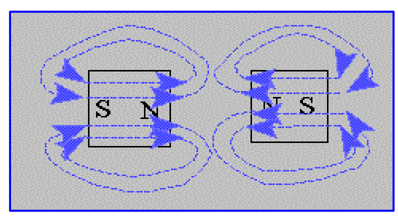
When we are referring to static magnetic fields, we are generally talking about the magnetic flux density (number of magnetic flux lines/area) rather than field strength. The number of flux lines per unit area is called flux density, it is denoted by B and is measured in webers/m^2 or teslas, T.



- In electromagnetics, magnetic flux lines exist in continuous loops.
- Magnetic flux lines leave the north of a magnetic source, and return at the south.
- If unlike poles of two permanent magnets are brought together, the magnets will attract, and the flux distribution will be as shown at left.



- If like poles of two permanent magnets are brought together, the magnets will repel, and the flux distribution will be as shown at left.



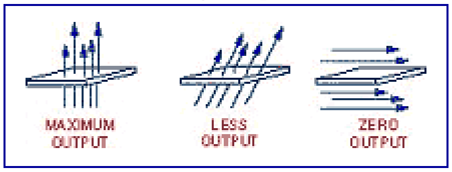
A Hall sensor is a four-terminal, solid-state device capable of producing an output voltage V H , proportional to the product of the input current, l c ,the magnetic flux density, B, and the sine of the angle between B and the plane of the Hall sensor. A reversal in the direction of either the magnetic field or the control current will result in a polarity change of V H . A reversal in the direction of both will keep the polarity the same. By holding the control current constant, the Hall voltage may be used to measure magnetic flux density. Multiplication may be accomplished by varying both the control current and the magnetic field.

Sources of Error

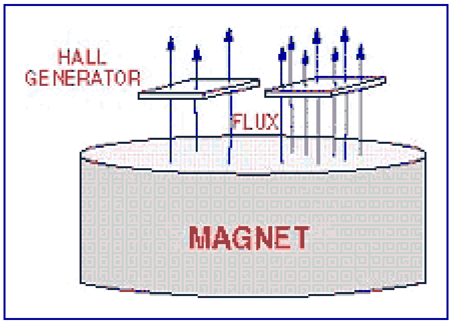
Zeroing or nulling the Hall probe and meter is one of the most important steps toward obtaining accurate flux density measurements. Most Hall devices produce an offset signal in the absence of a magnetic field. Second, the internal circuitry of the meter itself is likely to produce a small offset signal even in the absence of an input signal. Finally, local flux from the Earth (~0.5 G) or nearby magnetic sources will affect the Hall sensor. The process of zeroing eliminates these errors.

The probe is frequently placed in an assembly called a zero flux chamber to shield the device from all local flux. In other situations it may be desirable to zero the probe without the chamber so that all future readings are relative to the local flux condition.

Pay attention to the angle of the probe relative to the flux being measured. The highest output is generated when the flux lines are perpendicular to the Hall sensor. This is the way each Hall probe is calibrated and specified. It is often incorrectly assumed that the plane of the Hall generator is exactly the same as the axis of the probe's stem, but because of variations in material and manufacturing this alignment is not a certainty. The user should always peak the probe, a process in which the probe is rotated and tilted in several planes to obtain the highest possible output for a given field.



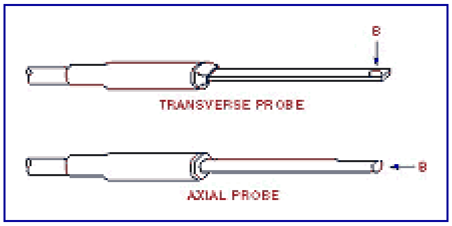
A hall generator output is related to the angle at which the flux lines pass through it. Maximum output is achieved when the lines are perpendicular to the sensor. At other angles the output follows a cosine function.



Measurement of permanent magnets can lead to confusing results:
Flux density decreases as the distance from the pole face increases. The Hall generator will always be some finite distance from the pole face because there will always be material (the stem and air) between it and the magnet. Flux lines are seldom distributed evenly across the pole face of a magnet. Interior flaws such as cracks or bubble, or an inconsistent mix of materials, can result in flux density variations.

The Hall device will respond to this if it is much smaller than the than the face of the magnet.

Materials in the area
Finally, problems can arise from ferrous materials in the area where the test is being conducted. A steel workbench can redirect the flux lines from a magnet and cause erroneous results. Temperature effects, linearity errors, and reversibility errors should be taken into consideration. The user should always refer to the specifications and take advantage of additional performance data if the manufacturer offers them.



BROOKHAVEN NATIONAL LABORATORY

Static Magnetic Fields Principle of Measurements
Job Performance Measure (JPM) Completion Certificate

Candidate's Name	Life Number:

Knowledge of the Principle of NIR Measurements

Criteria	Qualifying Standard	Unsatis-factory	Reco v-ered	Satisf-.actory
SMF Principles	Understands the concepts of B and H field strength.			
	Understands the confounders of magnetic fields measurements.			
Hazard Analysis	Understands the basis of the need to perform field survey. i.e., the triggering events.			
Personal Protective Equipment	Understands the need to be aware of the potential hazards from SMF and to determine the needed controls			
Sampling Protocol	Understands the way to use meters to measure SMF- probe location and angles.			
Sampling Equipment	Knows the type of equipment needed for the procedure.			
	Understands the need to know if the probe is tri-axial, or if measuring on one plane- is transverse or axial.			
Analysis of data	Knows the occupational exposure limits for SMF.			
	Understands the need to perform analysis on the data to assess potential exposure to the worker			
Record forms	Knows how to correctly and completely fill all forms associated with this SOP.			
Employee Notification	Knows how to timely and properly notify workers and management of problem areas.			

Employee: I accept the responsibility for performing this task as demonstrated within this JPM and the corresponding SOP.

Candidate Signature:	Date:

Evaluator: I certify the candidate has satisfactorily performed each of the above listed steps and is capable of performing the task unsupervised.

Evaluator Signature:	Date: