RELATIVITY MISSION
GRAVITY PROBE-B

MAGNETIC CONTROL PLAN - SCIENCE MISSION

STANFORD GP-B PROCEDURE P0057
Revision B per ECO # 727

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1.0 GENERAL

Realization of GP-B mission objectives requires that the ambient magnetic field at each of the gyroscope rotors not exceed:

A. Steady state (dc) field of 2 $x10^{-7}$ Oersted or less.
B. Time varying field of 5 $x10^{-13}$ Oersted RMS or less at a roll period of 1.0-10.0 minutes.

These low levels of ambient field will be required beginning at the cool down of the gyro assembly and continuing until the end of the mission.

The magnitude of the ambient field at the location of the gyros rotors depends on the effectiveness of the outer and inner shields of the dewar well volume and the magnetic cleanliness of all parts of the science instrument.

In order to meet these requirements, it will be necessary to employ stringent magnetic controls. The high degree of magnetic control established by this document requires proper selection of materials, fabrication processes, and assembly techniques; the avoidance of magnetic contamination, and the magnetic testing of all probe parts in critical zones on a 100% basis.

The maximum dc magnetic field value to which the magnetic shield system will be exposed during use is 600 millioersteds. This value represents, for flight operations, the highest ambient field of the earth as seen on orbit plus the fields produced by the spacecraft. For ground operations involving lead bag expansions, the 600 millioersted value is the maximum Earth ambient field. The maximum ac magnetic field amplitude on orbit will be 500 millioersteds. These values of exposure, in any arbitrary orientation, will be used to determine the performance of the inner and outer well shields.

Note should be made that the maximum magnetic field values specified at the gyros shall be met after integration on the operating spacecraft. The three major systems which can produce these fields are the Stanford-produced science instrument assembly, the LMSC-produced probe assembly, and the Dewar and spacecraft hardware.

The magnetics requirements given in this document flow from the *Gravity Probe-B Twelve Fundamental Science Requirements (T002)* document, the *Science Payload Specification* (PLSE-12), and *System Design and Performance Requirements* (T003).

1.1 MAGNETIC CONTROL ZONES

The requirements on the magnetic cleanliness of a part used in the science instrument depends very strongly on the location of that part relative to the science gyroscopes. For convenience in establishing and maintaining the appropriate magnetic requirements, the volume of the science instrument has been divided into several *magnetic control zones*, or *magnetics zones.* These zones are defined as indicated in Table 1.

Table 1. Magnetic Control Zones

Zone 1: The regions inside each of the local superconducting magnetic shields.

Zone 2: The region inside the lead bag shield (not already included in Zone 1) starting at the bottom of the lead bag and extending upward to a position 10" (25 cm) above the location of the uppermost gyroscope. Zone 2 is further subdivided into Zones 2A and 2B:

> Zone 2A: The portion of Zone 2 which includes all locations within a 9 cm distance from the center of any gyroscope.
>
> Zone 2B: The remaining portion of Zone 2.

Zone 3: The region of the interior of the lead bag extending from the end of Zone 2 to the top of the lead bag.

Zone 4: The region within the Cryoperm magnetic shield but not within the lead bag.

Zone 5: All regions of the instrument, Dewar, and spacecraft not included in other zones.

Zone SP: The region interior to the probe and above station 199* [the top of the Cryperm shield}, and the region between the probe and the Dewar well.

Figure 1 illustrates the locations corresponding to these zones.

Figure 1. Magnetic Control Zones.

Zone SP (for special) exists to control two special magnetic risks. Materials located in the probe region above station 199* need not meet stringent magnetic standards if there is no potential for particles of these materials to detach and fall into zones 1-4. However, if materials in zone SP can generate particulates via abrasion during probe operation and/or assembly, then they are subject to more stringent requirements. Materials located interior to the probe well but outside the lead bag must be controlled carefully to ensure that there are no large background fields from the dewar well at the time the first lead bag is cooled.

1.2 HIGHLIGHTS OF MATERIAL QUALIFICATION AND ASSEMBLY REQUIREMENTS

The system of superconducting and ferromagnetic shields used in the science instrument is capable of providing the required low levels of dc and ac magnetic fields. However, all materials used in instrument fabrication must be very carefully controlled with regard to magnetic properties if these extremely low field levels are to be attained in the final complete instrument. The following characteristics must be considered when evaluating materials as to their acceptability for use in a particular magnetic zone.

A. Remanent magnetic moment. Materials which exhibit any significant remanent magnetization after exposure to magnetic fields of the levels encountered during probe assembly could lead to an unacceptably large dc magnetic field at the gyroscopes.

B. Magnetic susceptibility. In zones where moderate magnetic fields are encountered, materials having excessive magnetic susceptibility could lead to increased dc magnetic fields at the gyroscopes. In coupon testing, susceptibility measurements and criteria allow a more sensitive indication of ferromagnetic contamination than remanent moment measurements.

C. Unwanted superconductivity. This characteristic can result in flux trapping and consequent dc magnetic field effects. The readout system is affected by this characteristic in Zone 1.

D. High electrical conductivity. Significant volumes of material with high electrical conductivity can produce Johnson noise currents which lead to magnetic field noise in the gyroscope readout system.

The standards for magnetic acceptability for materials to be used in the various magnetic zones are given in Table 2.

Magnetic Zone	**Rem. Moment**[1]	**Susceptibility**[2]	**Superconduct.**	**Resistivity**[3]
1	**$<1 \times 10^{-7}$ d^3emu**	**$< 5 \times 10^{-6}$/G/g**	**Only as required**	**>1 μΩ-cm@2K**
2A	**$<2 \times 10^{-6}$ emu**	**$< 5\times 10^{-6}$/G/g**	**Only as required**	**>0.2 μΩ-cm@2K**
2B	**$<4 \times 10^{-6}$ emu**	**$< 1\times 10^{-5}$/G/g**	**Only as required**	**>0.1 μΩ-cm@2K**
3	**N/A; field rqt.**	**N/A**	**Only as required**	**> N/A**
4	**N/A; field rqt.**	**N/A**	**Only as required**	**N/A**
5	**N/A; field rqt.**	**N/A**	**N/A**	**N/A**
SP	**Particle rqt.**	**N/A**	**N/A**	**N/A**

Table 2. Material Magnetic Requirements by Zone (d is distance in cm from rotor surface)

Table 2 Notes:

1. Measured after exposure to a dc field of $30<H<120$ Oe.
2. Measured with an excitation field of $30<H<120$ Oe. Susceptibility criteria are set so as to verify freedom from magnetic contamination. These levels will be met by all non-ferromagnetic materials that are sufficiently free of ferromagnetic contamination.
3. These requirements only apply in Zone 2 to uses exceeding 100 grams of a particular material.

The verification techniques for the material parameters are shown in Table 3.

Parameter	Zone(s)	Verification Method
Remanent moment	1-2	Cryogenic coupon moment measurement
	3-4	Room temperature coupon remanent field measurement
	5	Material type; no test
	SP Particult'g	Cryogenic coupon moment measurement
	SP Non-part'g	Material type or permeability tests
Susceptibility	1-2	Cryogenic coupon susceptibility measurement
Superconductivity	1-2	Cryogenic coupon susceptibility measurement
	3-4	Material type; published data
Conductivity	1-2	Published conductivity values

Table 3. Verification Techniques for Magnetics Requirements on Materials.

Table 4 gives the magnetics requirements on finished parts

Magnetic Zone	**Rem. Moment[1]**	**Rem. Field [2]@ 3.5 cm**	**Rem Field[3] @ Sta. 199**
1	**$<1 \times 10^{-7}$ d^3emu**	**< 1 µG**	**N/A**
2A	**$<2 \times 10^{-6}$ emu**	**< 1 µG**	**N/A**
2B	**$<4 \times 10^{-6}$ emu**	**< 1 µG**	**N/A**
3	**N/A; field rqt.**	**< 10 µG**	**N/A**
4	**N/A; field rqt.**	**< 10 mG**	**N/A**
5	**N/A; field rqt.**	**N/A**	**0.1 G**
SP	**Particle rqt.**	**Particle rqt.**	**0.1 G**

Table 4. Finished Part Magnetic Requirements by Zone (d is distance in cm from rotor surface)

Table 4 Notes:
1. All remanent moment requirements are after exposure to a 2 Gauss dc field. Demag. after measurement.
2. Measured after exposure to a field of $30<H<120$ Oe. Parts to be demagnetized after measurement.
3. Station 199 corresponds to the top of the Cryoperm outer magnetic shield.

The verification methods for finished part requirements will be given in Table 5.

In zones 3 and 4, testing requirements (to be discussed later) are based on the room temperature measurement of the magnetic field produced by the part at a standard distance. A distance of 1.4" (3.5 cm) has been used in the past and will continue to be the reference distance. The criteria for magnetic acceptability for a part in zones 3 and 4 are based on this evaluation technique, with the requirements as stated above in Table 4.
μμ
Parts in zone SP need only be examined for material type if there is no mechanism by which particles from the part could migrate into Zones 1-4. If such particle migration could occur, then the largest conceivable particle which could migrate must meet the standards for Zone 2A under the assumption that the particle is magnetized at the level produced by a 10 Oersted magnetizing field.

Magnetic cleanliness tests shall be performed either at room temperature or at liquid helium temperature as indicated in Table 5. All testing at cryogenic temperatures will be conducted by Stanford unless otherwise directed. Materials tested and approved for fabrication and finished parts shall be uniquely inventoried and separately stored from unscreened materials.

Magnetic Zone	Coupon Testing *	Finished Part Testing *
1	Cryogenic	Cryogenic Moment Measurement
2A	Cryogenic	Cryogenic Moment Measurement
2B	Cryogenic	Gradiometer - Room Temp. or Cryogenic
3	Room Temp.(Optional)	Room Temp.
4	Room. Temp.(Optional)	Room Temp.
5	None	None; Survey parts by material type
SP	Material type or permeability test - parts with no particulation potential Level 2A coupon testing on parts with particulation potential	

TABLE 5. MAGNETIC TESTING REQUIREMENTS
(* Testing requirements differ for fused quartz parts)

As indicated in the Table, cryogenic temperature testing shall only be performed on materials used in magnetic zones 1 & 2. Zone 2A & 2 B parts too large for the cryogenic test apparatus will be treated on an individual basis and may be approved based on room temperature gradiometer test results combined with coupon result analysis.

Magnetic cleanliness tests at room temperature shall be performed on a 100% basis on all parts (except for fused quartz parts) located in the shielded dewar well Stations 121 to 200; i.e., magnetic zones 1,2,3,4, including all folded lead bags and items located in magnetic zone SP in accordance with the GP-B Procedure for Magnetic Screening No. P0080 (Stanford) or the LMSC GP-B Magnetic Screening Plan.

Fused quartz parts only require a sample coupon to be tested from the same lot of material from which the parts were fabricated. This sample coupon is to receive Cryogenic testing if the material is to be used for parts to be placed in Zones 1, 2A, or 2B. Room temperature testing of the sample coupon will be used in all other fused quartz cases. The finished parts do not need to be tested since optical inspection and the surface etching and cleaning procedures followed with quartz parts eliminate magnetic risk.

Test items will normally be tested using the room temperature or cryogenic test equipment designed for this purpose. Items too large for this equipment shall be screened at the NASA-Ames magnetic test facilities:

Room temperature magnetic screening shall include magnetic measurements after exposure of the test item to a momentary DC magnetizing field of >40 gauss (but < 120 Gauss) and again after demagnetization. Cryogenic coupon testing shall include the measurements after exposure to a field H such that 40 Gauss < H < 120 Gauss but shall not include the demagnetized measurements. Cryogenic finished part measurements shall be made after exposure to a 2 Gauss dc field, with the part demagnetized after measurement.

2. 0 PERFORMANCE SPECIFICATIONS

The magnetics performance of the GP-B science instrument is determined by the shielding furnished by the inner and outer magnetic shields and the control of remanent magnetic fields from the Stanford-produced quartz block assembly and from the LMSC-produced probe. The term outer shield used in this document refers in each instance to the ferromagnetic shield mounted on the exterior surface of the dewar well. The term principal inner shield in this document refers in each instance to the lead bag shield mounted against the interior surface of the well. The inner shield system consists of the principal inner shield (lead bag) along with local ac superconducting shields around each gyroscope and other superconducting shielding features.

Specifications have been established to permit magnetic acceptance tests of the hardware furnished by the LMSC GP-B program separately from the Science Instrument Assembly (SIA) produced by Stanford. These specifications cover the performance of the outer shield, the inner shield, the net field produced by the LMSC portion of the probe at the locations of the four gyros, and the net field produced by the SIA assembly at the gyro locations. A subdivision of the allowable total field has therefore been made and is reflected in the following specifications.

2.1 SHIELD AND INSTRUMENT SPECIFICATIONS

The outer shield shall yield a dc magnetic field of not more than 30 millioersteds at cryogenic temperatures (4K and less) throughout the volume occupied by the expanded lead bag. This requirement shall be satisfied for any orientation of the shield relative to a uniform dc environmental field of 600 millioersteds.

The outer magnetic shield shall produce, at LHe temperature, an ac field amplitude of not more than 2.5 milligauss in the transverse direction and 25 milligauss in the longitudinal direction throughout the volume

occupied by the lead bag when exposed to an 0.005 + 10% Hz environmental field of 500 millioersteds transverse to the shield axis. The ferromagnetic shield shall be characterized at room temperature before and (optionally) after installation on the well, with the low temperature performance extrapolated from data on the temperature dependence of the shield material's permeability. Data from the outer shield vendor, Vacuumschmelze GMBH (Test Report of 4/16/87), indicates a permeability increase by a factor of 1.3-1.5 on cooling from room temperature to liquid helium temperature, so room temperature qualification standards for the outer shield are: dc field less than 42 millioersteds; transverse ac field of less than 3.5 milligauss; longitudinal ac field of less than 35 milligauss throughout the lead bag volume under the conditions stated above.
The principal inner shield shall yield a residual dc magnetic field not more than 1.5 x 10^{-7} oersted in the volume occupied by any gyro. The principal inner shield shall also attenuate a 0.005 Hz ac longitudinal field by a factor of not less than 10^{10}, and an ac transverse field by a factor of not less than 4 x 10^{7}. This requirement shall be satisfied for any orientation of the shield relative to a uniform DC environmental field of 600 millioersteds. The ac and dc shielding factors at the location of the gyros shall be measured cold and with the well empty.

The magnetic field produced at any gyro location (i.e., at the surface of any gyro rotor) by the Stanford Science Instrument Assembly shall not exceed 1 x 10^{-7} Oe.

The magnetic field produced at the gyro locations by the LMSC furnished GP-B probe shall not exceed 1 x 10^{-7} Oe.

The top of a principal inner shield just prior to expansion extends above the location of the mouth of the outer ferromagnetic shield. During cool down and expansion of each successive bag the entire length of the folded bag shall be maintained at a field of not more than 30 millioersteds. Temporary means may be used during the expansion process to meet this field requirement such as field canceling coils and/or additional ferro-magnetic shielding.

Materials and parts used in the instrument shall have magnetics approval. Approval will be automatic if materials and parts meet the standards of Tables 2 and 4. Materials and parts not meeting the standards of Tables 2 and 4 may be approved by the GP-B Magnetics Committee after suitable analysis.

2.2 MAGNETIC DESIGN & IMPLEMENTATION

2.2.1 MAGNETIC CLEANLINESS DESIGN

The magnetic cleanliness design requires that all parts and materials installed in the shielded dewar well, except for the gyros themselves, shall not produce magnetic fields at the location of the gyros above the previously stated limits.

To meet this requirement, all parts and materials installed in the shielded well shall be free of magnetic alloys, e.g. alloys containing iron, nickel, chromium, cobalt, or rhodium in significant concentrations; magnetic contaminants; unintentional superconductors; and non-isothermal electrically conducting materials that can produce significant thermoelectric (Thompson Effect) currents. An example of an unintentional superconductor would be the use of indium for a seal. Materials conventionally classed as non-magnetic may be unacceptable; for example, stainless steel and certain brasses. Non-magnetic materials approved for previous flight projects such as Pioneer may be unacceptable for GP-B because of the much lower limits permitted for this mission. Unusually high levels of diligence and systematic work will be necessary to meet this requirement.

Fabrication processes can cause otherwise non-magnetic material to fail magnetic screening tests. This happens as the result of surface contamination. The most common sources of surface contamination are magnetic particles transferred to the part from coolants, grinding wheels, saws, drills, and lathe tools and the application of coatings containing iron, nickel, chromium, rhodium, or cobalt. Suppliers furnishing non-magnetic parts will be furnished with guidelines which identify proper techniques for magnetic cleanliness.

2.2.2 MAGNETICS REVIEW BOARD

In the event that a suitable non-magnetic material cannot be found for an essential part or assembly, an application for waiver shall be submitted to the GP-B Magnetics Committee. A decision will be rendered based upon the justification for use of the nonconforming material, the magnetic field that would be contributed by each part made of the granted material at the location of the gyros and the magnetic effect of any parts previously waived. Any part failing to pass magnetic screening shall be submitted to the Magnetics Committee for similar consideration. The Magnetics Committee may also approve magnetic shields which fail to meet the specifications given in this document if it can be determined that the complete shield system still meets the fundamental science requirements.

2.3 TESTING REQUIREMENTS

Magnetic cleanliness tests shall be performed both at room temperature and at liquid helium temperature as outlined in Table 5. All testing at cryogenic temperatures will be conducted by Stanford unless otherwise directed. Materials tested and approved for fabrication and finished parts shall be uniquely inventoried and separately stored from unscreened materials.

Cryogenic temperature testing shall only be performed on materials used in magnetic zones 1 & 2 or on coupons of materials which could migrate to zone 2 via particulation.

Each of the instruments used to perform magnetic tests shall be periodically calibrated, traceable to national standards and shall not be used beyond the calibration expiration date.

2.3.1 ROOM TEMPERATURE MAGNETIC SCREENING OF PARTS

Magnetic cleanliness tests at room temperature shall be performed on a 100% basis on all parts (except fused quartz parts as per the discussion of Section 1.2) to be located in the shielded dewar well Stations 121 to 200; i.e., magnetic zones 1,2,3,4, including all folded lead bags and items located in magnetic zone SP in accordance Table 5 and with the Stanford GP-B Procedure for Magnetic Screening No. P0080 or the LMSC Magnetic Screening Procedure. Room temperature screening may be omitted on parts which undergo cryogenic screening. Parts may be tested at any level of assembly prior to installation into the Probe or Science Instrument Assembly. There is no requirement to test individual parts prior to their incorporation into a sub-assembly; however, it is recommended that the REE initiate such testing of individual parts prior to the assembly of large sub-systems to lessen the risk of magnetic failure of the sub-system.

Room temperature magnetic screening shall include magnetic measurements after exposure of the test item to a momentary DC magnetizing field of >40 gauss (but < 120 Gauss) and again after demagnetization.

A room temperature measured field greater than one (1) microgauss at a distance of one inch from any surface of a test item earmarked for magnetic zones 2A and 2B shall be considered a failure to pass.

A measured field greater than ten (10) microgauss at a distance of one inch from any surface of a test item earmarked for magnetic zones 3 shall be considered a failure to pass.

A measured field greater than ten (10) milligauss at a distance of one inch from any surface of a test item earmarked for magnetic zones 4 shall be considered a failure to pass.

Non-particulating parts in Zone SP made of stainless steel may be approved for use if the measured permeability is less than 1.15 as measured with a permeability indicator conforming to specification MIL-I-17214.

Magnetic property acceptance tests at room temperature shall be performed on the outer shield. It shall be demagnetized, tested for remanent magnetization, reluctance discontinuities, mechanical deformations, radial and longitudinal AC and DC shielding factor and net interior field, flux concentration at the mouth and magnetic dipole moment. A reference ambient field for these tests shall be 600 millioersteds.

2.3.2 CRYOGENIC TEMPERATURE MAGNETIC TESTING.

Certain materials which pass room temperature magnetic screening can become magnetically unacceptable at cryogenic temperatures. Consequently, coupon samples of materials used in magnetic zones 1 & 2 will be tested on a 100% basis at liquid helium temperatures. The sample size shall be per Stanford drawing 212400 and be taken from the same stock as will be used for part fabrication. The sample coupon is normally a cylinder of diameter 0.230"±0.005" with a length of 0.250"±0.005". Material which is not available in a form which permits such a coupon to be prepared should be formed so as to stay within the envelope of the standard coupon while filling the envelope volume as completely as possible. Coupons with lengths in the range 0.20"-0.50" may be used if fabrication of a standard coupon entails unusual difficulty.

Finished parts (except for fused quartz parts) in Zones 1 and 2A will also receive cryogenic magnetic testing on a 100% basis. Finished parts in Zone 2A may be tested at any level of sub-assembly. There is no requirement to test individual parts prior to their incorporation into a sub-assembly; however, it is recommended that the REE initiate such testing of individual parts prior to the assembly of large sub-systems to lessen the risk of magnetic failure of the sub-system. Finished parts in Zone 1 must be tested on an individual basis since their magnetic acceptability is based on their exact distance from the gyroscope rotors.

A procedure shall be established to provide a data sheet with each sample forwarded for testing which describes the sample material and magnetic zones involved. The data sheets shall be serialized and a computer spreadsheet log shall be maintained showing the results of all cryogenic tests.

2.3.3 MAGNETICS TESTING OF ASSEMBLIES

Assemblies for which all parts (except fused quartz parts) and materials have passed magnetic acceptance testing prior to assembly do not require further magnetics testing. It is required that the assembly data package include complete traceability to the parts magnetics test data. Magnetics testing of assemblies is required if any part (except fused quartz parts) in the assembly was not magnetically screened prior to the assembly. It is recommended, but not required, that assemblies be magnetically screened at the highest feasible level of assembly to reduce the risk of unexpected magnetic contamination.

2.4 MAGNETIC ACCEPTANCE TESTING

The individual performance of the inner and outer shields shall be determined by measurements. The attenuation factor and residual field in the interior of the outer shield shall be measured cold prior to insertion of the first inner shield.

The net DC magnetic field at the locations of all four gyro assemblies shall be measured after expansion of the final lead bag and before insertion of the probe assembly.

These measurements will include but not be limited to the region of the gyros and the region of the mouth of the shield. Since these tests will be conducted at liquid helium temperatures a sensor appropriate for these measurements and temperature will be required to determine compliance with the net field and attenuation specified for the gyro locations.

The assembled LMSC probe shall be tested for compliance with the fundamental requirement of a remanent field at the gyro locations of less than 10^{-7} Gauss. This acceptance test shall be made both after exposure to a 5 Gauss magnetic field and after demagnetization. The probe shall be left in the most nearly demagnetized state attainable (following the demagnetization procedure of the *Screening Plan)* and shall be protected from field exposures exceeding 5 Gauss though integration in the Dewar.

3. 0 MAGNETICS DOCUMENTATION

3.1 DESIGN GUIDELINES

The document *Drawing Notes For Magnetic Control of Parts* details design requirements and drawing notes that are applicable within the individual magnetic control zones 1,2, 3, 4, and SP.

A list of all candidate materials for the various magnetic zones shall be maintained and updated as new items are added. This document may be identified as the *GP-B Candidate Materials List (Magnetics) - Revision A*. However, use of materials from this list does not eliminate the need to screen finished parts according to the standards discussed above.

GP-B Magnetic Test Status Report. A complete tabulation of all parts and materials which have been magnetically screened shall be maintained in written and/or electronic form by both Stanford and LMSC GP-B. Current practice is to maintain this tabulation as an Excel spreadsheet. Results of room temperature and cryogenic temperature tests shall be posted to these document.

The information in this report shall be used as the basis of specification compliance forecasts and by the Magnetics Committee and for guidance in the consideration of any waivers.

The result of each of the magnetic cleanliness tests shall be available to the Chair of the Magnetics Committee via the *Test Report*. As test data arrives, it will be reviewed for completeness and for specification compliance. The data shall then be posted in the Stanford GP-P Magnetic Test Status spreadsheet or the equivalent LMSC database.

3.2 TEST PROCEDURE AND DATA FORMS .

Approved test procedures and data sheet forms shall be made available to the test conductor before each test. These procedures shall specify the instrument sensitivities required, the distance between the sensor and the test item (when appropriate) and the criteria for pass (fail).

The unique identification of each test item, test sequence number, test date, test conductor's name and test results shall be posted on magnetic screening data sheets designed for this purpose. This requirement includes results of testing fabricated parts and assemblies and coupon tests at ambient and cryogenic temperatures.

The magnetic screening procedures are given in the *GP-B Procedure for Magnetic Screening* documents prepared by Stanford (Procedure P0080) and LMSC.

3.3 MARKING AND INVENTORY CONTROL OF TESTED MATERIALS AND PARTS

Magnetically-tested parts for flight shall be marked and their inventory controlled is to be done according to relevant procedures as prepared by Stanford and LMSC GP-B organizations. .

4.0 FABRICATION AND ASSEMBLY REQUIREMENTS

A set of drawing notes (*Guidelines for Non-Magnetic Fabrication Practices*) provides direction to suppliers of non-magnetic parts.

Assembly of non-magnetic parts will require tool and fixture control to prevent magnetic contamination. Only approved tools shall be used for assembly of magnetically screened parts.

It is essential that all GP-B parts which have passed screening remain magnetically clean during assembly and test operations. It is therefore necessary that certain precautions be taken to prevent contamination.

All tools, tooling and support equipment used for assembly and test of GB which could increase the ambient field at the location of the science instrument are subject to the Magnetic Control Plan. Tools, tooling, fixtures, and support equipment will follow the magnetics guidelines set forth in *GP-B Magnetic Procedures (LMMS Procedure 5835029H)* documents prepared the LMMS GP-B magnetics consultant.

Prior to integration with the QBA, the probe shall be in as completely a demagnetized state as is attainable. QBA components shall be in a similar demagnetized state. Demagnetization will be done according to the appropriate procedures as given in the *Screening Plan (P0080).*

4.1 DRAWING NOTES FOR MAGNETIC CONTROL OF PARTS

The GP-B instruments have parts in Magnetic Zones 1, 2, 3, 4, 5, and SP. Every drawing shall specify the magnetic zone in the box provided on the drawing (adjacent to the title block). See Table 1 for a definition of the magnetic zones. If a part occupies more than one magnetic zone, the applicable drawings shall identify which zones apply to which segments of the part and show which magnetic requirements and drawing notes apply to each segment. The selection of materials is the responsibility of the designer in every zone. The fabricator shall not have the option of substitution.

All parts, except those in zone 5, will undergo magnetic screening after fabrication.

Plating of surfaces must be carefully monitored since industry practice often calls for the use of plating understrikes involving ferromagnetic materials. Appropriate drawing notes should be included when any plating operations are called for; these notes must specify the plating process so that unacceptable ferromagnetic contamination will not occur. Refer to the plating discussion in Section 5.

The document *Drawing Notes For Magnetic Control of Parts* gives specific drawing notes.

5.0 DESIGN GUIDELINES FOR MAGNETICS

Adherence to the design guidelines specified below along with the fabrication practices already described should lead to the production of parts which will pass final magnetic screening.

5.1 ZONE 1-2 DESIGN REQUIREMENTS:

Zones 1 and 2 are the most critical magnetic zones.

Materials should be selected from the GP-B Candidate Material List (Magnetics). The addition of materials to the list which are not completely non-magnetic is very unlikely. Superconducting materials are to be avoided except when explicitly required. High conductivity metals in general are to be kept to a minimum. Electrical contact between dissimilar metals should be avoided.

The actual chemical analysis of candidate materials for Zones 1-2 should be examined for a total content of (Fe+Ni+Cr+Co) of less than 0.01%. Vendors may be able to pre-select materials having such chemistry.

Coupons of the actual materials used will be tested and approved by the Magnetics Manager prior to part fabrication. The coupons shall be tested at room temperature and/or at cryogenic temperatures as specified in the Magnetics Screening Plan and in Table 5 of this plan. Coupons of the lot and heat of material to be used in fabrication are required. In some cases, where it is impractical to obtain a coupon sample of the raw material, samples of finished items, e.g. wire or small connectors, which can be configured to fit within the coupon envelope can he screened instead. Substitution of a finished item sample for a raw material coupon may be approved by the Magnetics Manager on a case by case basis.

Platings must not use a ferromagnetic understrike such as nickel, chromium, or iron. Rhodium may be used if magnetic testing indicates that it is free of ferromagnetic behavior at cryogenic temperatures.

5.2 MAGNETIC ZONE 3-4 DESIGN REQUIREMENTS

All materials should be selected from the GP-B Candidate Materials List (Magnetics). If his list does not contain an acceptable material, the designer may propose materials to the Magnetics Committee for approval.

Platings may use an Ethone process (non-magnetic) nickel understrike if there is no possibility that the plating could be subject to abrasion during probe operation or assembly.

Requirements for non-magnetic cutting tools do not apply to Zones 3 and 4.

5.3 MAGNETIC ZONE 5 DESIGN REQUIREMENTS

The Magnetics Manager is to be consulted regarding the use of any permanently magnetized material on Zone 5.

5.4 MAGNETIC ZONE SP DESIGN REQUIREMENTS

No magnetic particulates may be generated in this zone which can migrate into zones 1-4.

Non-magnetic materials shall be used unless they are incompatible with design objectives or availability. Magnetic materials such as Kovar or Dumet may be used in special circumstances provided that prior approval is granted by the Magnetics Committee.

Parts capable of producing magnetic particles shall be plated with non-magnetic surfaces that will prevent shedding caused by time, temperature, motion or friction associated with assembly, test, operation, transportation and launch.

Stainless steel and all metals which contain iron nickel or cobalt should be considered magnetic unless proven otherwise. This includes the 300 series of stainless steel. Samples of the 300 series in the annealed and demagnetized condition are only mildly magnetic but become substantially more magnetic as a consequence of cold forming and machining. Stainless 304L can be used in zone SP.

Parts in Zone SP which may generate particles which could migrate into Zones 1 and 2 (i.e. fasteners, connectors, bellows, etc.) may be gold plated over rhodium if such a process is qualified by coupon tests. The gold plating should be cobalt free. Other platings such a palladium may prove to be less of a magnetics risk in locations where a plating is needed. Plated parts which require a nickel passive diffusion barrier to prevent migration from substrates such as copper into gold shall have drawing notes which identify the specific electroless nickel formulation in addition to the MIL-C-26074 Class I, Grade B call out. The use of nickel, however, is not recommended and is to be cleared by the Magnetics Manager.

APPENDIX A - UNITS

The cgs-emu system of units has been widely used in the Gravity Probe-B literature. The unit for magnetic field strength, H, in this system is the Oersted (Oe) and applies to fields produced by a source such as a permanent magnet or coil. To convert from Oersted to the SI unit, Ampere/ meter (A/m), one multiplies by $(1000/4\pi) = 79.58$.

The Gauss (G) is the unit of flux density (B) in the cgs-emu system, To convert from Gauss to the S.I. unit, Tesla (T), one divides by 10,000. All magnetic sensor data is expressed in terms of Gauss or Tesla.

The value of permeability is dimensionless in the cgs-emu system of units and is equal to unity for free space. To convert to permeability values in the S.I. system in Henries/meter (H/m) or Wb/(A-m), one multiplies by $4\pi \times 10^{-7}$. The permeability of free space in S.I. thus has the value of $4\pi \times 10^{-7}$ H/m.

The unit of magnetic moment in the cgs system is the emu (electromagnetic unit), which corresponds to one erg/Gauss. To convert to the S.I. unit A-m^2, one multiplies by 1000.

The unit of volume susceptibility in the cgs-emu system is the emu/cm^3; this is sometimes written as emu/G to make it distinct from the units of magnetic moment. To convert to the dimensionless S.I. unit, one multiplies by 4π.

The unit of mass susceptibility in the cgs-emu system is the emu/g; again, this is sometimes written as emu/G/g to emphasize that it is a susceptibility. To convert to the S.I. unit m^3/kg, one multiplies by $4\pi \times 10^{-3}$. Mass susceptibility values may be obtained by dividing volume susceptibility values by the mass density of the material.

Magnetic permeability μ in the cgs-emu system is defined by the relation $B = \mu H$. The permeability is related to the magnetic susceptibility χ_m by the relation $\mu = 1 + 4\pi\chi_m$. In the SI system, magnetic permeability μ is again defined by the relation $B = \mu H$ and relative permeability μ_r is defined by $B = \mu_r \mu_0 H$. Relative permeability is related to magnetic susceptibility by the relation $\mu_r = 1 + \chi_m$.

In analyzing the effect of a magnetic moment at a certain location, it is useful to note that the H field at a distance r from a moment of strength m is maximum along the dipole axis, with the value

$$H(r) = 2\, m / r^3.$$

APPENDIX B - Table of Cryogenic Resistivities of Metals

Metal	Temperature	Resistivity(μΩ-cm)	Reference
Copper (pure)	1.55K	0.002	de Hass et al. (NBS)
Silver (pure)	2K	0.02	de Haas
Gold	2K	0.002	Meissner
Beryllium	2K	1.0	Meissner
Aluminum (pure)	2K	0.02	Meissner
Titanium	2K	11.3	Meissner-Voigt
Aluminum 6063-T5	2K	0.2	Inferred from thermal cond. (Scott)
Aluminum 2024-T4	2K	2.0	" "
Beryllium Copper	2K	4.0	" "
Brass	4K	4.0	Richardson & Smith

APPENDIX C - Table of Cryogenic Magnetic Susceptibilities of Metals and Insulators

Metal	Temperature	Susceptibility(10^{-6} emu/G/g)	Reference
Titanium	2K	3.0	Kittel
Niobium	10K	2.0	Kittel (extrap.)
Copper99.999%	4K	$0.04/cm^3$	Simmonds
Brass	2K	2.4	Simmonds
Alumina (Alcoa)	2K	3.8	Salinger&Wheatley
Copper Magnet Wire (Anaconda)	2K	0.035	" "
Teflon (Du Pont)	2K	<0.1	" "
Boron Nitride (A)	(295K)	0.5	Keyser&Jefferts