MAGNETIC CALIBRATION STAND (2T) FOR TESTING OF IRRADIATION INFLUENCE ON MAGNETIC FIELD SENSORS

A.V.Karpukhin, S.I.Kukarnikov, V.M.Lachinov, V.K.Makoveev
Joint Institute for Nuclear Research, Dubna, Russia

Abstract

Parameters of modern experimental set-ups depend on the precision of the magnetic field monitoring in the conditions of a real experiment. As a rule, the conditions of modern experiments (ATLAS, CMS, ALISE, LHC-B) have their special requirements to radiation hardness of the magnetometric apparatus used in the given set-up. Specialized magnetic-calibration stands have been manifactured (0.025÷5T) to investigate sensors of the magnetic field for radiation hardness at the Joint Institute for Nuclear Research (JINR). The «warm» stand has a function of the magnet field up to 2 T with a field uniformity up to 0.01%/cm in a gap of 30 mm and diameter of 50 mm. The sensors were irradiated at the IBR-2 reactor, JINR [1], by fast neutrons with the mean energy <E>=1.35 MeV till the fluence of 10^{15} n/cm^2.

1 METHODS OF RESEARCH

Methods to study the influence of the neutron irradiation on the parameters of the magnetic field sensors on the Hall effect (HP) are based on comparison of the results of measurements of the HP parameters on a specialized magnetic calibration stand before and after exposure.

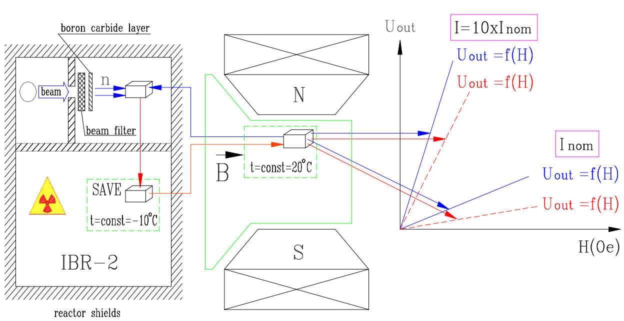


Fig 1: Scheme of the working stages on testing HP

The main stages of the work while investigations of the radiation hardness (HP) on the stands at JINR were:

1. Exposure of the samples by fast neutrons on the IBR-2 reactor at different values of fluences from 10^{13} to 10^{15}n/cm^2. These values of fluences correspond to the calculated data on the neutron background of most of advanced detectors.
2. Storage of irradiated samples was performed at the temperature of -10^0 C to exclude possible annealing of radiation defects in the samples before their invesigation on the stand.
3. Increasing of the absolute sensitivity of HP by one order due to the pulse (τ=0.5ms) current supply with the amplitude of I=10xI_{nom}.
4. Study of the HP parameters at the permanent temperature t = +20^0 C ($\pm0.1^0$) before and after exposure.
5. HP absolute calibration in the units of the magnetic field using the NMR-magnetometer, which provides fixing the magnetic field value in the uniformed region with the absolute accuracy better than 0.01%.
6. Installation of the cassette with HP and NMR probe into one and the same point of the uniformed region before and after exposure with the accuracy better than 0.1 mm by means of a specialized mechanism.
7. Multiple investigation of HP after exposure to find the reconstruction rate of initial HP parameters.

2 MAGNETIC CALIBRATION STAND

The block–scheme of the magnetic calibration stand is shown in Fig.2. The basis of the stand is an H-like electromagnet.

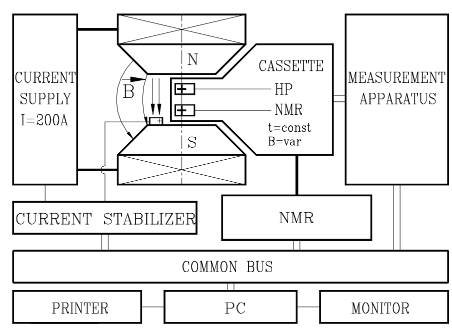


Fig.2: The block- scheme of the magnetic calibration stand

The reference magnetic field B_{ref}~ 0÷2T (∅ 120 mm, d up to 30 mm) is provided by the permanent current supply (~ 0.1%) up to 200 A with a gradual regulation of its value. The supply system of the magnet coils, including the negative reward tie on the current and a reference regulated voltage allows one to give gradually the supply current to the electromagnet and stabilize it. In its turn the reward tie on the field allows to stabilize additionally the magnetic field in the gap (up to 10^{-4}xB_{ref}). The water cooling is used to reduce the temperature errors of the supply system and thermal loading of some elements of the scheme. In the central part of the gap (the operating volume with ∅ 50 mm) the uniformity of the reference magnetic field B_{ref} reaches 0.01%/cm (Fig. 3).

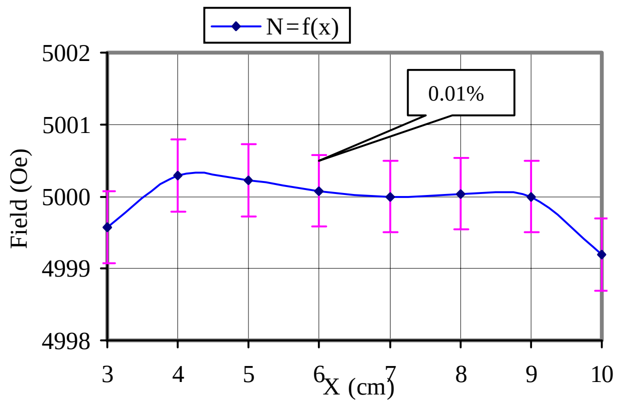


Fig.3: The distribution of the magnetic field on the axis of the magnet gap

A relatively high uniformity of the magnetic field in the operating volume is provided by specialized pole ends made of the magnetic alloy (permendur), having polished pole surfaces and an opportunity to regulate their parallelicity. The control and indication of the reference magnetic field B_{ref} in the operating volume was carried out with the help of the NMR-magnetometer having a high absolute accuracy (better than 0.01%).

3 THE SYSTEM OF POSITIONING HP IN THE MAGNET GAP

A specialized three-axis positioner provided displacement and fixation of the position of the tested samples in the operating magnet gap with an accuracy of ~ 0.1 mm (Fig.4). Each of the four HP was placed in the cassette made of non-magnetic material and its base-plate was fixed on a specialized support plate.

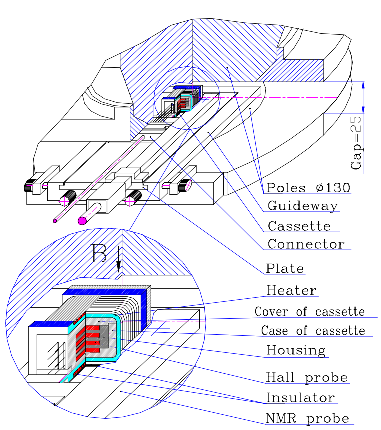


Fig. 4:The system of positioning the sensors in the magnetic field

The cassette was placed in one and the same fixed position of the central part of the electromagnetic gap with a garanteed uniformity of the field of ~ 0.01%/cm. The cassette with HP and the apparatus probe of the nuclear magnetic resonanace (NMR) were fixed hard relatively each other on the displacement mechanism.

4 MEASURING APPARATUS

The accuracy of measuring the HP parameters is determined by the quality of the sensors of the magnetic field themselves as well as by the accuracy of the measuring apparatus (Fig. 5). To measure the parameters of the magnetic field sensors, a modernized version of the magnetometer H3M developed at JINR was used [2].

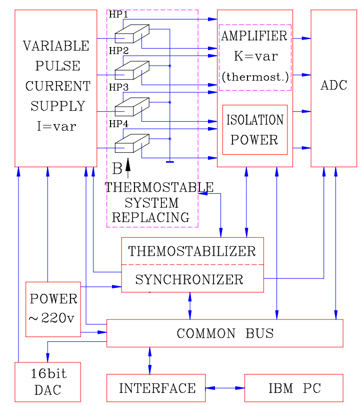


Fig. 5: The block- scheme of the measuring apparatus for testing the magnetic field sensors

The absolute calibration of HP under conditions of the reference and controlled magnetic field on the magnetic calibration stands compensates the non-linearity of the HP sensitivity. Thermostabilization of HP (t=+20^{0}C ±0.1^0) and of the separate knots of the apparatus (t=+35^{0}C ±0.1^0) makes the error minimal in dependence on the temperature. While testing HP, the pulse HP current supply was used (τ=0.5ms) with the increased current value of I=0÷10xI_{nom} and an interval ratio of 1:1000. This method has provided to improve the absolute HP sensitivity (proportional to the HP current) and to reduce the mean power (temperature). The measuring apparatus by the usage of the methods described above as well as the scheme solutions at the averaging of the measurement results by means of the computer, allowed us to obtain a rather high relative accuracy of ~ 0.05%.

.

CONCLUSION

The stand created at JINR allows one to study the main HP parameter – the calibration curve rather quickly before and after exposure by neutrons. The main characteristics of the stand are :

- The magnetic field range - 0÷2 T
- Non - uniformity of the magnetic field in the operating volume - 0.01%/cm

- Dimensions of the working area - ∅ 50 mm in the air gap up to 30 mm
- The current source - 0÷200 A
- HP supply current - $0 \div 10 x I_{nom}$
- Temperature of HP thermostabilization - t=+(20 ÷ 50^0C) $\pm 0.1^0$
- Accuracy of HP displacement in the operating volume – 0.1 mm

The investigation is supported by the project ISTC # 639.

REFERENCES

[1] A.Cheplakov et al., Large-scale samples irradiation facility at the IBR-2 reactor in Dubna, Nucl. Instr. And Meth. A 411 (1998) 330.
[2] V.Makoveev, H3M, Proccedings of the IMMW-9, vol.2, Sacley, 1995.

MAGNETIC CALIBRATION STAND (5T)

N.I.Balalykin, A.V.Karpukhin, S.I.Kukarnikov, V.M.Lachinov, V.K.Makoveev, V.G.Shabratov
Joint Institute for Nuclear Research, Dubna, Russia

Introduction

At present in the experimental and acceleration physics there are widely used magnetic systems with the level of the magnetic field up to 5 T at a high resolution on the field. Besides, the conditions of modern experiments put forward strict requirements to the radiation hardness of the magnetometric apparatus used in the given set-up. Realization of these magnetometers is impossible without corresponding magnetic calibration stands. A specialized superconducting magnetic calibration stand (SCMCS) with the “warm” magnetic field up to 5T was constructed at the Joint Institute for Nuclear Research in Dubna (JINR).

1. STRUCTURAL SCHEME OF THE STAND

A structural scheme of the stand is shown in Fig. 1. The basis of the stand is a cryostat with a superconducting magnet having a “warm” operating volume which is created by the anticryostat.

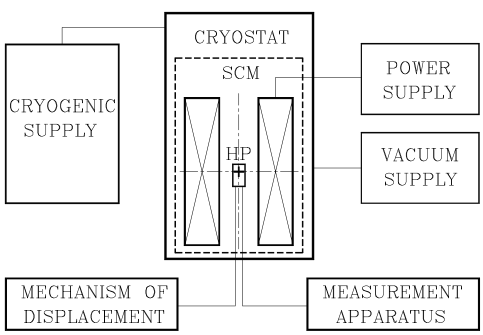


Fig.1: Structural scheme of the stand

Cryogenic and vacuum equipment provides the corresponding conditions for the work of the superconducting magnet in the cryostat. The supply system provides the permanent stable current (~0.01%) from 0 up to 150 A to obtain the working magnetic field from 0 up to 5 T. Measurements and control of the magnetic field value are provided by the NMR-magnetometer. A specialized coordinate mechanism carries out the installation of the cassette with the Hall-sensors and NMR-probe into the fixed point of the uniformed region of the magnetic field with the accuracy better than 0.1 mm.

2. CRYOSTAT

The cryostat of the stand (Fig. 2) placed vertically is manufactured of the stainless steel and consists of a helium vessel (1), on whose bottom there is a superconducting magnet (5), of a nitrogen screen with the liquid nitrogen (2), a vacuum box (3) and an anticryostat (4).

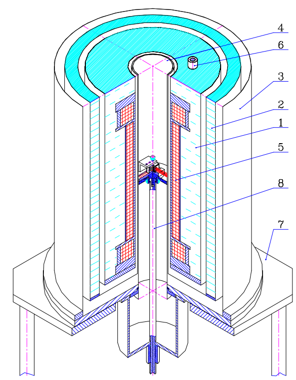


Fig 2: The cryostat of the stand

The cryostat is located on the support (7) with regulation on the height (840÷980 mm). A coordinate mechanism is fixed to the lower flange (8). On the cap of the cryostat there are precaution exits (to throw out gas in case of emergency), the valve of the throw and pumping of the gaseous helium, current guides and inputs of the system to control the liquid helium level and the temperature of the magnet. The outer diameter of the cryostat is 450 mm, height -1340 mm. The diameter of the “warm” operating volume created by the anticryostat is equal to 84 mm. The volumes of the helium and nitrogen vessels are equal to 35 l each.

3. SUPERCONDUCTING MAGNET

Due to the hard requirements to the magnetic field (induction up to 5T, uniformity up to 0,001%/cm in a relatively large volume), the solenoid coil was chosen in the shape of a cylindrical coil with correcting coils on the edges [1]. This solenoid is more compact, requires less of the superconducting wire and provides high uniformity in a big volume. To minimize the use of the superconducting wire, the main and correcting coils have different current density, i.e., they are wound by the wire of a different diameter, that provides to use one current source and one superconducting key for the regime of the “frozen-in” magnetic field.

The box of the superconducting solenoid coil is made of duralumin, which surfaces are isolated by textolite and press-spahn. Outside the coils are strengthened by the bandage of the stainless wire. All the sections are shunted with the protecting resistance. The welded connections of the exits are made with indium on the copper matrices.

The current guides are made of copper wire of the alternative cross-section with the reward flow cooling.

The working region of the magnet is a uniformed part of the magnetic field in the center of the solenoid. The magnet in the regime of the "frozen-in" magnetic field provides a stable working field of B=0÷5 T in the "warm" volume of ~60 cm^3 with the uniformity of ~0,001 %/cm. The high uniformity of the magnetic field in the operating volume was obtained in the result of using the qualitative sorts of stainless steel and a specialized technology of welding to get the maximum magnetic transparency of the cryostat body.

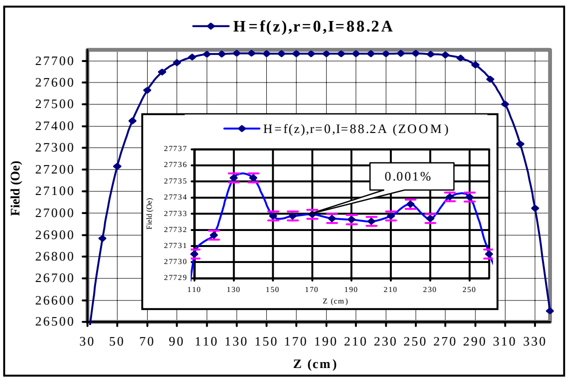


Fig.3: The distribution of the magnetic field on the solenoid axis

As a reference measurer of the magnetic field we have used a NMR-magnetometer of the type PT2025 (Metrolab Model), which provides measurements of the magnetic field in the uniformed region with the absolute accuracy better than 0,001%. To measure the magnetic field in all the volume of the solenoid, a modernized version of the magnetometer H3M [2] with a relative accuracy of measurements ~ 0,02% was used.

The distribution of the magnetic field on the solenoid axis is given in Fig.3. The uniformity of the magnetic field in the central part on the length of 60 mm was ~0,001%, and on the length of 100mm it was ~0,002%. Long-time stability of the magnetic field in the «frozen-in» regime was not less than 0,005% during the working hours (8).

4. SYSTEMS OF VACUUM AND CRYOGENIC SUPPLY

The system of cryogenic supply includes gas lines with a gasholder, a gas board with control bodies, a vacuum pump to wash the gas system through and pump out the vapor of the liquid helium to reduce the temperature from 4,2 K up to 1,8 K, a siphon to pour the liquid helium from the dewar into the cryostat, helium and nitrogen dewars. Electronics controls the temperature of the magnet, the level of the liquid nitrogen and helium in the cryostat. Measurements are carried out by calibrated resistive sensors [3]. The current of the sensors is generated by a high stable source of permanent current 10/100 mkA. The output voltage of the sensors is increased and measured by ADC. The control is performed by a personal computer (PC) on the CAMAC bus.

The vacuum in the cryostat is created by separate pumps and is maintained operational at the level of ≤10^{-4} torr.

5. THE SUPPLY SYSTEM OF THE SUPERCONDUCTING MAGNET

The supply system of SCMCS consists of three main knots: a rectifier, a current stabilizer and evacuator of the energy.

- High current (up to 150 A) low voltage (up to 6 V) rectifier consists of a three phase voltage transformer and a three phase rectifier.
- The current stabilizer contains supplementary supply blocks, a regulating element, an error amplifier, a controlling scheme, and a support (shunting) resistor. The knot of current stabilization is assembled on the classical scheme with a negative reward tie on the current. In the selected scheme the stability of the loading current is 10^{-4}I_{max}. Besides, while «frozing» the field in the solenoid, the current source is switched off from the solenoid and the stability of the magnetic field improves till 10^{-5}B_{max} during 8 hours of work. The regulating element consists of 24 transistors switched on in parallel with equalizing resistors in the emitter. The controlling scheme contains an analogous integrator for gradual current change being involved into the super conducting solenoid. The regulated rate of the current change from 0,05 A/s to 1 A/s with the stability of 10^{-4}.
- The knot of the energy evacuator serves to protect the super conducting magnet and the current source in case of emergency when the magnet is out of the superconducting state. The practice has shown the reliability of the simplest systems of the ballast resistors switched on in parallel to the coil of the magnet. In the scheme of the current source there are electronic means of protection against overvoltage and limitation of the maximal current before the regulating transistor.

6. THE COORDINATE MECHANISM

The coordinate mechanism (Fig.4) is purposed for displacement of the sensors (1) in the uniformed area of the solenoid magnetic field. It is fixed on the lower flange of the cryostat and consists of the displacement mechanism, a rod (6) and a plate (5), which can be turned by 360° around its axis. On the plate, whose axis is perpendicular to the solenoid axis, there is a cassette fixed (2) with the sensors in the thermostat.

The coordinate mechanism provides:

- Displacement of the probe on the solenoid axis Z = ±200 mm according to the center of the working area with an accuracy of ±0.1mm;

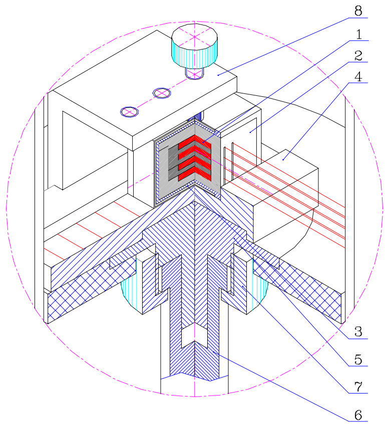


Fig.4: The coordinate mechanism.

- Displacement of the probe over the radius from 0 till 35 mm with an accuracy of ±0.1mm;
- Rotation over the angle from 0° to 360° with an accuracy of ~0.5°.

CONCLUSION

The stand has been manufactured at JINR with the following parameters to carry out precision magnetic calibration :

- Maximal working magnetic field B - 5 T
- Non-uniformity of the magnetic field in the operating volume (60 cm^3) - 0,001%/cm
- Long – time stability (8 hours) - 0,005%
- Current source - 0÷150 A
- Change current rate - 0,05÷1 A/s
- Vacuum in the cryostat T=4,2 K - ≤10^{-4} torr
- Helium flow rate (for I=100A) - ~2.5 l/h
- For cooling and operation of the stand during 8 hours, it is necessary to have ~150 l of liquid nitrogen and 120 l of liquid helium.

The investigation is supported by the project ISTC # 639

REFERENCES

1. V.F.Burinov et al. SMS. JINR, P9-85-567, Dubna, 1985.
2. V.K.Makoveev et al. Devices for test measurements of c-tau Factory in magnetic systems. 2 Workshop on JINR Tau-Charm Factory. April 1993.
3. V.I.Datskov Carbon resistors for temperature measurements from 4.2K to 450K,PTE,1981,4.

Measurement of Integral Field in Helical Dipoles

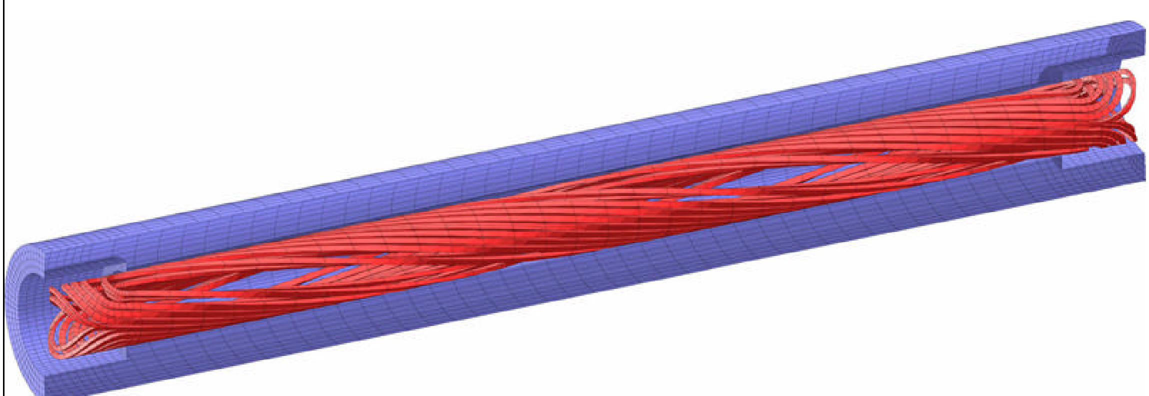
Animesh K. Jain

Brookhaven National Laboratory

11th International Magnet Measurement Workshop
September 21-24, 1999

Brookhaven National Laboratory, Upton, NY 11973-5000

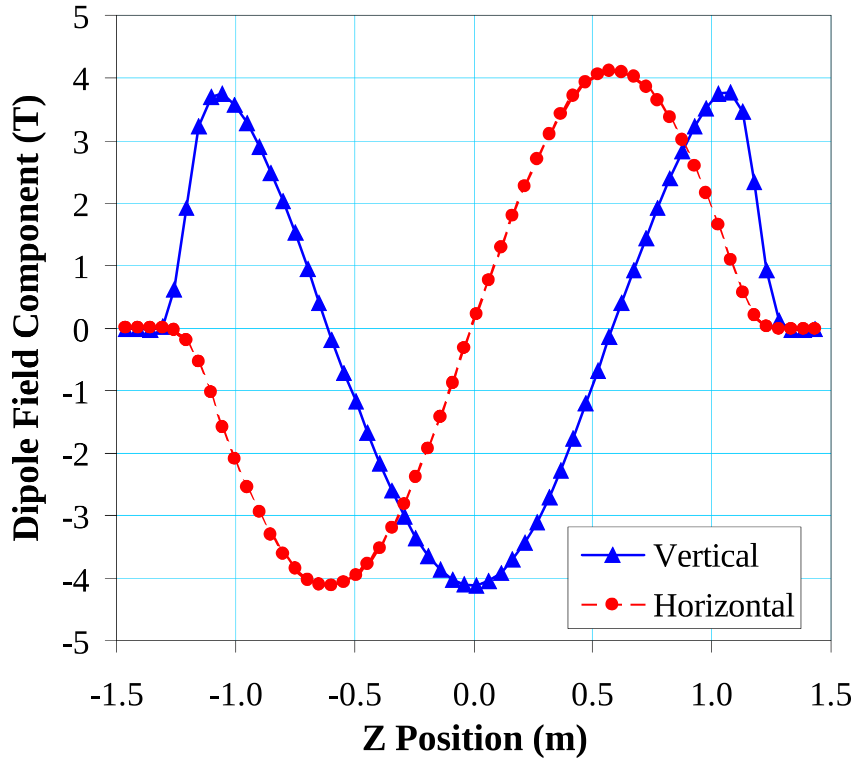
Schematic View of Helical Dipoles



(OPERA-3D model by Masahiro Okamura, RIKEN, Japan)

The dipole field rotates by 360 degrees over 2.4 m length

Dipole Field Components in HSD102 at 329 A



Both the vertical and the horizontal components should ideally integrate to zero over the length of the magnet.

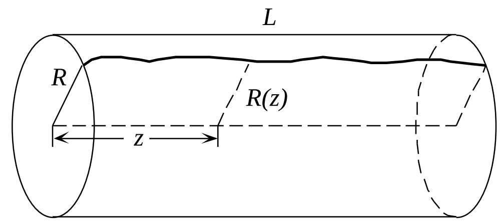
Integral Dipole Field using a Long Coil

- Single position measurement
  (not sensitive to coil position and orientation errors)
- Simple, quick method
  (single DC loop gives all the integral data needed)
- A suitable 3.57 m long measuring coil already available from RHIC CQS measuring program

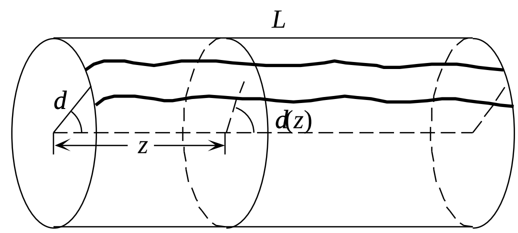
Tolerance: $\left[\left(\int B_y(z)\,dz\right)^2 + \left(\int B_x(z)\,dz\right)^2\right]^{1/2} < 5\times10^{-2}$ T.m

Sources of Errors in Integral Measurement

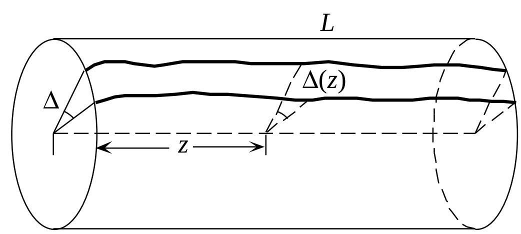
Variation of coil radius along the length



Variation of angular position of coil along the length



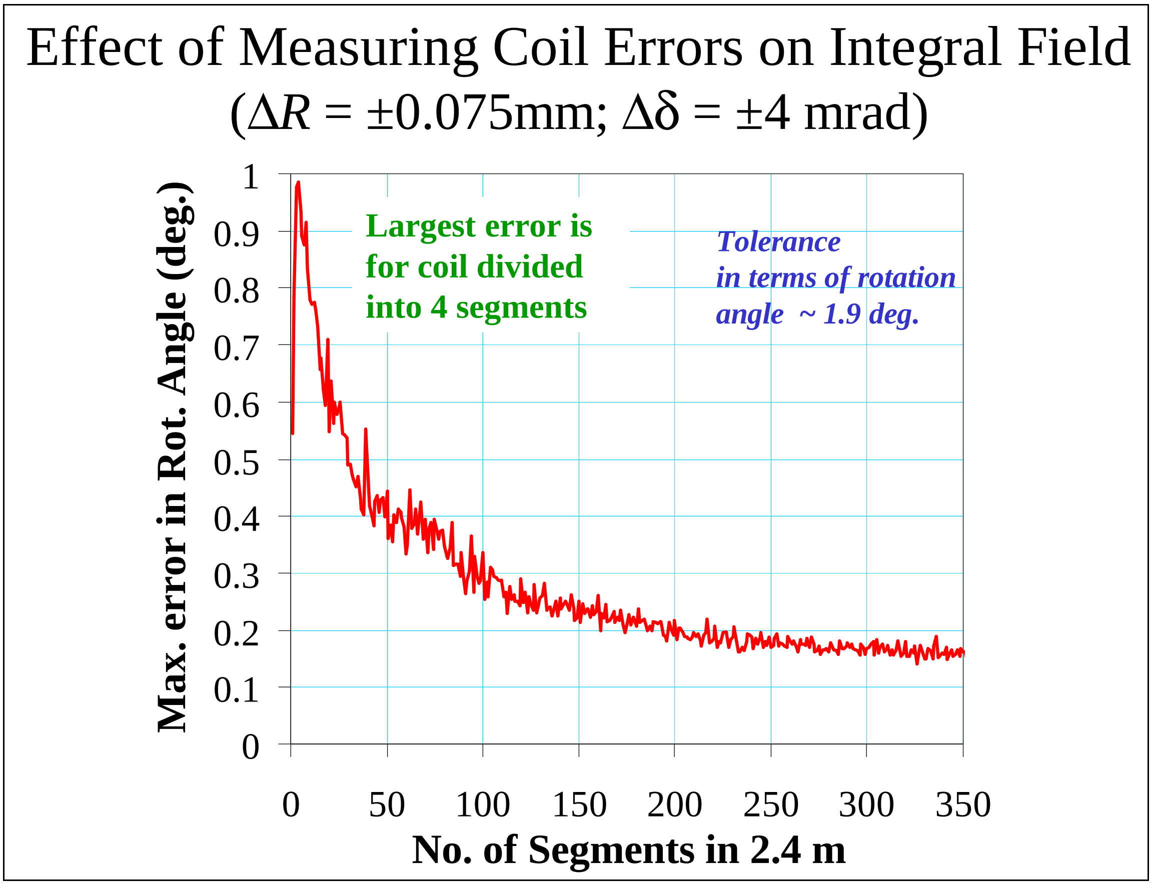
Variation of opening angle of coil along the length

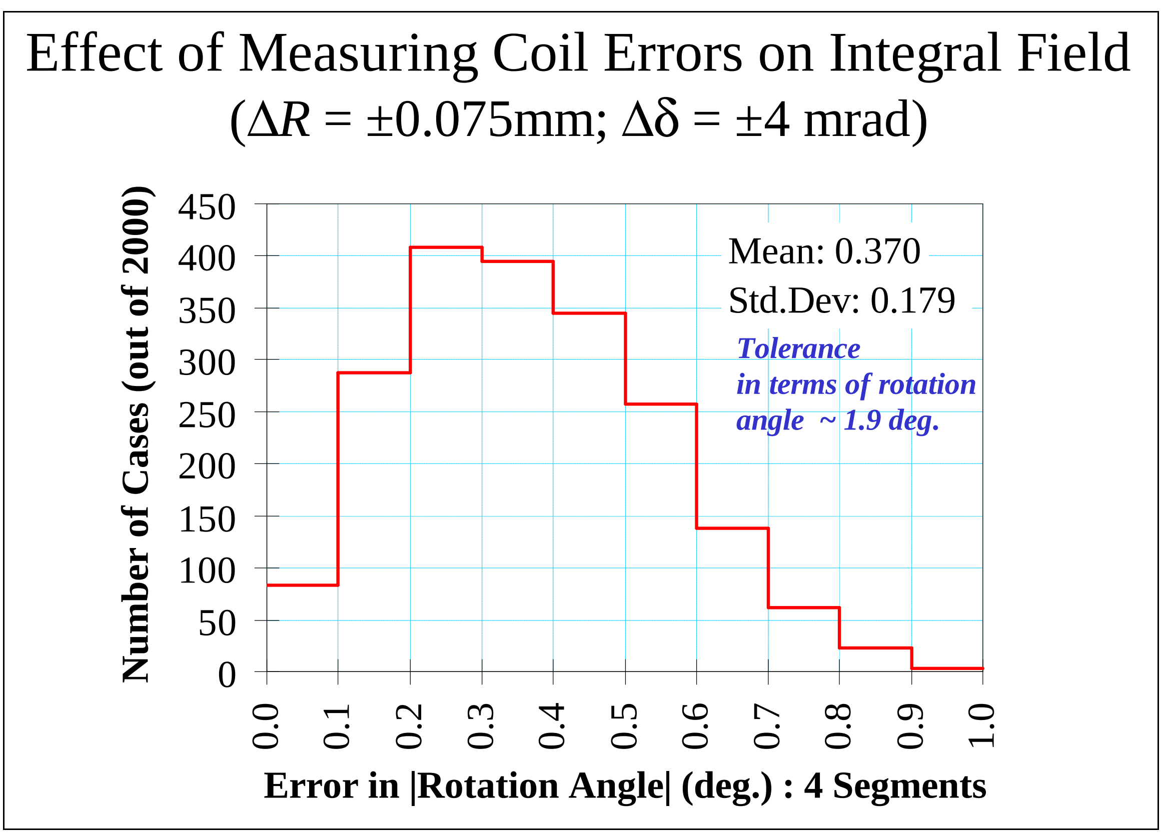


Can the magnets be certified to be within tolerance ?

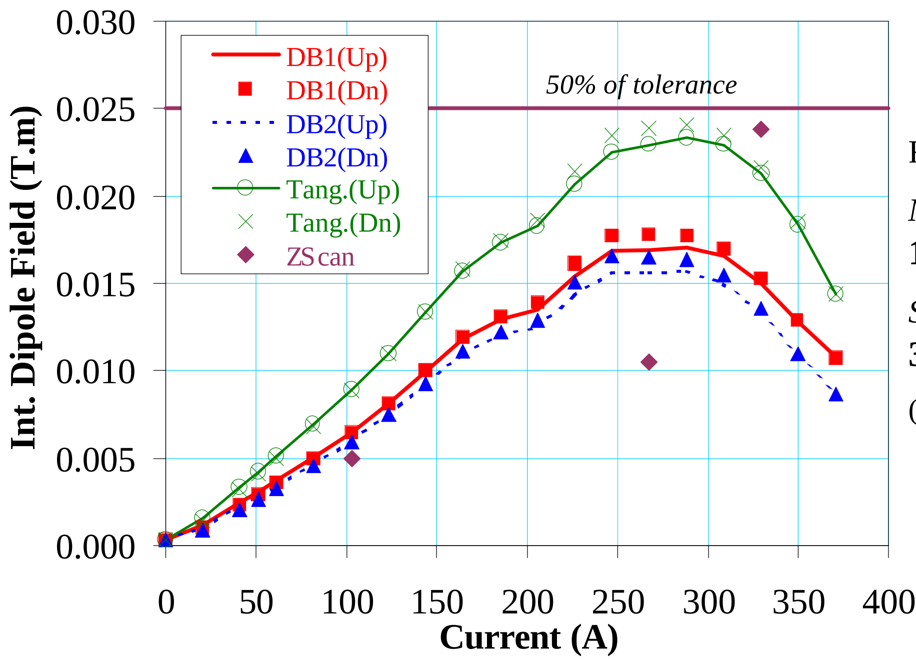
Estimation of Measurement Errors (Integ. Field)

- Divide the measuring coil into a number of sections
- Assign random radius and angular position errors at the ends of each section (*uniform distribution within* $\Delta R = \pm 0.075$ mm, $\Delta\, d = \pm 4$ mrad)
- Assume a linear variation of parameters within a subsection
- Calculate integrated field components for a **perfect** helical magnet (*uniform twist of* 2π *over* 2.4 m, *constant field*)
- Repeat for a large number of cases to see the distribution of errors


Effect of Measuring Coil Errors on Integral Field
(ΔR = ±0.075mm; Δδ = ±4 mrad)
Max. error in Rot. Angle (deg.)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
50
100
150
200
250
300
350
No. of Segments in 2.4 m
Largest error is for coil divided into 4 segments
Tolerance in terms of rotation angle ~ 1.9 deg.


Effect of Measuring Coil Errors on Integral Field
(ΔR = ±0.075mm; Δδ = ±4 mrad)
Number of Cases (out of 2000)
450
400
350
300
250
200
150
100
50
0
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
Error in |Rotation Angle| (deg.) : 4 Segments
Mean: 0.370
Std.Dev: 0.179
Tolerance in terms of rotation angle ~ 1.9 deg.

Integral Dipole Field Measured in HSD102



For 4 magnets:

Mean:

1.70×10^{-2} T.m

Std. Dev.:

3.8×10^{-3} T.m

(max. DB1 values)

Conclusions

- It is shown that even relatively small coil construction errors can seriously affect the measurement of integral field in helical dipoles.
- Worst case scenario with typical coil construction errors gives an error of about 1 deg. in effective rotation angle, still about a factor of two better than RHIC tolerance.
- Experimental results in helical dipoles are consistent with expectations based on numerical simulations.

Status of Magnetic Measurements at Lawrence Berkeley National Laboratory

Mike I. Green

October 1993

- Bob Schermer, Don Nelson & Mike I. Green retire
- Magnetic Measurements Group dissolved
- Paul Barale Programming for Space Sciences
- Dave Van Dyke part time technician for Magnetic Measurements and Electronics Installation

1995-1997

- PEP II – B-Factory at SLAC
- LBNL Responsible for Low Energy Ring
- Dipoles, Quadrupoles & Sextupoles manufactured in China
- Mike I. Green rehired, Paul Barale & Dave Van Dyke measure magnets using existing equipment

1998

- B- Factory Magnetic Measurements completed
- Magnetic Measurements Group dissolved

1999

Superbend Magnets for Advanced Light Source

- Replace four ~1 meter long Storage Ring resistive Dipole Magnets with short Superconducting Magnets
- Steve Marks in charge of Magnetic Measurements
- Mike I Green “Consultant”

Magnetic Measurements System

- PC
- National Instruments LabWindows CVI
- Dual Metrolab GPIB integrator
- Applied Geomechanics Gravity Reference
- Existing Dipole & Quadrupole Harmonic Coils
- System under development

Search Coils for LHC Magnet Measurements

J. Billan, CERN

Introduction

The LHC machine requires more than 6000 magnets, most of them superconducting. The machine will be very sensitive to the quality of the magnetic field and all magnets will have to be measured with high precision. The magnetsare costly and very delicate to produce, but magnetic measurements at room temperature, hence at low current, have proved their efficiency. The fields to be measured range from some 10^{-5}T for control during production to 9T in dipoles during final measurement.

As we are mostly interested in the field integral, search coils are the best sensor for magnetic field measurements. About 1500 search coils have already been made, and still 300 remain to be produced.

The field accuracy must be high but the harmonic content of the field has also to be percisely known. Harmonic analysis from rotating search coils is definitely the most efficient tool for measuring the small and long cylindrical apertures of the LHC superconducting magnets. A choice between radial and tangential search coils has been made.

Design criteria

In 1991 a first study was launched, to estimate the advantages and disadvantages of radial and tangential search coils. At that time the cold bore tube diameter was 43mm in dipole magnets. The use of tangential search coils wound in grooves machined in cylinders made out of non-conducting material was considered too delicate and not precise enough for a large number of turns. Moreover, the technique needs a rather complex bucking coil system, especially for quadrupole fields. A preference rose for assembly with individual and identical search coils, evenly spaced and tightened between two flat base plates,in the case of radial search coils. Such an arrangement with five coils can be used to measure any fields up to decapole magnets. Nevertheless, for dipole magnets, a tangential arrangement of identical coils was preferred.

Individual coils permit precision in coil windings of

±0.050mm	on width	(about $\pm 5.10^{-3}$ on surface area)
±0.020mm	on height	
±0.020mm	on parallelism	(about ±2 mrad mis-orientation)

But by exploiting the high precision of recent CNC machines, a reproducibility of

±0.010mm on core dimensions is obtained

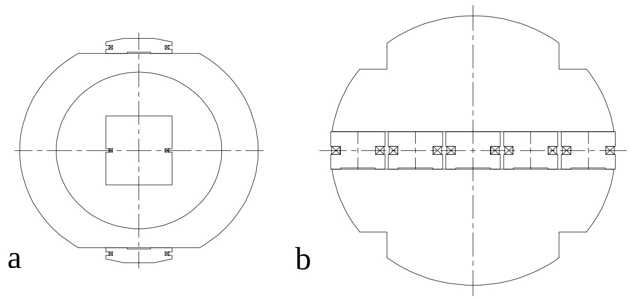
and limitations in coil accuracy are mostly due to the winding wire positioning

Individual coils also permit series production, hence:

- lower cost
- making coils with a large number of turns easier
- repairs by changing coils become possible

sorting in batches of identical coils after precise and dedicated calibrations

Fig. 1 a) tangential search coils for dipoles
b) radial search coils for quad



Basic features

Only racetrack or solenoidal coils can be made accurately, even with a large number of turns. The space inside the winding must be large enough to place positioning and fixing and wiring board. The positioning of the coils is made with precision pins.
Pins are reference to:

- ensure the symmetry during machining of the core
- control the symmetry and distance of the bottom of the winding grooves before winding
- control the symmetry and distance of the top of the winding after completion
- maintain the symmetry and distance separating the two parts of the coil winding
- ensure proper positioning inside the assembly

The core material should first be an insulator. It should be stable at room temperature as well as at LHe temperature, not fragile and easy to machine with accuracy. An epoxy mat glass fibre reinforced material has been chosen.

Small and square winding cross-section eliminates the need for correction for harmonic component calculations and has been chosen as often as possible. To keep high sensitivity in very low fields, a large number of turns made with a fine wire are necessary. Moreover, small pads on the core permit the adjustment of parallelism between coils, by scratching the pads. Scratching of only 0.01mm corresponds to a correction of about 1mrad for most coils. This allows the parallelism between coils to be kept within 1mrad, giving a “skew” bucking ratio superior to 1000 in dipole measurement.

Other features are wiring board and outlet cable. To keep the coil squeezed between two planes, nothing should ptotude. The wiring board and outlet cable must be embedded inside the core. Moreover, no extra loops should be created by the connection to the wiring board, and miniature coaxial or twisted pair cables should be used.

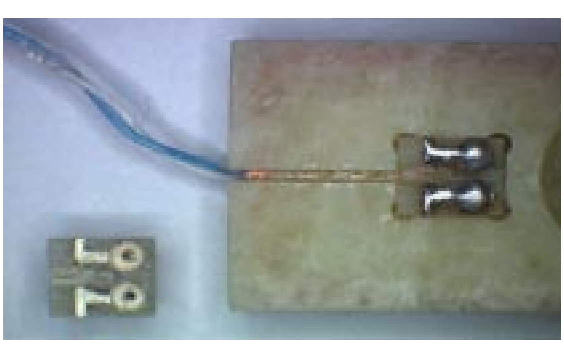
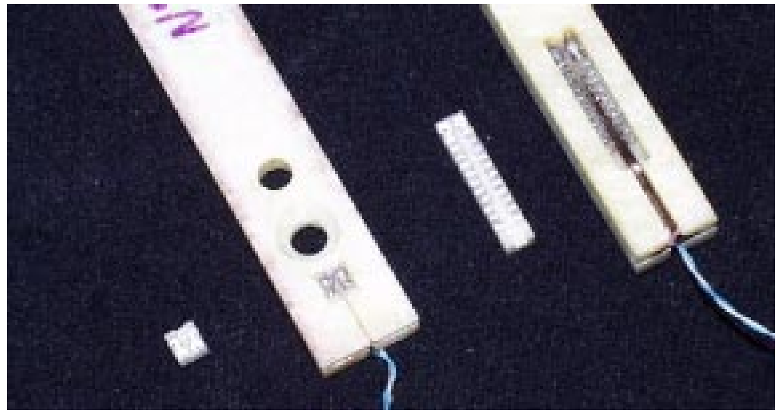


Fig.2 Single wire coil wiring board

Fig.3 20 strand multiwire wiring board

Coaxial cables are 1mm diameter and twisted pairs 2 x 0.35mm diameter.

Fig.4 Wiring board and outlet cable for single and multi wire coils. The width of both wiring boards is 3.5mm



Single and multi wire search coils

The choice between single and multi wire winding techniques depends mainly on the length of the coils. Our single wire winding machine is limited to 265mm.

Single wire search coils

Fig.5 shows the winding cross-section of a 200mm long coil dedicated to the measurement bench of the SC strand magnetisation at 1.8K. These coils have 1000 turns of 32μm diameter copper single wire. The cross-section is already difficult to be made perfect for such a short coil on a precise and automatic winding machine, and it becomes impossible for long coils.

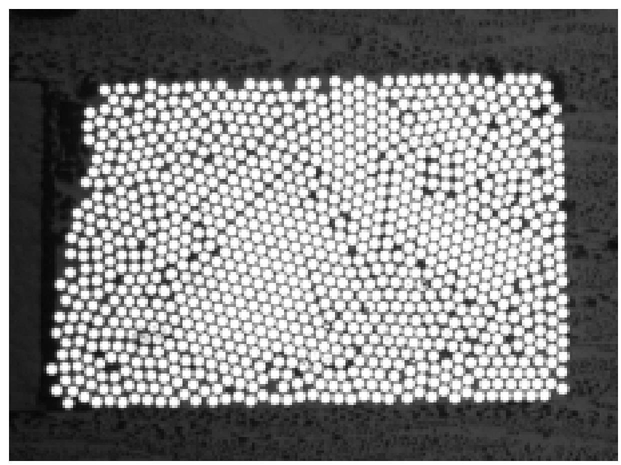


Fig.5 32μm single wire, 1000 turn coil

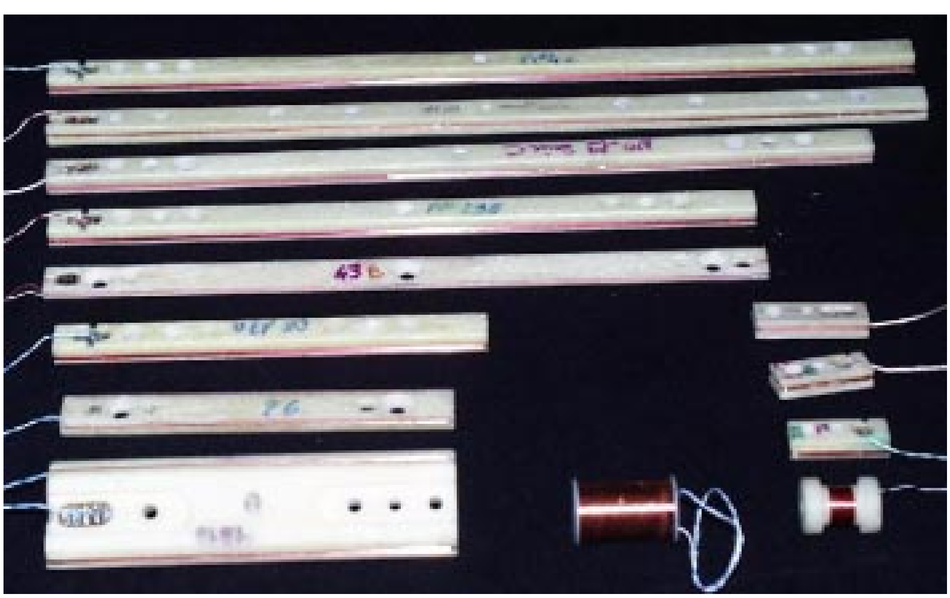


Fig.6 The different types of single wire search coils used in LHC magnet measurements

Table 1 Single wire search coil characteristics

Type	Application	Length mm	Width (diam) mm	# turns	Wire diam. µm	Surf area m^2	Number
Solenoid	11.5T solenoid	6	6	30’000	32	0.16	10
Race track	1m models dip Field meas..	25	10	1000	32	0.21	40
"	"	115	10	150	50	0.15	30
"	"	200	10	150	50	0.27	75
"	"	240	10	150	50	0.32	60
"	"	262	10	150	50	0.35	60
"	1m models dip Quench anten.	200	10	150	50	0.27	170
"	Long dip. proto Field meas.	25	10	1000	32	0.21	40
"	"	30	10	800	32	0.21	20
"	Long dip. proto. Quench anten.	70	10	40	50	0.028	90
"	"	100	10	120	50	0.12	90
″	Geom. mole	100	10	600	32	0.6	25
"	SC wire magnetisation	200	6	1000	32	1.15	25

Multiwire search coils

For coil length from 275mm to 2250mm a new technique using cables from MWS, has been developed [1]. Four different cables - with 20 and 8 wires of 50µm diameter, 10 wires of 70µm and 6 wires of 80µm - have been used.

Fig 7 The different types of multi wire search coils for LHC magnet measurements

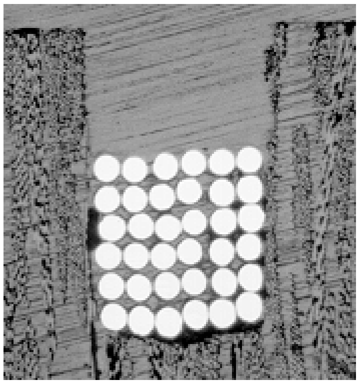


Fig. 8 The 36 turn winding cross-section of the 1150mm long tangential search coils

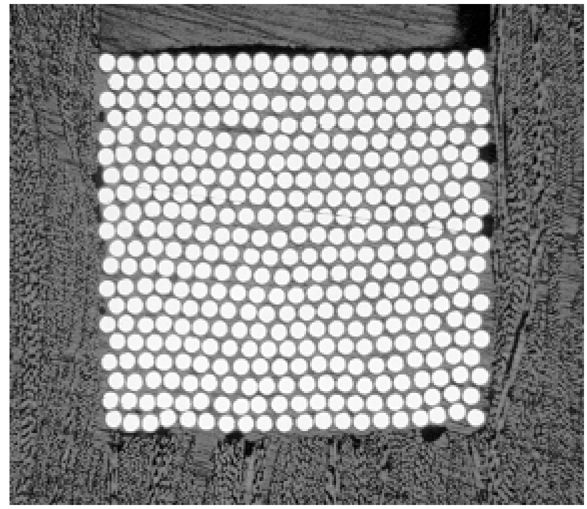


Fig.9 The 400 turn winding cross-section of thesearch coils for the different warm measurement systems

Several wiring boards have been made, corresponding to the type of cable. But with experience, the dimensions of these wiring boards that the type for 20 strands can be used for any other cable.

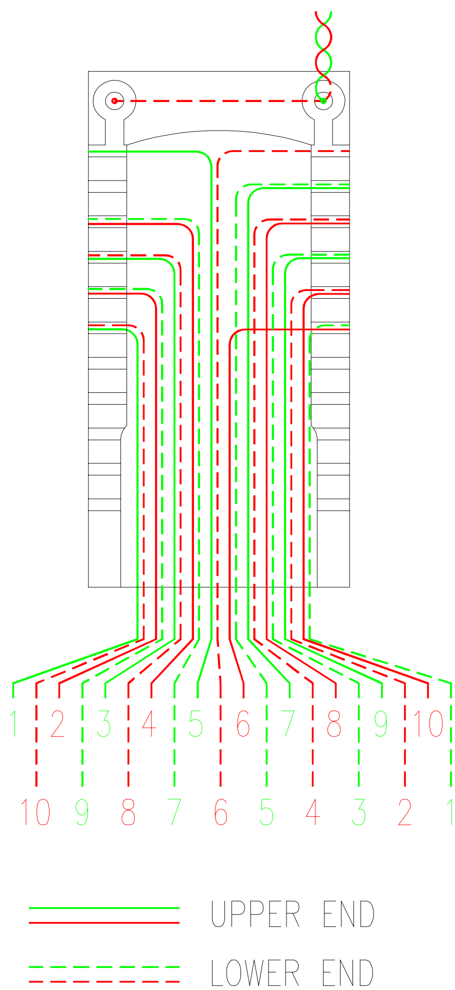


Fig. 10 Interconnection of a 10 strand multiwire in a 20 strand wiring board. In the flat cable, strands are alternately red and green

Table 2 The multiwire search coils

Application	Number of wires	Length mm	Width (diam) mm	# turns	Wire diam. µm	Surf area m^2	Number
Dip. cold meas. Field meas..	6	1150	8.5	36	80	0.35	450
"	10	750	10.0	50	70	0.33	15
"	10	275	10.0	50	70	0.145	20
Quad. cold meas Field meas.	8	600	7.1	64	50	0.23	30
"	10	700	7.0	50	70	0.27	16
Dip. warm meas. Field meas.	20	750	12.0	200	50	1.59	15
"	20	750	10.7	400	50	2.75	15
"	20	750	12.0	400	50	3.04	15
"	20	750	13.1	400	50	3.43	25
"	20	750	14.1	400	50	3.73	25
Quad. warm meas. Field meas.	20	750	8.4	400	50	1.97	30
"	20	500	10.0	400	50	1.41	25
Long dip. proto. Quench antenna.	20	1060	10	120	50	1.29	100
"	20	2250	10	40	50	0.91	50

Applications

Four major applications of these different search coils can be distinguished

1m long models in vertical cryostats [2]

A large number of 1m long model magnets are being tested in vertical cryostats to improve the design of the LHC superconducting magnets. Most of them are dipoles but some short magnets such as tuning quadrupoles and correctors are also being measured. The adopted solution was to fit a shaft with several sets of three or five radial search coils for measuring dipole or any other magnets. Fig.11 shows a shaft with 5 sets, one being exploded to display the individual coils.

During the first tests with such a shaft, induction voltages were observed just before quenches. Thus, the radial coils could also be used as quench antenna. But a dead angle remains in the plane of the coils and sixteen tangential coils were added to the assembly in four groups of four coils to complete the quench antenna. One line of four tangential coils is shown in Fig. 11. In vertical position, the shaft rotates on a ball placed at the bottom of the magnet. It turns directly in superfluid helium. Motorization and encoder are placed at room temperature on the top of the cryostat. Passage of the lambda plate is made by a stainless steel tube through sleeve bearings. The wiring of the 31 coils passes inside the tube up to a flat connector embedded and glued to the top of the tube. Finally the protective sheathing surrounding the coils lends the shaft a cylindrical shape.

Fig. 11 Search coils in vertical shaft for measuring 1m long models

<u>10m long dipole prototypes</u> [3], [4]

Magnetic measurement probes

These probes are made of sets of radial search coils translated and rotated at the end of a 13m long ceramic shaft. They work at room temperature inside a 35mm diameter warm bore tube of an anti-cryostat. Field measurements are made at low temperature with 750mm long 50 turns search coils. Measurements were also performed at room temperature but with 750mm long 400 turns search coils. For measuring the field modulation due to the 115mm pitch of the superconducting cable, a special probe with an array of 7 search coils, 25mm long and with 1000 turns, has been designed. This array covers 175mm, more than one pitch, and makes it possible to measure the modulation and phase of the main field, and other components.

Long quench antenna

Two different 10m long assemblies of sets of 90° radial search coils, as shown on Fig. 10 for one short set only, have been built. To study the localisation of the quenches during magnet training, one assembly is placed inside each 35mm anti-cryostats. The initial system was made of two assemblies plus one spare set of 4 coils of 40 turns each. The central region of the magnet was covered by four 2250mm long sets and both ends of the magnet coils were covered by three sets of 70mm long in order to get better resolution in these delicate regions. After this first trial a second system was built with eight 1060mm long sets terminated at each ends by three 100mm long sets. These sets were made of 4 coils of 120 turns each.

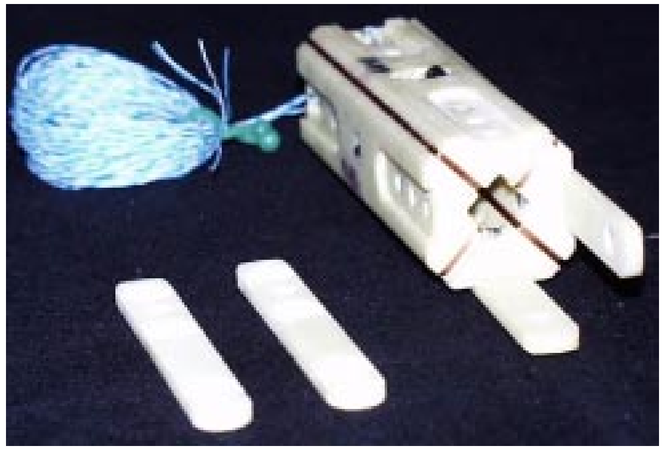


Fig.12 A 100mm long set of the long quench antenna, showing the 4 radial search coils and the securing lugs to assemble the sets between them along the quench antenna. The wiring of the coils passes through the square hole inside the sets, up to the ends of the anticryostat.

15m long dipoles

Tests on the 10m long prototypes showed that the magnetic field exhibits a large time constant and the time taken to cover the 15m of the magnet with z-scan measurement is too long. It was therefore decided to built a long measuring shaft covering with 13 elements the whole length of the magnet. The basic material of these elements is ceramic in order to reduce as much as possible the torsion between the first and the last element during the rotation of harmonic analysis measurement. In ceramic tubes, the easiest and most precise machining operations are grinding flat surfaces and drilling holes. For that reason the solution was to have thin tangential search coils with one internal compensation coil inside the tube. The result is that the stiffness of the tube is still very good and the three coils are identical. Moreover this arrangement of the coils allows them to be used also as quench antenna

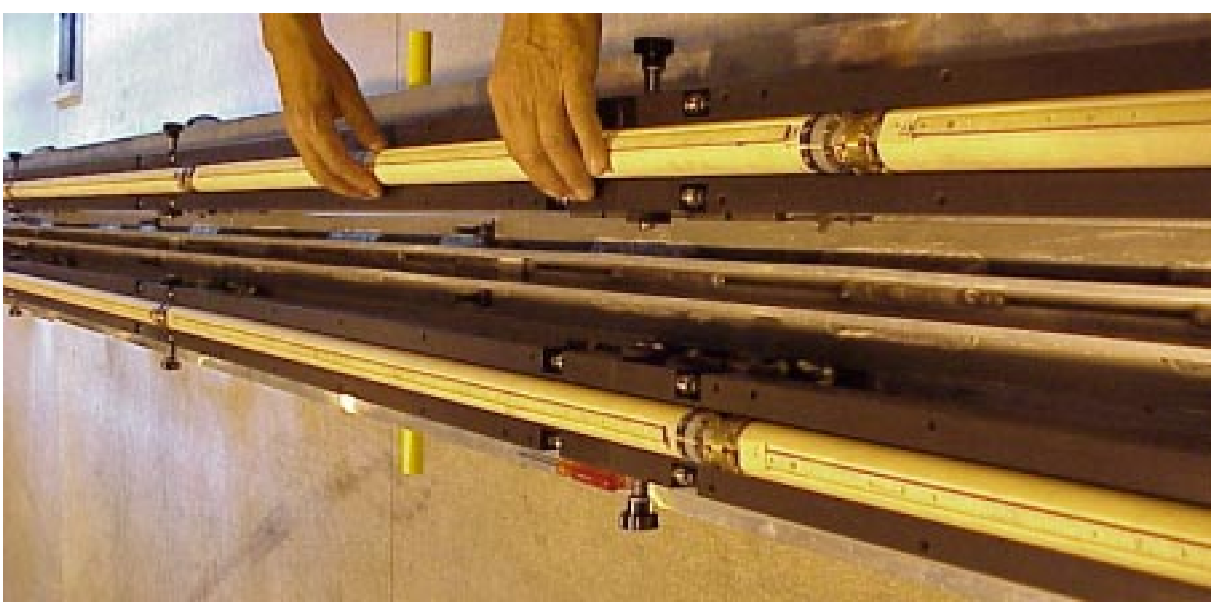


Fig. 13 Some of the 13 elements of the two long search coils

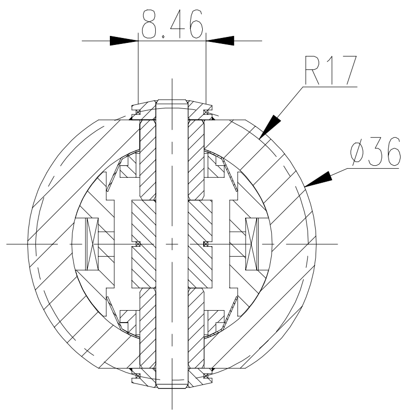


Fig. 14 Cross-section of the long ceramic measuring shaft with the main dimensions and centering and alignment of the three coils with one central long ceramic pin and two precise ceramic sleeves

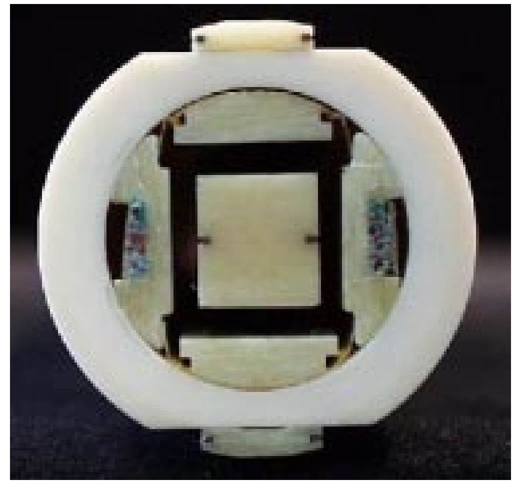


Fig. 15 Photograph of a section of a fully equipped ceramic shaft with the two lateral coil wiring channels and their spring supports

One of the most delicate problems was to pass the coil wiring through all 13 elements to the end of the complete shaft. Moreover all elements must be absolutely identical to permit true interchangeability. The solution was subminiature connectors with a pitch of 0.625mm (0.025”), as shown in Fig. 14

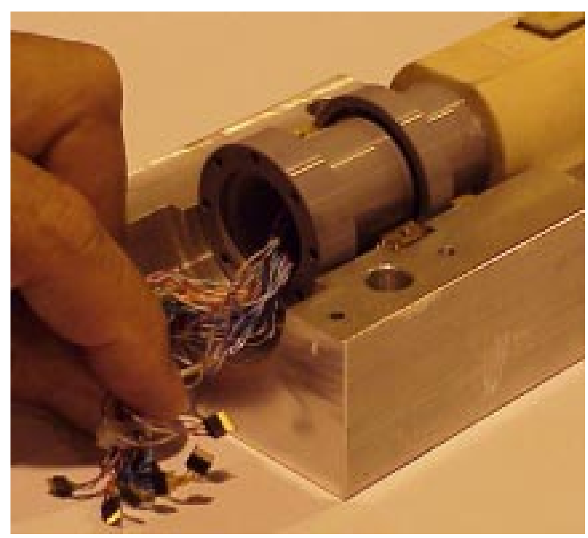


Fig.16 The subminiature connectors at the end of one element of the long measuring shaft

Moles for measurements at room temperature

An essential part of control procedures during magnet fabrication is the so-called “warm” measurement performed at room temperature with a very low current in the magnet coils. An exctation current of 10 to 20A is possible, instead of 12000A as at low temperature. In dipole magnets a field of less than 0.01T is thus available. To get sufficient sensitivity the surface area of the search coils should be around $2m^2$. Length of the search coil is limited to 750mm for sag reasons and a number of turns of 400 made with 20 layers of a 20 strand multiwire cable provides a reasonable approach.

Fig. 17 shows a complete mole for quadrupole measurement and the different elements it is made up of.

Fig. 17 Mole for quadrupole measurement at room temperature

Calibration [6]

Calibration is an important phase in search coil fabrication. The parameters of each search coil and their assemblies have been thoroughly measured in two reference magnets located in part of the tunnel of the former ISR machine, at a place which has the advantage of being very stable in temperature

Calibration in a reference dipole magnet

Fig. 18 Calibration of a search coil assembly in the reference dipole magnet

First of all, the magnetic field of this magnet is completely mapped with an NMR probe at 1T and this measurement procedure is repeated periodically. Its stability is within 10^{-5} T as long as the excitation cycle remains the same. The same NMR probe measures the field at a single point during every calibration process, in order not to depend on the excitation current.

The surface area of each individual search coil is measured by π-rotations, inverted to eliminate any eventual integrator drift and reproduced three times for a sufficient statistical check. When measuring an assembly of three or five search coils, all coils are measured simultaneously. The five integrators can be seen in Figs.18 and 19

In the reference dipole, the parallelism between all the various search coils in assemblies is measured. Coils are placed tangentially to the field and any flux variation between them measures their lack of parallelism. Mainly this is less than 1mrad and the assembly is accepted. Otherwise the search coil pad can be smoothly ground, with a dedicated apparatus, to correct the defect.

Calibration in a quadrupole reference magnet

Search coil assemblies are calibrated in a reference quadrupole magnet. As explained in [6], the coil rotation radius can be measured with an accuracy of some μm. This system measures radial and tangential coil assemblies.

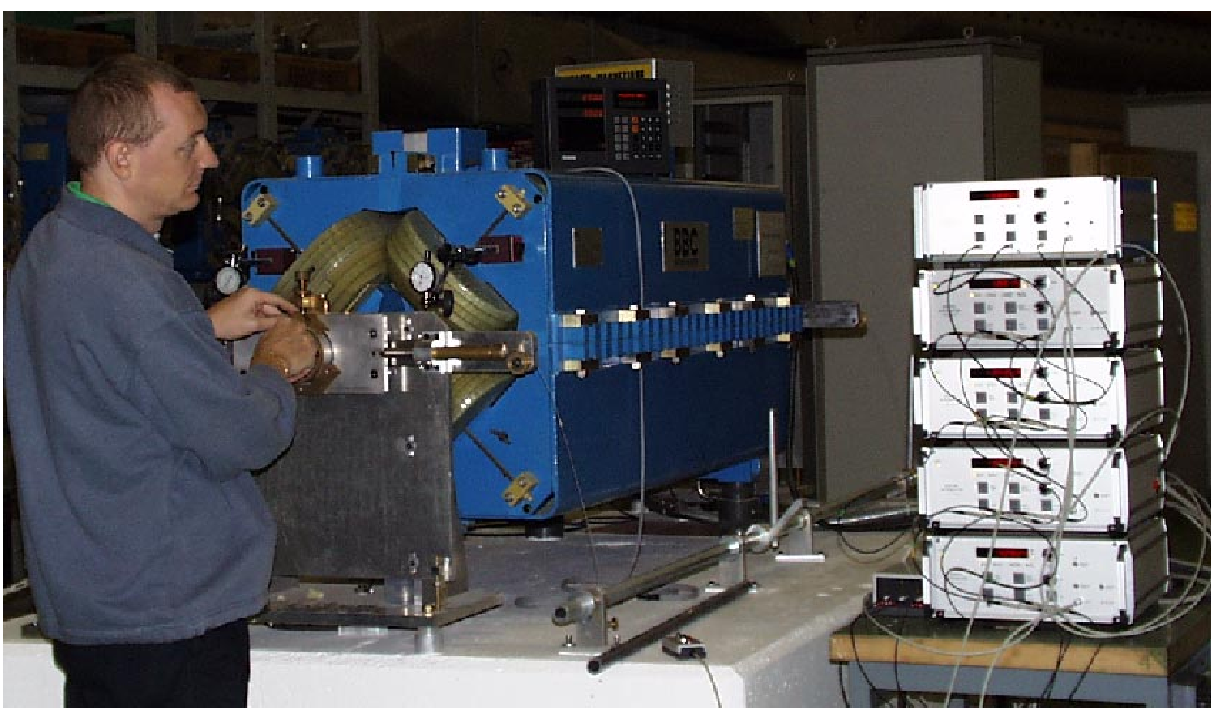


Fig.19 Calibration of a search coil assembly in the quadrupole reference magnet

The complete moles for LHC dipole and quadrupole warm measurement are also counter-checked in this refence quadrupole magnet. Fig.20 shows the drive shaft and two motors for respectively levelling the mole and rotating of the coil assembly. The magnet is equipped with two identical systems, to operate from any side of the magnet.

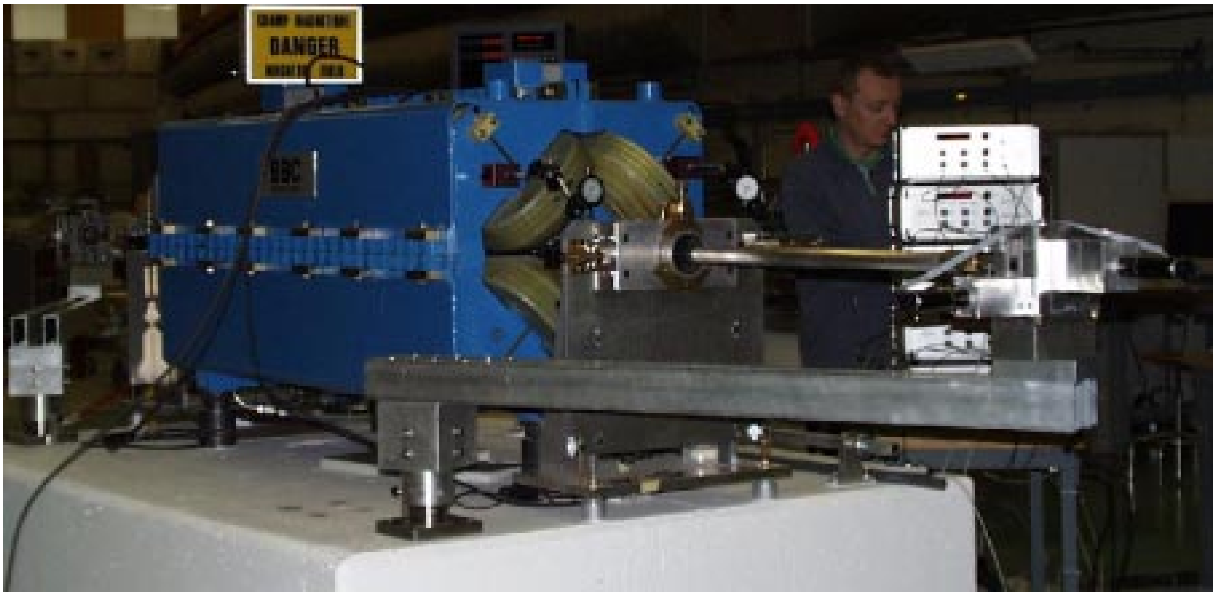


Fig.21 Calibration of a warm measurement mole in the quadrupole reference magnet

Bibliography

[1] "New development in search coil design and fabrication", J. Billan, S. Bidon, F. Fischer, C. Sanz, IMMW9, Saclay, 1995

[2] J. Billan, C. R. Gregory, P. Legrand, L. Oberli, A. P. VerWeij, L. Walkiers, "Test of 1m long Model Magnets for the LHC", Proc., 12th Int. Conf. on Magnet Technology, Leningrad, (June 1991)

[3].J. Billan, J. Buckley, R. Saban, P. Sievers, L. Walkiers, “Design and test of the benches for the magnetic measurement of the LHC Dipoles” Proc. Conf. MT13, Victoria (Sept. 1993)

[4] L. Walkiers, Z. Ang, J. Billan, L. Bottura, A. Siemko, P. Sievers, R. Wolf, “ Towards series measurements of the LHC superconducting dipole magnets”, Proc. 1997 PAC conf., Vancouver, (May 1997)

[5] J. Billan et al., “Manufacturing features and performances of long models and first prototype for the LHC project”, presented at the EPAC`98 conference, Stockholm, (june 1998)

[6] “Calibration of the harmonic coil systems for LHC magnet measurements” J. Billan, Presented at IMMW10, Fermilab, 1997

Annex 1

Main features in the assembly of search coils

Radial search coils

Fig.22 Assembly of a three radial coil system for measuring dipole magnets. The coil is first tightened to one of the two half supports, then the same screw is used to tighten the second half support. After checking the parallelism in the reference dipole, one of the pads of the coils can be ground to improve the parallelism. Screws of the lateral coils are in another plane.

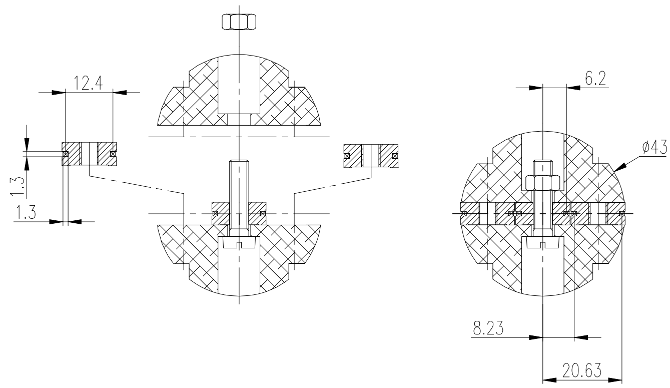
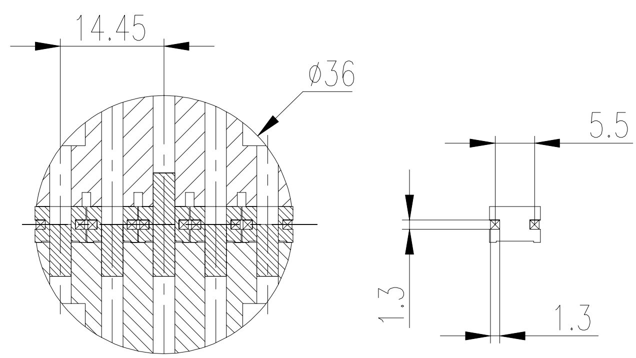
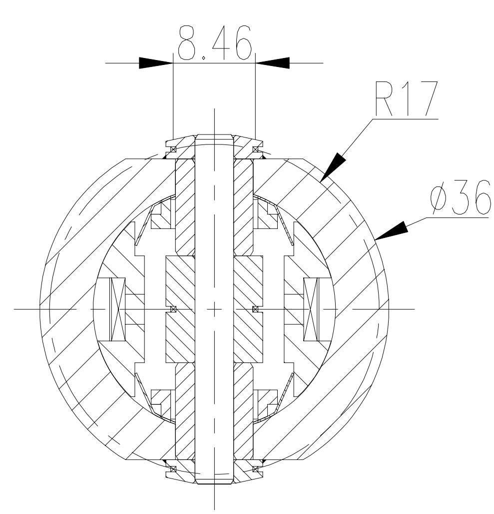


Fig.23 Assembly of a five coil system for measuring quadrupole, sextupole and other multipolar magnets. This figure shows the smallest diameter realised for such an assembly. Ceramic pins of 4mm (or even 3mm) are used for positioning the coil during its fabrication and mounting at during assembly



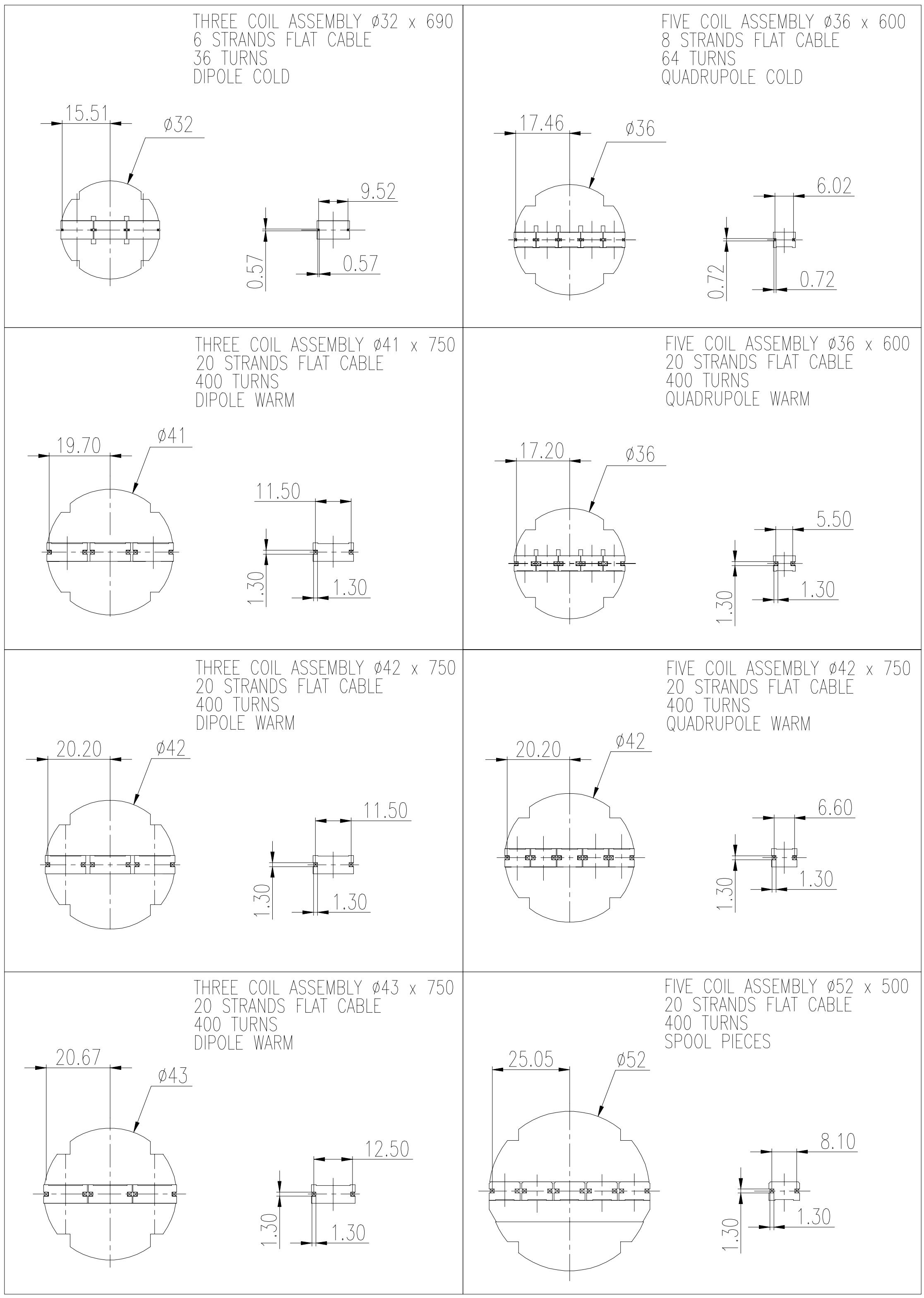
Tangential search coils

Fig.24 Cross-section of the tangential search coil assembly used for measuring the LHC 15m long dipole magnets. One tangential coil makes the measurement, the opposite coil is a spare. The central coil, of the same surface area, is used to buck the dipole field. All three coils participate to the quench localisation. In this design, only simple and very precise machinings of the ceramic tube are required. Accuracy of the order of 0.01mm is obtained on a length of 1.15m. The association of two precise ceramic sleeves and one long ceramic pin makes for excellent positioning of the three coils.



Annex 2

Selection of radial search coil assemblies used for LHC magnets



MAGNET MEASUREMENTS FOR

'ISAC' PROJECT AT TRIUMF

Doug Evans

Triumf, Vancouver, B.C.

Canada

September, 1999

Isotope Separation & Acceleration

The ISAC facility is planned to be an isotope separator coupled to an accelerator. In the isotope separator short lived nuclear species are produced by TRIUMF's 500 MeV cyclotron in bombarding a thick target. These isotopes are heated out and transported into an ion source, where they get ionized. This beam of short lived isotopes is then mass analysed and transported to either low energy experiments or into an accelerator. After acceleration these beams of short lived isotopes are used for nuclear reaction studies, in particular in the field of nuclear astrophysics.

WHAT DO WE NEED TO BUILD ISAC?

1) MONEY! - CANADIAN GOVERNMENT ANNOUNCES FUNDING IN 1995

2) NEW BUILDING

BUILT IN 1996 - 1997

3) NEW PROTON BEAMLINE - BEAMLINE "2A" BUILT FROM THE CYCLOTRON TO TRANSPORT 500 MeV., 100 uA. PROTON BEAM TO ISAC IN 1997.

4) MANY NEW MAGNETS - 132 IN ALL FOR ISAC PHASE I

40 DIPOLES	(24 MEASURED SO FAR)
88 QUADRUPOLES	(41 MEASURED SO FAR)
4 SEXTUPOLES	(4 MEASURED SO FAR)

(All Magnets are DC and Room Temp.)

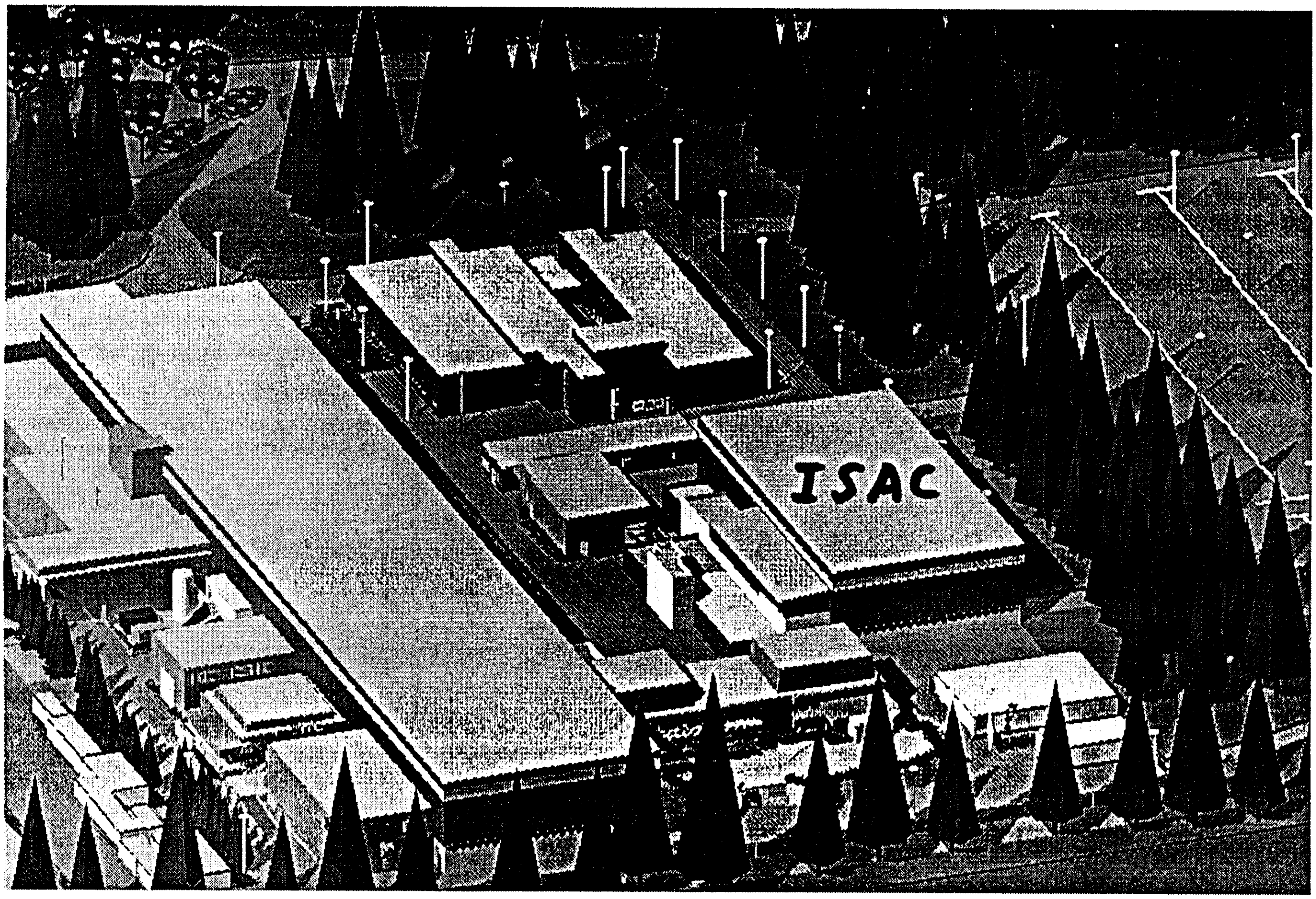


fig. 1 TRIUMF BUILDINGS LAYOUT - JULY 1998

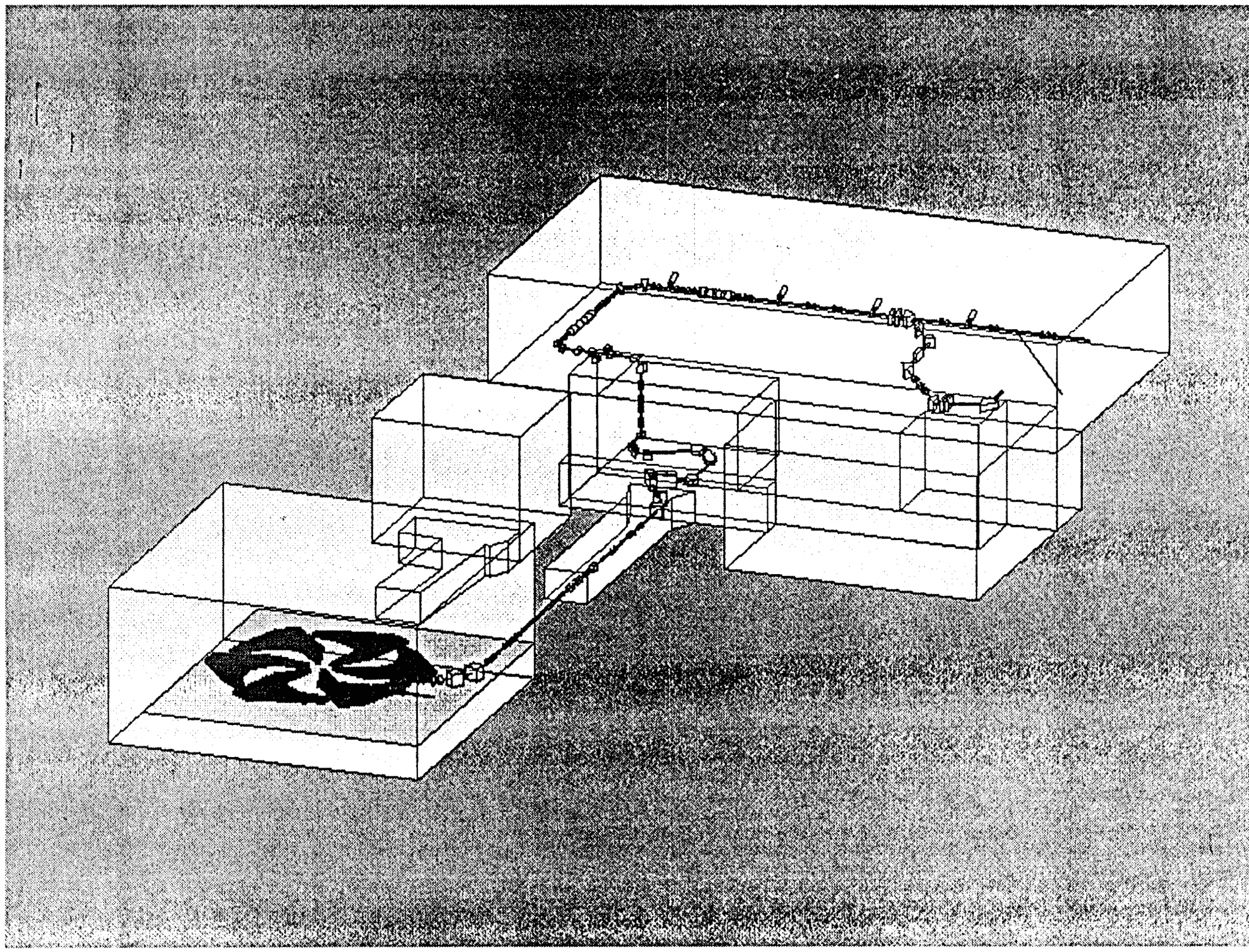


fig. 2 3D SKETCH OF BEAMLINE 2A AND ISAC BUILDING

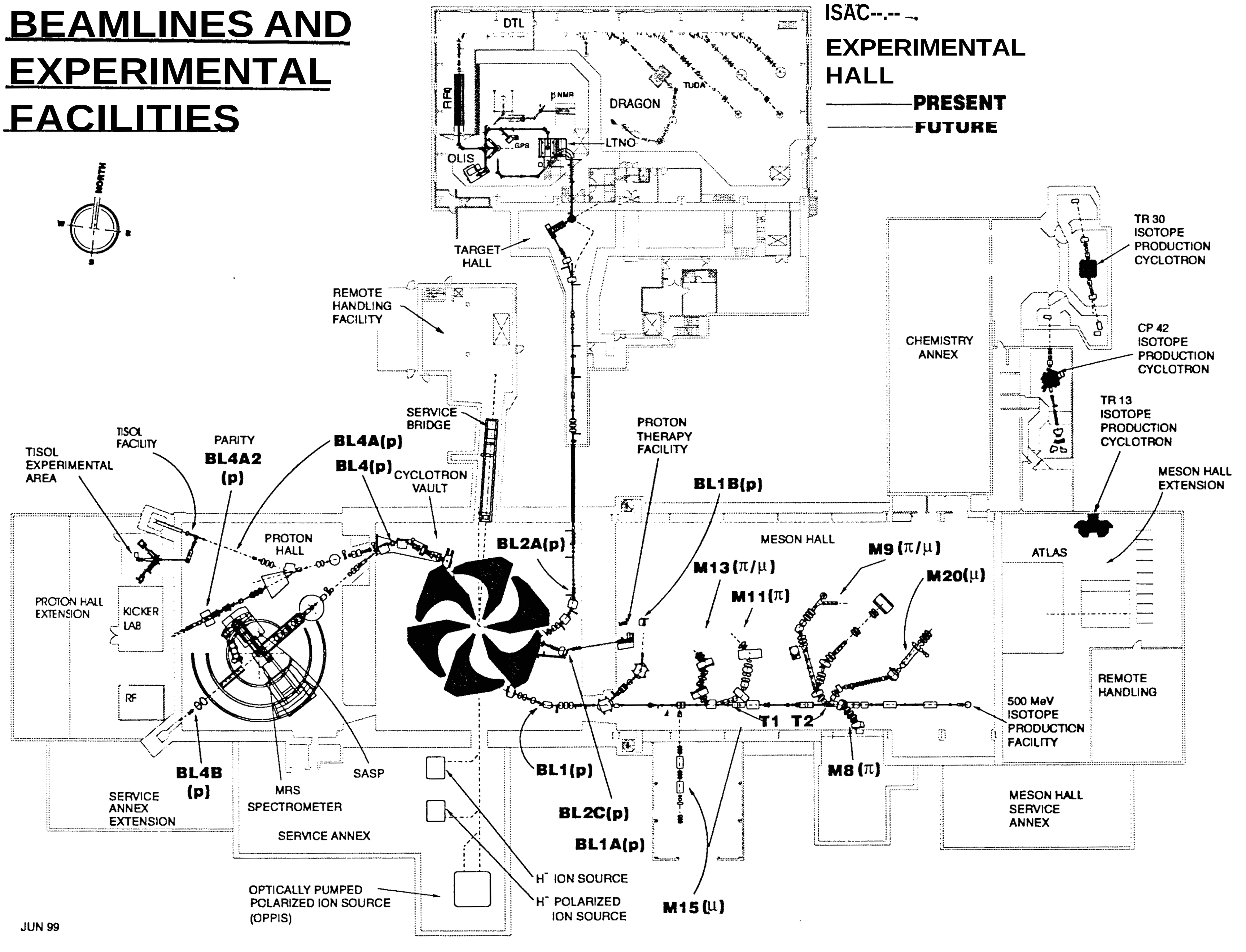

BEAMLINES AND EXPERIMENTAL FACILITIES
NORTH
ISAC
EXPERIMENTAL HALL
PRESENT
FUTURE
DTL
RFQ
DRAGON
TUDA
LTNO
OLIS
GPS
TARGET HALL
REMOTE HANDLING FACILITY
SERVICE BRIDGE
CHEMISTRY ANNEX
TR 30 ISOTOPE PRODUCTION CYCLOTRON
CP 42 ISOTOPE PRODUCTION CYCLOTRON
TR 13 ISOTOPE PRODUCTION CYCLOTRON
MESON HALL EXTENSION
TISOL FACILITY
TISOL EXPERIMENTAL AREA
PARITY
BL4A2 (p)
BL4A(p)
BL4(p)
CYCLOTRON VAULT
PROTON THERAPY FACILITY
BL1B(p)
PROTON HALL
BL2A(p)
MESON HALL
M9 (π/μ)
ATLAS
M13 (π/μ)
M20(μ)
M11(π)
PROTON HALL EXTENSION
KICKER LAB
RF
REMOTE HANDLING
T1
T2
500 MeV ISOTOPE PRODUCTION FACILITY
BL4B (p)
SASP
BL1(p)
M8 (π)
SERVICE ANNEX EXTENSION
MRS SPECTROMETER
BL2C(p)
MESON HALL SERVICE ANNEX
SERVICE ANNEX
BL1A(p)
H⁻ ION SOURCE
OPTICALLY PUMPED POLARIZED ION SOURCE (OPPIS)
H⁻ POLARIZED ION SOURCE
M15 (μ)
JUN 99

fig. 3

MAGNET MEASUREMENTS :

TWO SYSTEMS USED:

1) HALL PROBE AND 3D TABLE SYSTEM TO MEASURE DIPOLES AND SOME MULTIPOLE MAGNETS.

2) ROTATING COIL SYSTEM TO MEASURE QUADRUPOLES AND SEXTUPOLES;

HALL PROBE SYSTEM EQUIPMENT:

a) DECstation 5000/240 computer (Unixbased).

b) H.P. 3458A. DVM.

c) V.P. 3488A. Multiplexer

d) Bell BHT-910 hallprobes

e) Siemens SBV-613 hallprobes

f) Automated 3D Magnet Survey Table
Operates on Rectangular, Vertical Cylindrical and Horizontal Cylindrical Coordinate Systems.

g) Boron Fiber and Kevlar wrapped 3m. long Probe Arm

Post Processing:

- 2D and 3D plots, Effective Lengths, Integrated Flux Density and Homogeneity of Integrated Flux Density.

3D POSITIONING TABLE

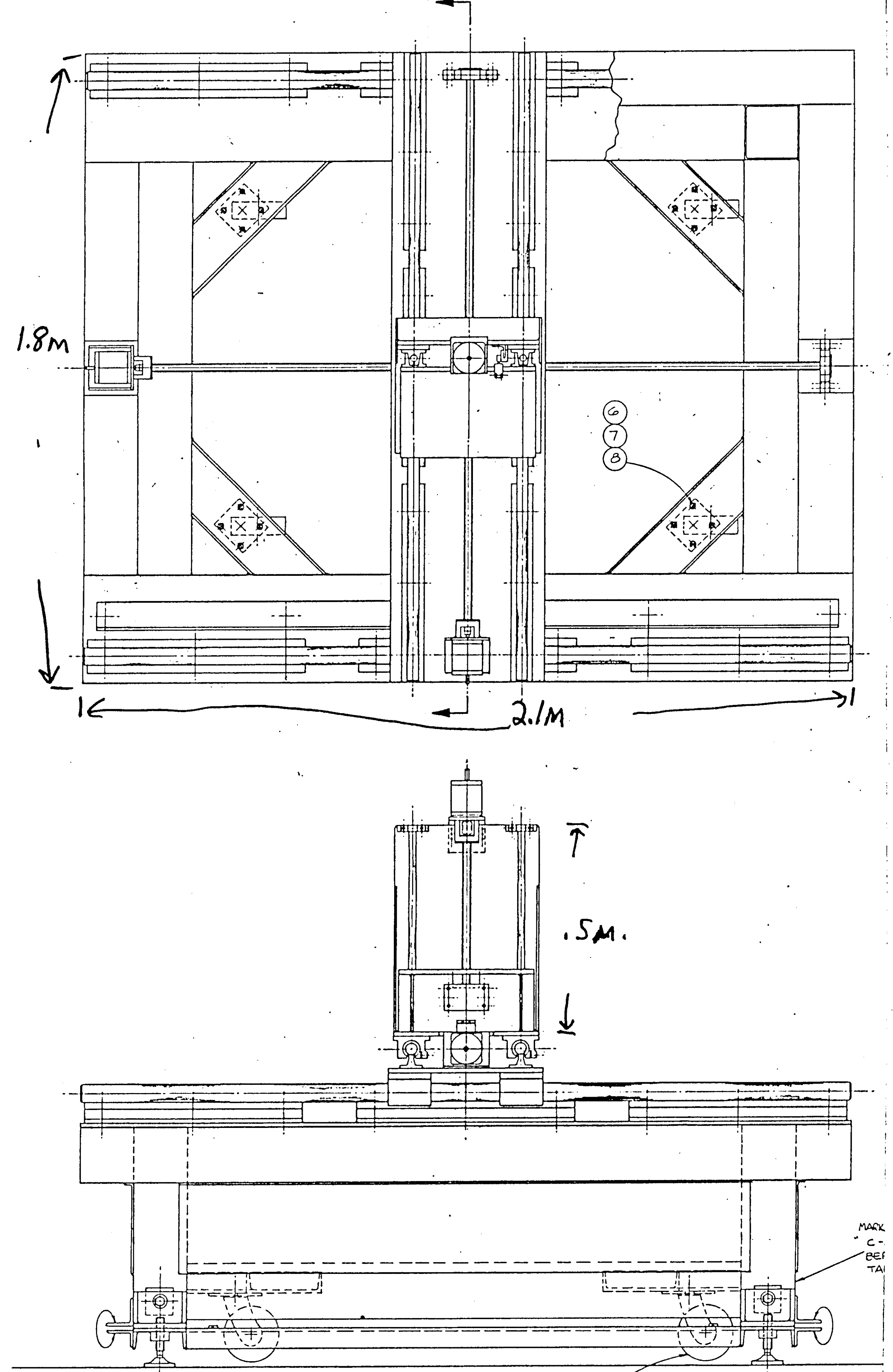


fig. 4

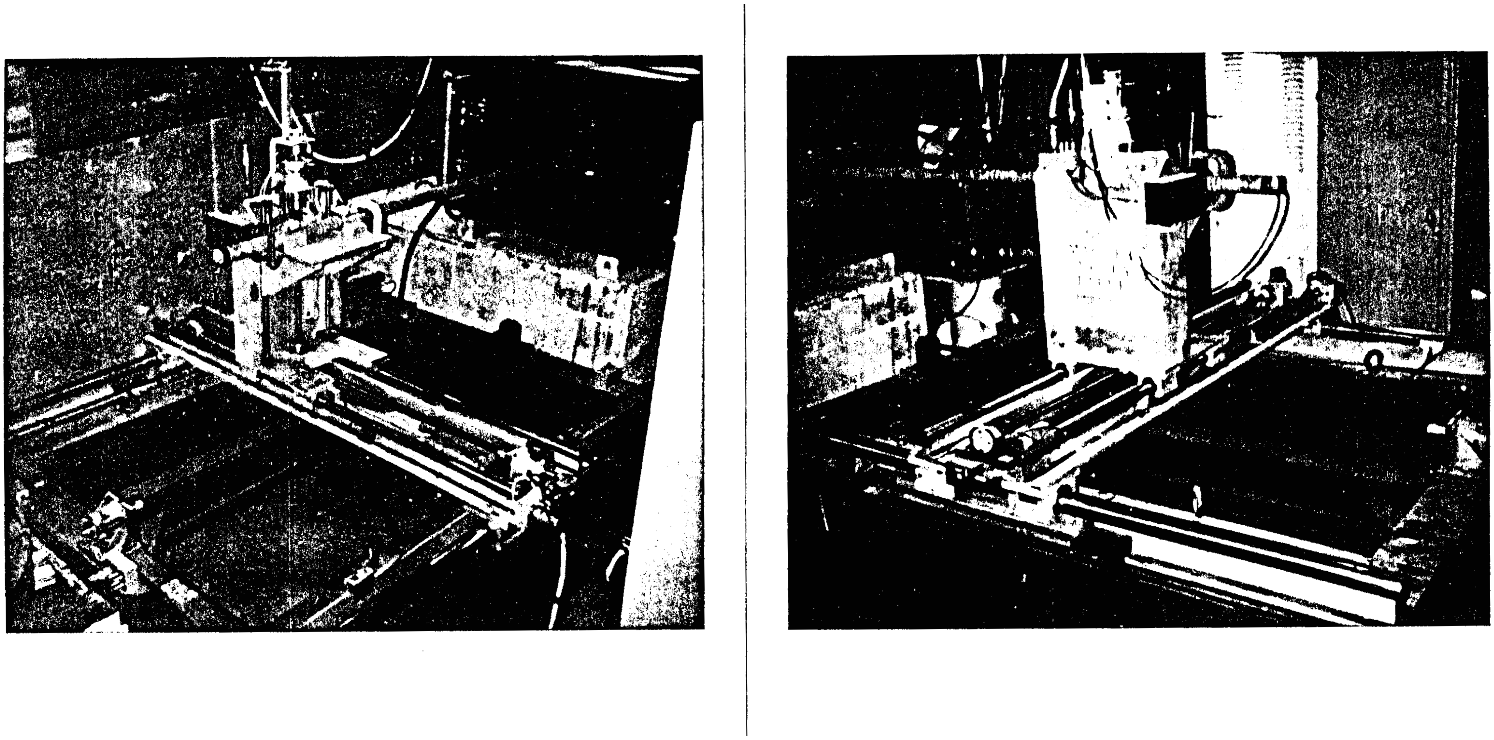


fig. 5 3D MAGNET MEASUREMENT SURVEY TABLE

ROTATING COIL SYSTEM EQUIPMENT:

a) WINBOOK XP5 Pentium Laptop Computer with Ethernet Card

b) National Instruments "DAQ-Card 1200" 12 bit resolution for data acquisition and timing.

c) Four Rotating Coils Exist (2", 4", 6" and 8" in dia.).
Each Coil has a Long (Integrated) coil and a Short (Point) coil.

Post Processing:

- Point and Integrated Harmonic Bar Graphs and charts, Effective Length, Pole tip field.

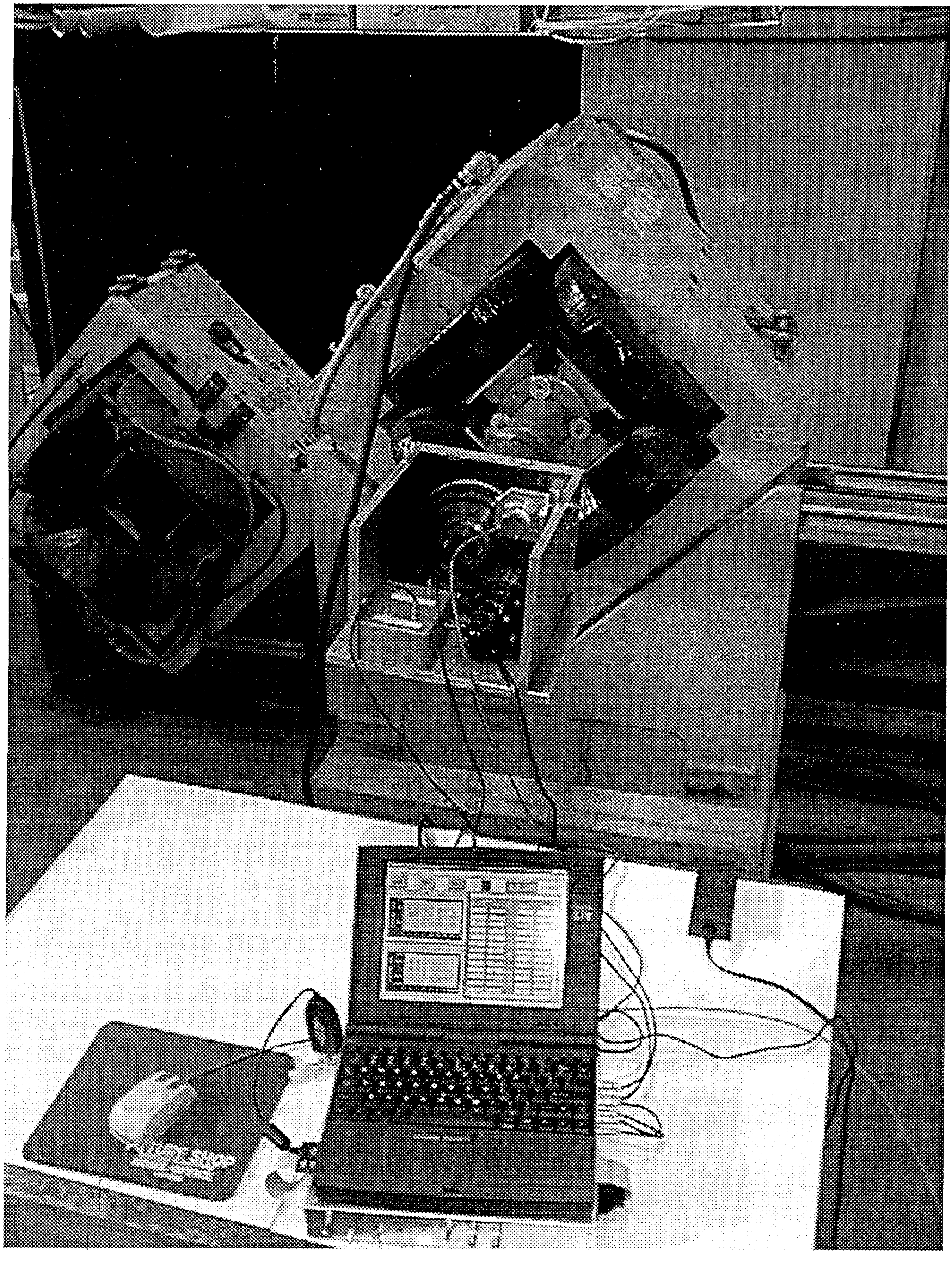


FIG. 6 ROTATING COIL SURVEY SYSTEM (4" COIL IN BEAMLINE 2A QUAD.)

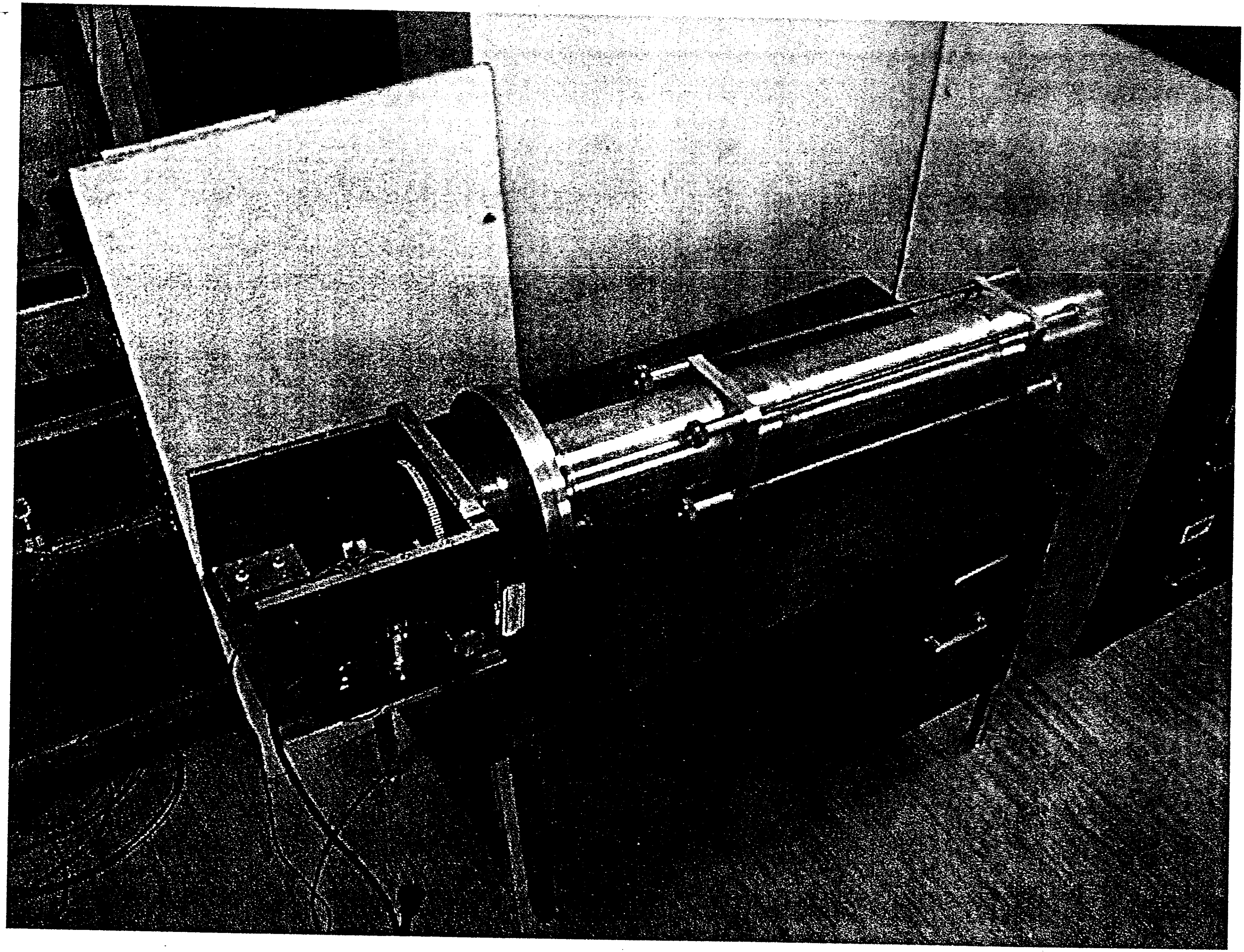


fig. 7 6" ROTATING COIL

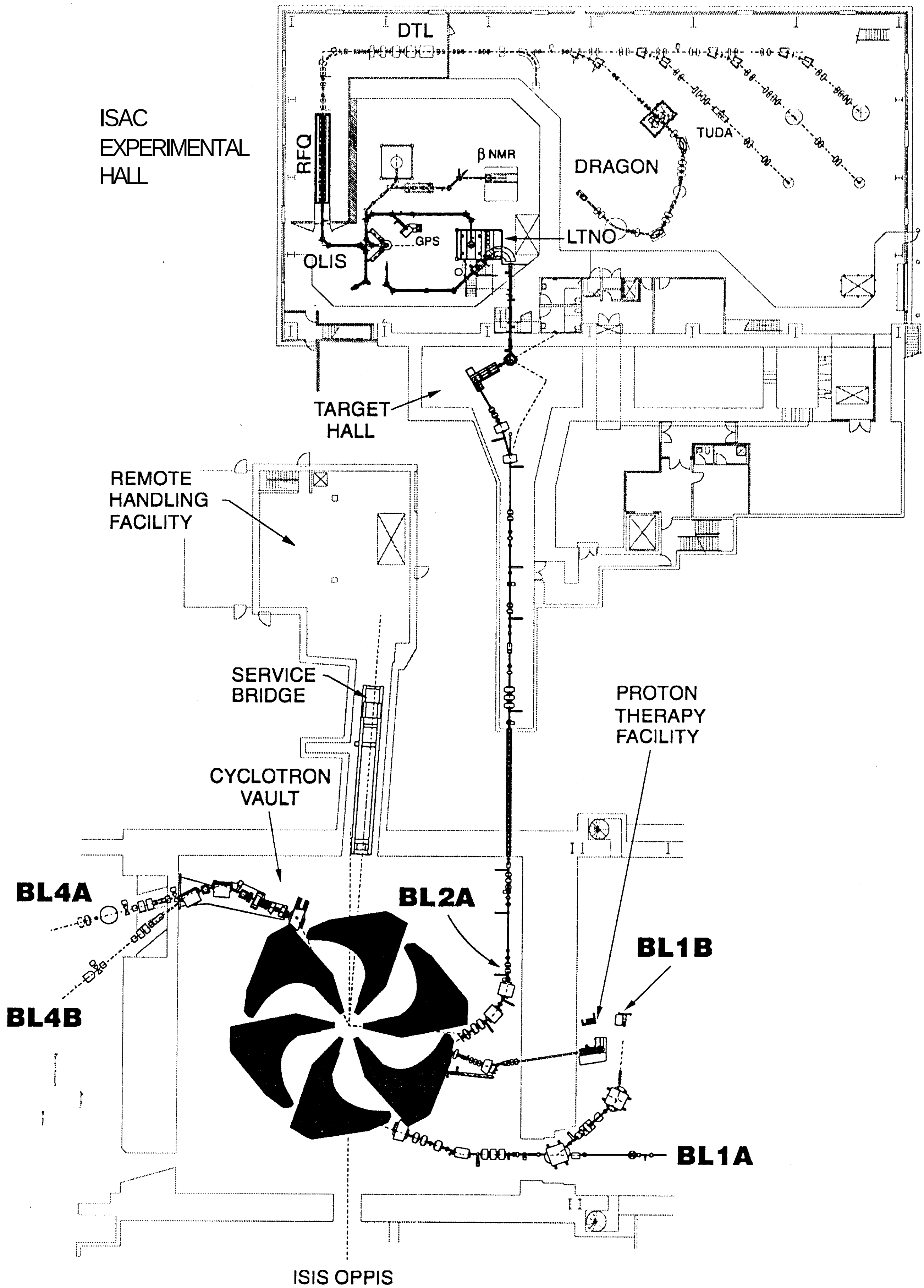


fig. 8 BEAMLINE 2A AND ISAC BUILDING LAYOUT

27.5 DEGREE DIPOLES FOR 2A

WEIGHT: 12,000 KG.

LENGTH: 1.46 m.

POLE GAP: 10 cm.

MAX. I: 650 amps

MAX. V: 70 volts

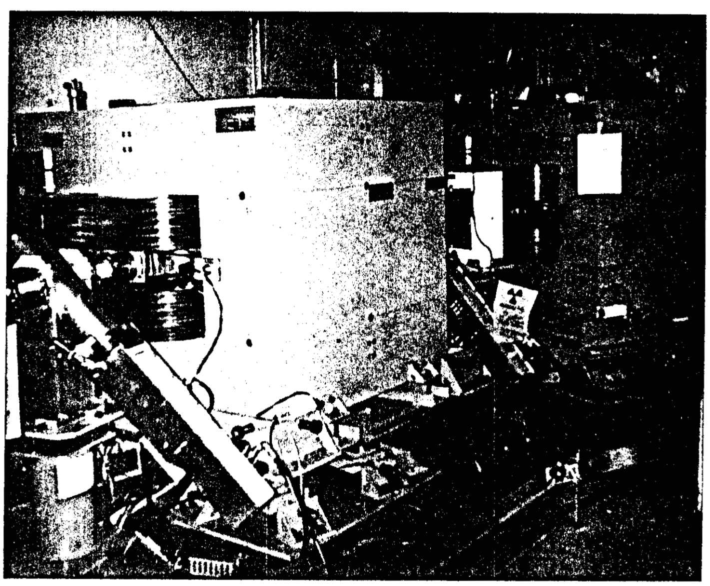
MAX. B: 1.56 T.

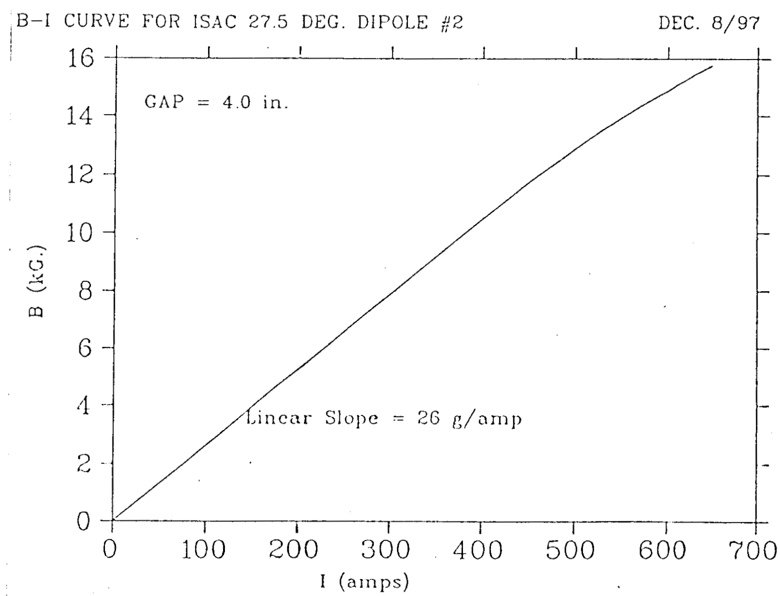
EFFECTIVE LENGTH: 1.221 m.

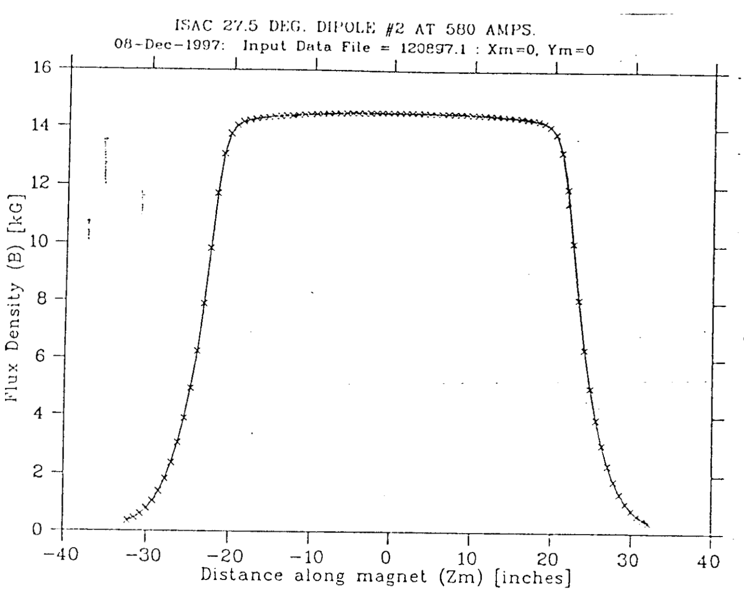
MANUFACTURER (STEEL): Sunrise Machine Works (Vancouver).
(COILS): Stangenes Industries (California).

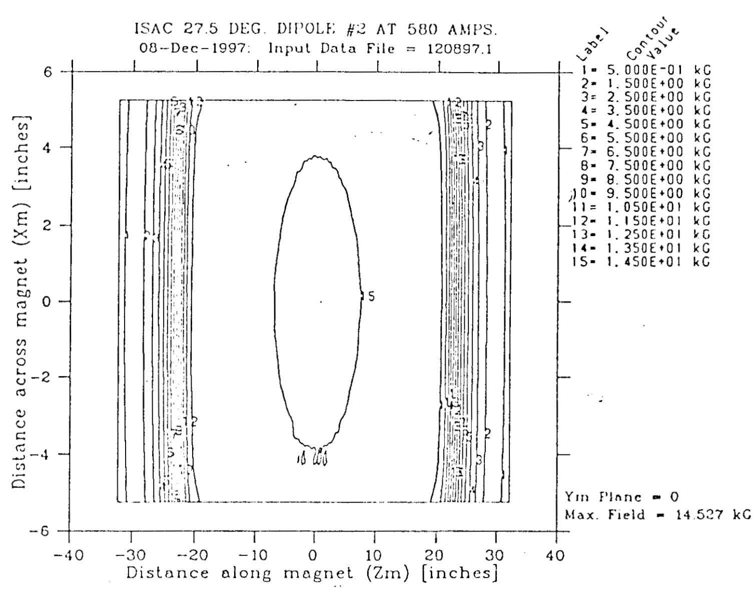
DATE MEASURED: Dec. 97

NO. OF MAGNETS: 2









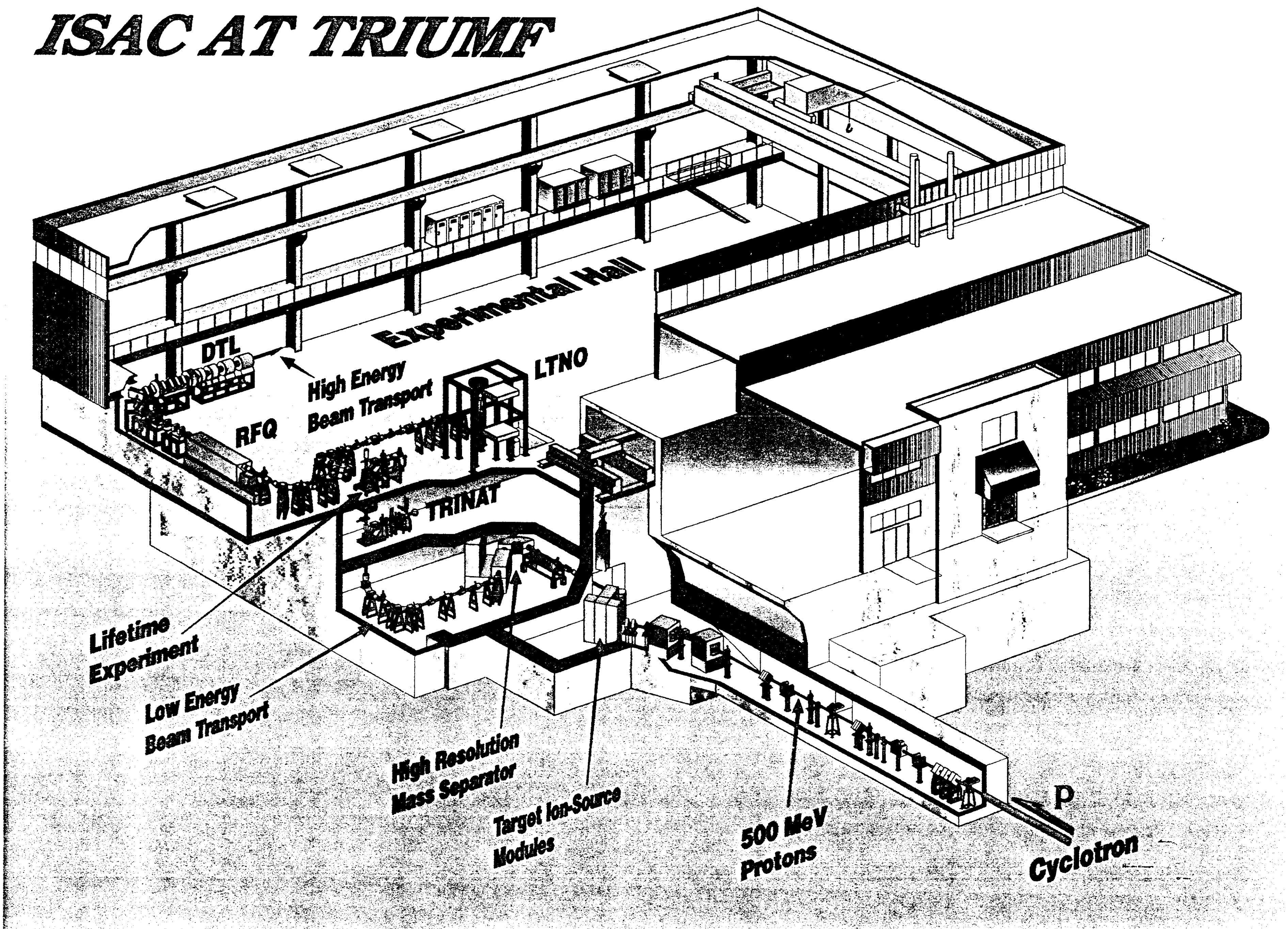


fig. 9 3D LAYOUT OF ISAC BUILDING

ISAC "BUNNY" QUADRUPOLES FOR 2A

WEIGHT: 445 KG.

YOKE LENGTH: 22 cm.

BORE: 10.3 cm.

MAX. I: 310 amps

MAX. V: 17.9 volts

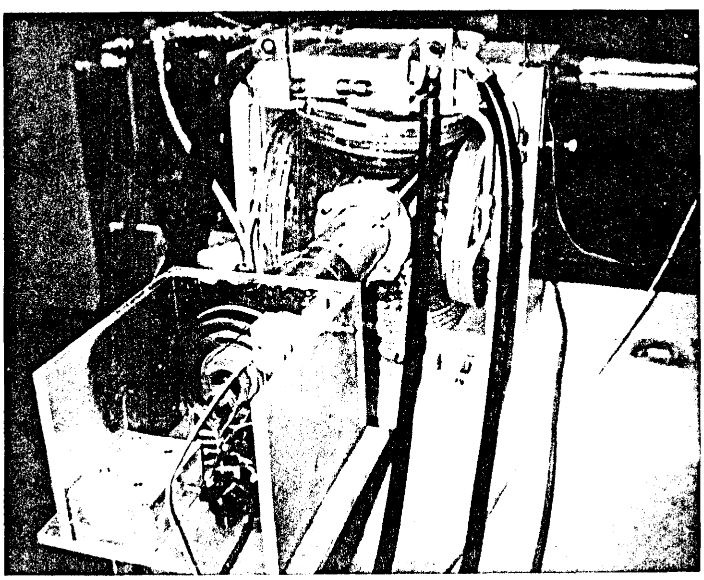
MAX. POLE TIP B: ·79 T.

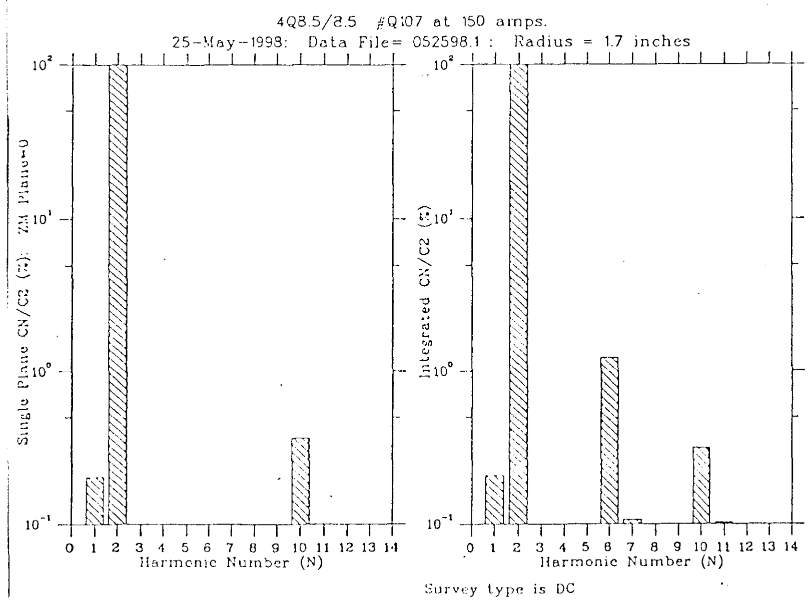
EFFECTIVE LENGTH: 26.2 cm.

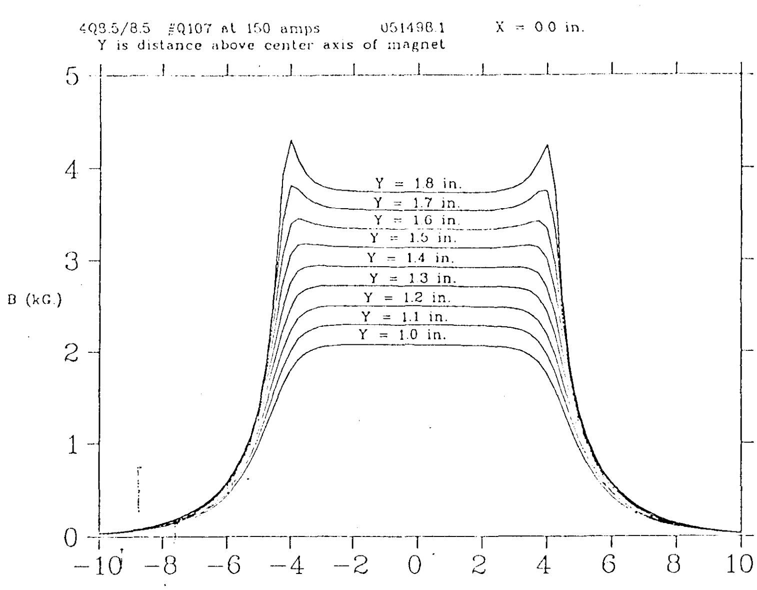
MANUFACTURER (STEEL) : SUNRISE MACHINE WORKS (VANCOUVER)
(COILS) : EVERSON ELECTRIC (PENNSYLVANIA)

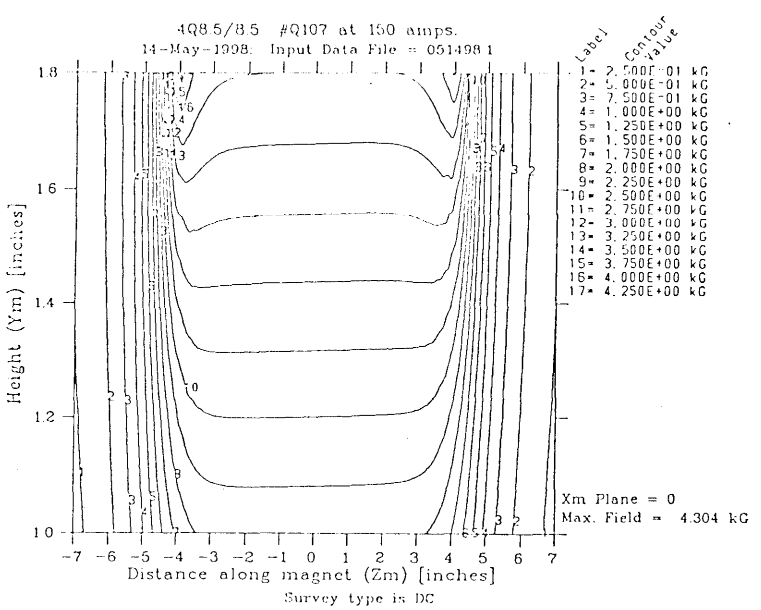
DATE MEASURED: MAY 1997 - APR. 1998

NO. OF MAGNETS: 24









15 DEGREE DIPOLES FOR 2A

WEIGHT: 5000 KG.

LENGTH: 1.14 m.

POLE GAP: 10 cm.

MAX. I: 600 amps

MAX. V: 45 volts

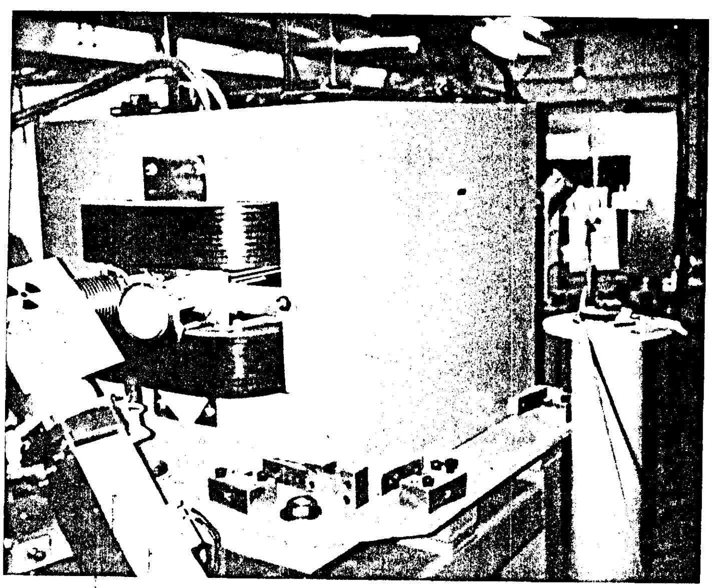
MAX. B: 1.14 T.

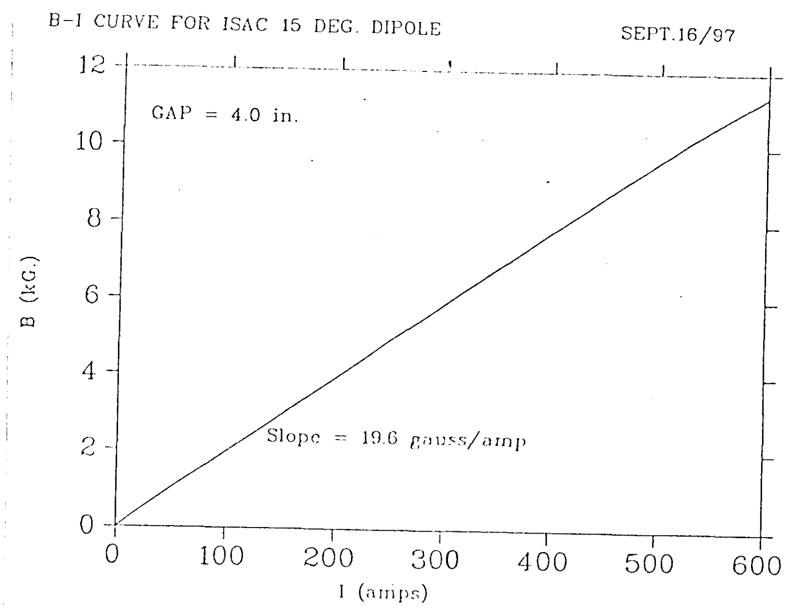
EFFECTIVE LENGTH: 94 cm.

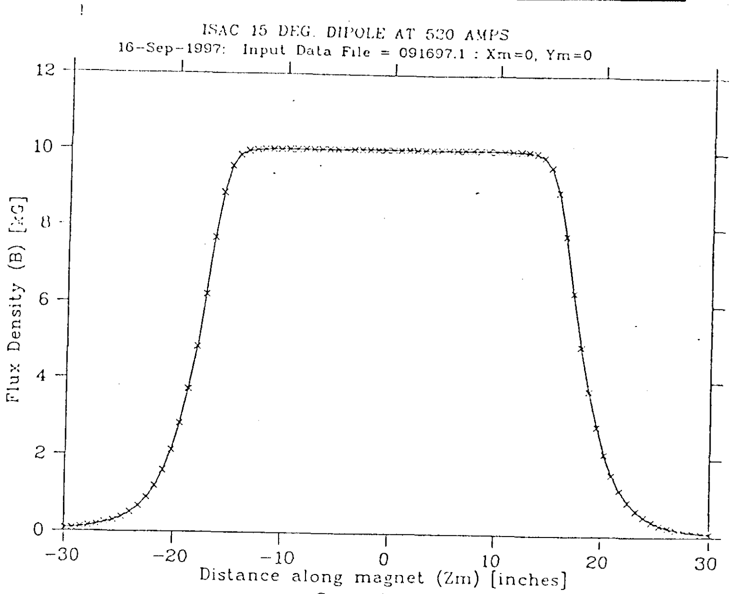
MANUFACTURER (STEEL): Sunrise Machine Works (Vancouver)
(COILS): Stangenes Industries (California)

DATE MEASURED: Sept. 97

NO. OF MAGNETS: 2







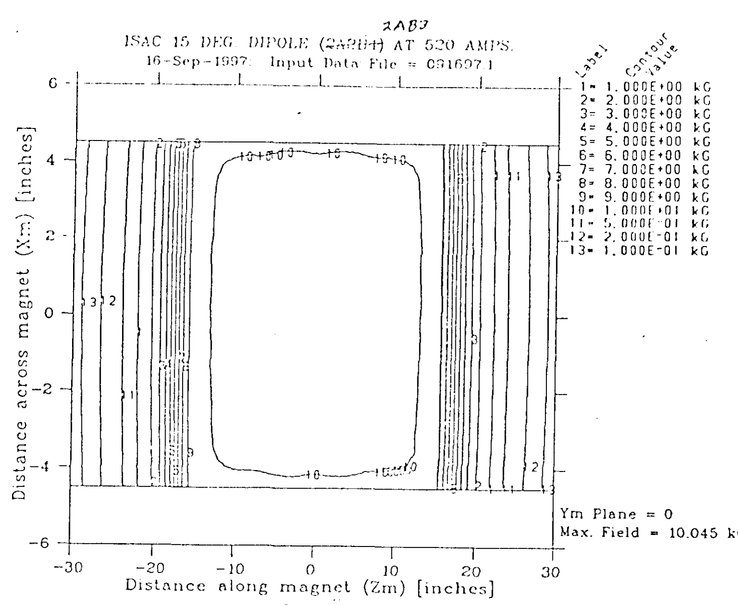
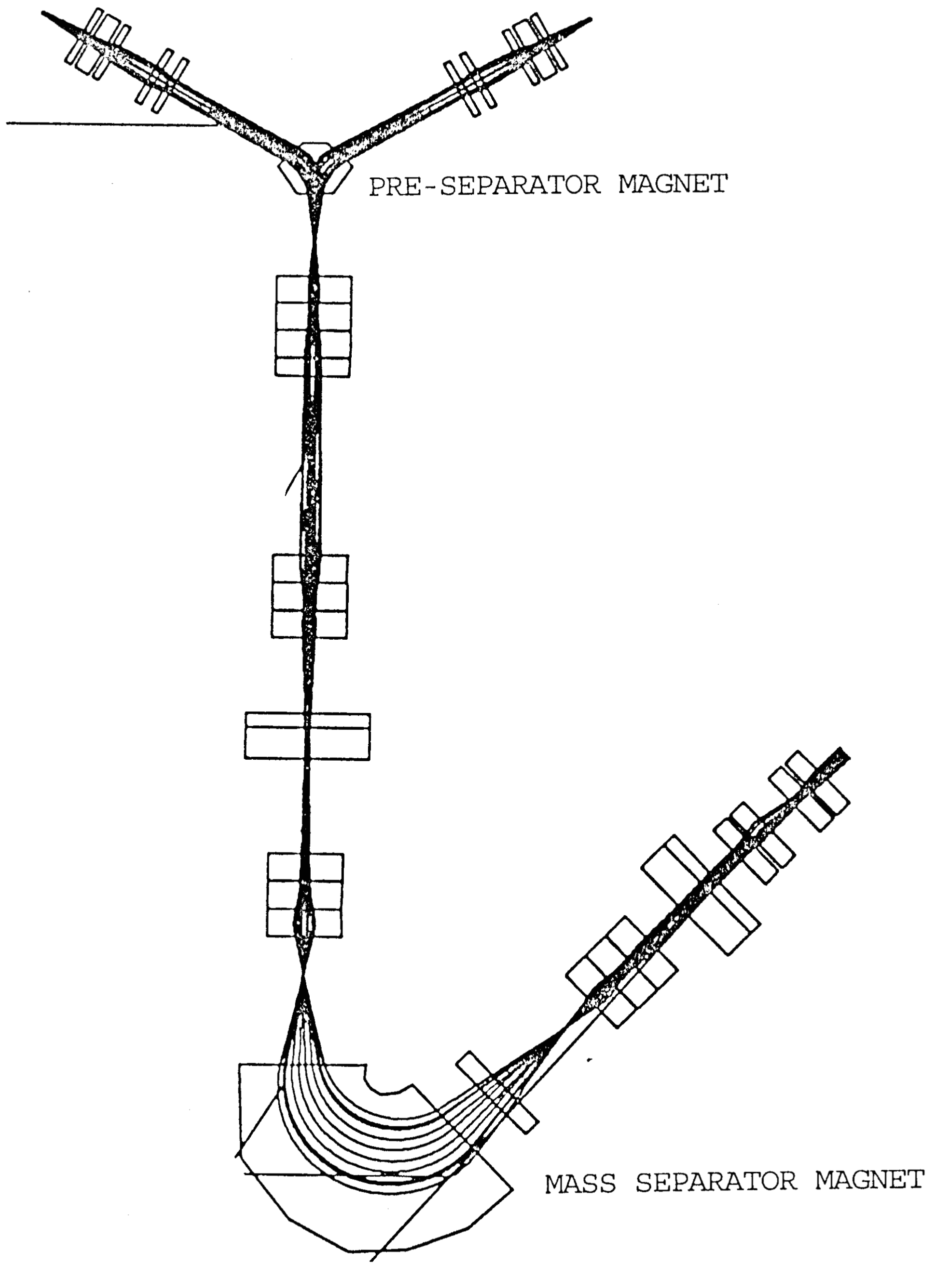
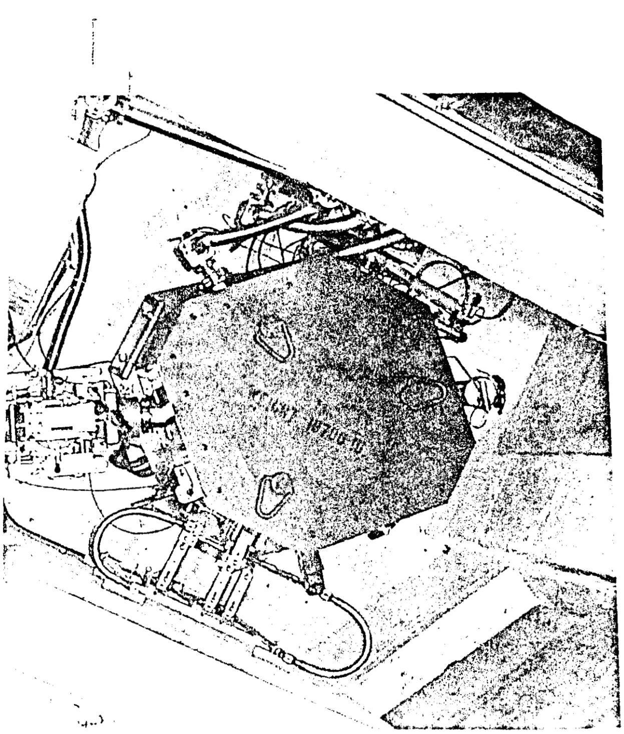
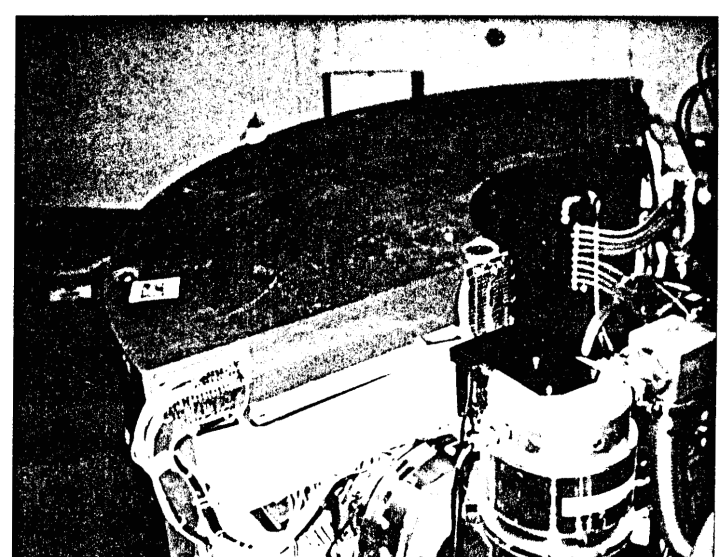


fig. 10 ISAC SEPARATOR SECTION







PRE-SEPARATOR DIPOLE

WEIGHT: 5000 KG.

LENGTH: 1.2 m.

POLE GAP: 7.0 cm.

MAX. I: 500 amps

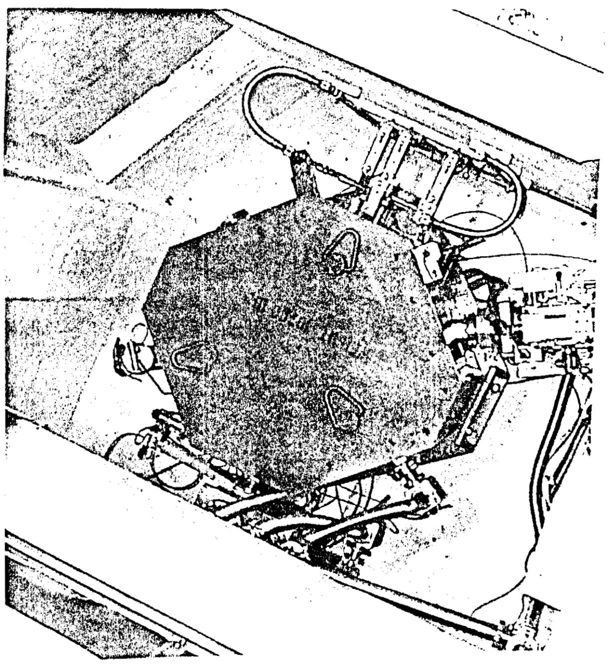
MAX. I: 27.4 volts

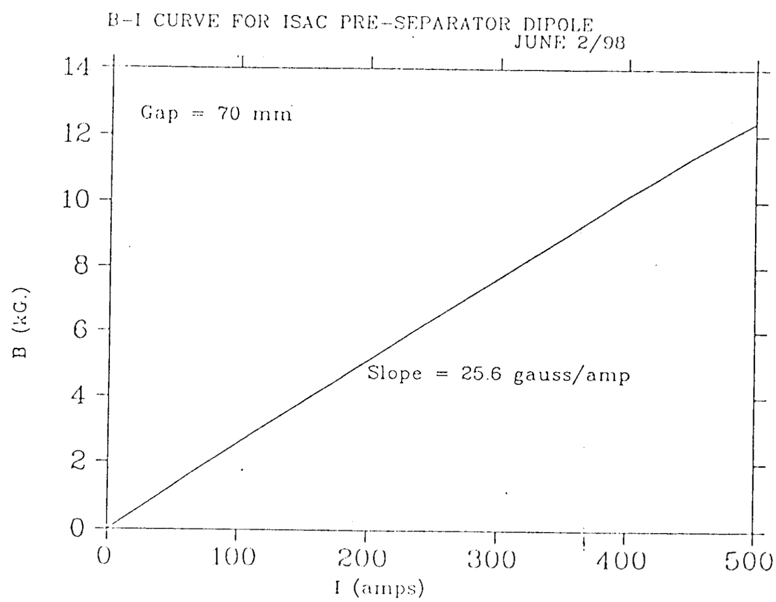
MAX. B: 1.24 T.

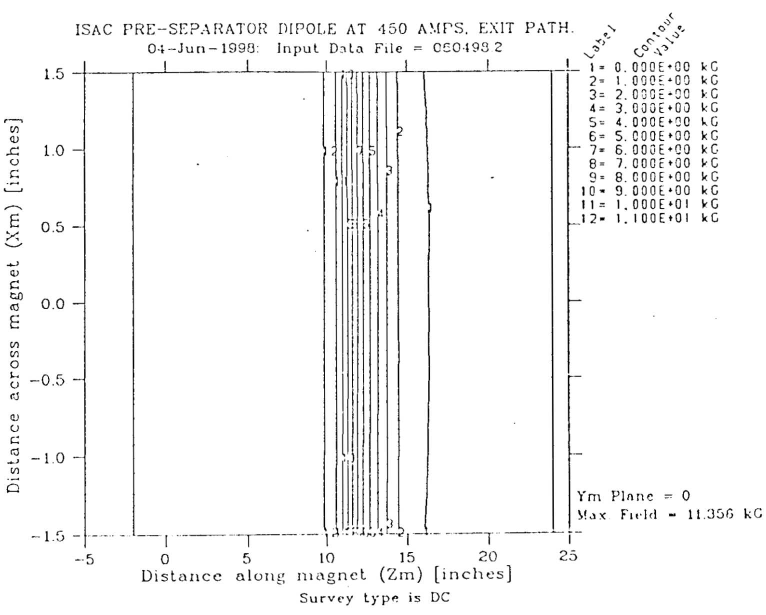
MANUFACTURER (STEEL): SUNRISE MACHINE WORKS (VANCOUVER)
(COILS): STANGENES (CALIFORNIA)

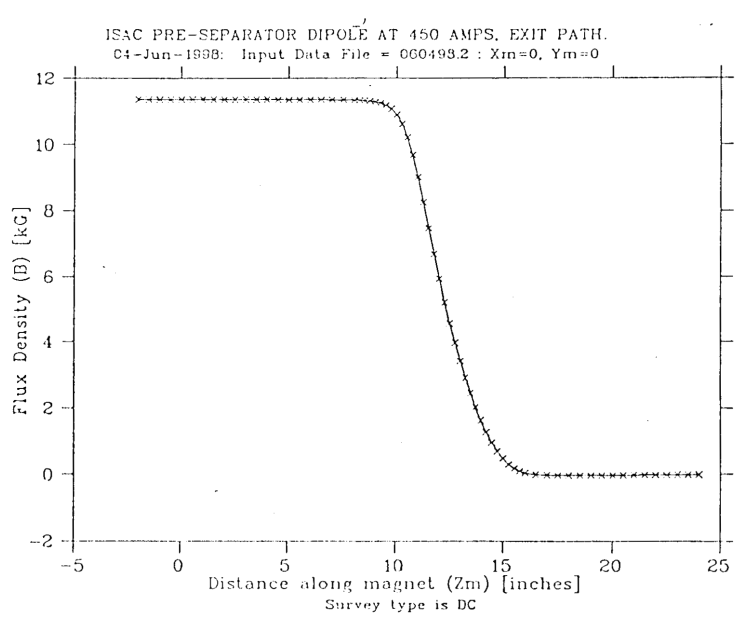
DATE MEASURED: JUNE 1998

NO. OF MAGNETS: 1









ISAC MASS SEPARATOR MAGNET (135 Degrees)

WEIGHT: 7500 KG.

LENGTH: 2.8 m.

POLE GAP: 6.35 cm.

MAX. I: 350 amps

MAX. V: 27.4 volts

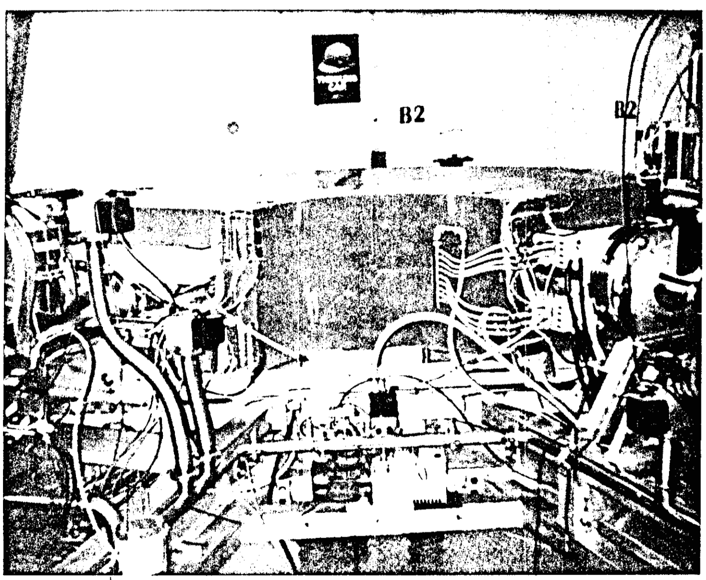
MAX. B: .62 T.

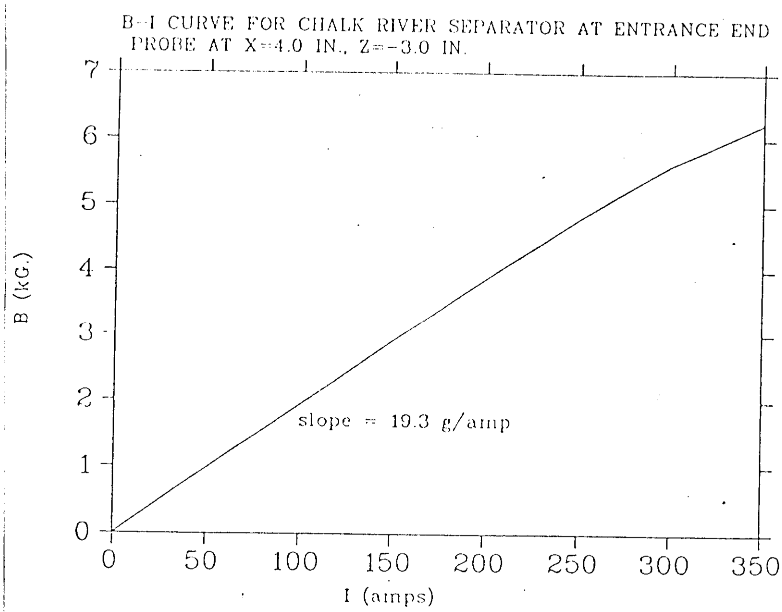
SOURCE: CHALK RIVER LAB., CANADA

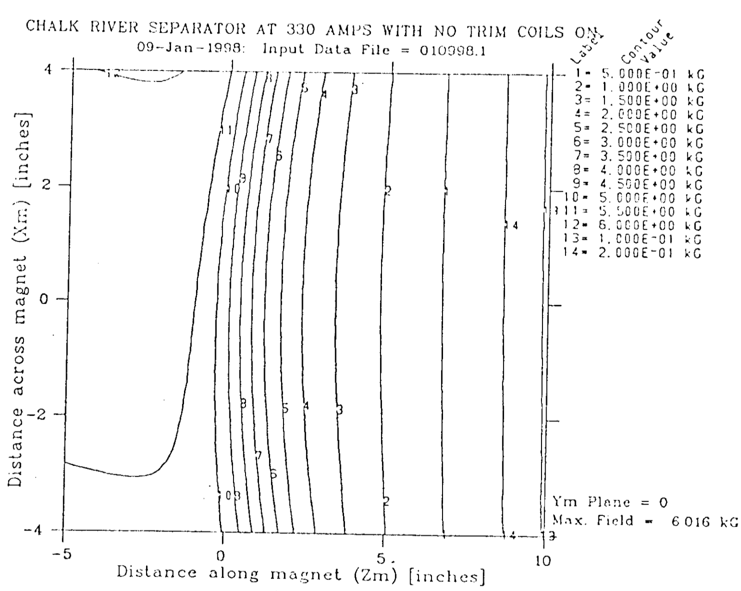
DATE MEASURED: JAN. - MAR., 1998

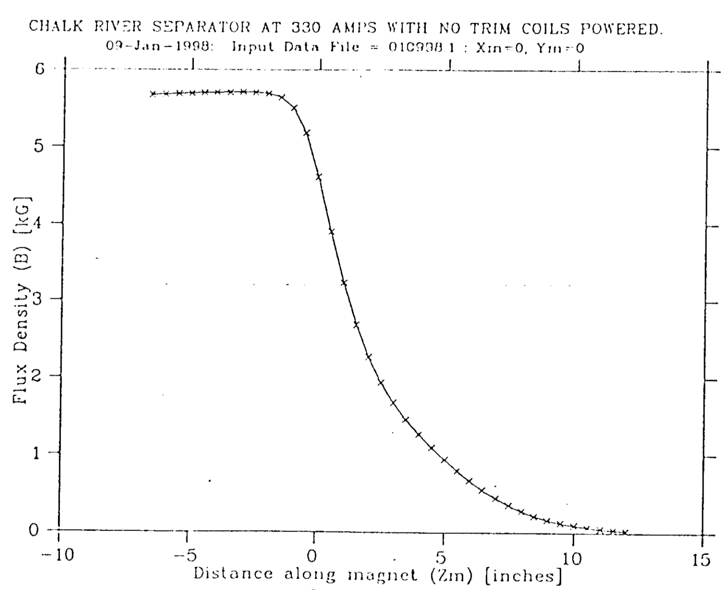
NO. OF MAGNETS: 1

(EQUIPPED WITH ALPHA AND BETA TRIM COIL PLATES.)









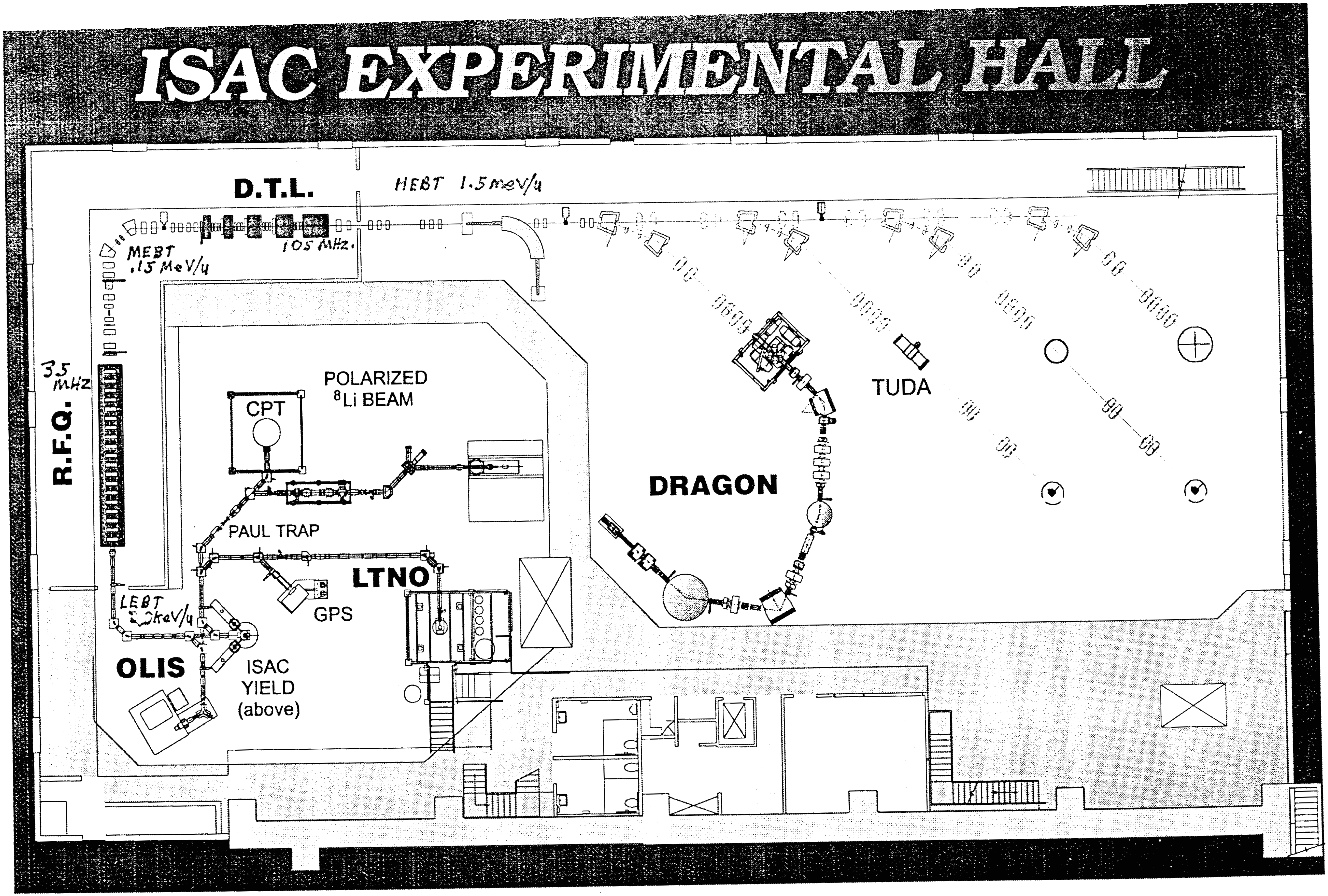

ISAC EXPERIMENTAL HALL
D.T.L.
HEBT 1.5 meV/u
105 MHz.
MEBT
.15 MeV/u
35 MHz
R.F.Q.
POLARIZED
8Li BEAM
CPT
PAUL TRAP
LTNO
GPS
LEBT
OLIS
ISAC
YIELD
(above)
DRAGON
TUDA

fig. 11

ISAC MEBT QUADRUPOLES

WEIGHT: 282 KG.

YOKE LENGTH: 18 cm.

BORE: 5.20 cm.

MAX. I: 100 amps

MAX. V: 30 volts

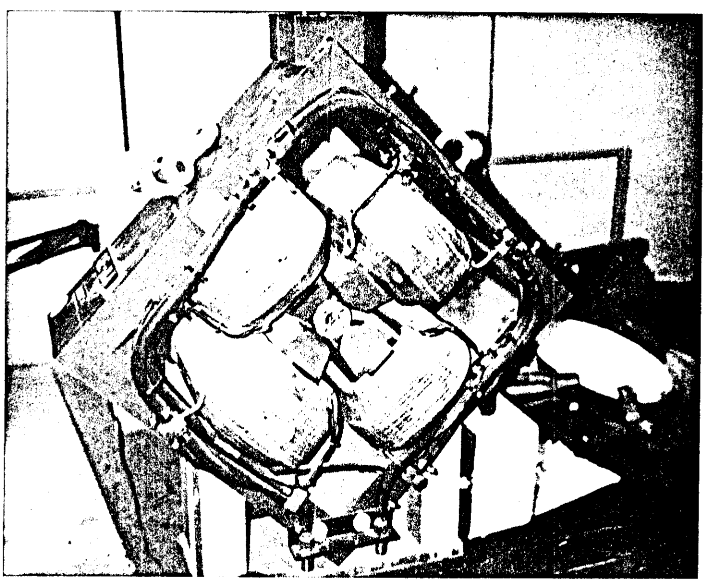
MAX. POLE TIP B: .77 T.

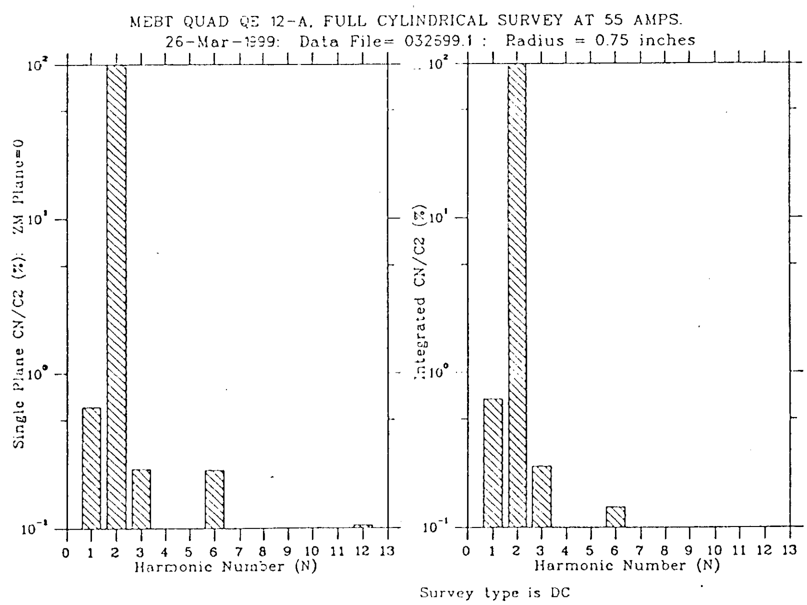
EFFECTIVE LENGTH: 18.2 cm.

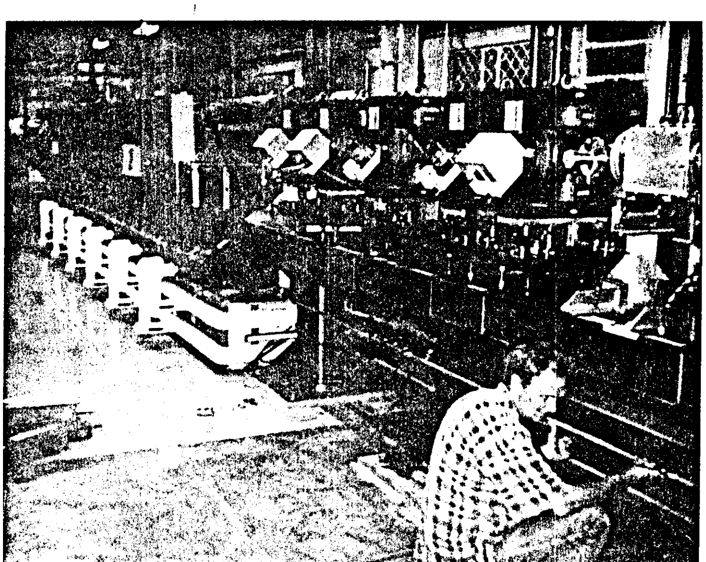
MANUFACTURER: DANFYSIK QUADS. FROM CHALK RIVER LAB, CANADA

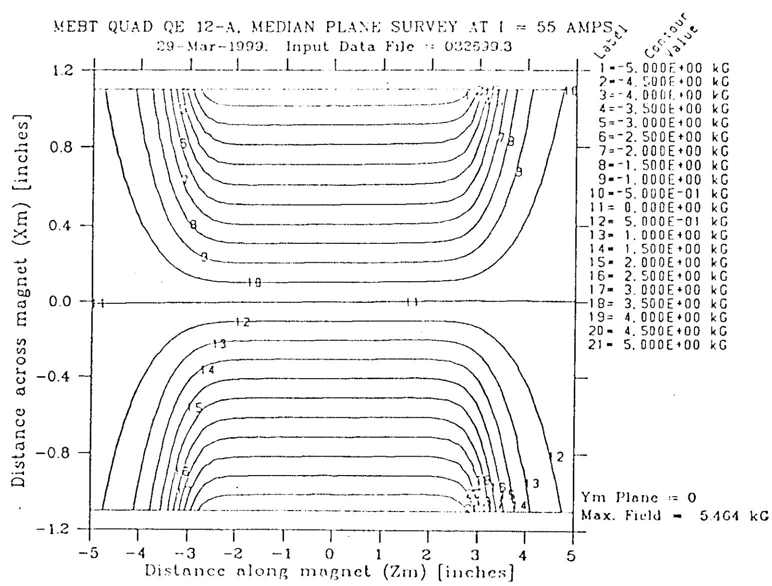
DATE MEASURED: MAR. - APR., 1999

NO. OF MAGNETS: 13









MEDIUM ENERGY BEAM TRANSPORT (MEBT) DIPOLES

WEIGHT: 1100 KG.

LENGTH: 43 cm.

POLE GAP: 5.7 cm.

MAX. I: 710 amps

MAX. V: 17 volts

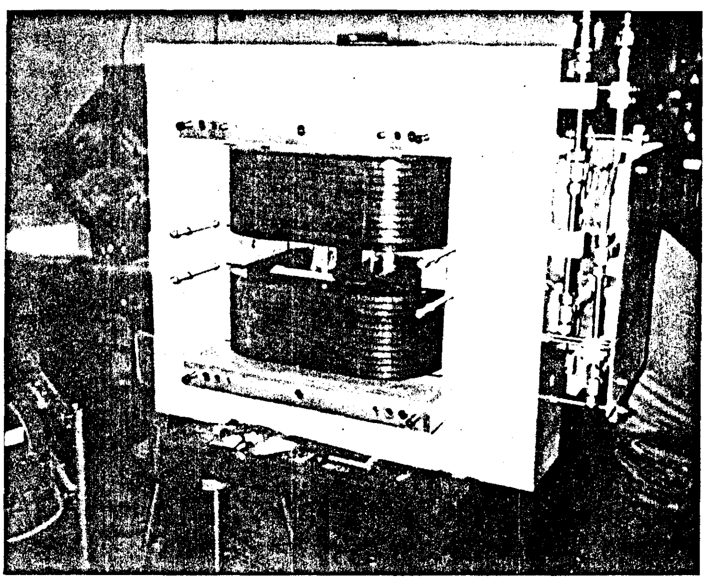
MAX. B: 1.30 T.

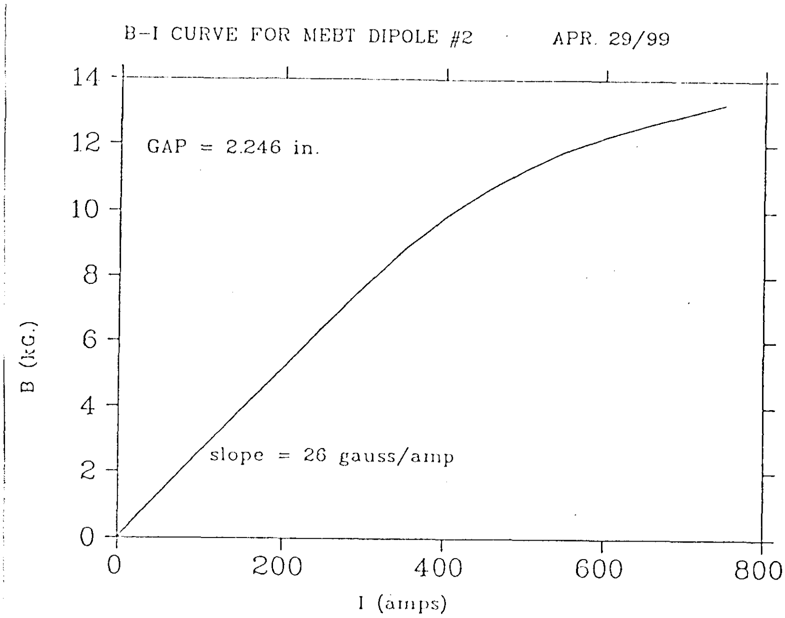
EFFECTIVE LENGTH: 23.1 cm.

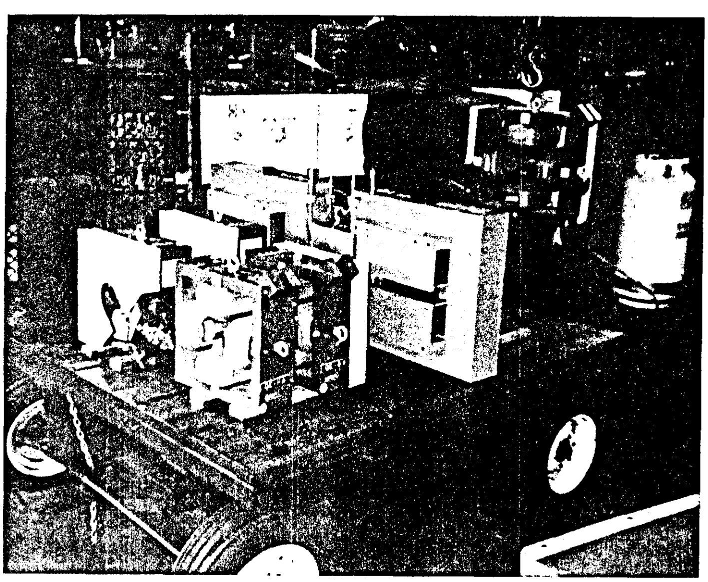
MANUFACTURER (STEEL): Talvan Machine Co. (Vancouver).
(COILS): Stangenes Industries (California).

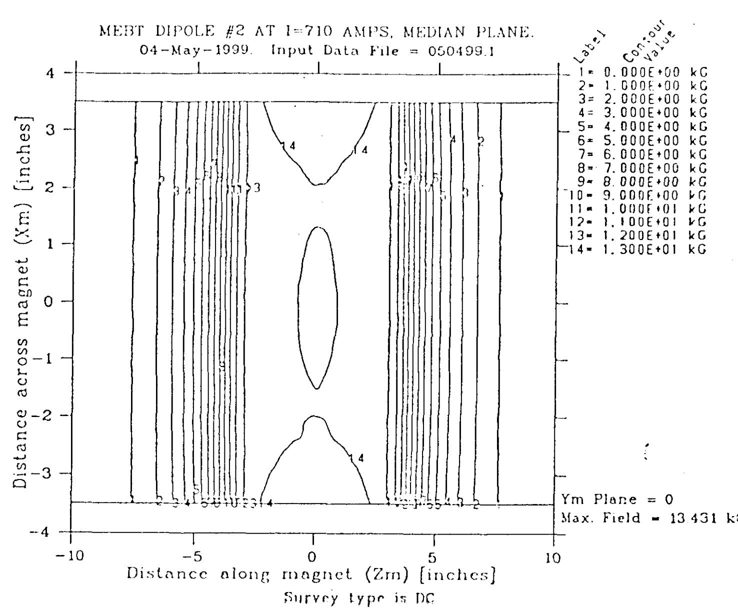
DATE MEASURED: May, 1999

NO. OF MAGNETS: 2









PRAGUE 90 DEGREE DIPOLE

WEIGHT: 4550 KG.

LENGTH: 2.9m.

POLE GAP: 5.1 cm.

MAX. I: 150 amps

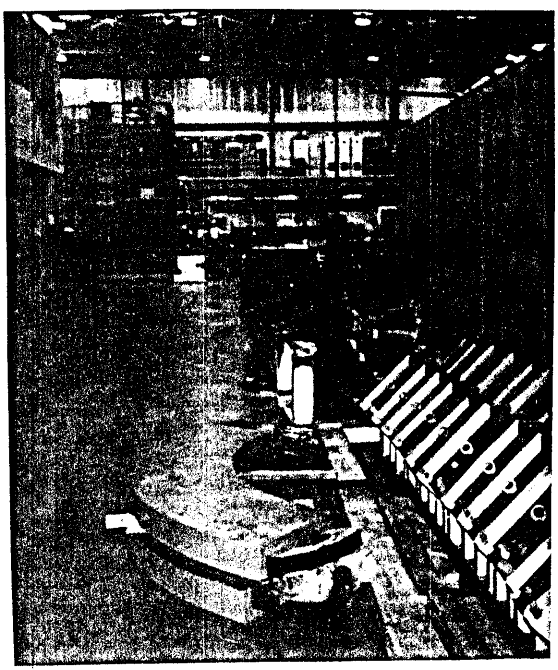
MAX. V: 55 volts

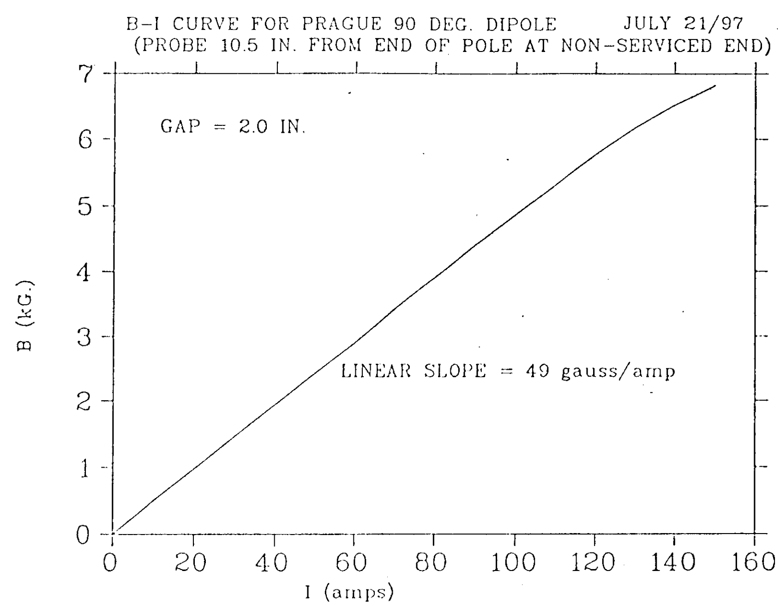
MAX. B: .68 T.

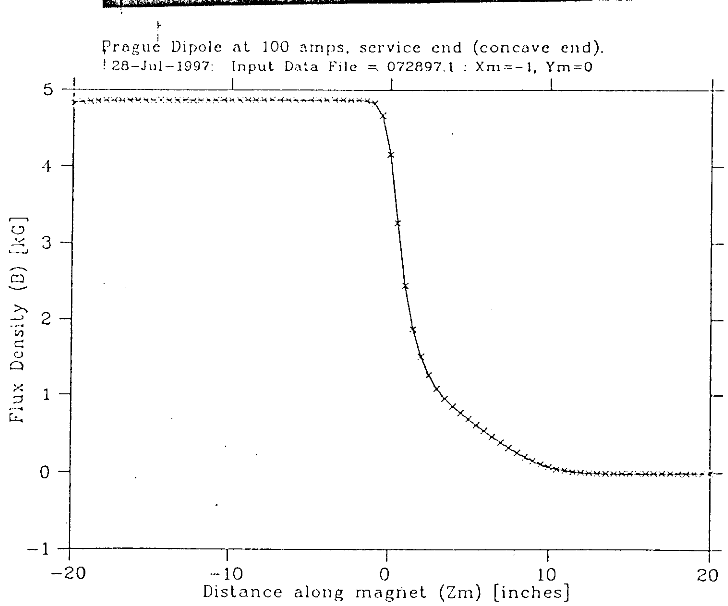
SOURCE: NUCLEAR INSTITUE (PRAGUE)

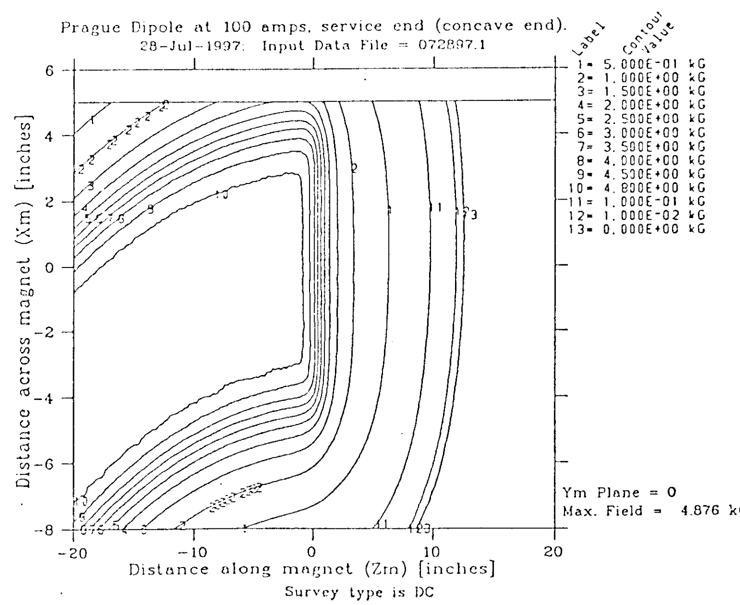
DATE MEASURED: JULY 1997

NO. OF MAGNETS: 1

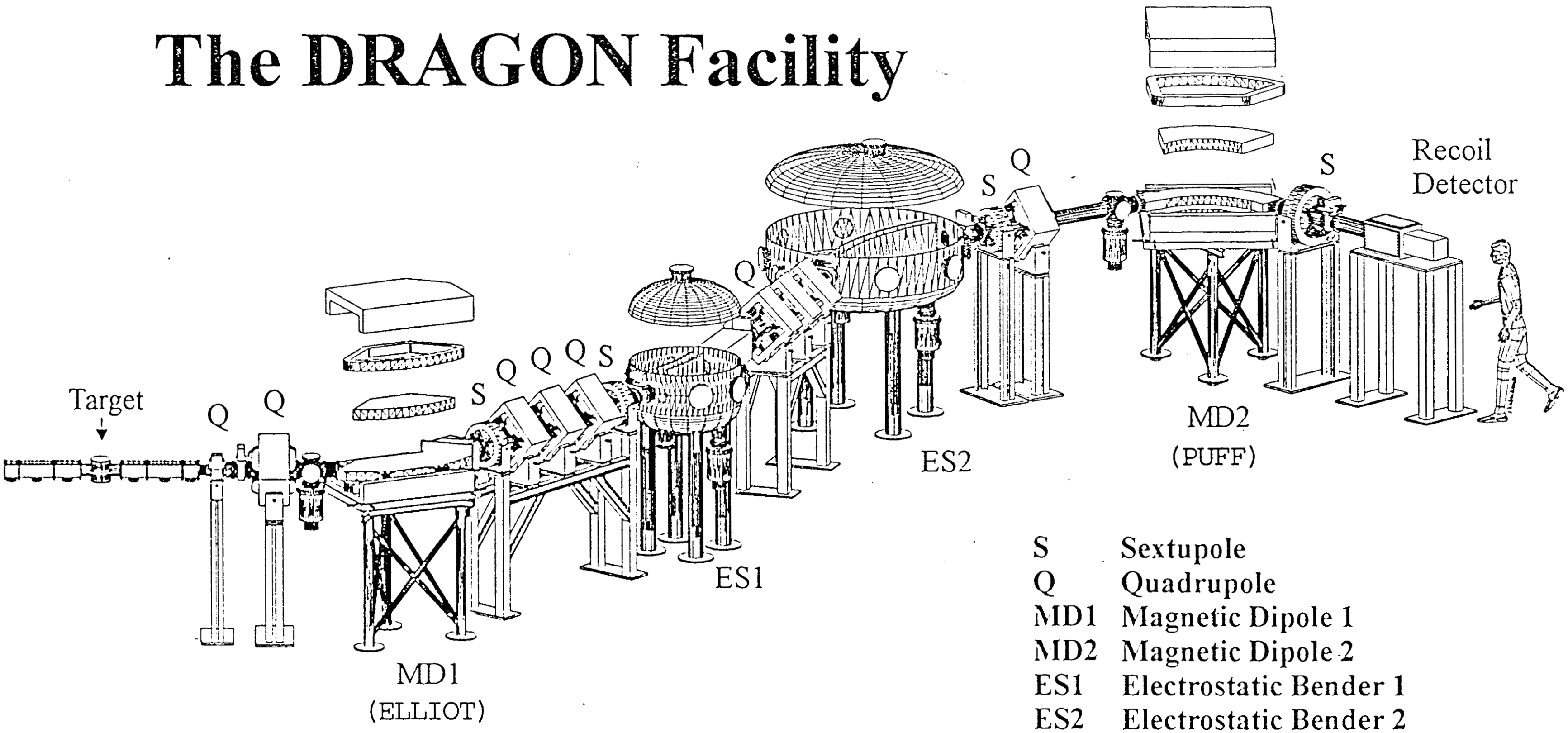








The DRAGON Facility



The "DRAGON" (Detector for Recoils And Gammas Of Nuclear reactions) facility in the ISAC complex will be installed in the high-energy area. The target at the far left will contain hydrogen or helium gas, and will be bombarded with a beam of the newly created, accelerated, radioactive isotopes. Some of these radioactive ions will interact with the target atoms. Unchanged isotopes plus any reaction products will move forward into the DRAGON detector. Here the magnetic dipoles and electrostatic benders will separate the particular product of interest from the much larger number of ions still present from the original beam.

fig. 12

DRAGON MD1DIPOLE ("ELLIOT")

WEIGHT: 3100 KG.

LENGTH: 1.09 m.

POLE GAP: 10 cm.

MAX. I: 500 amps

MAX. V: 29 volts

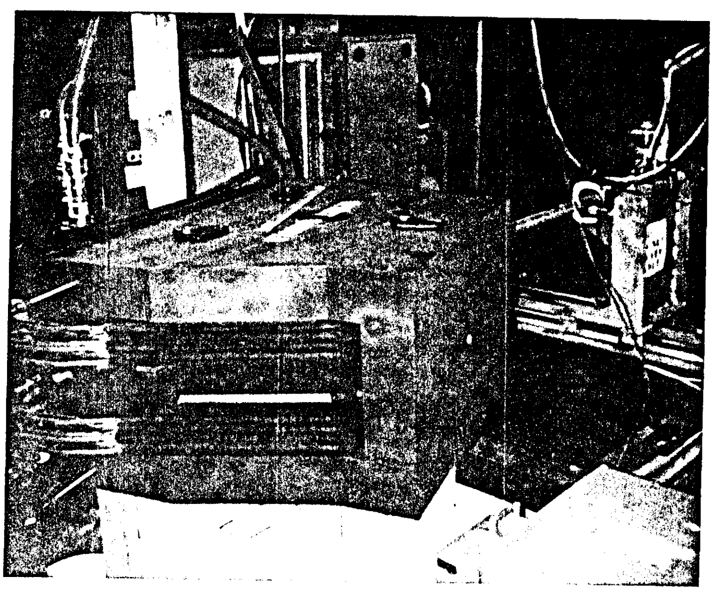
MAX. B: .59 T.

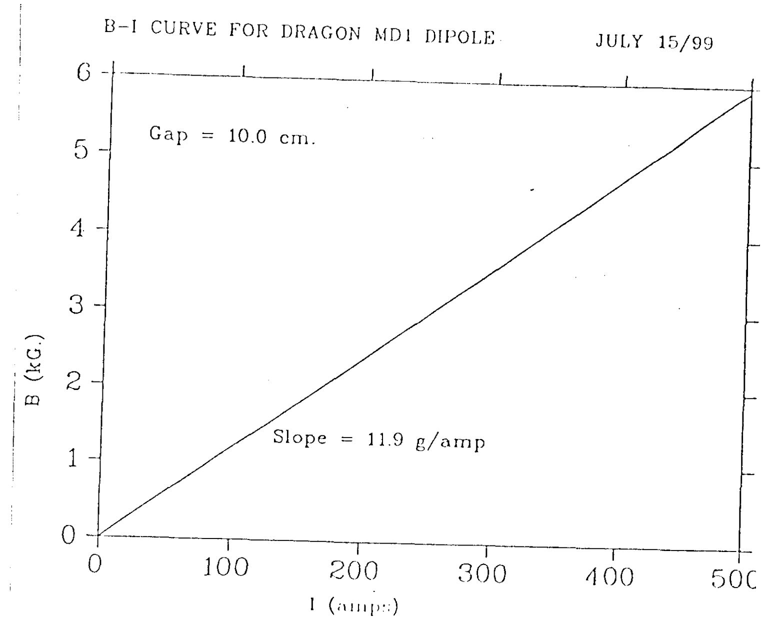
EFFECTIVE LENGTH: 87 cm.

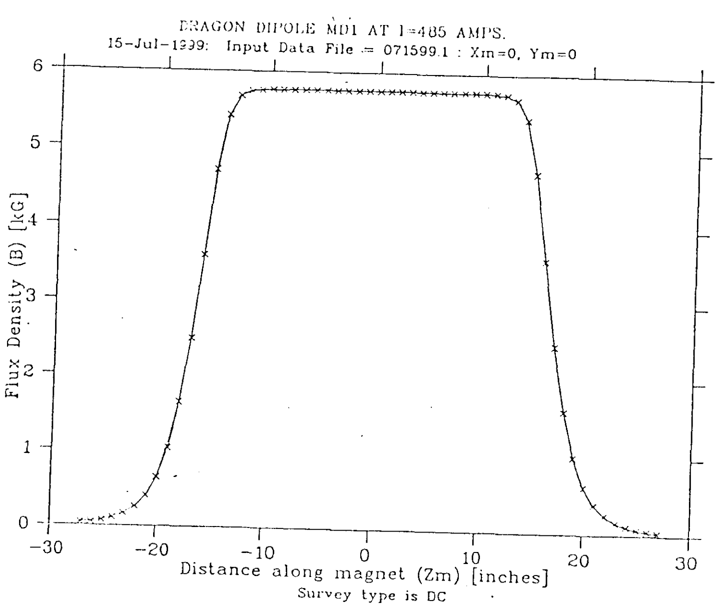
MANUFACTURER (STEEL): Sunrise Machine Works (Vancouver).
(COILS): Stangenes Industries (California).

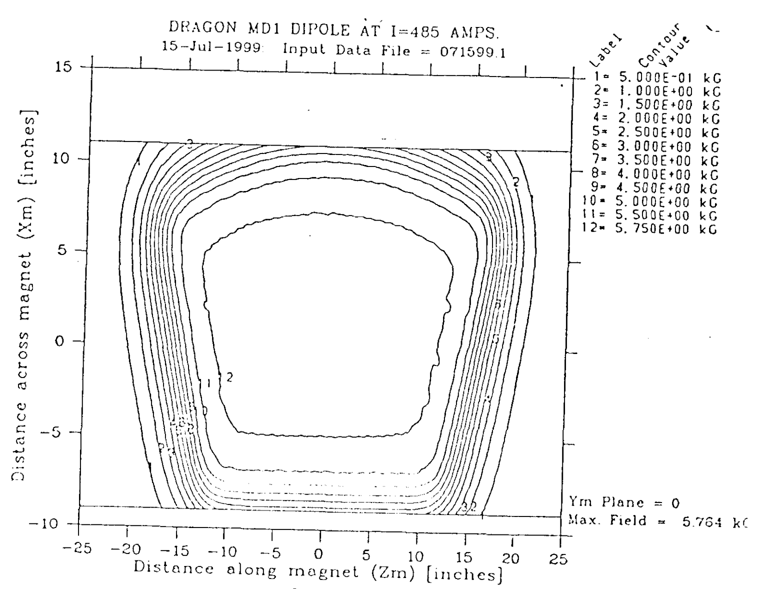
DATE MEASURED: July 1999

NO. OF MAGNETS: 1









DRAGON MD2 DIPOLE ("PUFF")

WEIGHT: 6400 KG.

LENGTH: 1.17m.

POLE GAP: 12 cm.

MAX. I: 500 amps

MAX. V: 58 volts

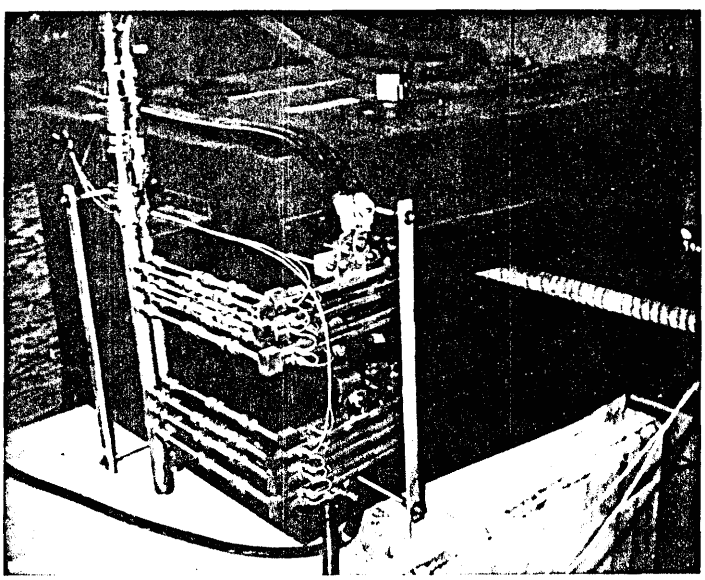
MAX. B: .825 T.

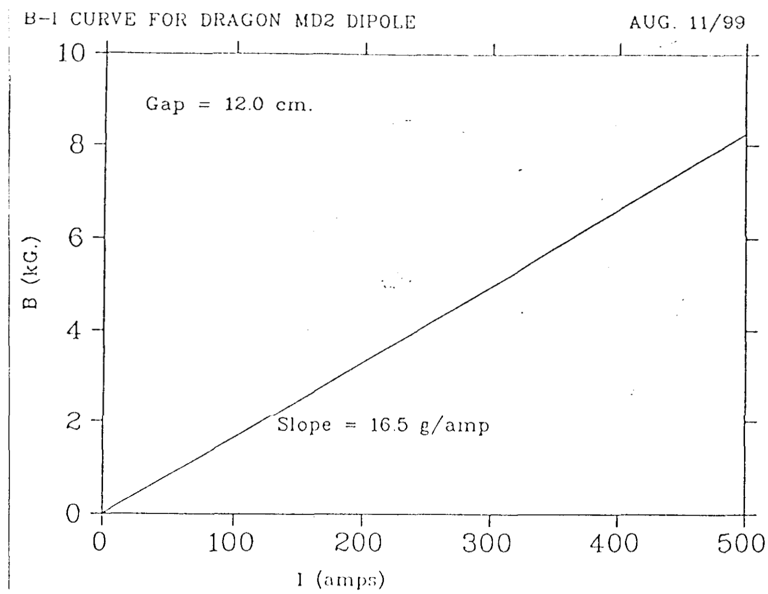
EFFECTIVE LENGTH: 104 cm.

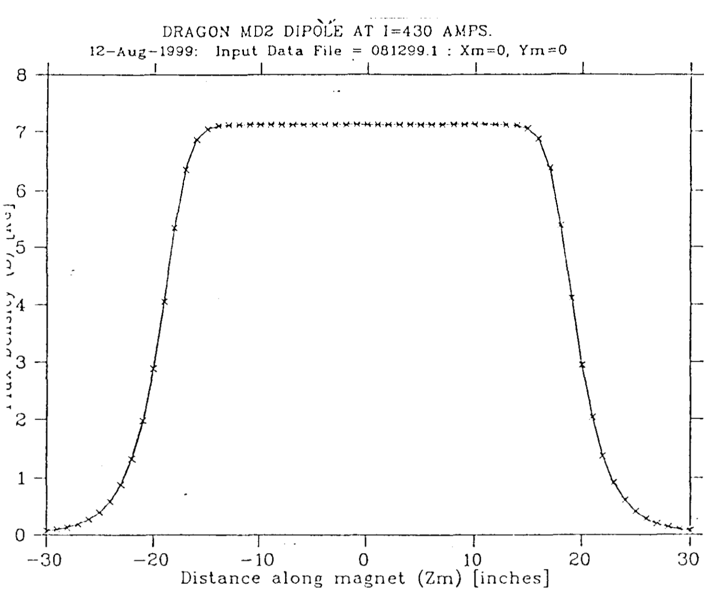
MANUFACTURER (STEEL): Sunrise Machine Works (Vancouver).
(COILS): Stangenes Industries (California).

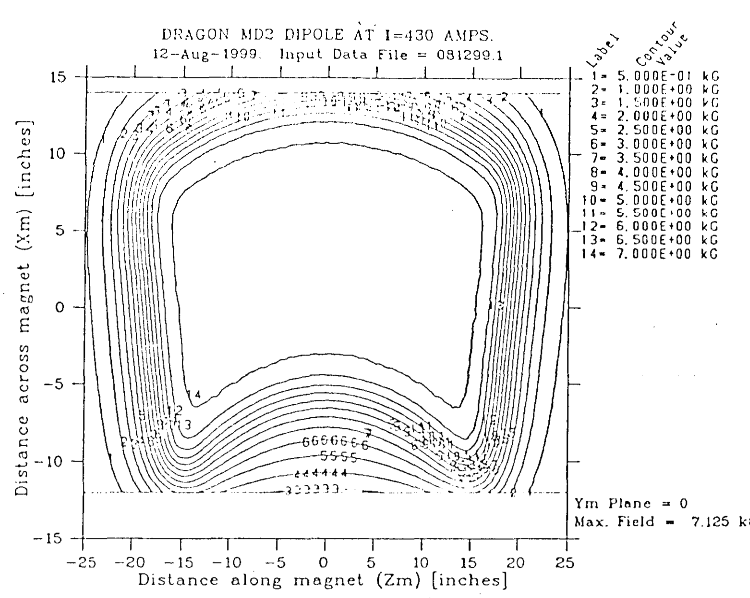
DATE MEASURED: Aug. - Sept., 1999

NO. OF MAGNETS: 1









DRAGON QUADRUPOLES (SMIT-ELMA)

WEIGHT: 545 KG.

YOKE LENGTH: 40 cm.

BORE: 15 cm.

MAX. I: 250 amps

MAX. V: 39 volts

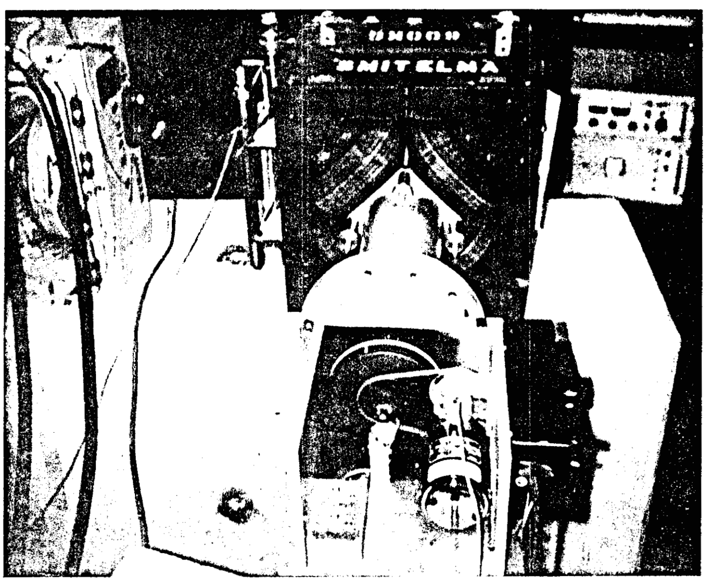
MAX. POLE TIP B: .47 T.

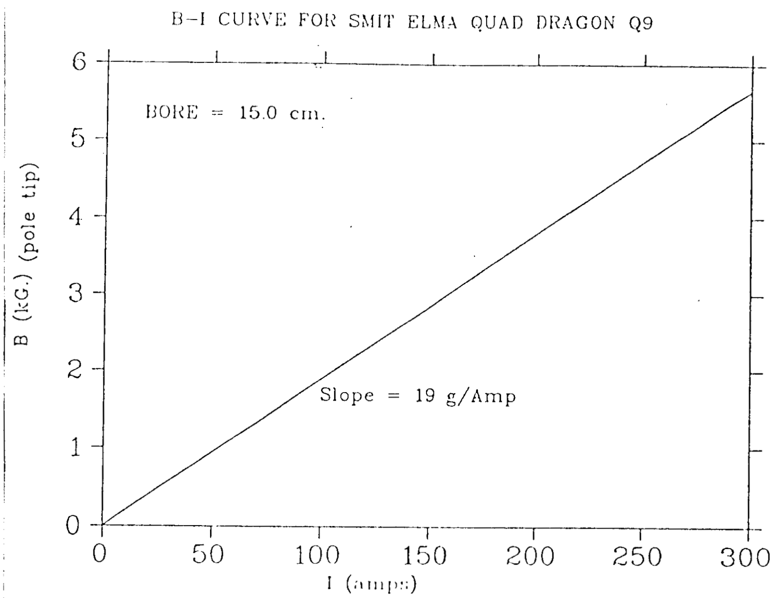
EFFECTIVE LENGTH: 46.7 cm.

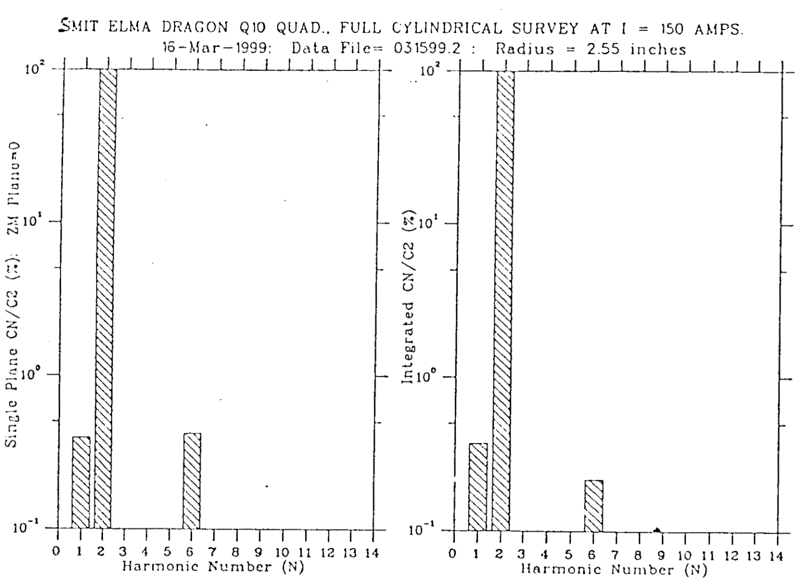
MANUFACTURER (STEEL): RECYCLED STEEL ASSEMBLIES FROM CERN (SMIT)
(COILS): STANGENES (ELMA)

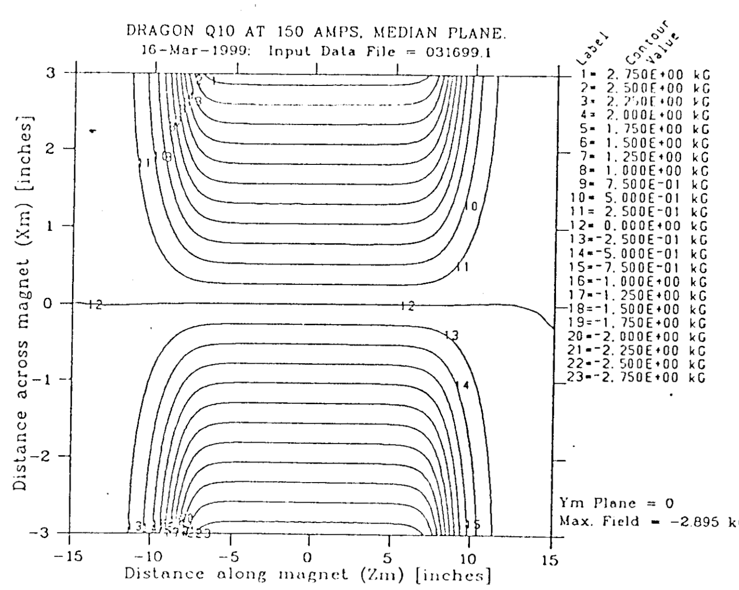
DATE MEASURED: FEB. - MAR., 1999

NO. OF MAGNETS: 2









DRAGON SEXTUPOLES

WEIGHT: 318 KG.

YOKE LENGTH: 15 cm.

BORE: 16 cm.

MAX. I: 80 amps

MAX. V: 13 volts

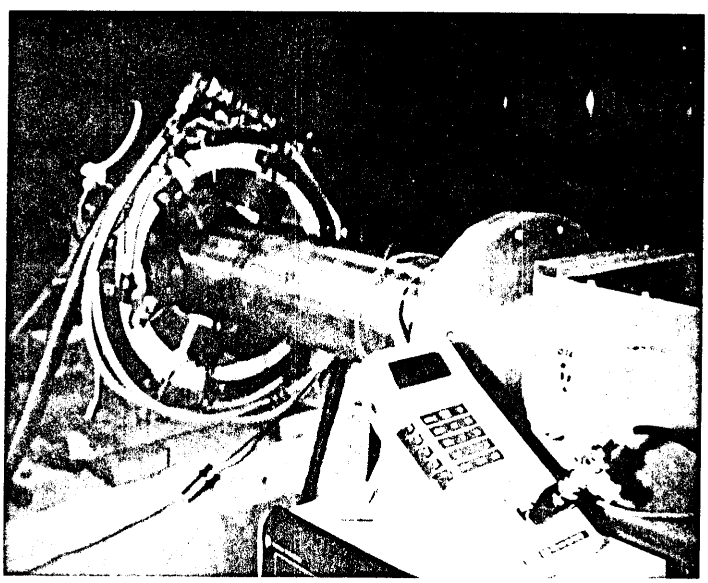
MAX. POLE TIP B: .146 T.

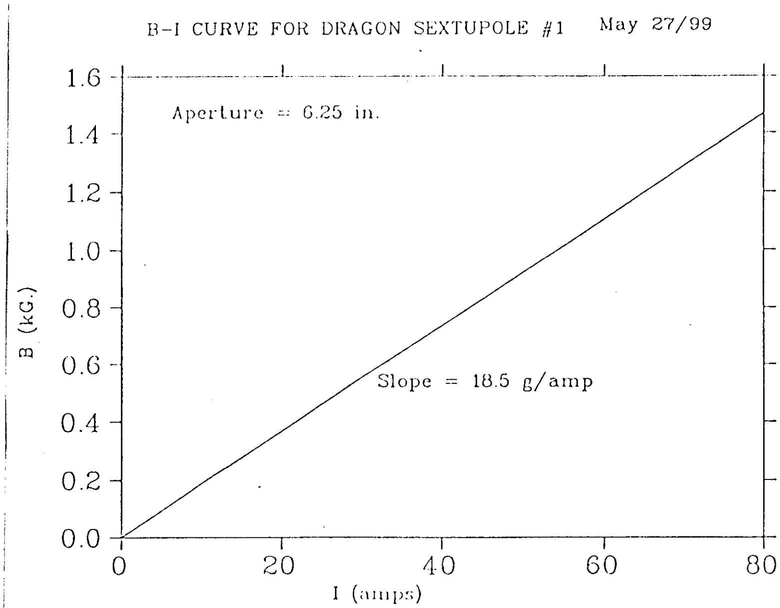
EFFECTIVE LENGTH: 18.5 cm.

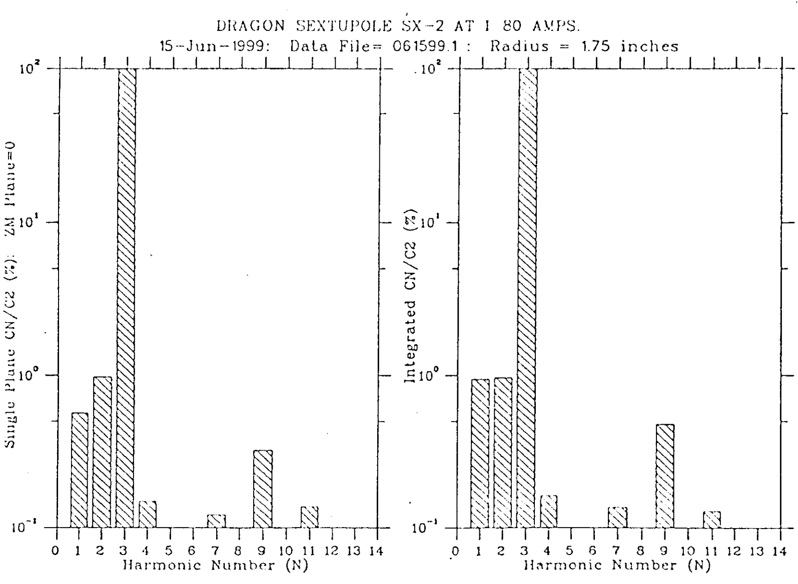
MANUFACTURER (STEEL): DECADE MACHINING (VANCOUVER)
(COILS): BEST COIL CO. (VANCOUVER)

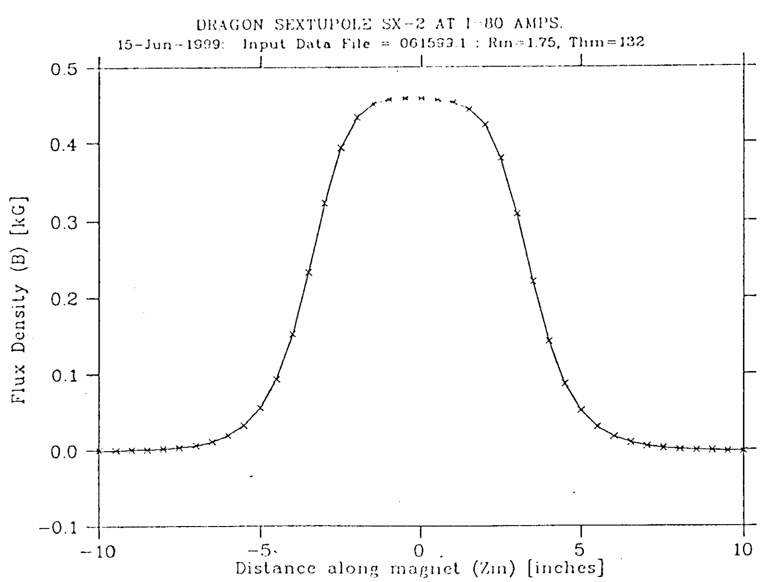
DATE MEASURED: MAY - JUNE, 1999

NO. OF MAGNETS: 4









ISAC II 2005

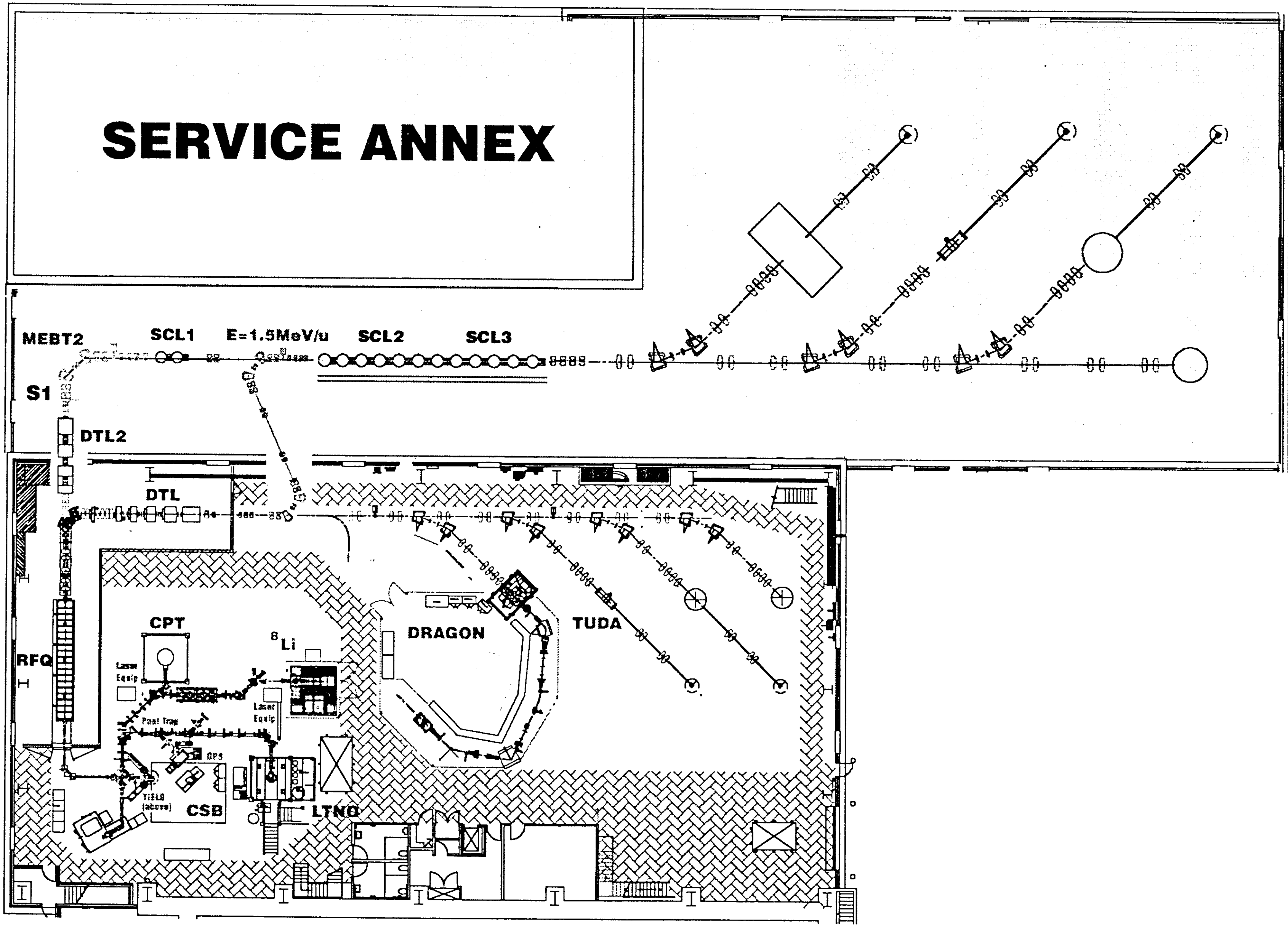


fig. 13

Magnetic Measurements

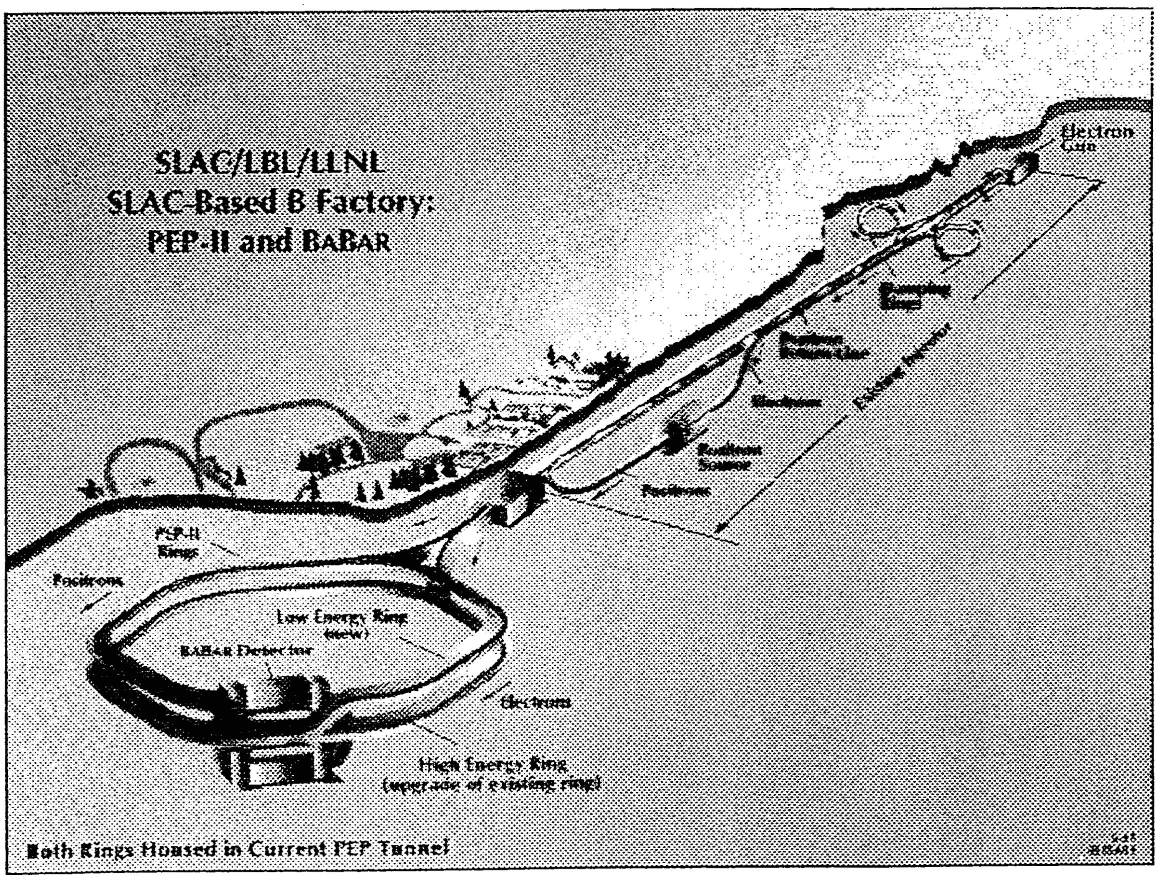
For The

PEP II Interaction Region

Permanent Magnets

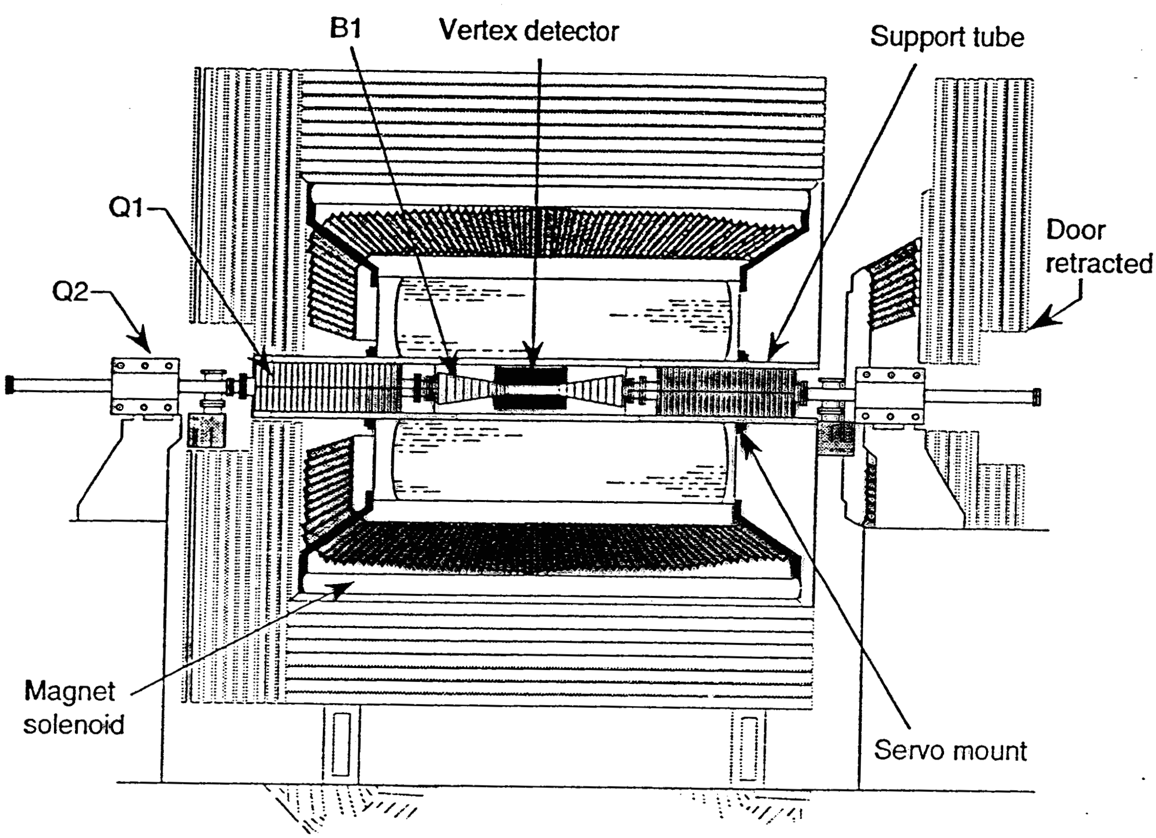
Zack Wolf
IMMW XI

PEP II

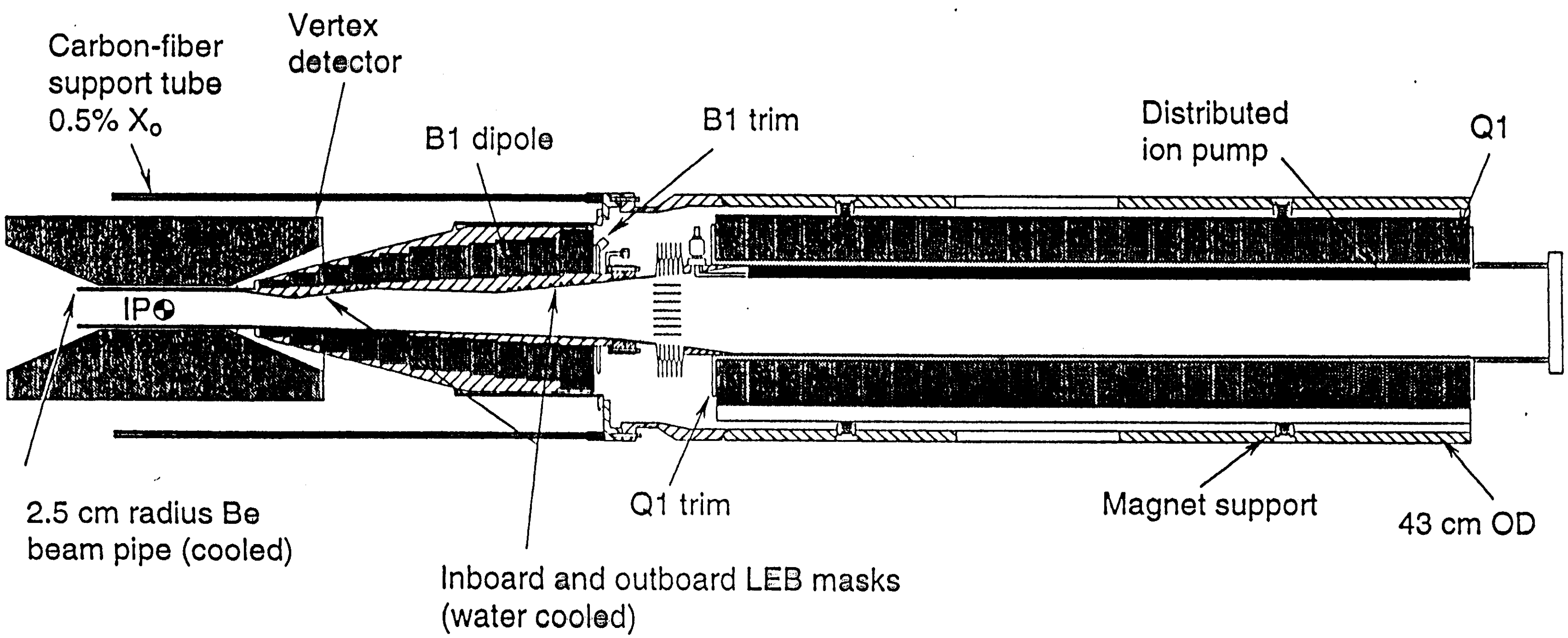


PEPII has one interaction region.

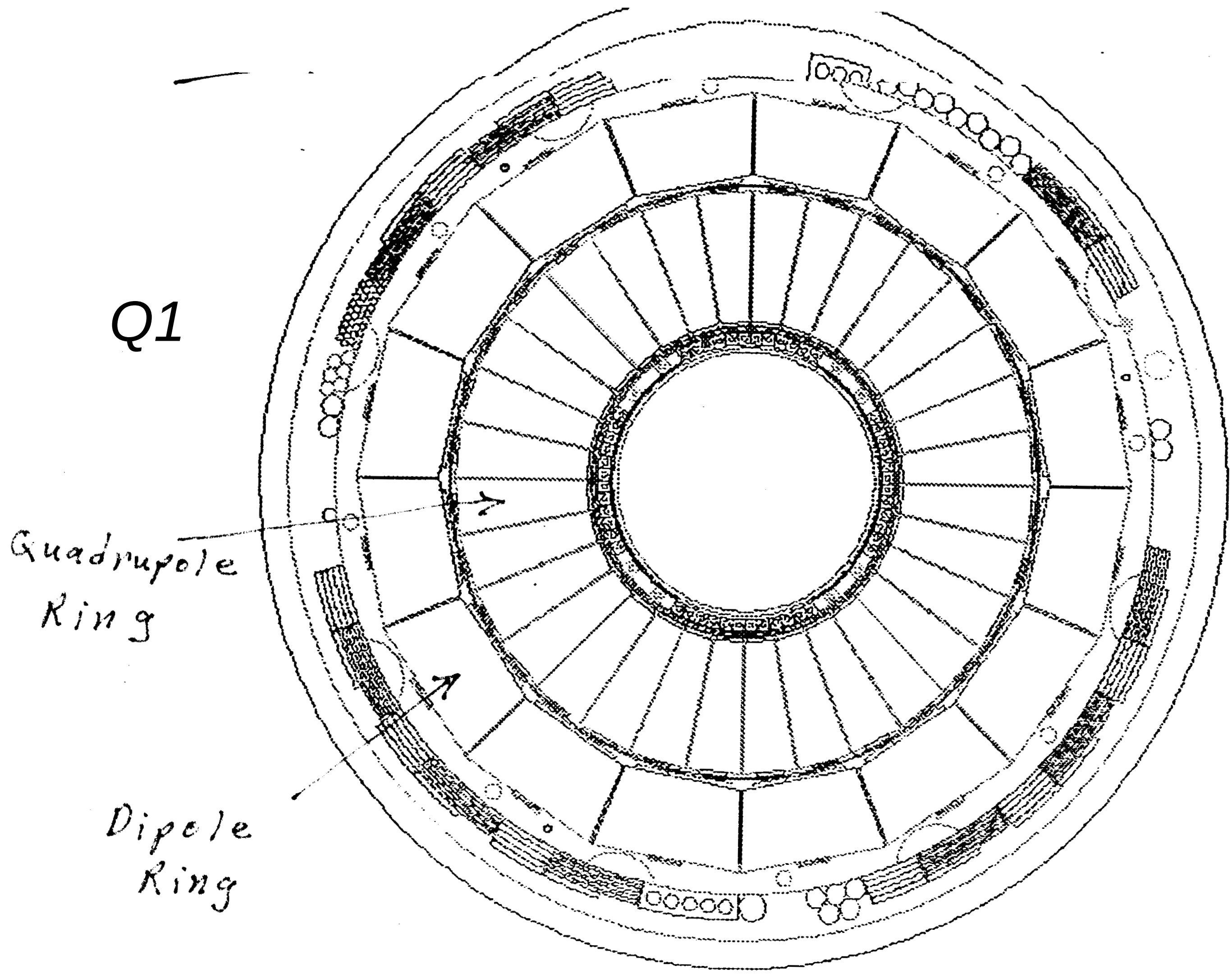
PEP II Interaction Region
Permanent Magnets
Q1, B1 left and right



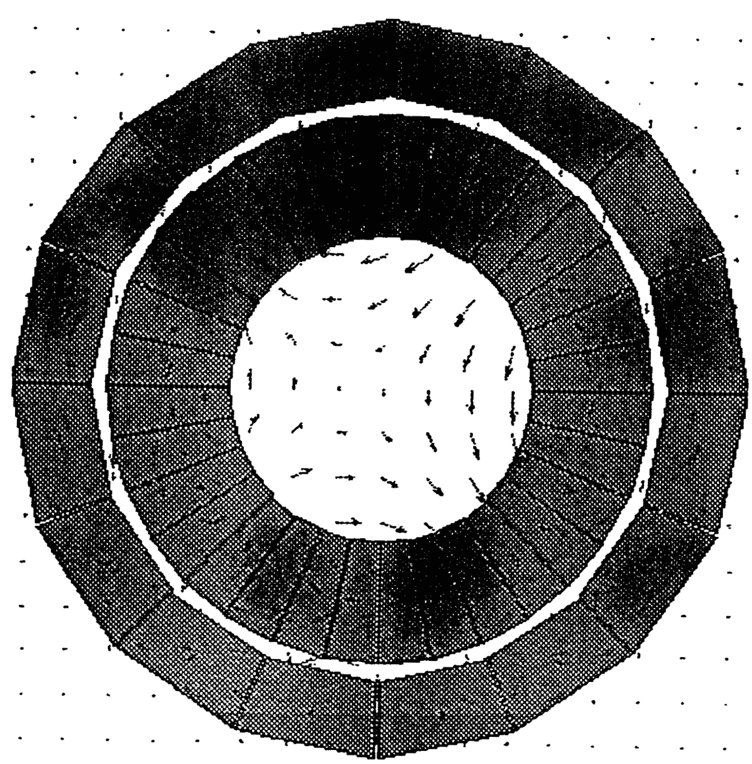
PEP II IR Magnets Cross Section



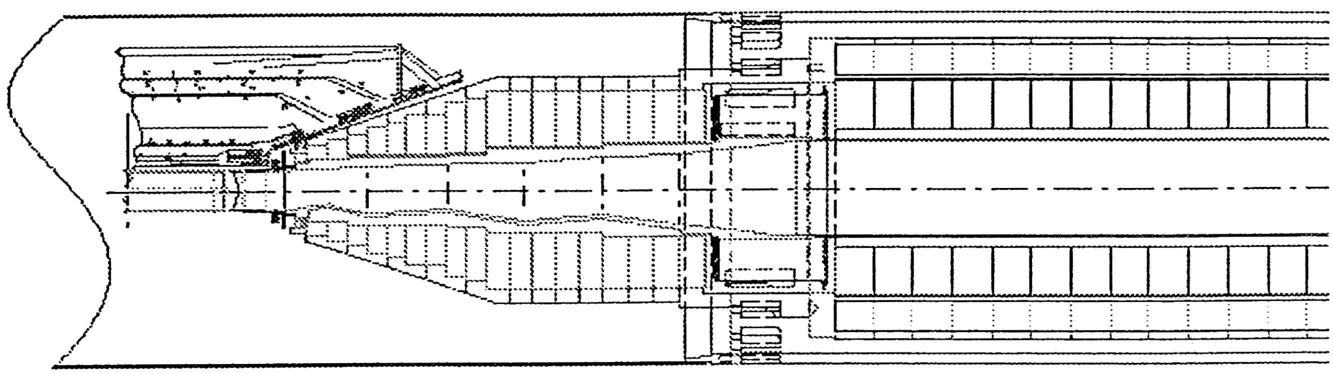
Q1

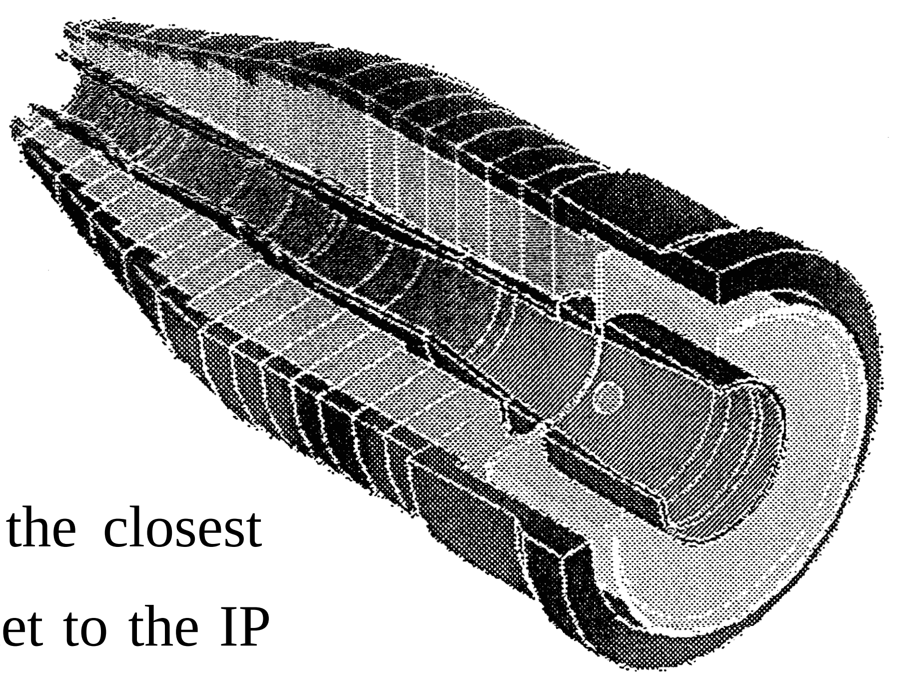


Q1 Field Pattern



B1





B1 is the closest magnet to the IP

Overview Of The Measurements

1) Measure the magnetic moment (m_x, m_y, m_z) for each permanent magnet block. *(Helmholtz coil)*

2) Measure the field quality of each magnet slice. Tune the slices. *(Vertical bucking coil)*

3) Measure the strength of the assembled magnet. *(Stretched wire)*

4) Measure the field quality of the assembled magnet. *(Bucking coil)*

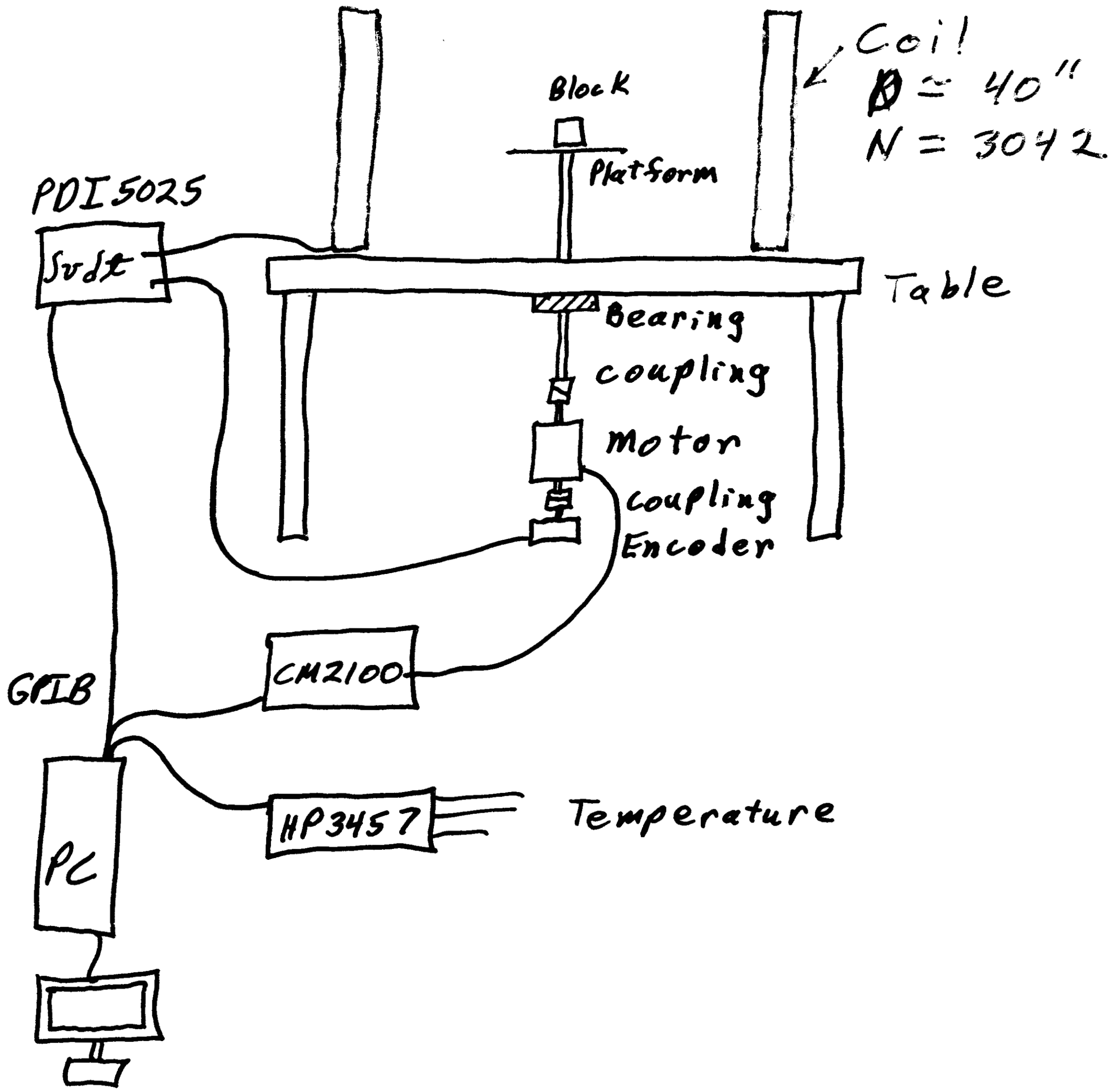
5) Fiducialize the assembled magnet. *(Stretched wire, bucking coil, rotate magnet end-for-end, alignment crew)*

6) Measure the strength and field quality of the trim electromagnets. *(Bucking coil)*

7) Measure the strength of the normal and skew fields as a function of rotation angle of the rotatable slices. *(Bucking coil)*

8) Study the effects of the 1.5 T detector solenoid field on the magnet. *(Hall probes, large electromagnet)*

Helmholtz coil

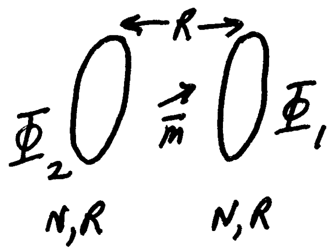


Signal

Treat the block as a magnetic moment.

$$\bar{B}(\bar{x}) = \frac{3\,\bar{m}\cdot\bar{x}\;\bar{x} - \bar{m}\,x^2}{x^5}$$

Find the flux in the Helmholtz coil.



$$\Phi = \Phi_1 + \Phi_2$$
$$= \int_1 \bar{B}\cdot d\bar{S} + \int_2 \bar{B}\cdot d\bar{S}$$
$$= \frac{8}{5\sqrt{5}}\,\frac{N}{R}\,\mu_0\, m_z$$

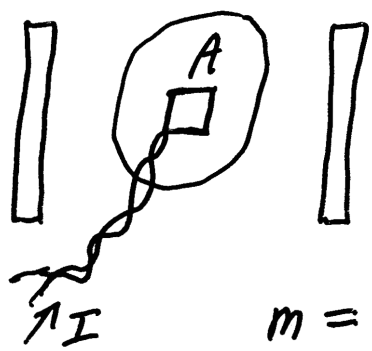
Procedure:

Rotate block
measure $\int v\,dt$ vs θ
FFT
$VT_1 = \frac{8}{5\sqrt{5}}\,\frac{N}{R}\,\mu_0\, m$
gives m
FFT phase give magnetic moment direction w.r.t. reference

(This technique is used by LBL, Argonne, .

Calibration coil

Known magnetic moment



$m = IA$

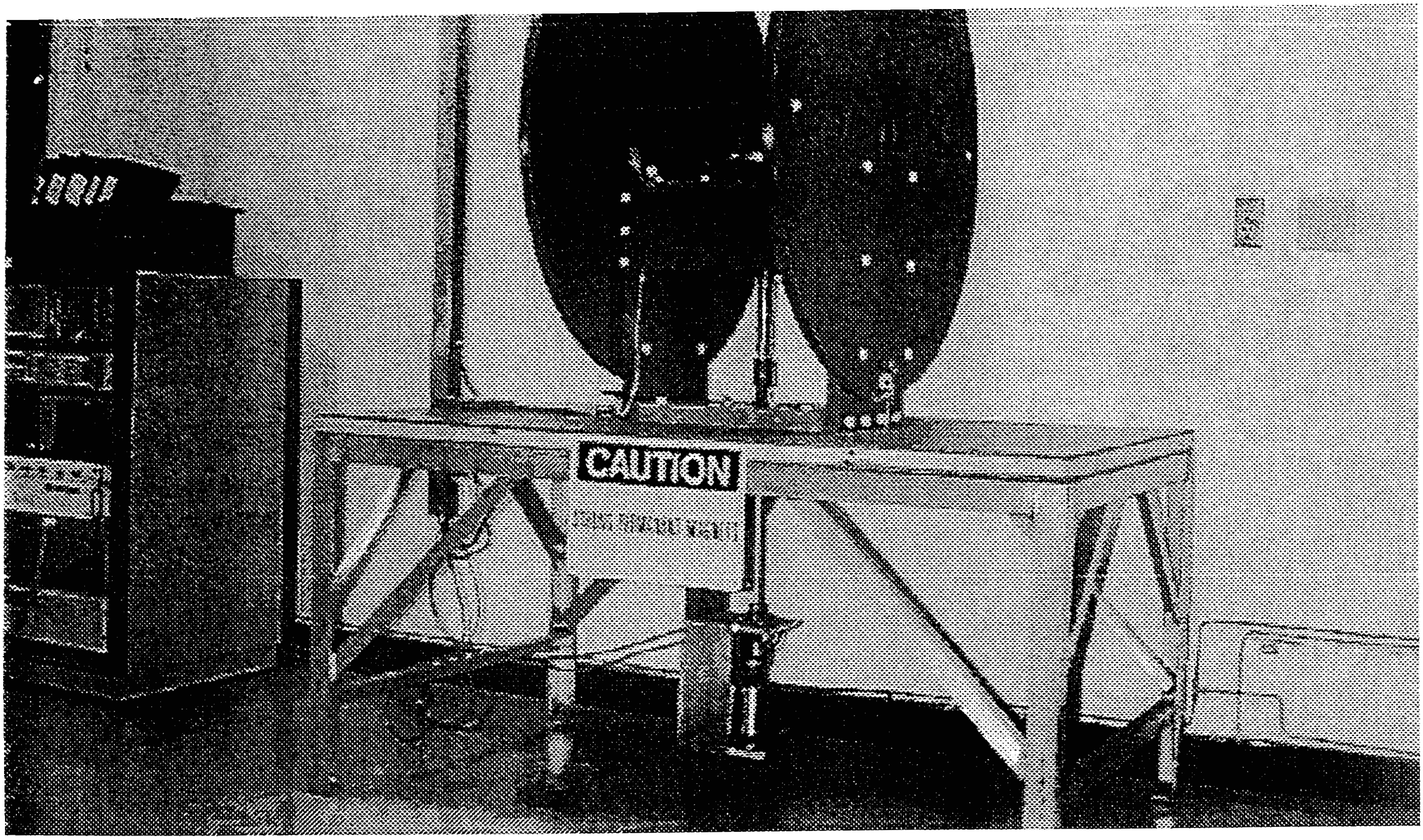
measure I with a transductor
measure A by flipping the coil in a calibration magnet

Know $m = IA$ very accurately

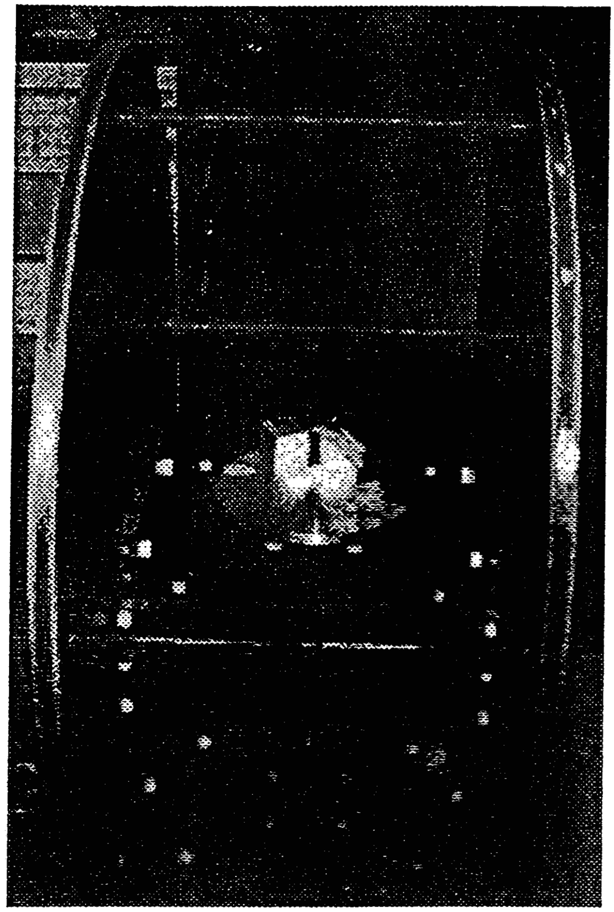
Use the known m to accurately determine the radius of the Helmholtz coil

Also use for periodic calibrations (a reference block is used for daily checks)

This coil is also used to set the reference direction.



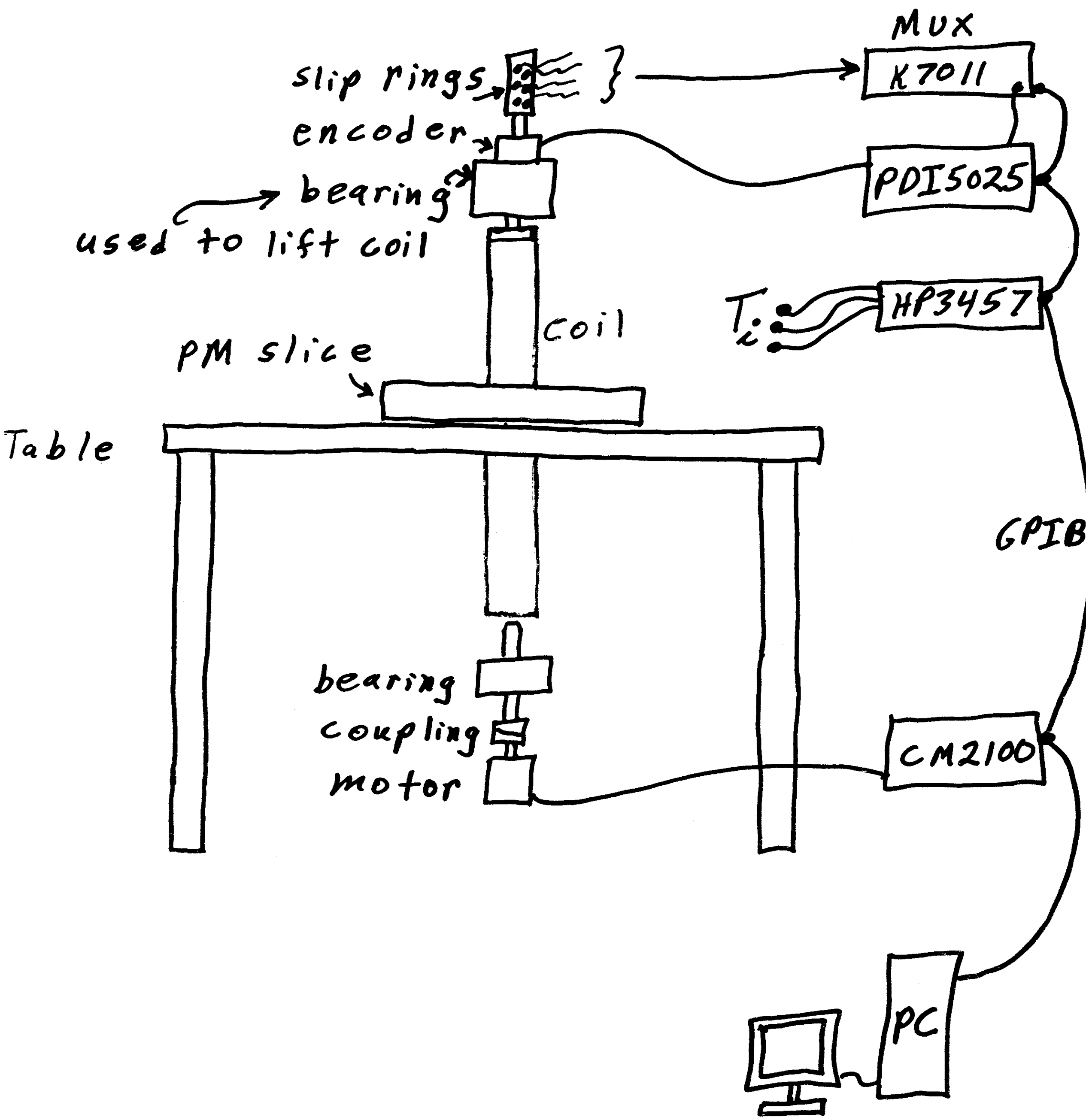
Helmholtz coil



Platter used to spin a block

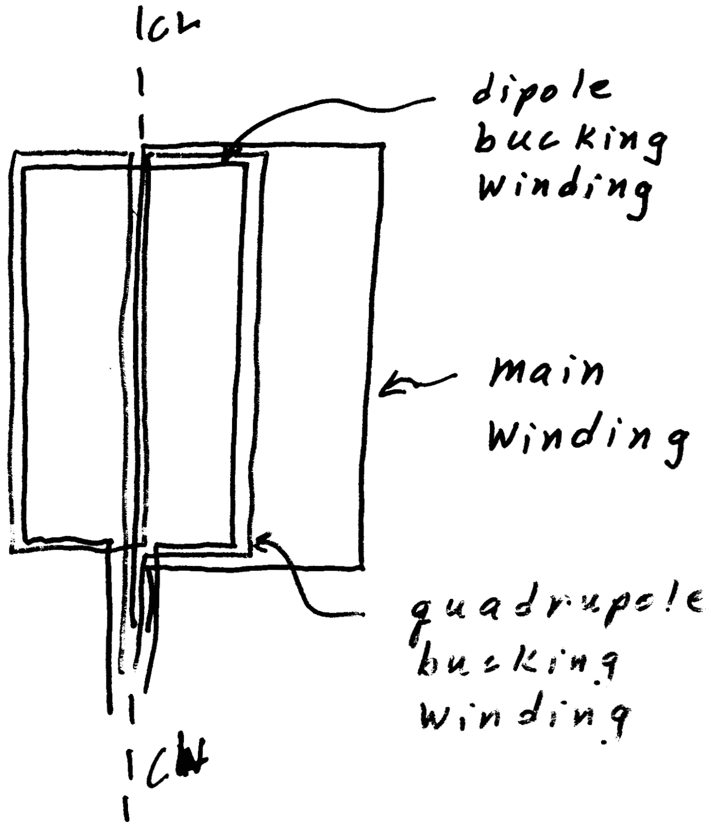
in the Helmhoiltz coil

Vertical Bucking Coil



The vertical coil is used to tune the slices. The PM blocks are moved in and out radially to optimize the field quality.

Bucking Coil Configuration

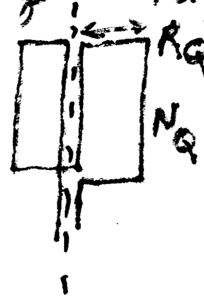


main winding

$R_m = 1.576''$

$N_m = 20$

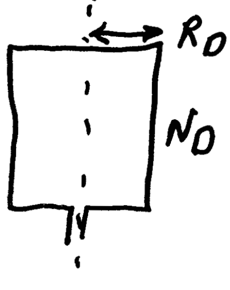
quadrupole bucking



$R_Q = R_m/2$

$N_Q = 2 N_m$

dipole bucking



$R_D = .630''$

$N_D = 25$

↑ Dimensions of the first vertical bucking coil.

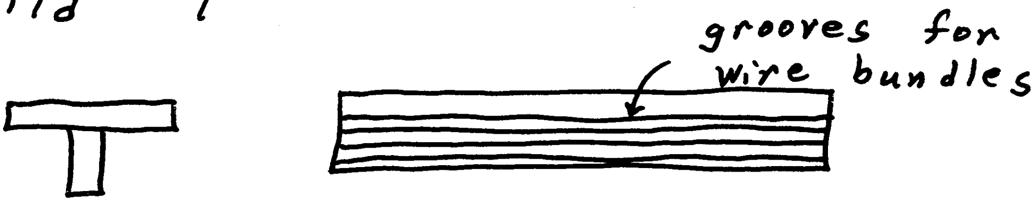
Requirements:

$$N_m R_m^2 = 2 N_Q R_Q^2$$

$$N_m R_m = 2 N_D R_D$$

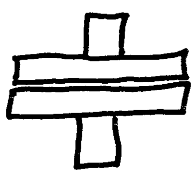
Coil Construction

1) Build T



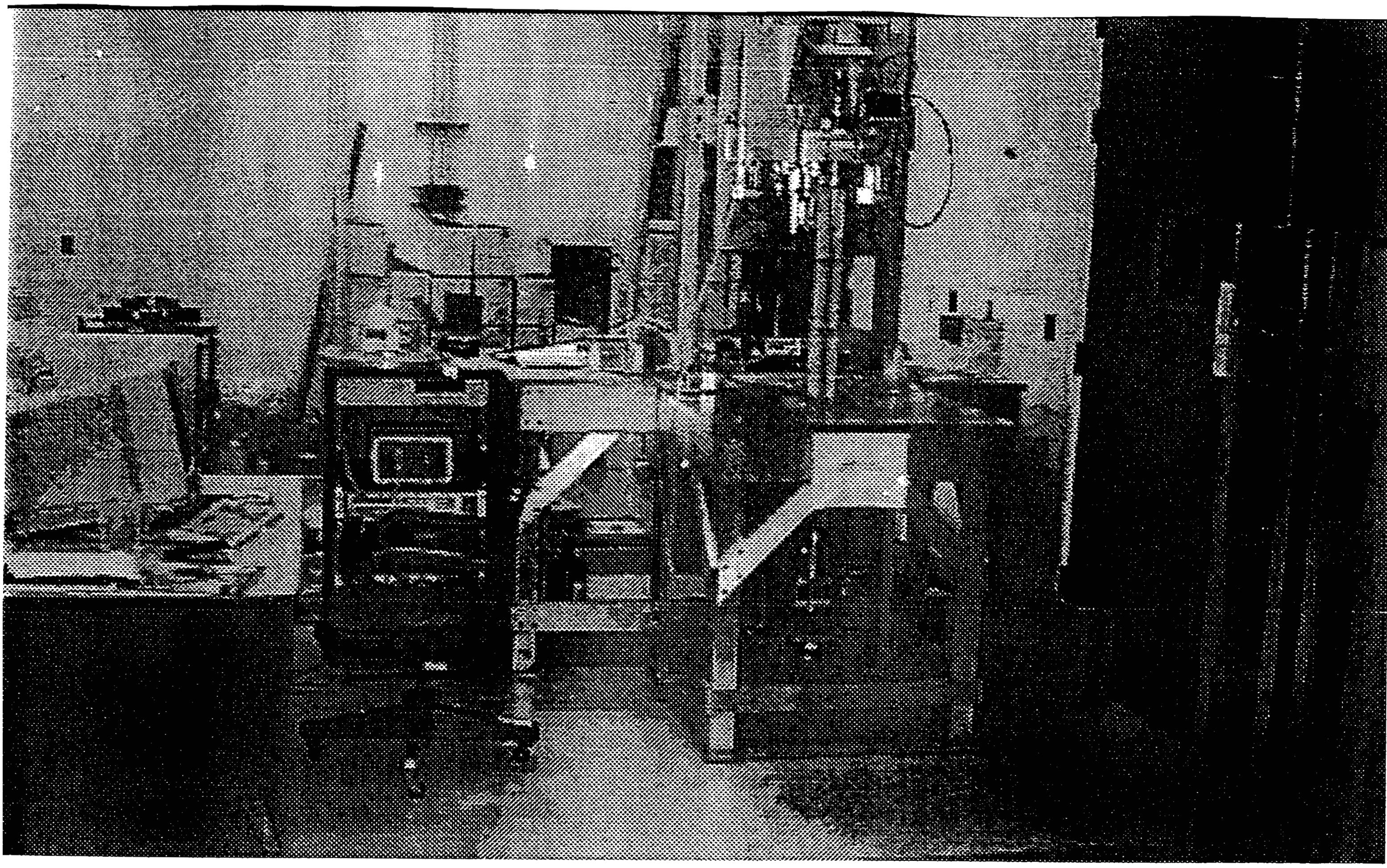
2) Epoxy coil bundles

3) Bolt on symmetric T



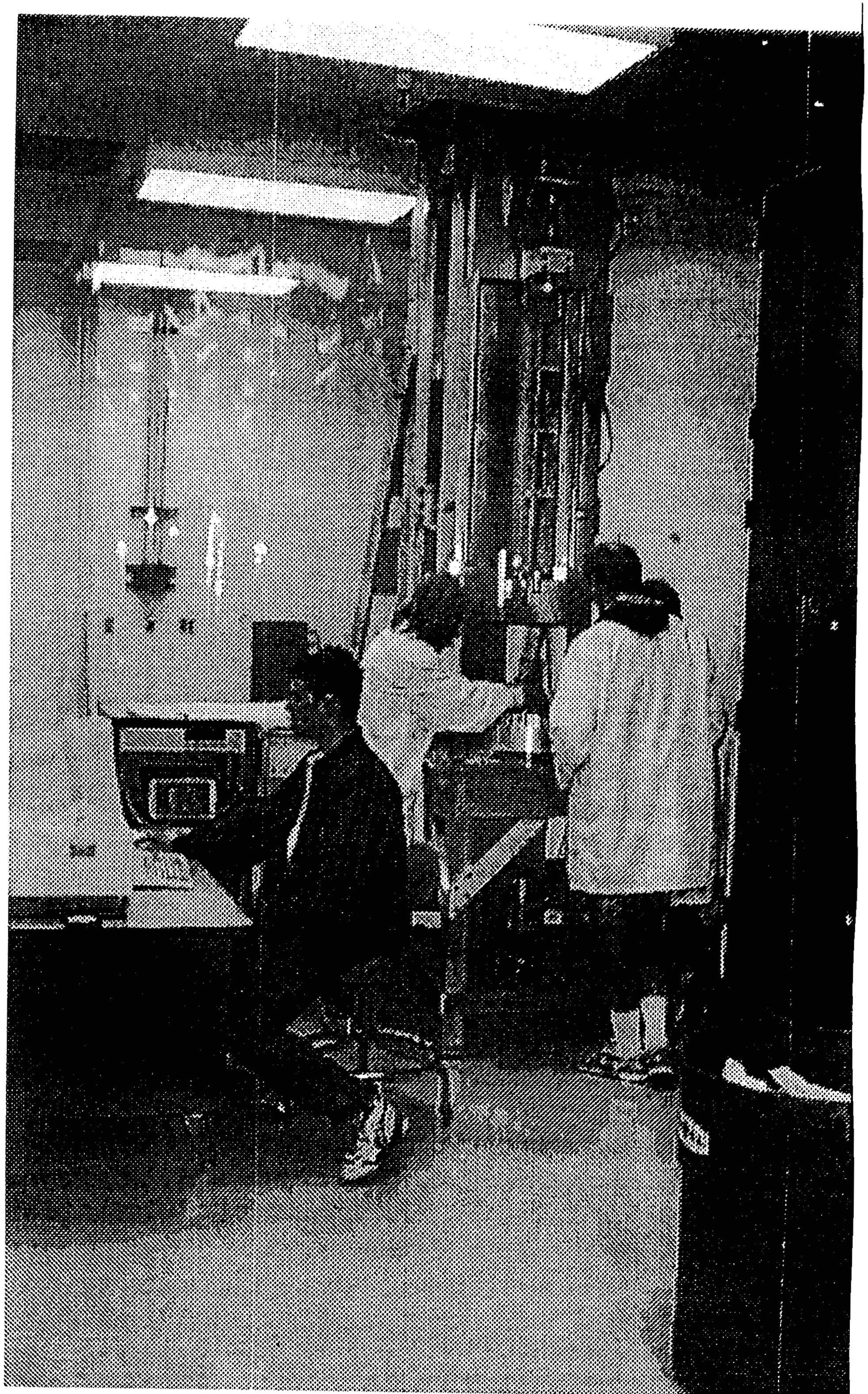
4) Solder the wire strands in series to make coils with N turns

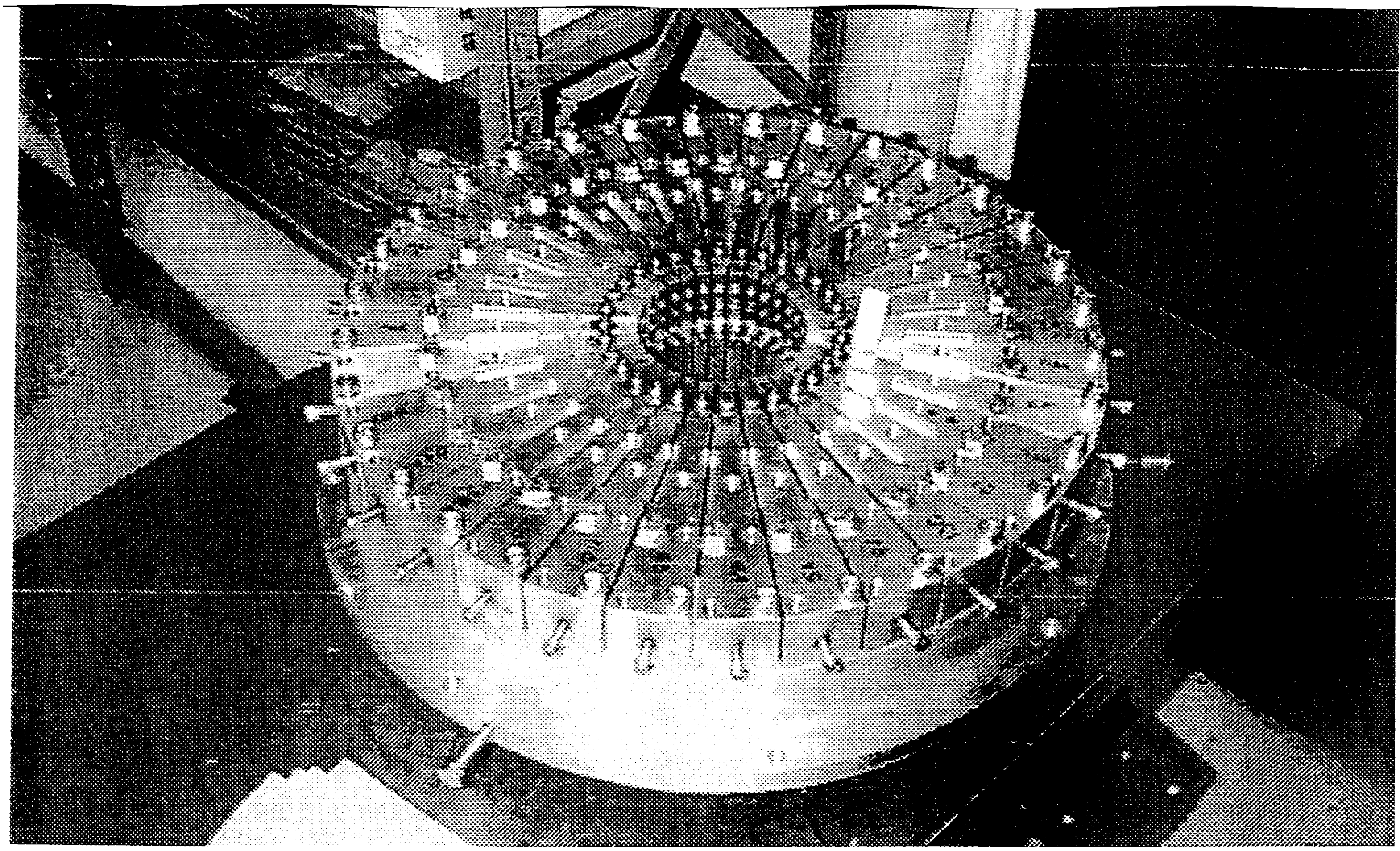
5) Attach end pieces



Vertical coil built to tune
the B1 and Q1 permanent magnet slices

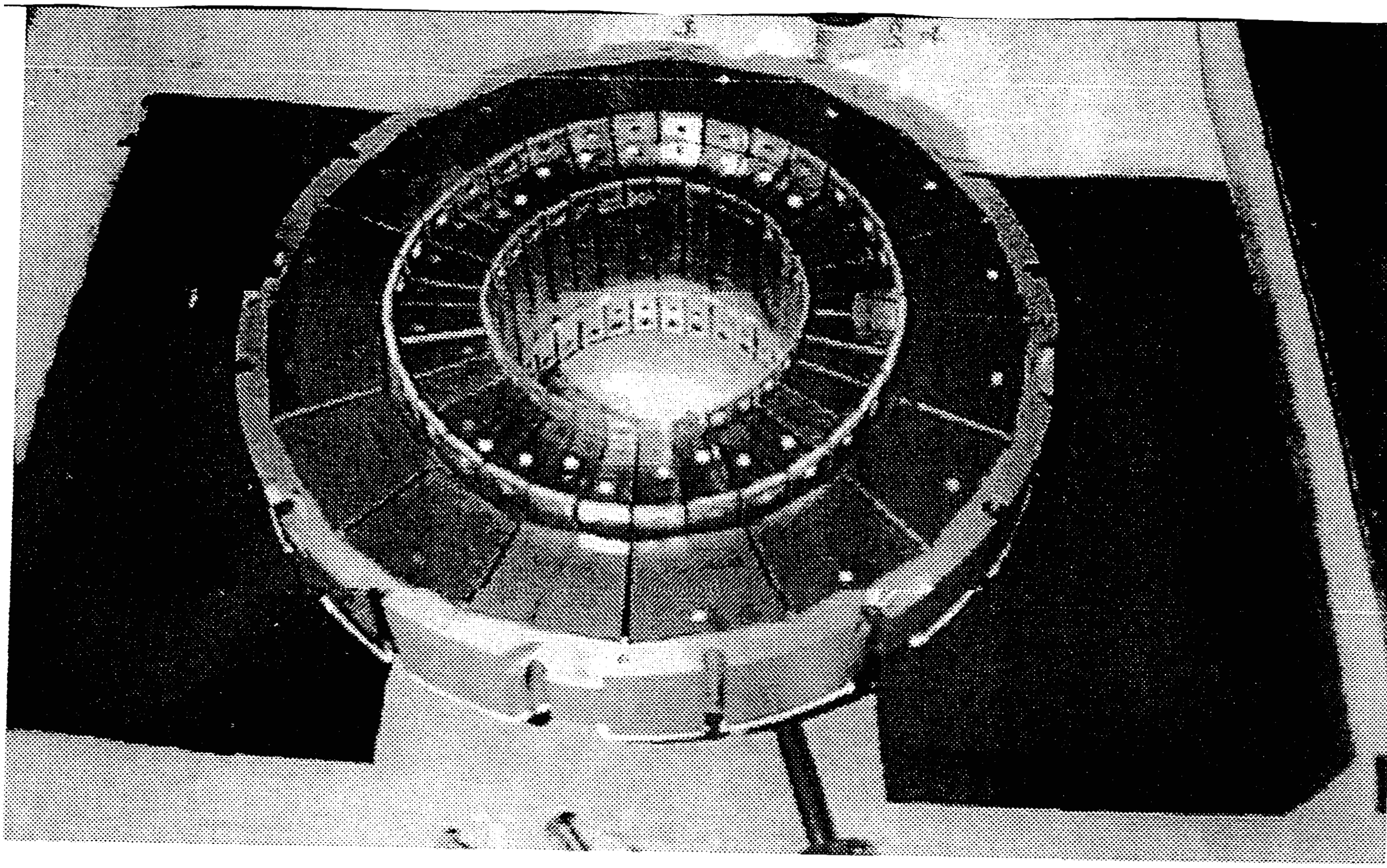
A Q1 slice in the process of being tuned



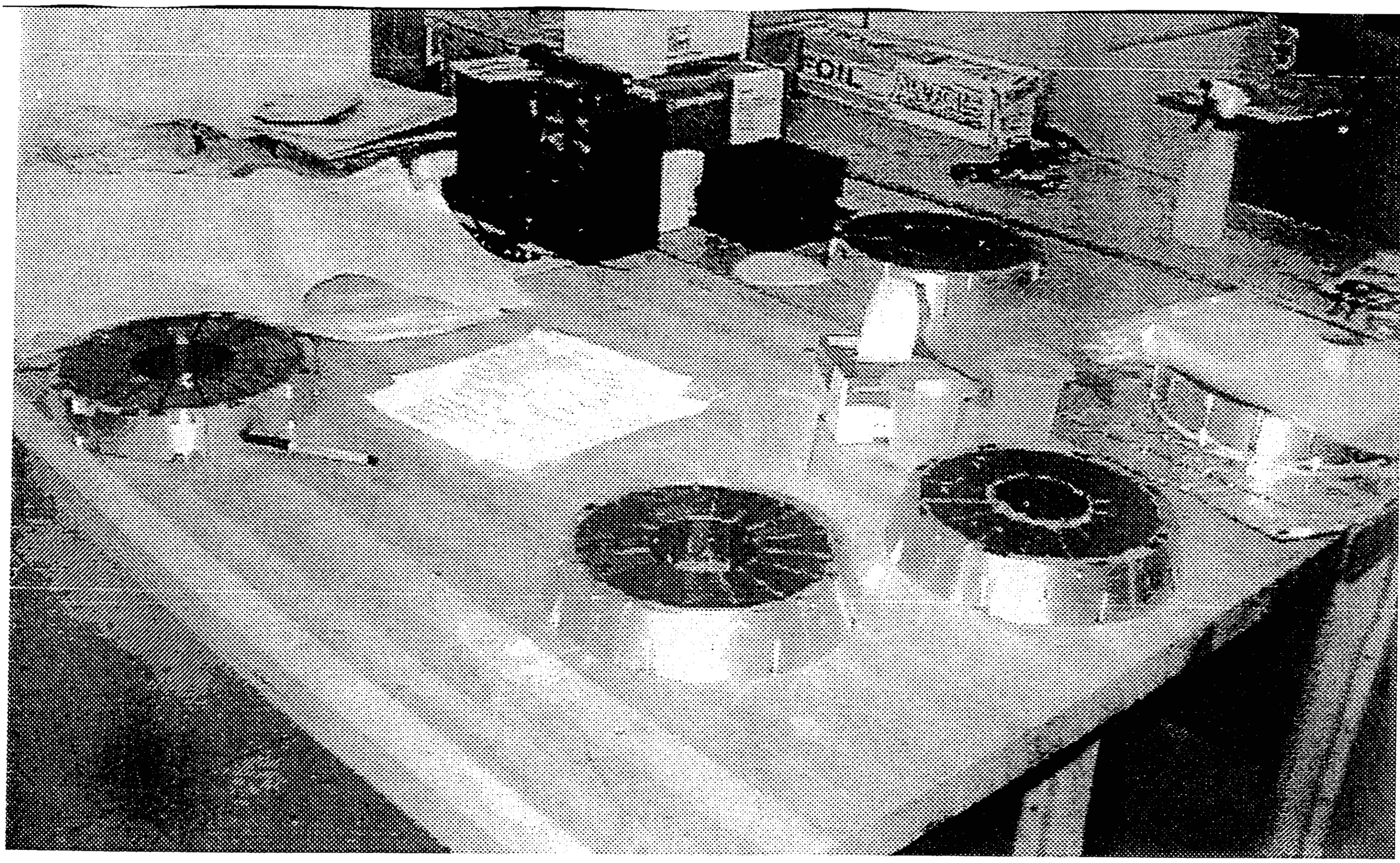


A Q1 slice with arms attached

to move the blocks

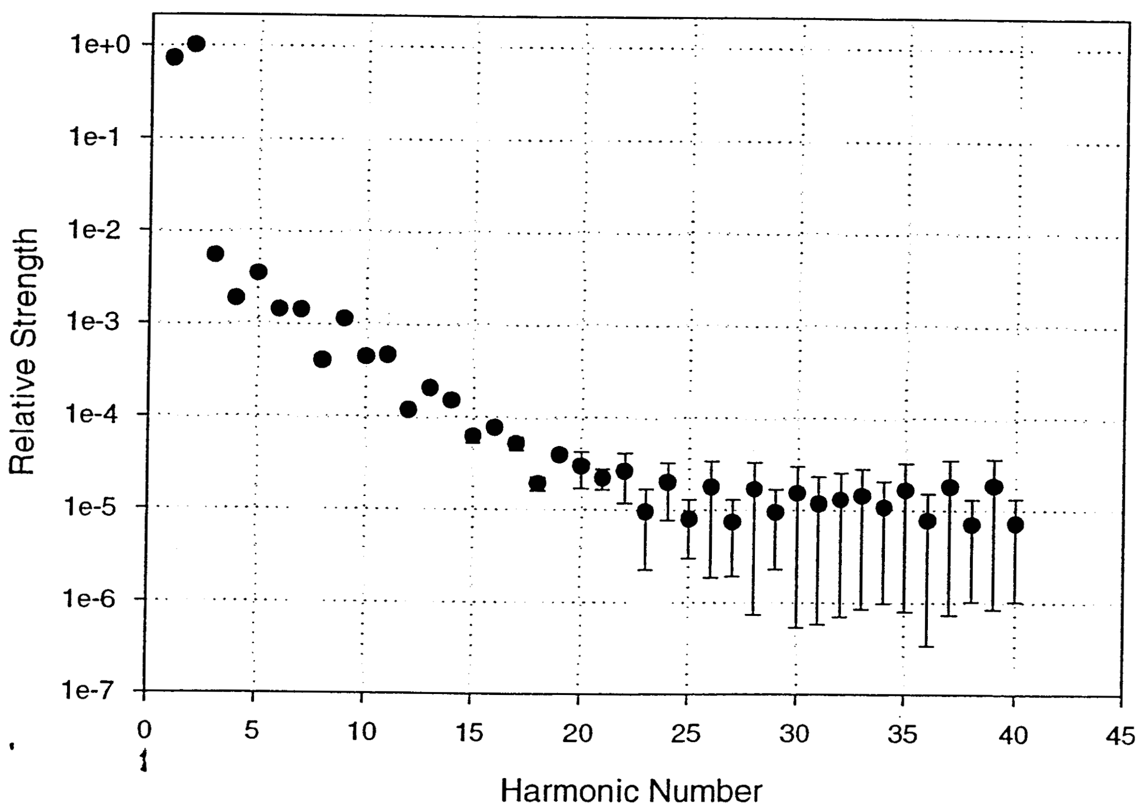


Epoxy is poured in after tuning to fix the blocks. The arms are then removed.



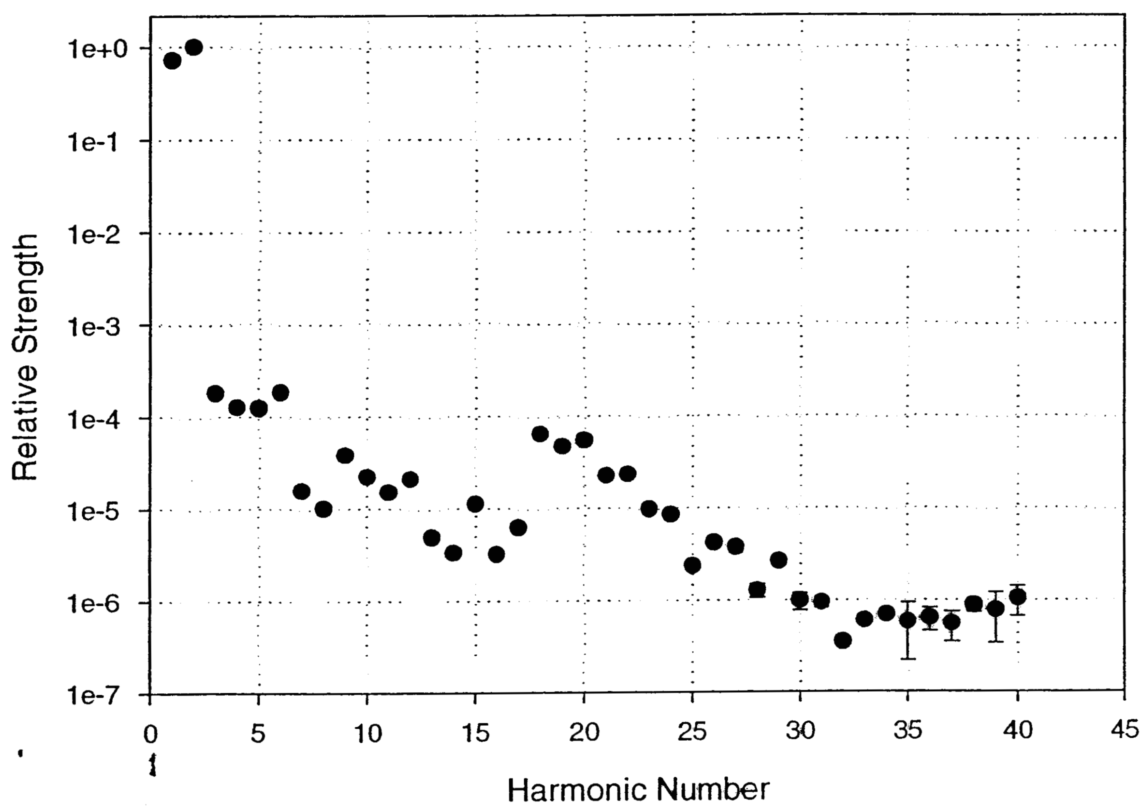
B1 slices after potting

Q1 Slice Before Tuning



Field harmonics before tuning

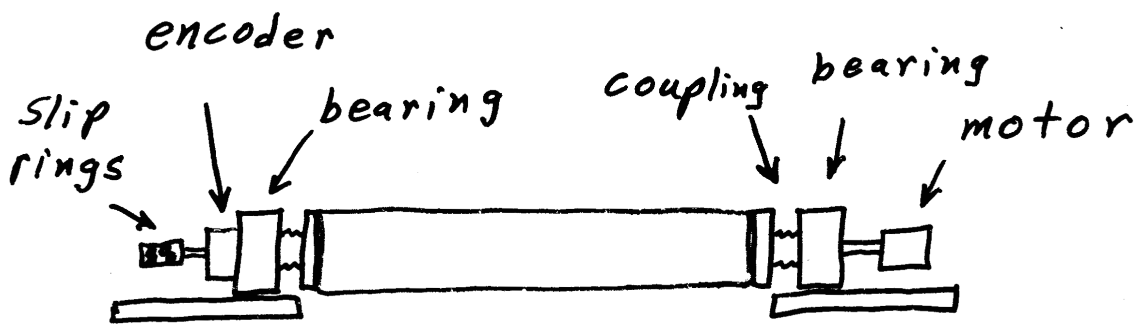
Q1 Slice After Tuning



Field harmonics after tuning

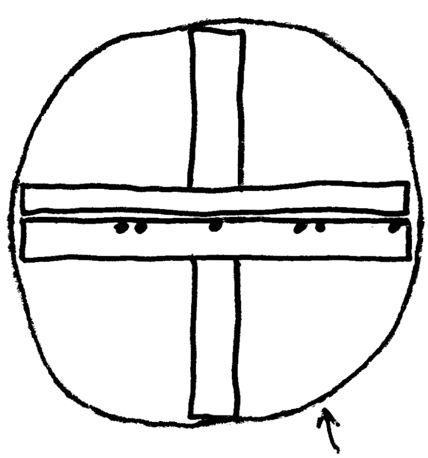
Horizontal bucking coil

(Used after the slices are assembled in to the completed magnet.)

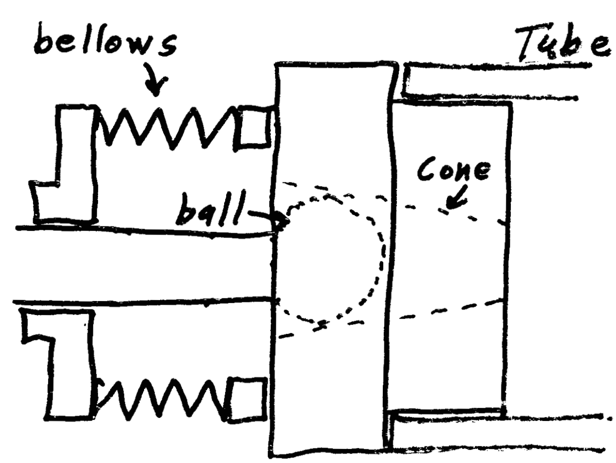


The horizontal coil uses the same configuration and electronics as the vertical coil, except:

<u>coil construction</u>



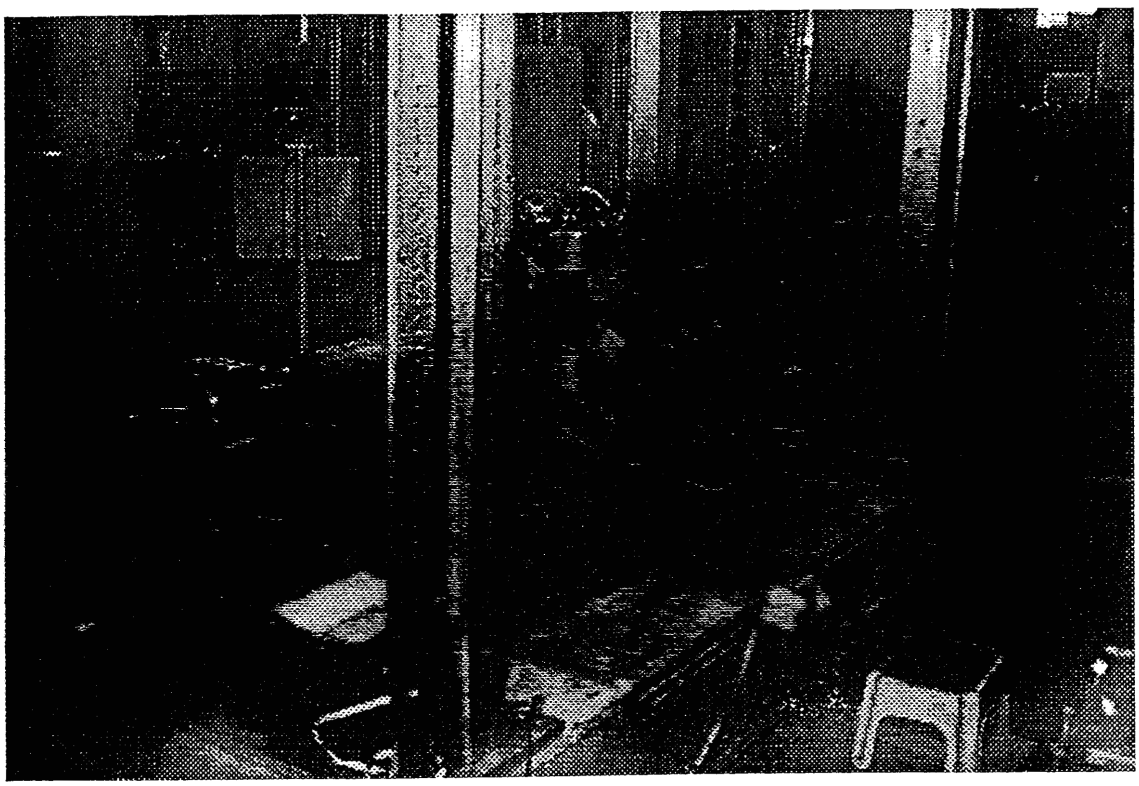
<u>coil ends</u>



ball in cone for positioning

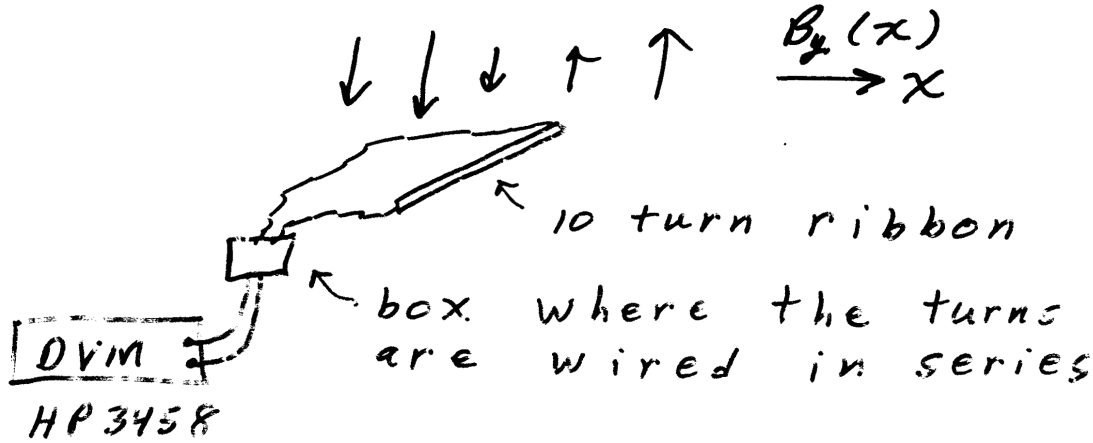
bellows to drive

Horizontal bucking coil

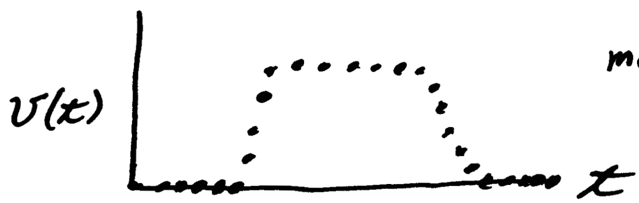


(Not measuring Q1, however.)

Stretched wire



move wire Δx

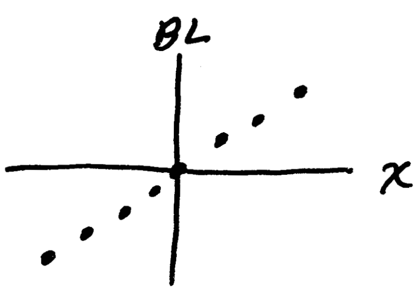


$$\int v\,dt = \sum_i v_i\,\Delta t$$

$$N\,\Delta\Phi = \int v\,dt$$

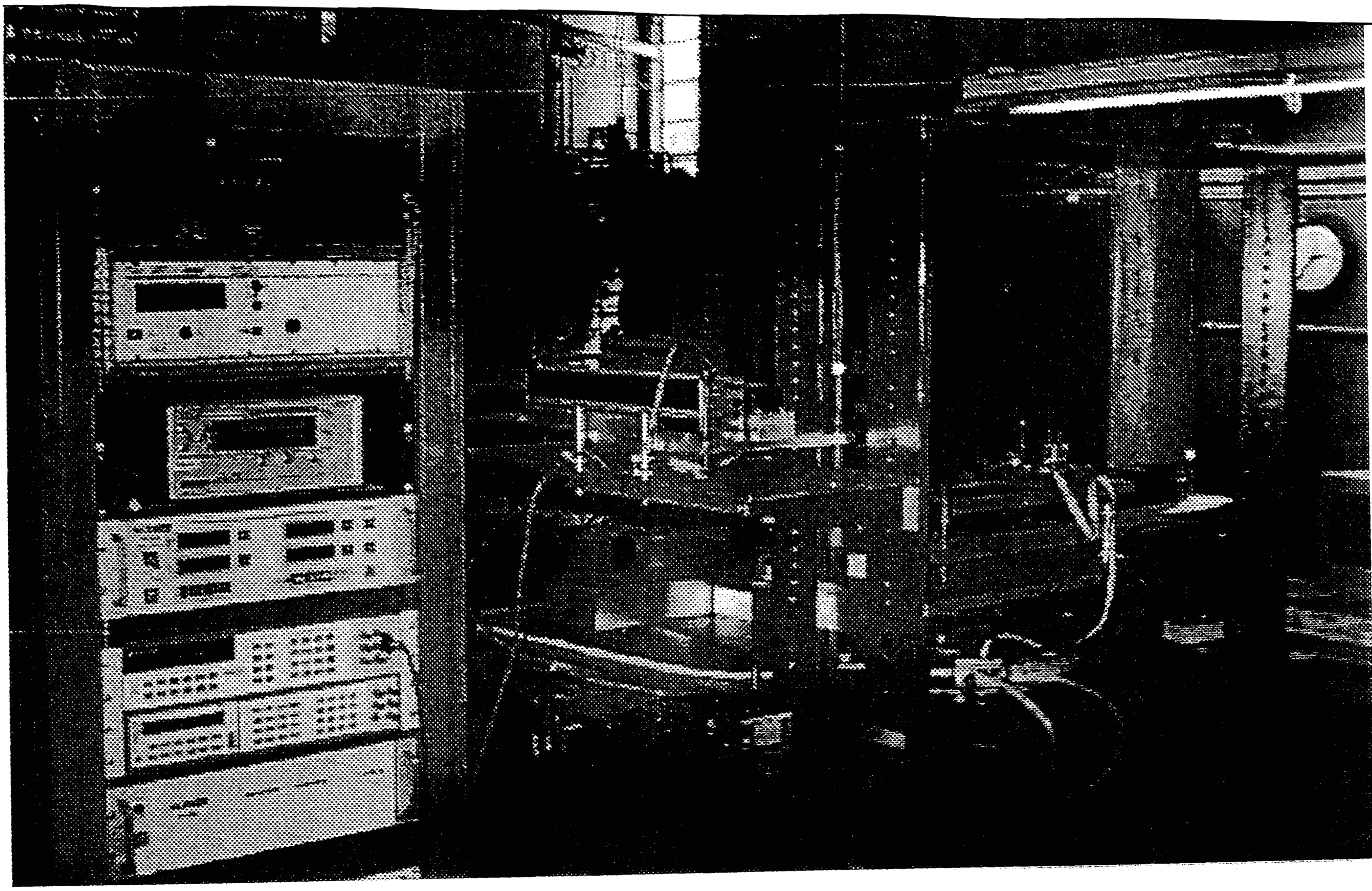
$$\Delta\Phi = BL\,\Delta x$$

$$BL = \frac{1}{\Delta x}\,\frac{1}{N}\int v\,dt$$



BL vs X gives
GL quadrupole
SL sextupole

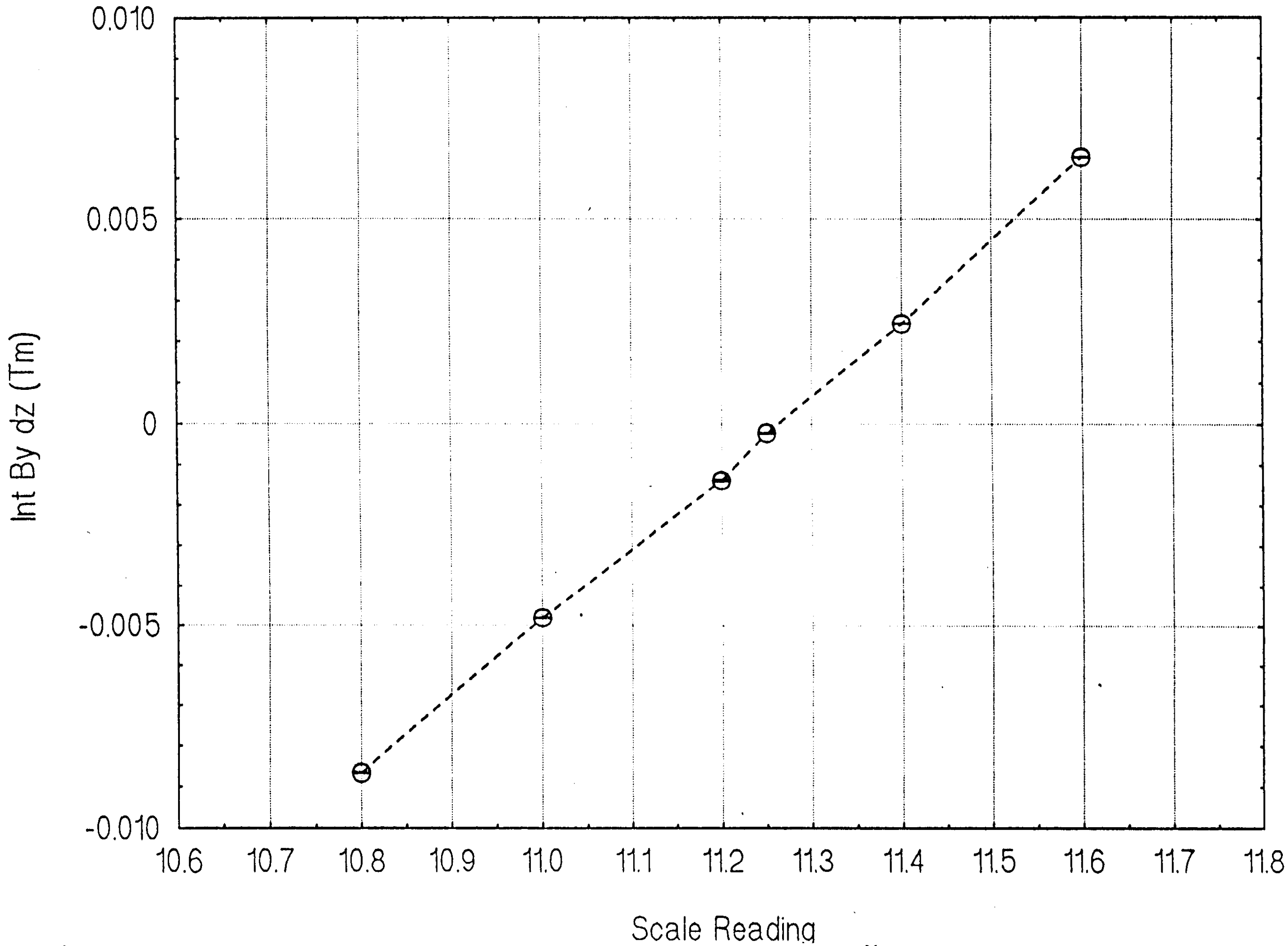
(Used to measure magnets strengths. Also used to set the roll angle of the B1 PM dipoles.)



Stretched wire system

Klinger stages

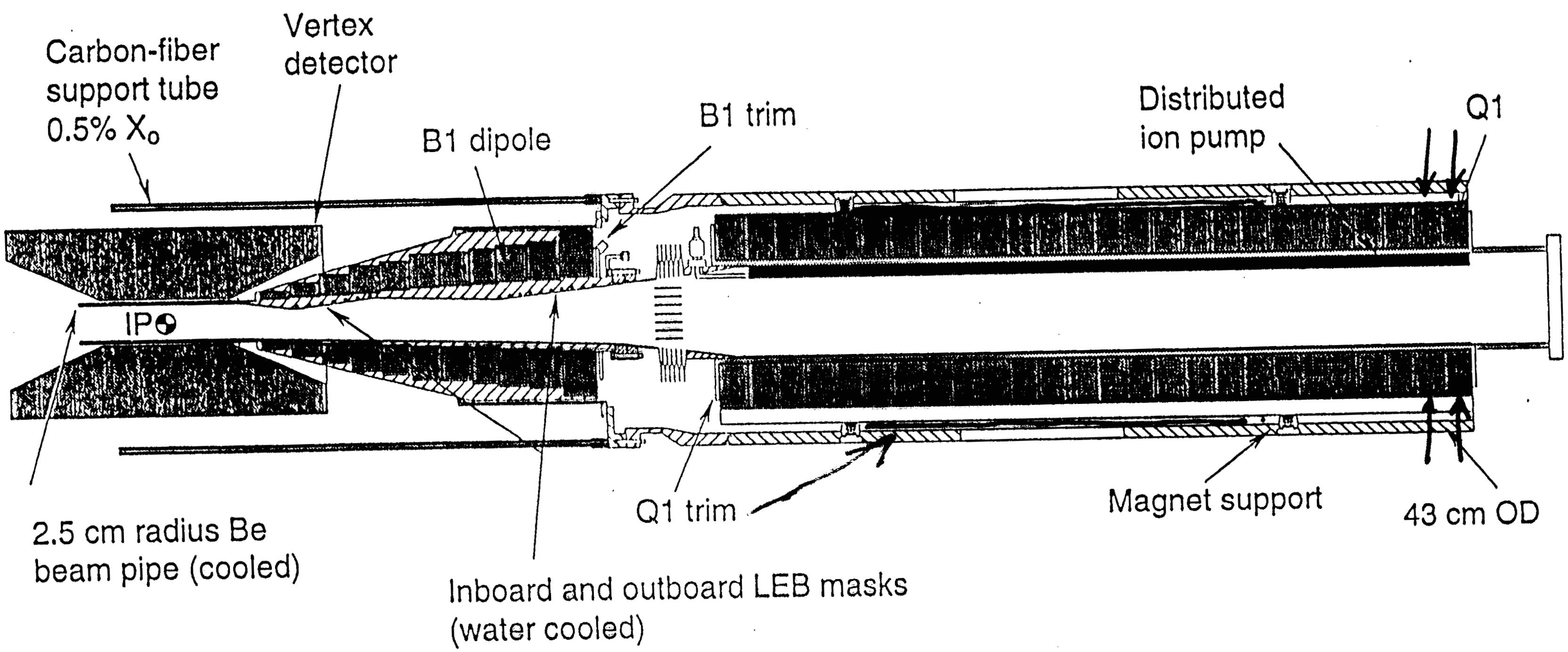
B 1 Right, Fine Roll Angle Determination



The wire was set up to move in the horizontal plane. The B1 dipole was rolled until $\int B_y \, dz \simeq 0$. The field was then horizontal. Tooling ball positions were determined.

The last two slices of Q1 both rotate

through 360 degrees



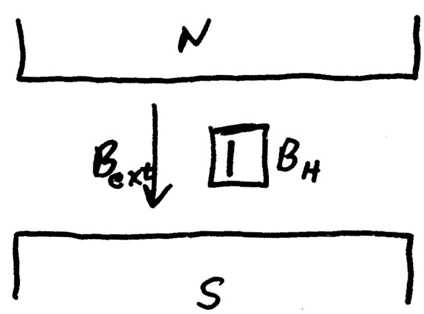
This gives a range of coarse normal and skew strength adjustment.

Trim windings are used for fine adjustment.

Permanent Magnet Block
In an External Field

Study the effect of the 1.5 T detector solenoid field on the B1 and Q1 magnets.

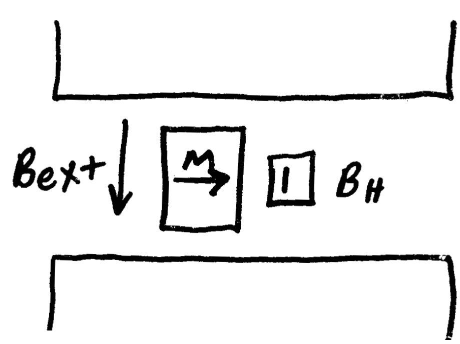
1) Align Sentron probe with the external field.



$B_H < 1\,G$ *

for $-1.5T < B_{ext} < 1.5$

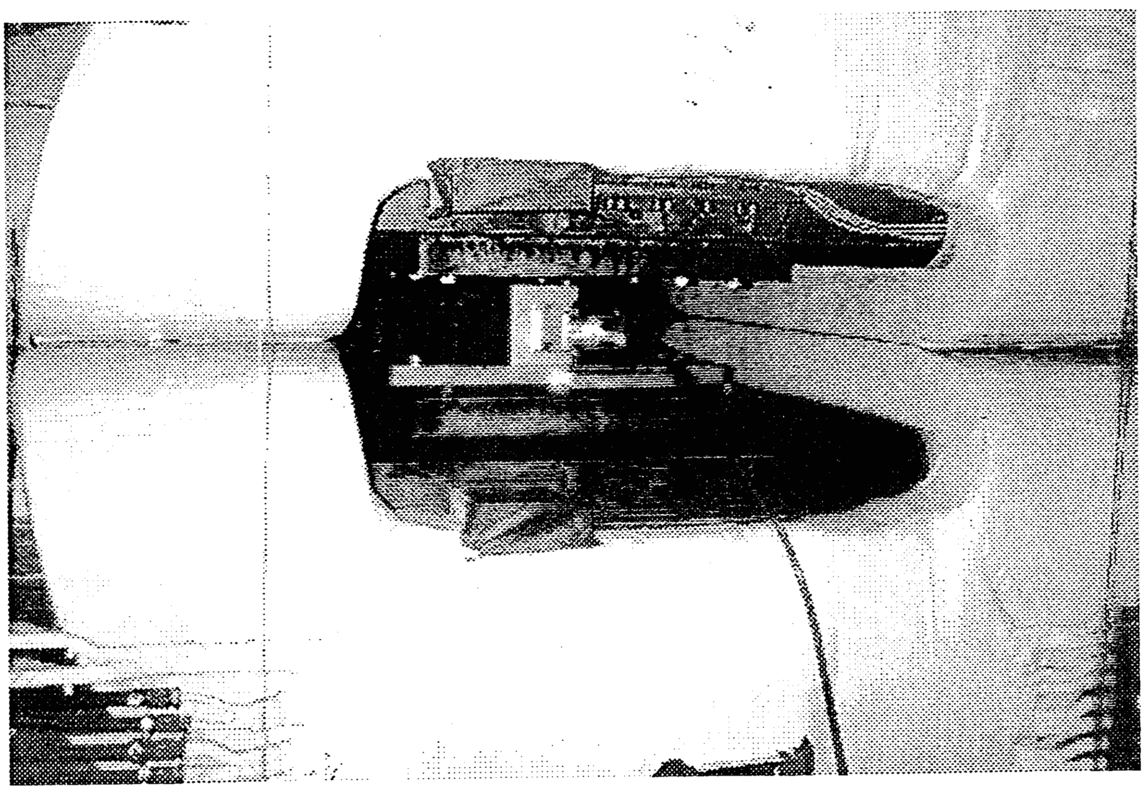
2) Insert PM block and measure B_H vs B_{ext}.



* The sentron probe has the desirable property that once it is aligned, it will read zero as Bext goes from −1.5 T to +1.5 T.

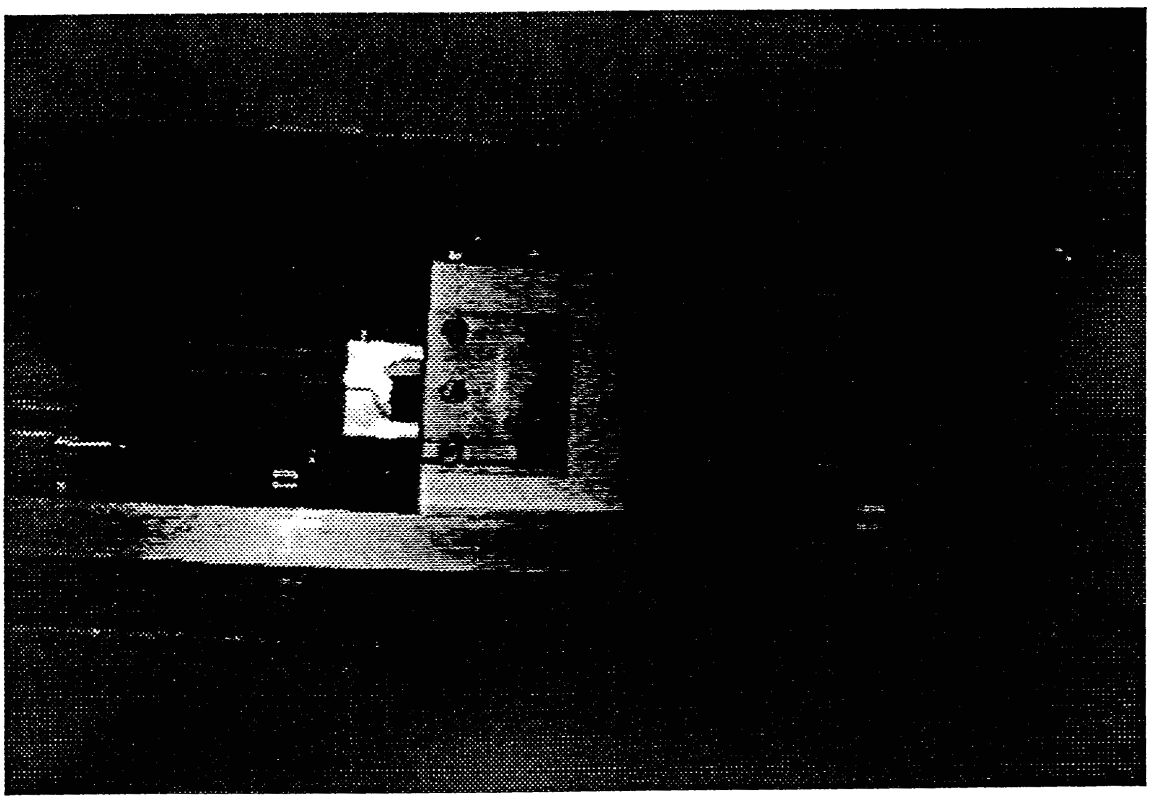
Permanent Magnet Block

In External 1.5 T Field

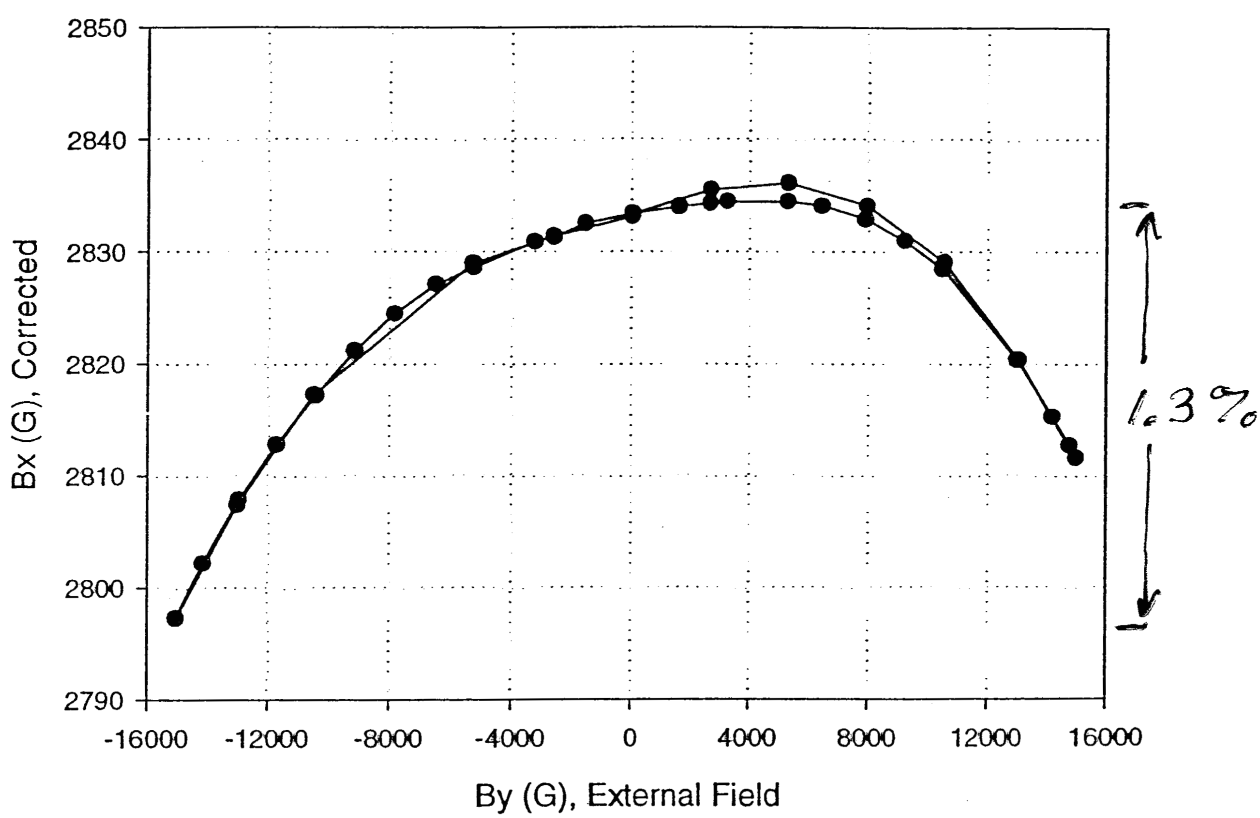


Permanent Magnet Block

In External 1.5 T Field



PEP II IR Permanent Magnet Block
In An External Field



This means that the fields in the B1 and Q1 magnets will change by about 1% as the Babar solenoid is turned up.

$\Delta \bar{M}$ Effect

The accelerator physicists do need to increase the strengths of B1 and Q1 by about 1% when the Babar solenoid is on.

This is within the range of the trim windings.

The effect on the harmonics is unknown.