

A PERMANENT MAGNET SEXTUPOLE

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Abstract

A permanent magnet sextupole has been designed and built for use with cold atomic hydrogen beams. The poletip field is 7 kG with an open bore of 4 cm diameter. The axial variation of the field is on the order of 10%.

Introduction

Polarized atomic beams are formed by passing hydrogen atoms through a inhomogeneous magnetic field. Traditionally, a sextupole field has been used¹ to form practical atomic beams. The requirements on a sextupole magnet to provide the necessary spin separation and focusing to a beam of cold hydrogen atoms are: 1) the magnet must have a sufficiently high poletip field, 2) the open bore of the magnet should be reasonably large, and 3) the mechanical construction must provide radial pumping to the magnet bore to reduce the atomic scattering on molecular hydrogen, formed by atoms recombining on the warm pole surfaces, or on defocused hydrogen atoms. The electromagnets designed by ANAC do not have very large open bores and are unable to

provide any radial pumping since the coils fill the volume between adjacent poles. Later electromagnet designs, such as those of SIN/ETHZ² and TUNL³, had a larger open volume between poles due to a large diameter yoke and open bores of 14 - 30 mm diameter. Maximum poletip fields on the order of 10 kG are reported. Permanent magnet ring sextupoles of the modulated magnetization direction⁴ and modulated width⁵ types could achieve higher poletip fields; however, the ring magnet geometry precludes the effective use of radial pumping.

A prototype permanent magnet sextupole has been designed to meet the above criteria. This Technical Note describes the design and presents measurements of the field achieved in the prototype.

Description of Magnet

The device consists of three main parts: the yoke, the magnets, and the clamps. A photograph of the assembled unit is shown in Figs. 1a and 1b.

The magnet yoke is made from a single piece of 1018 steel. It is 200 mm long with an outer diameter of 121 mm and an inner diameter of 77.5 mm. The poles are located by six 0.4 mm deep grooves machined along the length of the inner diameter. A set of 24, 12.7 mm wide slots has been machined between the poles through the yoke to provide radial pumping capability.

The permanent magnets used to create the field are Nd-Fe-B magnets provided by Permag Corp.⁶ The material was machined into blocks 19 mm wide by 18 mm high by 50 mm long. The blocks were then magnetized to an energy product of 35 MGOe. The magnetization axis is parallel to the 19 mm dimension.

The magnet was assembled as follows. The surface field of each block was measured and four sets of six matched blocks were assembled. The blocks from each set were then loaded into the magnet yoke forming a single row. The orientation of the blocks' magnetic field were checked as each block was loaded and the orientation was checked from row to row.

Field Measurements

Three sets of field measurements were made on the magnet. The first set determined the radial dependence of the field. The second set measured the azimuthal dependence, and the third set measured the field along the length of the magnet.

The radial measurements determined the field along the diameter between adjacent sets of poles. The magnet was mounted on a machinist's indexing head for radial and angular positioning. A Bell transverse field Hall probe was rigidly mounted to an arm coming from the bed of the test stand. The position of the probe and magnet were adjusted so that the probe moved along a diameter formed by the mid-plane of opposing sets of poles. The orientation of the probe was then adjusted to maximize the maximum observed field strength. The magnet was moved in 2 mm steps beneath the probe. The depth of the probe in the magnet was 3 cm in order to be well away from the end field.

The azimuthal measurements were made with the same set-up as the radial measurements. The probe was positioned at a radius of 10 mm and the magnet rotated in 5 degree steps. The magnet was then moved so that the probe measured at a radius of 15 mm. The 15 mm data were taken at angular increments of 10 degrees. Between the two measurements, the zero angle reference suffered a 90 degree phase shift during the realignment.

The axial measurements were made with the magnet mounted in the vacuum chamber of the cold beam source. A Bell three axis Hall probe was installed in a holding fixture. The center of the probe was at a radius of 14.5 mm from the center of the bore. The magnet was moved on a linear motion bearing in 10 mm steps.

Results and Discussion

Figure 2a shows the radial field strength as predicted by the code PANDIRA. The results of radial field dependence measurements are shown in Figs. 2b - 2d. The starting and finishing points are denoted by (N1, N2), where N1 and N2 are the poles closest to the diameter traversed. The arrow defines the direction of traversal. A pure sextupole should yield an r^2 dependence. The deviations from a pure sextupole field are significant only in the region close to the pole radius.

The azimuthal data measured at $R = 10$ mm is shown in Fig. 3, with the data at $R = 15$ mm shown in Fig. 4. The curve in Fig. 4 comes from a harmonic analysis of the field performed by PANDIRA. The total harmonic content is less than 9% at a radius of 15 mm. The harmonic content is acceptable for use in an atomic beam source since only atoms reaching the outermost region of the field will experience a large nonlinear restoring force.

In Fig. 5, a plot of the axial variation of the total field is presented. (The probe and its fixture were not able to measure the entire length of the magnet which limited the end field measurements to only one end.) The measured field in the magnet shows a noticeable rise in the center of the magnet corresponding to the two center rows of magnets. The increased field strength was not more than 10% above the end rows. The end of the magnets and yoke were located at 187 mm, and it is clear that the field strength outside the magnet is quite small. The effective length of the magnet is estimated to be 195 mm.

Acknowledgements

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References

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3. T.B. Clegg, *Proceedings of the 8th International Symposium on High Energy Spin Physics*, Minneapolis, to be published.
4. K. Halbach, *Nucl. Inst. Meth.* 169 (1980) 1.
5. Xu Jiaming, Xu Qing, and Yin Zhaosheng, *Nucl. Inst. Meth.* A265 (1988) 371.
6. Permagan Corp. - Atlantic Division, 400 Karin Lane, Hicksville, NY 11801.

Figure Captions

- 1a. Side view of the assembled magnet showing pumping ports along the length of the device.
- 1b. End view of the assembled magnet. The black squares are the permanent magnets.
- 2a. Total magnetic field as a function of radius as predicted by PANDIRA.
- 2b. Total magnetic field as a function of radius measured along the mid-plane formed by pole pairs (4,5) and (1,2). The labeling of the poles is arbitrary. The measurements were made by stepping an indexing head in the direction from (4,5) to (1,2).
- 2c. Total magnetic field as a function of radius measured along the mid-plane formed by pole pairs (5,6) and (2,3).
- 2d. Total magnetic field as a function of radius measured along the mid-plane formed by pole pairs (6,1) and (3,4).
3. Azimuthal component of magnetic field measured at $R = 10$ mm.
4. Azimuthal component of magnetic field measured at $R = 15$ mm. The curve was obtained from a harmonic analysis performed by PANDIRA.
5. Total magnetic field measured along a line 14.5 mm from the center of the magnet. The measurements did not sample the field along the entire length of the bore.



Figure 1a

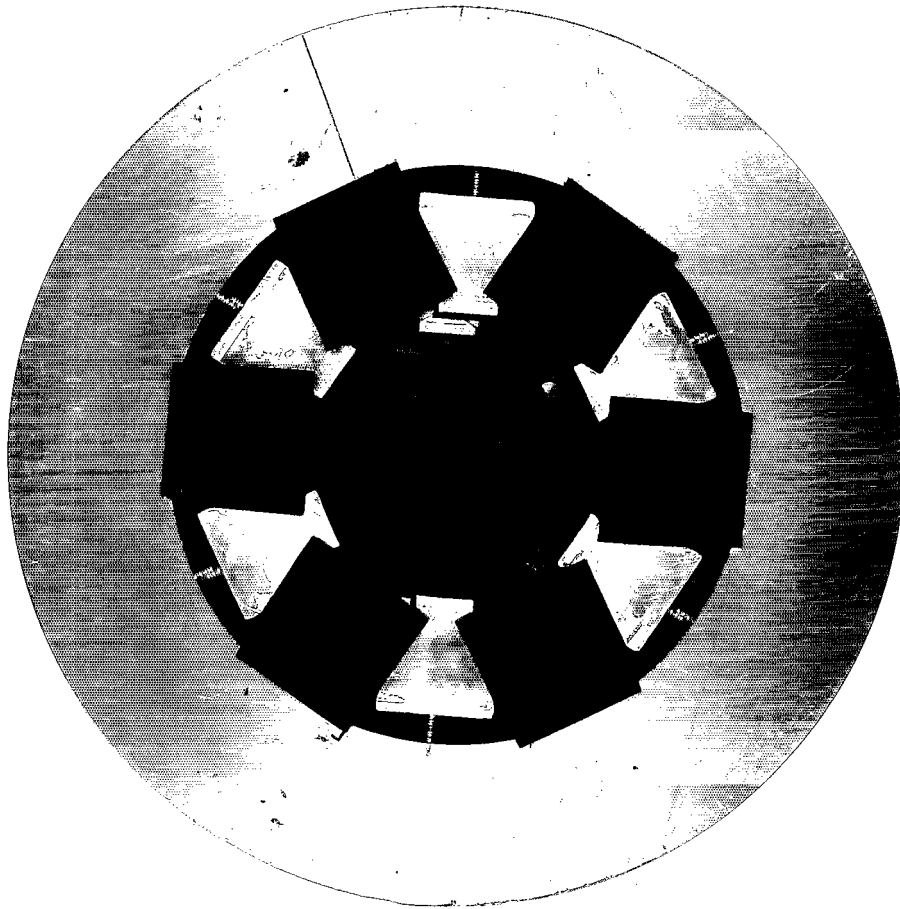


Figure 1b

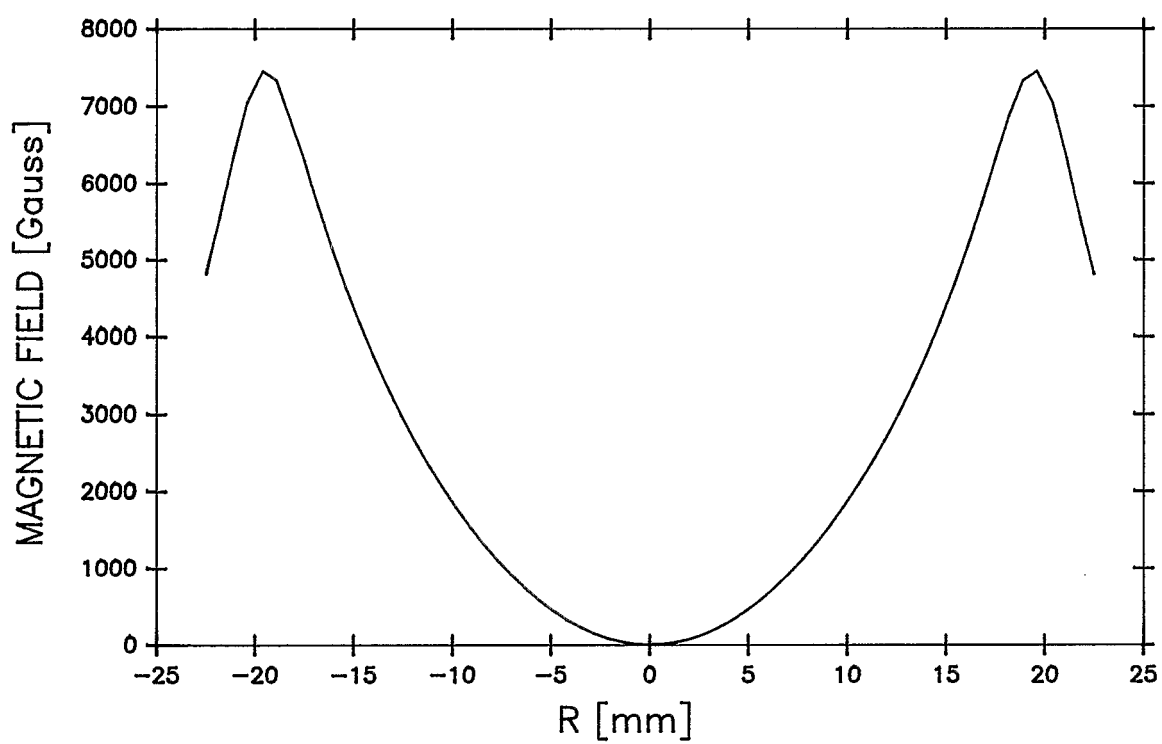


Figure 2a

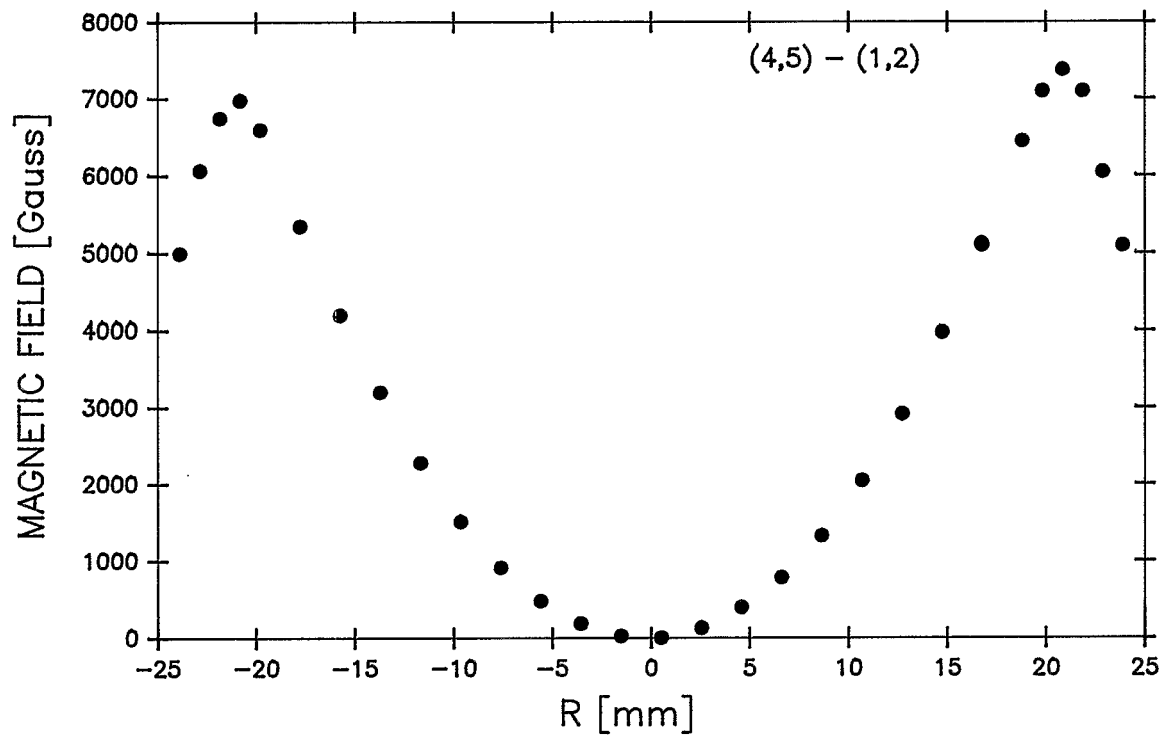


Figure 2b

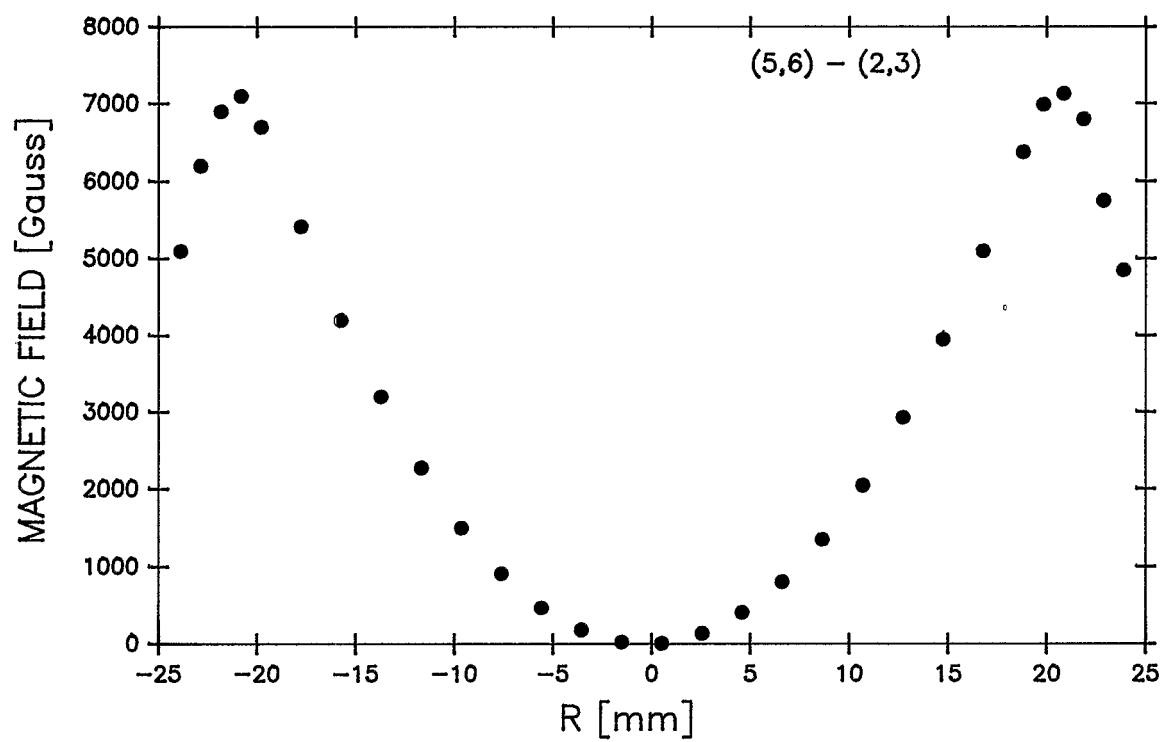


Figure 2c

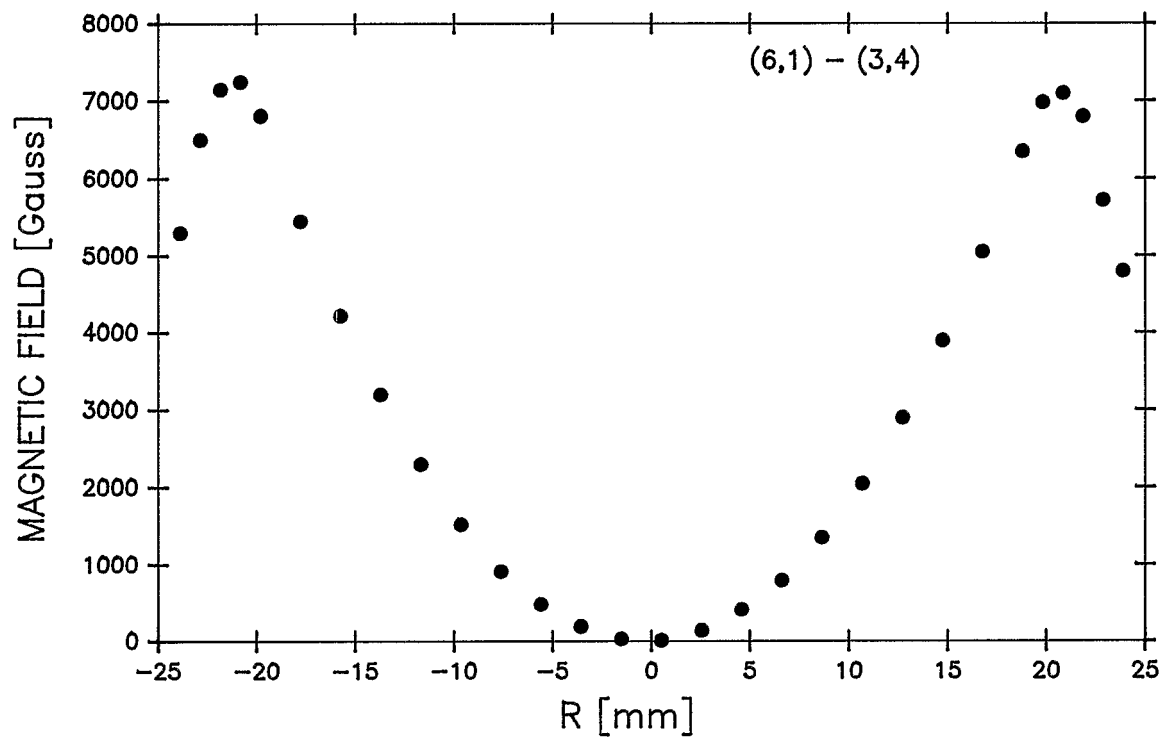


Figure 2d

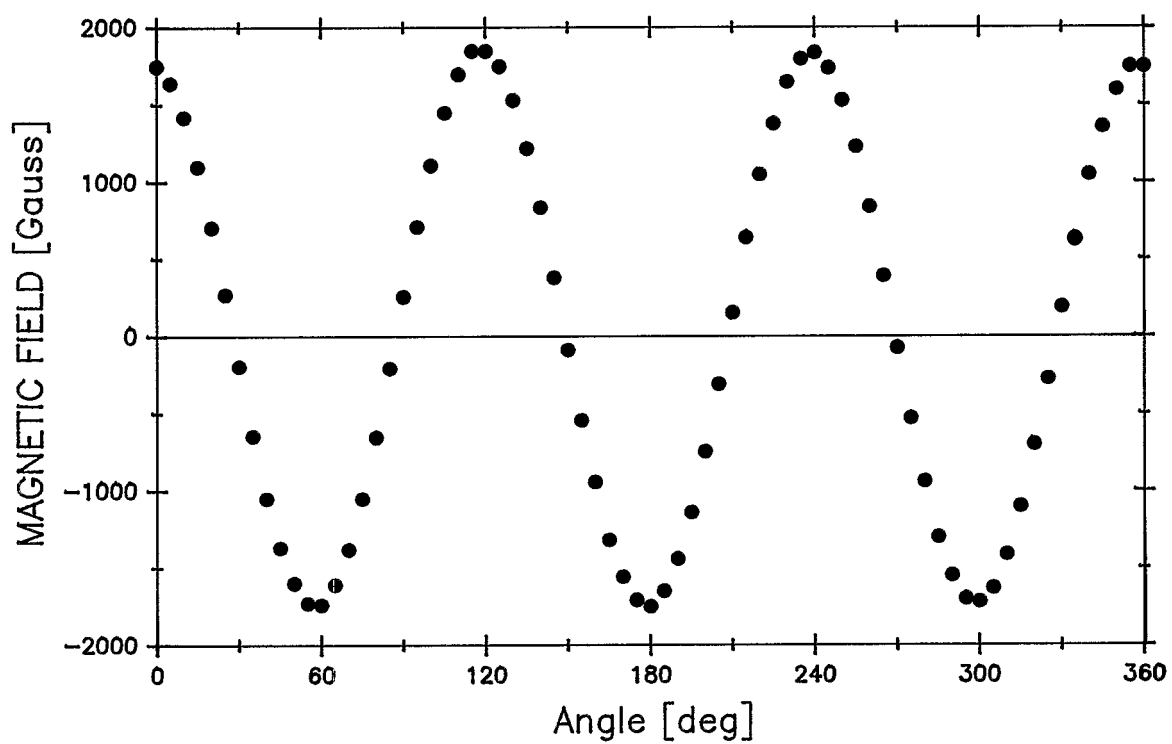


Figure 3

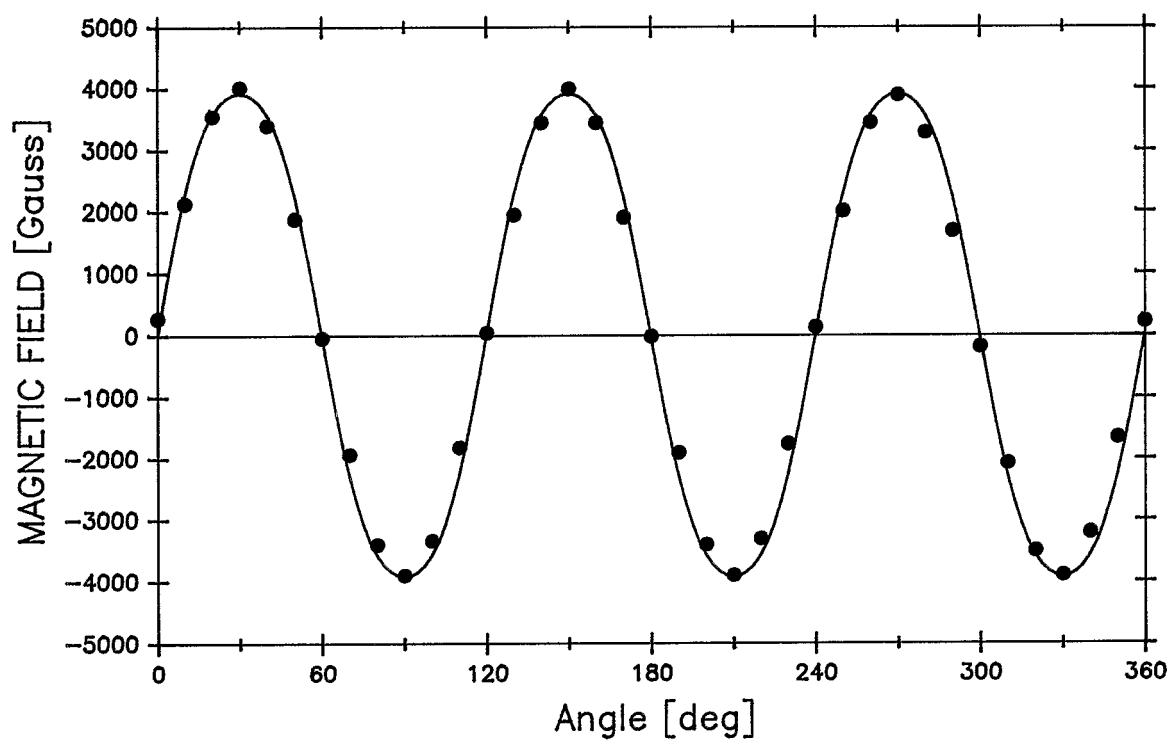


Figure 4

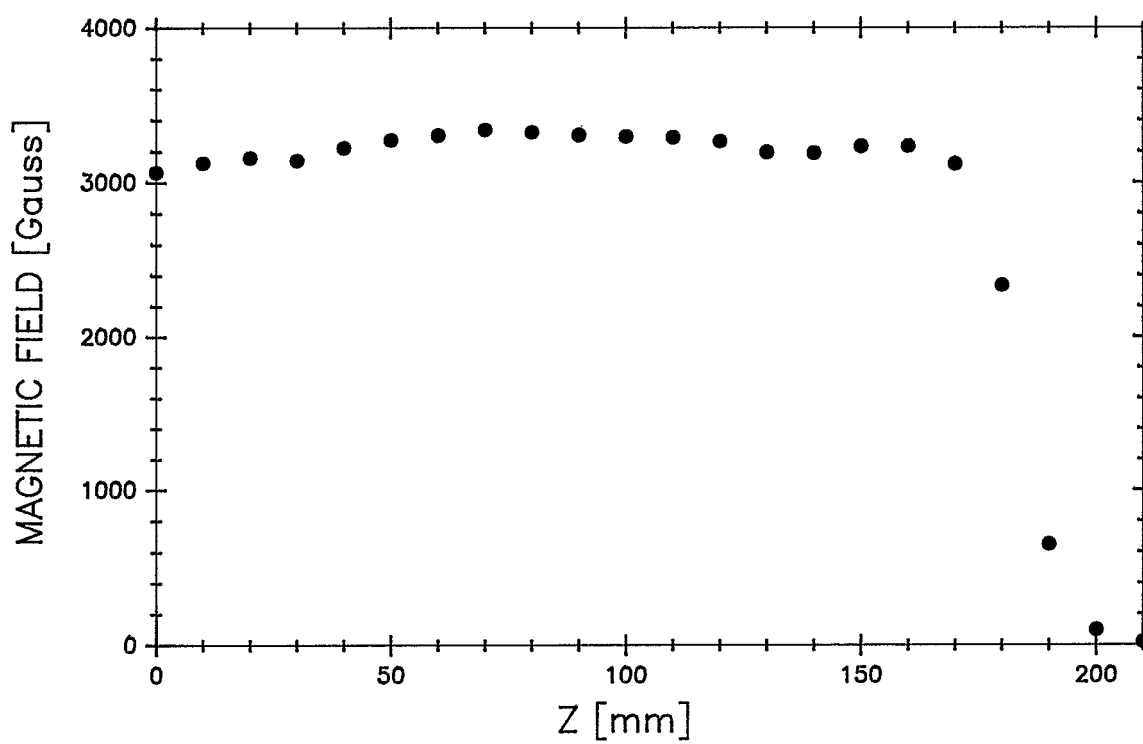


Figure 5