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March 1985

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A Mass Spectrometer Utilizing Permanent Magnets*

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Abstract

A fairly compact mass spectrometer suitable for vacuum use, and requiring no cooling, was built utilizing permanent magnets. A uniform, variable magnetic field, with a maximum of 2800 gauss, was produced in a .6 cm wide gap by using a rotating block of samarium cobalt permanent magnets, and an iron yoke assembly.

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Variable magnetic field momentum analysers are a common plasma diagnostic. If a particle of mass m and charge q is accelerated electrostaticly by a potential V , then injected into a uniform transverse magnetic field it will follow a circular path of radius

$$r = c \frac{mv}{qB} = \frac{c}{B} \sqrt{\frac{2m}{q}} V$$

For plasmas where the charge to mass ratio is different for each kind of charged particle, this device will yield the fractional populations. These devices are often called mass spectrometers since a great many plasmas have only singly charged ions ($q=e$).

A variable magnetic field is typically produced by varying the current through a pair of coils wound around the pole pieces. Such a device is straight forward to design and operate, but coils generate heat that must be dissipated, which is a major problem if they need to be mounted inside a vacuum chamber. Here the magnet assembly consisted of a magnetized rotor and a steel yoke (Fig. 1). The rotor was a rectangular block of permanent magnets surrounded by rounded side pieces to form a cylinder. The two side pieces on the magnet poles were steel; the other two were non-magnetic. The rotor fit into circular cutouts in the steel yoke which connected it to the rectangular pole pieces which had 4.6×10.2 cm faces and a .6 cm gap. As the rotor is turned between the yoke side pieces, the fraction of the total flux which passes through the yoke to the pole piece gap varies, so that when the magnetization axis of the block in the rotor is perpendicular to the yoke pieces, the magnetic field across the gap is maximum, and when the magnetization axis is parallel to the yoke pieces, the transverse gap field is zero (Fig. 2). The transverse gap field plot in the figure was for the first set of magnets used; the maximum has since been increased to 2800 gauss by

using a slightly better set of magnets. Since the yoke is not saturated, and magnets that are 50% stronger are available, it is reasonable to predict that this could be raised to 4000 gauss by using those magnets. The longitudinal field in the gap was too small to accurately measure, and did not degrade performance.

The block of magnets was actually composed of 24 individual magnets. Assembly was greatly facilitated by first assembling all of the analyser, except for the magnets, and then placing it in a large steel vise. With one of the non-magnetic side pieces of the rotor removed it was easy to insert all of the magnets since their fields were "shorted out" by the very low reluctance of the vise. There was no problem with mutual repulsion even with all magnets in place, and in fact a hole had to be drilled in the other non-magnetic piece in order to push the magnets back out. If the vise were not used it would have been impossible to mount more than a few of the magnets, and disastrous to remove the side piece if all were in place.

The rotor has four equilibrium points: the two maxima (of absolute field strength), and the two zero field points. When starting away from these points the magnets first exert a restoring torque on the rotor shaft, but this diminishes to zero, then reverses sign as the next equilibrium is approached. This torque is fairly large, and if the rotation drive is not completely rigid, there will be an uncontrollable jump in the gap field.

The rest of the analyser (Fig. 3) consisted of a Hall probe to measure the gap field, a beam extractor assembly, and a shielded, insulated graphite block into which was drilled a depression which served as the collector cup. The beam path was of 3.9 cm radius and focused at 155° , which was where a .08 cm wide defining aperture was located; immediately behind this was the

collector cup. The entire region in which the beam traveled was enclosed by a conducting box held at acceleration potential to intercept particles not traveling along the collection path. Since the analyser is a potential well, these particles could not leave it anyway, and if not intercepted, they would be deflected back into the analyser by the fringe electric field, and might thus reach the collector. The collector cup was also held at acceleration potential, but by a separate, shielded battery which was grounded through a picoammeter, which served as a very sensitive current to voltage converter. Its analog output and the Hall probe voltage were the inputs to an x-y recorder, which thus produced plots of collected current as a function of magnetic field.

Figure 4 shows a typical mass spectrum taken at 200 volts acceleration, on the multicusp, microwave plasma experiment,¹ for which this particular analyser was designed. Both the positive and negative spectra are shown; the polarity of both the Hall probe signal and the acceleration voltage were reversed when changing particle polarity. As can be seen the ion peaks are quite sharp, and easily distinguished. The positive and negative spectra are slightly shifted (look at H^+ and H^-) due to the positive plasma potential, which retards negative particles but accelerates positive particles.

The author wishes to thank Dr. Norman Abt for much useful discussion during the design of this device and Mr. Bob Wong for help during the final testing.

References

1. J. R. Trow, Ph.D. Thesis, LBL-19136 (Lawrence Berkeley Laboratory, 1985).

Figure Captions

- Fig. 1 Outline drawing of rotor and yoke assembly, steel parts are shaded.
- Fig. 2 Measured transverse gap field vs rotation angle.
- Fig. 3 Detail drawing of spectrometer insert.
- Fig. 4 Typical mass spectrum (collected current vs Hall probe signal).

XBL 8411-6366

Fig. 1

Rotation angle

XBL 8311-3392

Fig. 2

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Fig. 3

XBL 853-1590

Fig. 4

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