MEASUREMENT OF THE MAGNETIC MEDIAN SURFACE OF THE PRINCETON-PENNSYLVANIA ACCELERATOR*

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Summary. A description is made of the equipment used to determine the position and shape of the magnetic median surface (m.m.s.) of the P.P.A. weak focusing magnets far from the magnet ends. The reproducibility of the relative profiles of the m.m.s. was ±0.020 in. or better. The absolute location of the m.m.s. was uncertain to ±0.1 in.

The effects of current sheets through the pole piece face windings and current loops on the front spacer as well as the profile of the m.m.s. were measured for many values of B(r,t), from B minimum to B maximum.

Introduction. The vacuum chamber of the Princeton Pennsylvania Accelerator has a mean diameter of 80 feet and an inside height of only 2.44 inches. Therefore, the measurement of the location of the m.m.s. was of prime importance as well as the study of the effects of different methods for changing and for displacing it, since the vertical restoring forces and the amplitude of the vertical synchrotron oscillations depend on the vertical separation between the m.m.s. and the orbit of the proton.

The magnetic field may be described by

$B(t) = B_{min} + B_{ac}\,(1 - \cos \omega t)$

$= [.27 + 6.8(1 - \cos 38\,\pi t)]$ Kgauss

namely, the magnetic field never vanishes and any measurement made with search coils needs help from some other technique to get the constant of integration.

Theory. Since the radius of curvature of the orbit in the magnets is 360 inches and the radial aperture is ± 3.5 inches about the mean orbit, one may consider the problem as presented in a two dimensional geometry. In a current free region we have that $\nabla \times B = 0$, and from it;

$$\partial Bz/\partial r = \partial Br/\partial z$$

Recalling that $n = -(\partial Bz/\partial r)(r/Bz)$, we get:

$$\partial Br/\partial z = -n(Bz/r)$$

By definition, the m.m.s. is the locus of $Br = 0$. Then,

$$Br = [-n(Bz/Br)]\ \Delta z$$

and

$$\Delta z = -(r/n)\ \Delta\theta$$

where $\Delta\theta = Br/Bz$ = angle the Br measuring device makes with the geometric median plane (g.m.p.) for a null output. This shows that measurements of magnetic field components parallel to the g.m.p. of the gap, at the geometric center of the gap, provide the data to locate the m.m.s. with respect to the g.m.p. We thus see that the problem has two parts: a) the measuring of vanishingly small magnetic fields in a given direction (the signal to noise ratio limits the sensitivity of the method); and b) the mechanical alignment of the field measuring devices such that their magnetic centers be on the g.m.p. or at a known distance from it and oriented along the radius of the magnet at that point.

Field Measuring Devices. The measurements were divided into two magnetic field ranges, $Bz < 1$ to 1.2 Kgauss, and $Bz > 1 - 1.2$ Kgauss. In the first range the measurements were made with "peaking strips"[1] (used actually as second harmonic generators) driven by a second harmic free sine-wave generator and using a second harmonic tuned detector. In the second range, the measurements were made using a Garrett line dipole coil[2], and a Kintel operational amplifier used as an integrator.

The peaking strips were made of 0.001 inch diameter molybdenum permalloy wire, about 0.50 in. long, with the two coils wound directly on top of the wire. The coil connected to the sine-wave generator had the full length of the wire. The pick-up coil was centered and it was about 0.10 inch long. Both coils had two layers wound with .0012 in. diameter formvar covered copper wire. These assemblies were made under a microscope and potted under tension in ceramic boats. After the epoxy-resin had hardened, the excess permalloy wire was cut-off. Although there was no problem in making these assemblies, only about 10% of the units had enough directional sensitivity to be useful. We made twenty, and three were sufficiently sensitive to be useful. The oscillator was a 100 Kc crystal controled and of variable output, it fed the peaking strip through a 100 Kc, doubly tuned filter. The pick-up coil was connected to a 200 Kc filter and then to the Y-input of an oscilloscope. The direct or the integrated output of a coil in the same full scale magnet provided a sweep signal for the X-axis. If the peaking strip was perpendicular to Bz, then there would be no second harmonic output. The sensitivity of the system was maximum at the minimum usable 100 Kc amplitude.

The search coil was wound on a ceramic coil form made of three sections individually ground until the long sides defined parallel vertical and horizontal planes. Two layers were wound under

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a microscope to assure essentially perfect parallelism between the individual long runs of each turn and the long direction of the search coil. After the thin, twisted leads were connected, the two layers were sealed with paper, to protect them from the potting compound which was cast over the paper as over-all mechanical protection.

Positioning Devices. The P.P.A. synchrotron magnets have detachable pole pieces. These pole pieces were stamped and assembled so that their over-all dimensions are known to ± 0.0002 inch. Then, they are spaced from each other by precisely ground stainless steel spacers with ceramic top and bottom surfaces. Thus, the location of the geometric median plane is known to an over-all accuracy of ±0.0003 inch at each end of the pole pieces, or 3.7×10^{-5} rad in the angle the pairs of pole pieces form with each other. Since $z = -(r/n)\Delta\theta = -6 \times 10^{2}\ \Delta\theta$ inches, this uncertainty alone introduces an error of 3×10^{-2} in. in the absolute location of the m.m.s. with respect to the g.m.p.

Both peaking strips and the search coils were moved on an optically flat alumina plate which rested on the lower pole pieces on a sapphire leg and two leveling screws. The peaking strips and the search coil were then positioned on sapphire disks, 2 in. diameter, which had optically flat surfaces parallel to each other within half a wave length of the mercury green line. The peaking strip boats and the search coils also had sapphire legs ground as to make the magnetic axis of the devices parallel to the plane defined by the leg tips. When these devices were on the sapphire disks on the leveled alumina plate their axes were essentially on the g.m.p.

Initially, a source of inconsistency in the data was due to specs of dust on the alumina plates and the air layer between the sapphire disk and the alumina plate. The use of lens cleansing tissue solved these problems.

Procedure. The readings were taken in the following manner: 1) the alumina plate would be placed in the azimuthal position where a m.m.s. profile was needed. An autocollimation mirror (faces at 90°00'00"±0°00'01" to the base) would be placed on its far end (smaller radius); 2) the peaking strip would be positioned and the second harmonic pattern at a time (field) of interest studied; 3) the peaking strip would be tuned through 180° and the leveling adjusted to obtain again the same second harmonic pattern; 4) the alumina plate would be adjusted half way between the two levels; 5) the angle between the plate and the horizontal plane would be determined by autocollimation with an optical level; 6) a reference plate with three sapphire legs would replace the adjustable plate and the angle between the g.m.p. and the horizontal plane would be measured by autocollimation; 7) the difference between 5) and 6) would give the angle $\Delta\theta$.

For the search coil the method was similar, except that the constant of integration would be obtained from the peaking strips.

For relative profiles of the m.m.s., only the plate with the leveling screws was used and readings were taken of the change in leveling angle versus radial position of the device.

Results. Typical results for different pairs of pole pieces are shown in Figure 1. These profiles were reproducible to ± 0.020 inches.

The absolute location of the m.m.s. profiles with respect to the g.m.p. involved four times as many mechanical measurements.

Thus we obtained results consistent within ±0.1 inch.

To examine the effects of the mechanical assembly the magnet was disassembled and reassembled and the m.m.s. remeasured. The results were entirely consistent with those obtained initially.

The pole piece windings glued to the top and bottom of the outside of the vacuum chamber were designed to provide current sheets capable to correct for the location of the m.m.s. as well as the n at injection fields. For purposes of study they were divided in three sections and their effect on the m.m.s. are shown in Fig. 2.

It was found that a one ampere turn parallel to the front spacer could straighten the m.m.s. in the front.

Measurements of the m.m.s. as a function of Bz, showed essentially no motion of the m.m.s. with Bz in the region of "good n", e.g., about 2 inches from the front and back shimms of the pole pieces. Near the back shimm the m.m.s. moved about .05 inches and near the front shimm it moved .08 inches, from injection field to B(max).

After the magnets were completed and 3 Mev protons could be injected, the beam was found to be vertically centered; it was never necessary to make any m.m.s. corrections. The vertical coils were never actually connected.

References

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2. Brookhaven National Laboratories, Accelerator Development Dept., unpublished report LJL-2, L. Jackson Laslett, "Coil Systems For Measurement of Field and Field-Gradient In Two Dimensional Magnetic Fields". July 16, 1954.

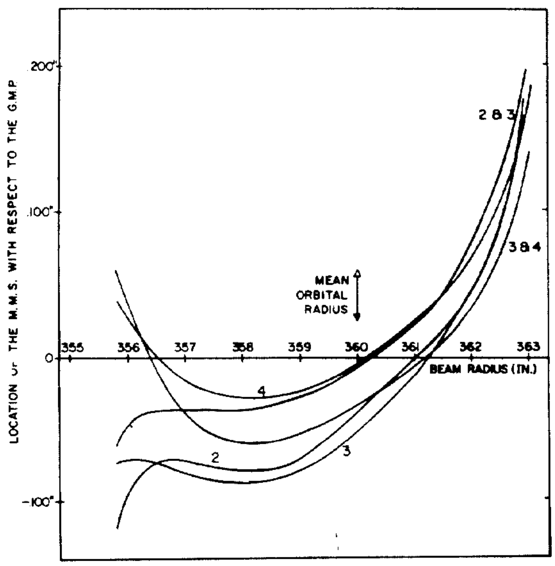

Fig. 1. This is a composite of several measurements of the magnetic median surfaces for different pairs of pole pieces. The differences in these profiles for a given pair of pole pieces were within ± 0.020 inch. The normalizing point was reproducible within ± 0.1 inch for any given pair.

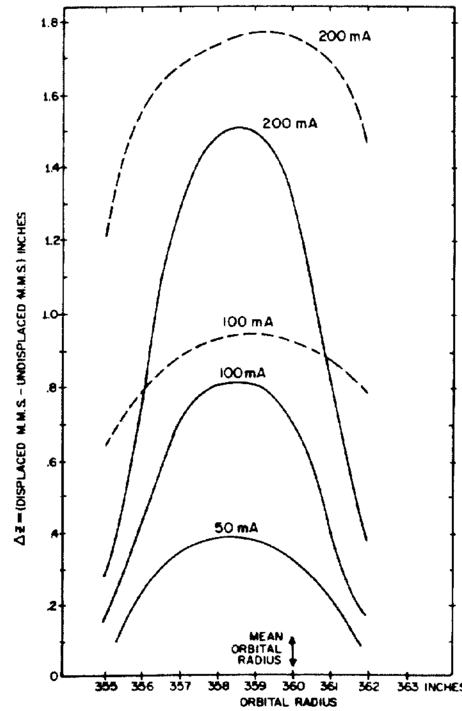

Fig. 2. Variations in the location of the magnetic median surface as a function of the intensity of current sheets on the pole pieces. Solid lines: central one third width current sheets, dashed lines: full width current sheets.

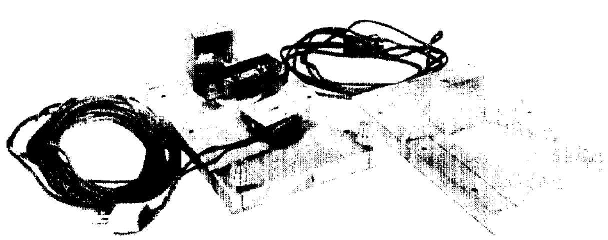

Fig. 3. Left: Photograph of the reference plate with leveling screws with autocollimation mirror, line dipole coil and peaking strip in ceramic boat. Right: Reference plate with ceramic legs and autocollimation mirror.

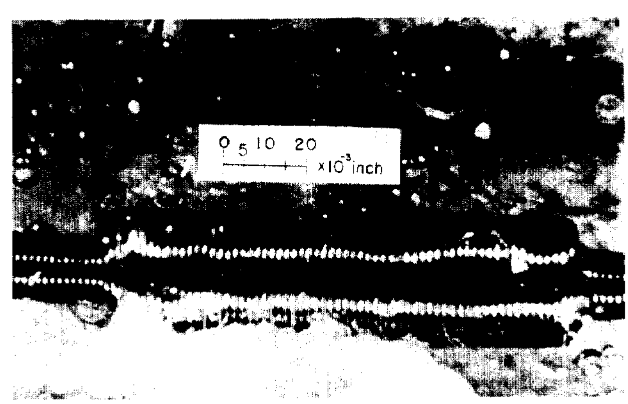

Fig. 4. Microphotography of peaking coil showing pick-up coil and part of the long coil.