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WIRE ORBIT RAY TRACING OF MAGNETS USING MAGNETOSTRICTIVE WIRE CHAMBER TECHNIQUES*

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We describe briefly a method for precise momentum calibration of magnets which combines the well-known floating-wire technique of tracing particle orbits through magnetic fields and electronic readout using magnetostrictive delay lines similar to those used in wire spark chambers. The advantage of this method lies in the rapid and accurate measurement of many particle trajectories in a relatively short period of time. The use of magnetostrictive readout electronics eliminates the tedious work of measuring individual trajectories optically, and provides means by which the procedure can be computer controlled.

1. Introduction

Recent advances in spark chamber technology and electronics have enabled physicists to connect spark chambers to on-line computers. A number of such systems exist today, and many of the wire spark chamber systems use magnetostrictive readout systems. For those who plan to use such systems in conjunction with bending magnets, we report here a technique which combines the features of the magnetostrictive readout system with the well-known floating-wire technique to give a rapid and accurate calibration of momenta of particle trajectories through a magnetic field. The details of the floating-wire method and the application of the magnetostrictive readout system to it are described in the following sections[1-3].

Briefly, the magnetostrictive readout system is used to determine the position of the floating wire in the same way as it detects to position of a wire carrying current from a spark discharge in a wire spark chamber. Several magnetostrictive pickups are laid at known positions in the plane of the floating wire. After the wire assumes its equilibrium trajectory through the magnet, a current pulse is sent down it which generates sound waves in the magnetostrictive ribbons. The time-of-flight of these sonic pulses with respect to fiducial pulses is digitized and stored on magnetic tape by an on-line computer. Further computer programming uses these data, plus the dc current and tension of the wire, to generate the momentum calibration of the magnet. Thus, the calibration method is quite similar to the way in which the magnet is used in an experiment to determine a particle's momentum.

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2. Techniques

The floating-wire teehnique is based on the fact that the curvature of a stretched, current-carrying wire in a magnetic field is the same as that of the trajectory of a charged particle of a particular momentum in the magnetic field. In practice, a current carrying wire is extended from a fixed point outside the region of magnetic field, passing through the magnet and over a pulley fixed in the field-free region beyond the magnet. A known mass M is fastened to the wire and allowed to hang freely below the pulley, providing a constant tention T in the wire, but allowing the arc-length of the trajectory between the first fixed point and the pulley to vary. Given a current I and tension T, and provided that the points at which the wire is held do not fall on the magnet's foci, the resulting trajectory of the wire is uniquely that of a singly charged particle passing through those two points with momentum given by

$$P(\text{MeV}/c) = 2.94\ T(\text{gm})/I\,(\text{A}).$$

By varying the current (or the tension), one is able to select trajectories of different momenta. By varying the positions of the "fixed points", trajectories of differing entrance and exit positions can be obtained. Thus, one can map out the entire family of trajectories of interest in a given magnet configuration. The limitations in the method arise from the difficulty of measuring accurately the location of the floating-wire for each separate trajectory. To circumvent this serious difficulty, we use a magnetostrictive wire spark chamber readout system to electronically digitize the position of the floating wire. In the external regions where no appreciable field exists, the trajectories are straight. We placed five magnetostrictive ribbon pickups, the same as those used in wire spark chambers, at uniform spacings, parallel to one another, on the entrance side of the magnet and similarly on the exit side of the magnetic field. The floating wire lies just on the surfaces of the pickup devices, lightly touching them (see fig. 1). To obtain the positions of the wire above the magnetostrictive pickups, a large instantaneous current is superimposed on the steady dc current standing in the wire, by discharging a capacitor through a spark gap connected to the floating wire[4]). The large transient current in the floating wire does not disturb noticeably its equilibrium orbit. At the same time, beginning and end fiducial wires are fired to provide the electronics with the usual start and stop signals. The power supply which provides the current is isolated from the discharge of the capacitor by a low pass filter to protect it from large transient voltage. A 100 Ω resistor is placed across the capacitor to damp large oscillating currents which otherwise occur due to the inductance of the floating wire. The fiducials which provide the start and stop signals for the electronics are placed at known positions at the beginning and end of the magnetostrictive ribbon. Currents are induced in the fiducial wires by connecting separate capacitors to the spark gap, thus insuring that all signal currents are triggered at the same instant. The position of the wire at each magnetostrictive pickup is obtained by interpolation between the known fiducial positions, in the usual manner. The position of the floating wire was digitized by the electronics to an accuracy of about 0.2 mm at five points on each side of the magnet. These values were used then to fit to two straight lines, which were sufficient to completely determine the trajectory. The errors in the fit to the form

$$y = mx + b$$

for the external part of the trajectories were typically

$$\Delta m \simeq 0.004, \qquad \Delta b \simeq 0.08 \text{ mm}.$$

Fig. 1 shows the general configuration of the calibration setup. To hold the electrical noise emanating from the high voltage trigger at the time of the discharge to a tolerable level, the power supply, digital volt meter, and computer were in a separate room, some distance from the test setup. It was also helpful to ground the magnetostrictive ribbons to a local ground common to the high voltage trigger.

3. Momentum reconstruction from particle trajectories

The method by which the data can be cast a useful form depends to some degree on the individual situation. Here we describe briefly our method which is adequate for the case of a simple bending magnet. This approach is suggested here only as one possibility for analyzing the data. No attempt is made to

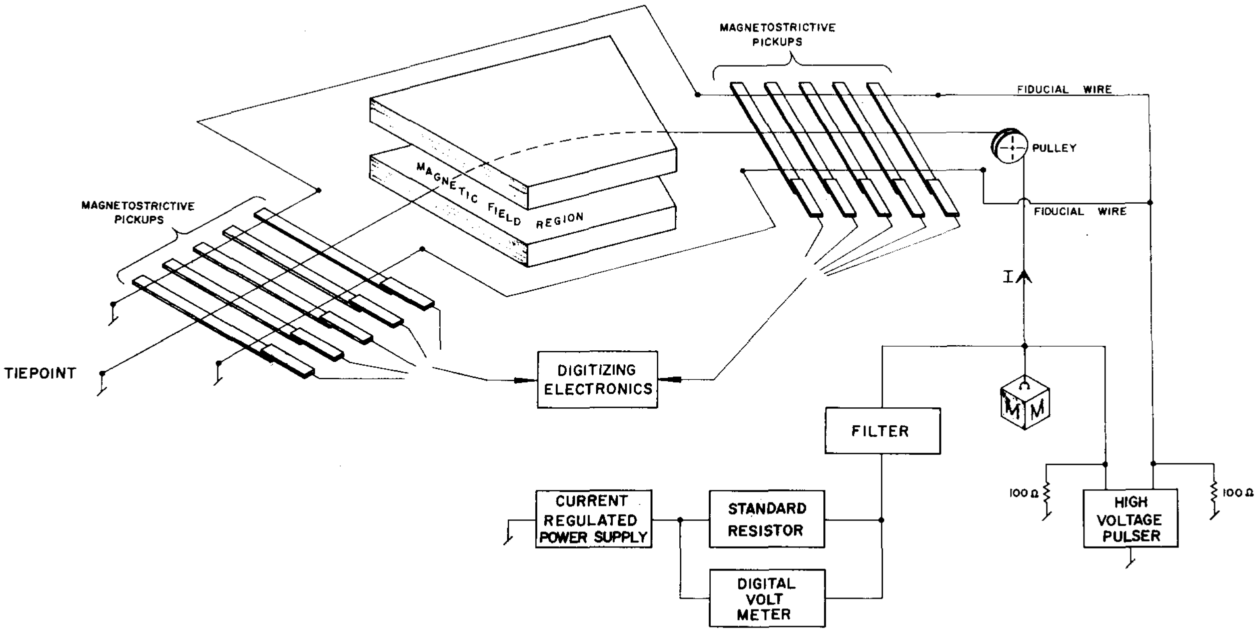

Fig. 1. Configuration of the equipment. The floating wire passes over the surface of magnetostrictive pickup devices. The trajectory of the wire is adjusted by moving the tie point and pulley laterally, as well as by adjusting the current I. The trajectory is measured by pulsing the wire with a large transient current which generates signals on the magnetostrictive pickups.

be completely general. Consider a single trajectory through a region of magnetic field lying in a plane perpendicular to the field direction. It is uniquely defined by a position on the entrance and exit sides, and by an angle of bend. We use the three parameters x_1, x_2, $\tan\theta$ (see fig. 2) and write

$$P = f(x_1, x_2, \tan\theta)\,.$$

We chose a central orbit whose momentum is measured to be P_0. and expand $f(x_1, x_2, \tan\theta)$ about that value. Then

$$P = P_0 + a_1\,\Delta x_1 + a_2\,\Delta x_2 + a_3\,\Delta(\tan\theta) + \ldots$$

We keep all terms through fourth order in Δx_1, Δx_2, $\Delta(\tan\theta)$ and perform a least squares fit to our data. There are 34 adjustable parameters to be fit to a much greater number of separate trajectories.

To insure a unique solution to the least squares

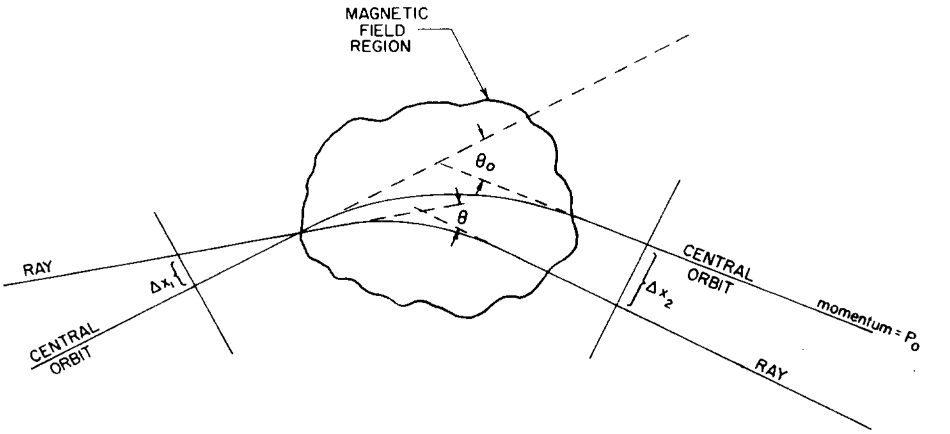

Fig. 2. Coplanar trajectories through a region of magnetic field. The momentum of particle trajectories in a plane is determined by two positions, x_1, x_2, and the angle of bend θ. The central orbit is chosen to satisfy experimental considerations. The momenta of other trajectories is determined from a power series expansion in the terms x_1, x_2, and $\tan\theta$, about the central orbit.

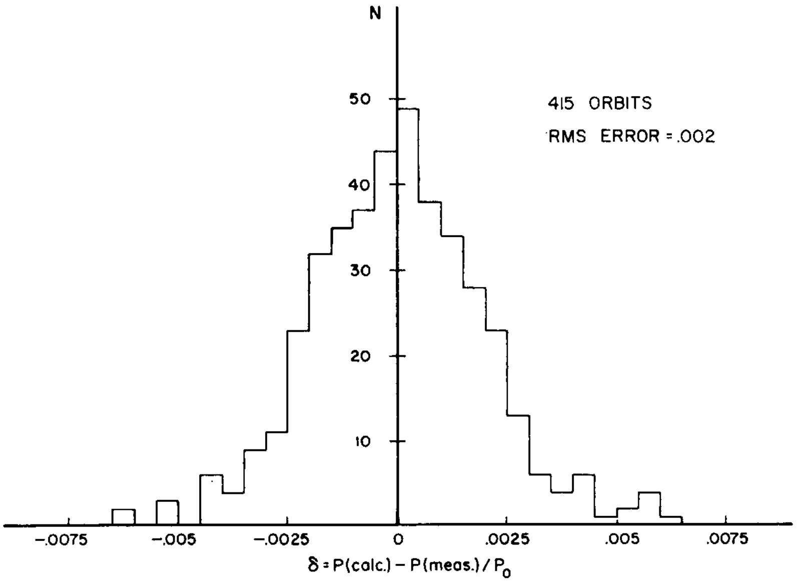

Fig. 3. Histogram of residuals from fourth order fit for sample magnet calibration. The fourth order residuals,

$$\delta = [P_{\text{(calculated)}} - P_{\text{(measured)}}]/P_0,$$

are plotted for 415 orbits for one magnet configuration, for various values of x_1, x_2, and θ. The momenta covered in the calibration range from 600 MeV/c to 1000 MeV/c. Typical error is 0.2%.

fitting procedure, the number of measured orbits must exceed the number of adjustable parameters. Clearly, the more parameters one keeps, the better the reconstructed momentum fits will be. However, one must be careful not to try to reconstruct momenta for trajectories which fall outside the range of x_1, x_2 or tan θ for which data were taken.

For particle trajectories not falling in the median plane of the bending magnet, the magnetic field in the region of the fringing fields will be different from that seen in the median plane. However, to first order in the pitch angle, the corrections to the fitted coefficients vanish. Where error due to the pitch angle cannot be neglected, the corrections can be calculated, or measured. For best results, wire orbits should be chosen which uniformly span the ranges of x_1, x_2, and tan θ.

In fig. 3 we show the goodness of a fourth order fit for the momentum calibration of a simple non-focussing bending magnet. The various orbits measured covered a momentum range of 600 MeV/c to 1000 MeV/c. Using coefficients calculated by the least squares fitting, we obtain a $P_{(\text{calculated})}$ for each orbit. From measured values of the current and tension in the wire, we obtain a $P_{(\text{measured})}$. For each trajectory we plot in a histogram the quantity

$$\delta = [P_{(\text{calculated})} - P_{(\text{measured})}]/P_0.$$

For this calibration P_0 was chosen to be 800 MeV/c and a central orbit corresponding to this momentum was chosen and carefully measured. From fig. 3 we see that the accuracy of the fit is good; the calculated momenta agree with the measured momenta to about 0.2%.

4. Reconstructed particle trajectories

In section 3, we answer the question "If you know the particle trajectory, what was its momentum?" Experimentally, when one uses a magnet, it is often necessary to know its momentum acceptance. Thus, we must ask the inverse question, "Given the incoming momentum and trajectory, where will the particle go?" One can use the same set of data to predict the outgoing trajectory of the particle given its incoming momentum and its incoming trajectory. In the field-free region beyond the magnetic field, the trajectories are straight lines, parameterized by a slope M and an intercept B. Following the procedure in section 3, we write

$$M = M(P, x_1, \tan\theta_1) \quad \text{and} \quad B = B(P, x_1, \tan\theta_1).$$

Where P is the given momentum, x_1 is the displacement of the incoming trajectory relative to the central orbit at some specified point, and θ_1 is the angle between the incoming trajectory and the central orbit. Again a power series expansion, for both M and B is carried out in terms of P, x_1, tan θ_1, with respect to the central orbit, keeping as many terms as is required to achieve the prescribed accuracy. The coefficients of the expansion are obtained, as before, by a least squares fit to the measured trajectories. The outgoing particle trajectories are given by the form

$$Y = Mx + B$$

in the free-field region.

5. Automation

The method described here allows one to digitize electronically the positions of the various orbits through a magnetic field. The techniques provide all the basic methods needed to automate the procedures if so desired. One must provide a means by which the positions of the orbits could be controlled by computer program and the current in the wire could be adjusted and measured. These problems are easily handled with present day techniques.

References

[1]) V. Perez-Mendez, Th. J. Devlin, J. Solomon and Th. F. Droege, Nucl. Instr. and Meth. **46** (1967) 197.

[2]) F. A. Kirsten and R. J. Rudden, A low-cost large scale magnetostrictive spark chamber system, UCRL 17938 (University of California, Febr. 1968).

[3]) A modular electronic data acquisition system for magnetostrictive readout of wire spark chambers, RHEL/R 157 (Chilton Rutherford Laboratory, Dec. 1967).

[4]) A spark chamber trigger circuit, such as the Scientific Accessories Corporation, Model 002A will suffice.