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DEVICE FOR THE MEASUREMENT OF THE MEDIAN PLANE POSITION

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This paper describes a device for the measurement of the median plane position based on the EDS Hall probe. The device is a component of the system for magnetic measurements. The design of the device's probe is given. The probe is positioned at the measuring point by remote control and the results are recorded automatically. When using a P339 digital voltmeter, the device's sensitivity is 0.5 cm. Possible sources of error are examined.

When shaping the magnetic field in a circular-orbit accelerator, it is essential to check the position of the plane of field symmetry -- the median plane. Locating the median plane in accelerators with weak focusing is a particularly difficult task. There are several papers describing methods for determining the position of the median plane[1-4], which are based on the measurement of the magnetic field components in its vicinity. The following expansions occur in an azimuthal-symmetrical field close to the median plane:

$$B_r = -nB_{0z}\frac{z}{r} + \frac{B_{0z}}{6}\left(r^2 n'' - 2rnn' - rn' + n^2\right)\frac{z^3}{r^3} + \ldots$$
$$B_z = B_{0z} + \frac{B_{0z}}{2}\left(rn' - n^2\right)\frac{z^2}{r^2} + \ldots \qquad (1)$$
$$B = \sqrt{B_r^2 + B_z^2} = B_{0z}\left[1 + \frac{1}{2}(rn')\frac{z^2}{r^2} + \ldots\right],$$

where B_{0z} is the field on the median plane, $n = -(r/B_{0z})(dB_{0z}/dr)$, and $n' = dn/dr$. For example, the median plane can be determined using the nuclear magnetic resonance technique by finding the extremum of value B in terms of the gap height. In order to determine the median plane to 1 cm accuracy in an accelerator with weak focusing, it is essential to have 10^{-5} - 10^{-6} accuracy in the measurement of magnetic flux density value, and this is difficult.

In our device, the position of the median plane is fixed in terms of the magnetic field's radial component which is measured using a Hall probe. The use of the Hall probe simplifies the measuring circuit considerably and enables the measurement process to be automated.

As the magnets are normally equipped with horizontal pole tips, it is convenient to make use of the direction of gravity in order to define the direction of the z-axis. Therefore the field's radial component is measured by a vertically oriented Hall probe using the technique proposed in Ref. 4. With this method, errors caused by the inaccurate vertical orientation of the probe are avoided by subtracting the results of measurements in the probe's initial position and in a position 180° from the vertical.

The design of the device's probe is shown in Fig. 1. The large copper cylinder to which the Hall probe is attached is suspended on a capron thread. The angle between the plane of the probe and the vertical is governed by two screws. Current is fed to the probe by means of thin wires 0.05 mm in diameter. The probe was placed inside a brass container (not shown in the diagram) and is secured in it. The probe is moved along the z-axis and turned through the vertical by moving the container.

In order to avoid sliding contact during the transfer from the moving part of the device to the fixed part, the conductors were constructed as a loop, which is stretched and compressed during rotation and translation. The copper cylinder serves as a damper of the pendulum-type oscillations of the Hall probe due to the counteraction of the Foucault currents. The latter condition enables measurements to be made almost immediately after the position of the probe at the selected point.

The block diagram for the measurement process is shown in Fig. 2. The Hall voltage is measured by a P339 digital voltmeter with a print-out facility. An automated co-ordinate system wired to the control unit enables the probe to be positioned at the selected point according to radius r, azimuth θ, height z, and the probe's angle of turn ϕ. When the probe is positioned at the point, the digital voltmeter's trigger signal is developed. After the voltmeter's code has been converted in the display unit and the four last figures for the Hall voltage have been checked, the coordinates r, θ, z and ϕ($\phi = 0$ or $\phi = \pi$) are printed on paper tape by a digital print-out machine.

Power is supplied to the Hall probe by a transistorized current regulator. The regulator's regulation coefficient is $\sim$ 150 and it provides a current of 15 to 50 mA at a nominal load of $\sim$ 300 Ω.

Thus, this system performs remote control of the probe and automated recording of measurements.

The device can determine the position of the median plane in two ways.

The first involves the absolute measurement of the value in the gap's mean geometric plane. In order to determine the position of the plane in this instance, it is essential to know the distribution of value B_x in the gap's mean geometric plane. Then the position of the median plane is found from the formula

$$Z = \frac{B_z}{\left(\frac{\partial B_z}{\partial z}\right)} \qquad (2)$$

This method is used when the distance between the median plane and the mean geometric plane does not exceed the limits of the linear dependence B_r on z (with the given accuracy of measurement). The measurement error Δz equals

$$\Delta Z = \frac{\Delta B_z}{(\partial B_z/\partial z)} + Z \cdot \delta\left(\frac{\partial B_z}{\partial z}\right), \qquad (3)$$

where ΔB_r is the error in measuring B_r and $\delta(\partial B_z/\partial r)$ is the relative error in determining the gradient. Error comes into (ΔB_r) when determining the sensitivity of the probe.

When using the P339 device with 100 μV sensitivity, a Hall probe with 100 μV/G sensitivity and a gradient of $\sim$ 2.5 G/cm, the sensitivity of our device equalled 0.5 cm. When using an M95 current device, it is possible to increase the sensitivity of the device, but in this case recording is not automatic.

The second method involves the relative measurement of the B_r value at several points on various sides of the median plane (normally at two points). The position of the median plane is found by linear interpolation.

In this case, there is no need to determine the B_z gradient and the detector's sensitivity. The device becomes essentially a "null device".

This greatly assists measurements, as in this case the slow temperature variations in the Hall probe's sensitivity are not significant. By subtracting two measurements to obtain the B_z value, the effect of slow current drift and the voltage of the Hall probe's non-equipotentiality is eliminated. If the pole tips are not horizontal, this can lead to considerable errors in the use of both methods. Even when the poles are only slightly out of horizontal, the field's vertical component has a substantial influence which is not offset when the probe is turned through 180°. When there is a parallel displacement of both pole tips through a narrow angle (see Fig. 3) the device will measure the field's horizontal component in the radial direction, which equals

$$B_{rop} = B_r - \Psi B_z \sin\vartheta , \qquad (4)$$

where θ is the azimuthal angle, counted off from the pivotal axis of the pole's plane counter-clockwise. To ensure that only a slight correction is needed, it is essential to fulfil the condition

$$\Psi \ll B_r / B_z \qquad (5)$$

The tolerable value for Ψ depends on the value of B_r, i.e. on the gradient $(\partial B_z/\partial r)$, and is usually of the order of $\sim 10^{-4}$.

The accuracy required for setting the probe's initial orientation and that for setting the angle of turn, equal to π, depend on the value of the azimuthal component B_ν. If the angle is set with Δ_ν accuracy, it is essential to have

$$\Delta \Psi \ll B_r / B_\vartheta \qquad (6)$$

It should be noted that the accuracy required for the setting of the angle increases with the displacement of the pole tips, as in this case the following component appears in the horizontal plane perpendicular to B_{hor},

$$B'_\vartheta = B_\vartheta - \Psi B_z \cos\vartheta \qquad (7)$$

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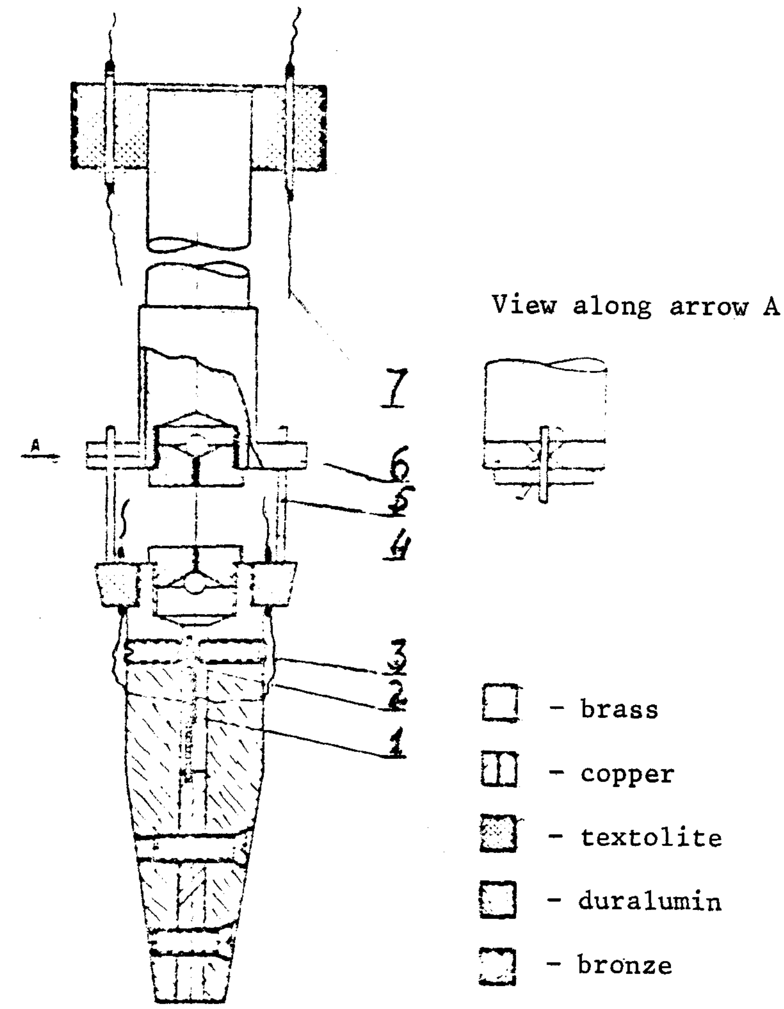

<u>Fig. 1</u>

Design of the device's probe

1. Hall probe. 2. Probe support. 3. Adjusting screws. 4. Capron thread. 5. Support. 6. Collimating forks. 7. Thin conductor - 0.05 mm.

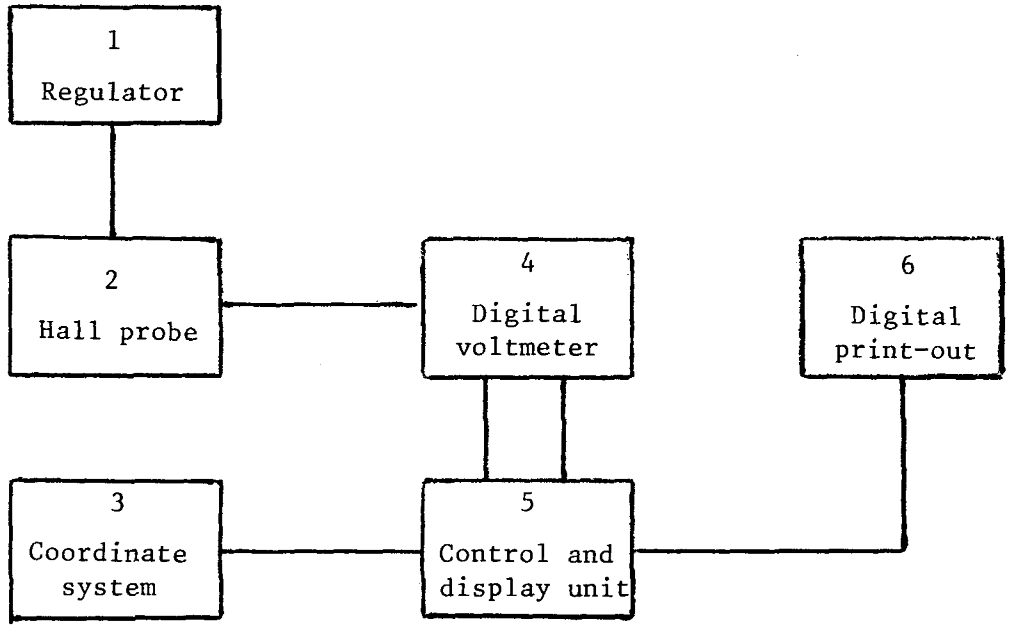

Fig. 2

Block diagram of the device

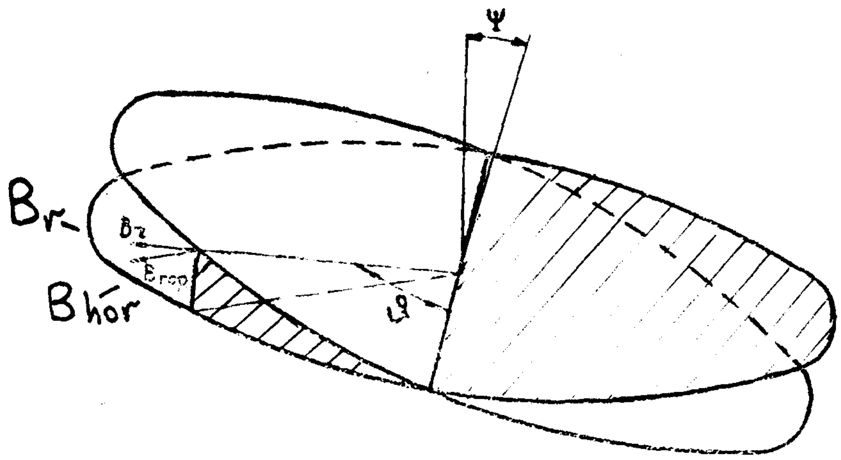

Fig. 3

Displacement of the pole-tip plane through angle Ψ and the radial B_r and horizontal B_{hor} field components in azimuth θ.