MEASUREMENTS, WITH PEAKING STRIPS IN THE GAP OF A WEAK-FOCUSING ELECTRONSYNCHROTRON, OF MEDIAN MAGNETIC SURFACES IN THE STATIC FIELD AND OF n AT THE INJECTION IN THE DYNAMIC FIELD *

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1. We want to describe the chief characteristics of the two methods of measurements worked out for the static measurements of the median magnetic surface (m.m.s.) and the dynamic measurements of n at injection. They are based on the use of peaking strips. These methods can also be used to satisfy the following requirements :

a) High sensitivity in dynamic measurements of the gradients at low fields.

b) High precision in the direction in static measurements of small components of strong magnetic field ($\leqslant 1000$ gauss).

2. The two measurements of the injection dynamic values of n and of m.m.s. at low field are particularly difficult in a weak-focusing electronsynchrotron. This is because of the low value of the magnetic field at the injection (22.7 gauss in the Italian electronsynchrotron), and of the low value of the ratio B_r/B_z between the radial and vertical components of the field ($\simeq 1/3000$ in our case). We have no information what measurements of this type have been carried out with the desired precision.

Our aim has been reached by giving up the old idea according to which the high permeability of the fine wires made of mumetal or similar alloys would certainly be lost as a result of bending or mechanical handling. It is known that in a ferromagnetic body a line of tension may form a direction for easier orientation of the domains. For example the permeability along such a line will be higher than the one measured in a normal direction. If an internal or external tension is applied it therefore produces an anisotropy in the permeability in the ferromagnetic material. If a mumetal wire (previously heated) is twisted we get a decrease in its permeability in an axial direction. If we subject it only to pure tension its axial permeabilty is increased.

Now to obtain high directionality, above all for measurements of m.m.s. it is necessary to keep the wires straight. This means that they must be put under tension, as far as possible without twisting them in any way.

For wires of mumetal M 1040 with a diameter of between 0.1 and 0.025 mm. (furnished by the Vacuum Schmeltz of Hanau) the problem has been solved in the following way.

A mechanical device can hold and twist the wires between a couple of Helmholtz coils. They submit the wire to an alternating magnetic field of 10^3 Hz and with an amplitude of 5 to 10 gauss. The wire, for example, 40 mm. long passes through a small glass tube (∅ int. 1 mm.), 20 mm. long. Around this tube is wound a pick-up coil joined to an oscilloscope by means of which we can observe the pulses of the e.m.f. induced during the inversion of the magnetization of the wire. The wire being longitudinally stressed (with 5 to 8 kg/mm^2) the twisting is regulated until the maximum pulse is reached. Then cold liquid araldite is introduced by capillary action. When it is quite solid the wire is cut at both ends of the little glass tube so that the peaking strip is ready for use. By this method the permeability of the wire remains high enough, the wire becomes straight and also rigidly attached to the glass tube.

The latter property is, for example, necessary for measurements in a strong and variable magnetic field. For the measurements of n it is necessary to measure shifts in the time of 10^{-8} seconds of the pulses with 5×10^{-6} seconds of the rise time.

A measurement by superposition of the pulses would perhaps be impossible. The difficulty has been overcome by transforming variations in the time of a pulse into variations of amplitude of a pulse difference of two others. This will be explained in detail later.

3. Now we want to describe a new use of the ferromagnetic wires for the determination of m.m.s. in the static field between 20 and 1000 gauss in the gap of a weak focusing synchrotron, with an error of ± 1 mm.

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* This paper was presented in title only.

in the absolute position. The differential probe constructed for this purpose is also employable for the determination of the field lines curvatures, i.e. for the measurements of the field index n to a predictable accuracy of about 5%. The latter kind of measurement will not be taken into consideration in this paper.

We shall now explain qualitatively the working principle of the device. Let two thin ferromagnetic wires of high permeability, supposed equal, parallel and straight, be subjected to an alternating sinusoidal magnetic field whose frequency is $\nu \simeq 1000$ cycles and whose amplitude is such as to saturate the ferromagnetic material. Let the field always be equal and opposite in the two wires, and each of them be surrounded in its central region by a pick-up coil (fig. 1a). Then a series of pulses of induced e.m.f., alternating in sign, may be obtained from each of the two coils. If we series-connect the two coils in the same direction, the pick-up e.m.f. will be zero (or minimum), since we shall have, altogether, pairs of like pulses, opposed and simultaneous (or very nearly). Now, if we subject the wires thus excited to a steady magnetic field, the pulses will shift in time in the direction indicated by the arrows in fig. 1b. The leading of a pulse of one coil will correspond to a delay of the corresponding pulse of the other one. Thus a pulse-difference whose peak-to-peak amplitude is proportional, within certain limits, to the applied, steady magnetic field will arise at the output of the two series-connected coils. If, on the other hand, we subject one wire to a steady field, equal and opposite to that acting on the other, we shall again have a e.m.f. zero (or minimum) at the output of the two series-connected coils and in the same direction, since the pulses will now be shifted as in fig. 1c, and a pulse delay coming from one coil will correspond to an equal delay of the corresponding pulse from the other one; a similar situation will occur for the leadings.

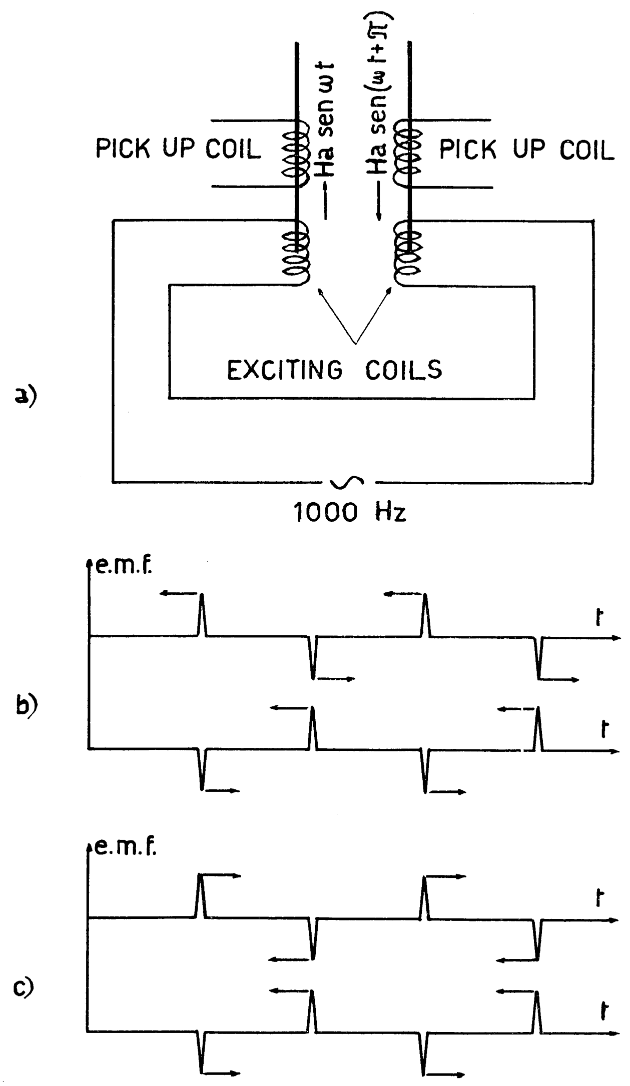

Fig. 1.

What we have said is valid in the case where the steady field is less than the alternating field-amplitude. We thus conclude that this device may be a very sensitive detector of the function "algebraic sum" of the components along the wires of a magnetic field. If the alternating magnetic field had the same sense in the two wires at every instant the device would reveal variations of the function "algebraic difference" of the components.

As detector of the function "algebraic sum" it is employable in the determination of the m.m.s. in the gap of a magnet of sufficient size, particularly in the gap of a weak-focusing synchrotron. In fact the m.m.s. is defined as the locus of the points in which the radial component B_r of the field is zero.

In the case of a synchrotron, we may indicate the radial and vertical coordinates with origins at the centre of curvature of the circular sector of the synchrotron and on the m.m.s. respectively by r and z. The later represents the surface of symmetry for the field-lines; in this way one will have inside the gap :

$$B_r(r,z) \simeq - B_r(r,-z), \quad B_r(r,0) = 0 \quad .$$

Now, if we put the wires parallel to each other, parallel to the vertical plane and to the radial direction, and displace them vertically so that this parallelism is maintained, the device will inform us when :

$$B_{1r}(r,z_1) + B_{2r}(r_1z_2) = 0 \quad ,$$

where z_1, z_2, B_{1r}, B_{2r} are coordinates of the centres of the two wires and the respective components.

Then also : $z_1 \simeq - z_2$ and the altitude of the m.m.s. will be that of the midpoint between the centres of the two wires, with sufficient approximation.

The wires are made straight by the method described in 2. Then they are made parallel to each other and in the median geometric plan (m.g.p.) of the gap, using a standard magnet, by the method of calibration described elsewhere[1]. This ranging must be kept in an angle $\Delta\,|\,\theta\,| \leqslant 2.5 \times 10^{-4}$ rad. so as to obtain an error $|\,\Delta z\,| \leqslant$ $\leqslant 1$ mm. in the determination of the m.m.s.

In fact if the wires are parallel to each other and to the radius R of the synchrotron, but form an angle θ with the m.g.p., then we have :

$$\Delta z = R/n \cdot \mathrm{tg}\,\theta$$

The necessary sensitivity is given by :

$$\Delta B = 2nB_z/R \cdot \Delta z \simeq \quad B_z/3000 \cdot \Delta z \quad .$$

For $B_z = 30$ gauss; $\Delta z = 1$ mm. we get $\Delta B = 10^{-3}$ gauss, which can be obtained by using an oscilloscope or an electronic device.

In a ferromagnetic wire, infinitely long, subsjected to an external perpendicular induction B_e, the induction takes the value :

$$B_i = \frac{2\mu}{\mu+\mu_0} B_e \qquad \begin{array}{l} \mu = \text{permeability in the wire} \\ \mu_0 = \text{permeability in the vacuum} \end{array}$$

also when $\mu = \infty$ we should have $B_i = 2B_e$.

If such a wire has the saturation induction $B_s = 6.000$ gauss, it is sufficient to have $B_i = 3000$ gauss to have complete transversal saturation.

Wires 20 mm. long and 0.025 mm. in diameter have been obtained, which when subjected to the normal field $B_z = 100$ gauss can still be used for m.m.s. measurements.

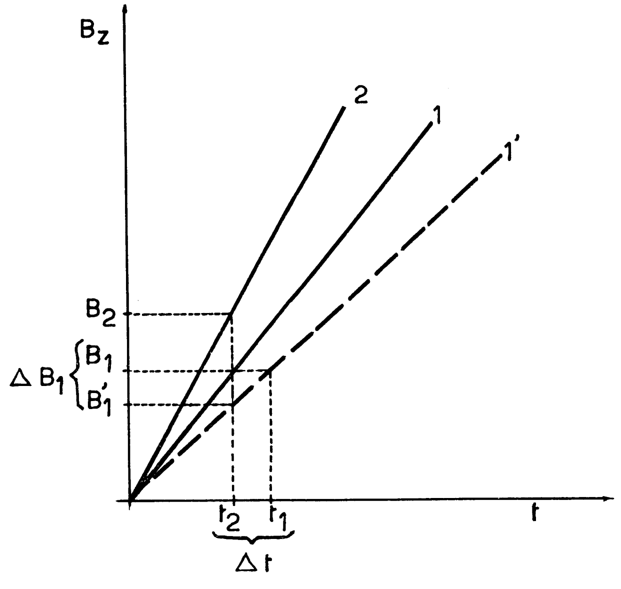

Fig. 2.

4. Let us now shortly explain the method for the measurement of n at the injection (22.7 gauss) with an absolute error of 5%, in alternating field, experimented with success on a model of scale 1 : 2.3 of the final synchrotron.

In fig. 2 the straight line 2 approximates $B_z(t)$ at a point of the mid-plane of the gap, while the straight line 1 approximates $B_z(t)$ at a point of the mid-plane as far from point 2.

The straight line 1′ represents $B_z(t)$ at a point radially removed of $\Delta r = 1$ cm.

The principle of the method is as follows :

A peaking-strip with a bias $B_z = 23$ gauss placed vertically at point 2 generates a pulse superposed on the one coming from a second peaking-strip with a bias B_1 ($\simeq 23$ gauss) placed at point 1. Mowing this second strip Δr radially, the relative pulse will shift to Δt, and the variation ΔB_1, necessary to renew the superposition of the pulses, will give us the value of the sought gradient. In a weak focusing synchrotron with $n = 0{,}6$ and $B_z = 23$ gauss, for $\Delta r = 1$ cm. ce get

$$\Delta B_z = B_z\,(n/R)\,\Delta r = B_z/600 = 0{,}038 \text{ gauss}$$

To measure such a variation at 5%, there must be a threshold sensitivity $\delta B_z \simeq 2 \cdot 10^{-3}$ gauss.

This corresponds to a shift of the pulse in the time :

$$\Delta\tau = \delta B_z/\dot{B}_z = 2 \cdot 10^{-3}/2 \cdot 10^{5} = 10^{-8} \text{ sec.}$$

The problem perhaps cannot be solved if we follow the way of reading directly on the time-axis of an oscilloscope a shift of 10^{-8} sec. of a pulse with a time of rise of 5×10^{-6} sec. Instead this can be done by changing the shift in the time of a pulse into a variation of its amplitude. This is got in a very simple way by placing in opposition the two pulses coming from the two peaking-strips.

Let us suppose the pulses equal in the form of an isosceles triangle and with the rise time $T/2 = 5 \cdot 10^{-6}$ sec., with amplitude of 0.05 Volt. When the pulses are superposed the resulting e.m.f. is 0. If a pulse shifts 5 μsec., the pulse difference of the two will have an amplitude of $\pm$ 0.05 Volt.

For a shift of 10^{-8} sec. there will be a variation of amplitude :

$$\Delta V = 10^{-8}/(5 \cdot 10^{-6}) \cdot 5 \cdot 10^{-2} = 10^{-4} \text{ Volt} \quad .$$

When suitably amplified this will easily be seen in the oscilloscope.

The peaking-strips used for these measurements are 20 mm. long, and have a diameter of 0.025 mm. They were held by small glass tubes filled with araldite according to the method described above. This allows the elimination of all movements of the wire caused by the torque produced by the magnetic field on the wire itself. The

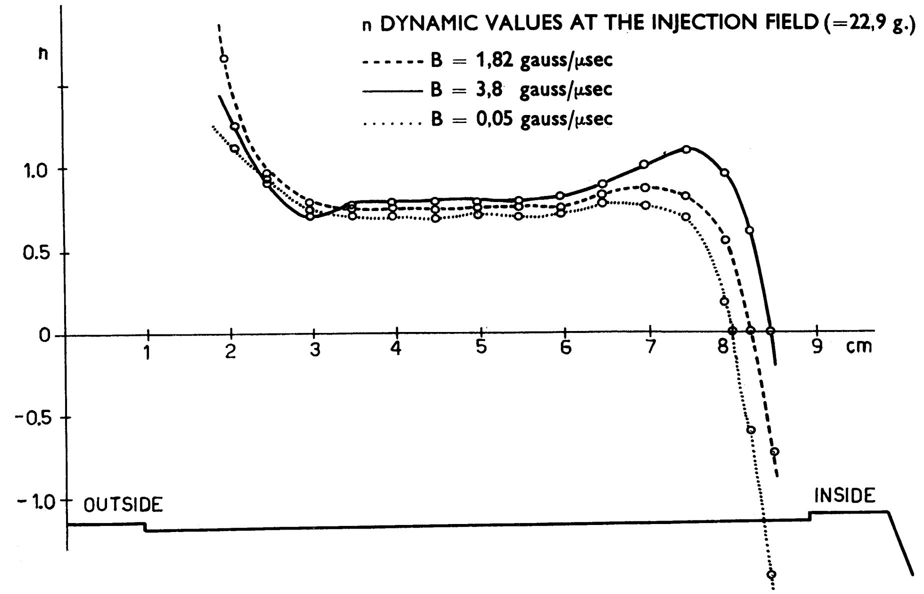

Fig. 3.

effect of the variation of $\dot{B} = dB/dt$ (when the peaker shifts from the position 1 to 1′) on the form of the pulse produces an error of less than $1^0/_{00}$. This can be easily controlled by measuring the gradient, first mowing the peaker from 1 to 1′ and then mowing it back from 1′ to 1.

In fig. 3 is given a graph of the dynamic values of n at the injection, measured by this method on a model (scale 1 : 2.3) of the synchrotron. The three curves obtained from different values of $\dot{B}$, show the influence of the eddy-currents.

LIST OF REFERENCES

1. Diambrini, G. A magnetic differential probe. Nuov. Cim., *3*, p. 336-49, 1956.