CERN-PS/CS 9a.

Note on the Application of the Hall Effect to Compute the Frequency Program for a Proton - Synchrotron. +)

In the computation process of the frequency program of a proton synchrotron it is advisable to make the intensity B of the guiding magnetic field the independent variable. If the voltage drop across the field coils or the current feeding the magnet windings were used instead of B, empirical corrections must be introduced, which complicate the computation process.

The computing system as a whole consists out of two main elements: (a) a device for measuring rather accurately the instantaneous magnitude of B, and (b) the computer proper, which produces the control signal. The latter influences the generator in such a way, that the generated frequency ω follows B according the familiar law

$$\omega = \omega_\infty \frac{B}{\sqrt{B^2 + B_0^2}} \qquad (1)$$

where

$$\omega_\infty = c / R_{eff}$$

and

$$B_0 = m_0 c / e R_0$$

are machine parameters.

The field measuring device should provide a direct determination of B rather than measure dB/dt and integrating with respect tot time, because in the latter case there will be an

+) This note describes in somewhat more detail a simplification of the Hall computer discussed in a preliminary note of June 9th, 1953.

uncertainty about the integration constant, i.e. about the exact value of the remanent field. This would necessitate special measures to provide the right frequency at injection, where the frequency tolerances are rather narrow (cf. Johnsen, KJ 18).

The computer should be of the analogue type, since digital computers are not only rather complicated but, for the present purpose, hardly fast enough. It should be remembered, however, that the desired accuracies, which are of the order 1000 and more, represent about the limits possible with analogue computing.

In this note we describbe a new method for computing the frequency program. The computer produces an AC voltage U_1, which varies with respect to B in the same manner as ω in eq. (1). Any generator, which can be made to follow U_1 in frequency linearily, i.e.

$$\omega = \text{const.} \times U_1, \tag{2}$$

may directly be used with this computer. Other types of generators need additional computing according to their individual control function.

The computer is thought, in particular, of controlling the frequency of a nuclear resonance controlled generator (cf. CS 2, 10 and 11) through the whole accelerating cycle. This is done by setting up a magnetic field controlled by, and varying linearily with U_1.

Principle og the method.

The principle of the proposed method is as follows: Field measurement is done with the Hall effect. The Hall electrode is placed directly into the guiding field B. The exciting current, I, is an alternating current of a moderately high frequency, say, of 100 to 1000 kc/sec. We then obtain a Hall voltage

$$U_1 = K_H \, B \, J. \tag{3}$$

The constant K_H is proportional to the Hall coefficient of the probe material.

The same current causes a voltage drop

$$\mathcal{U}_2^* = R\, \mathfrak{I} \qquad (4)$$

across a resistor. Now, a signal

$$\mathcal{U}_2 = k\,\mathcal{U}_2^*\, e^{i\pi/2}$$

is derived, by means of a suitable phase shifter, from U_2^+, and superimposed linearily upon U_1. Because of the mutual 90^0 phase shift, the sum voltage will have the amplitude

$$\mathcal{U}_{30} = \sqrt{\mathcal{U}_{10}^2 + \mathcal{U}_{20}^2} \qquad (5)$$

(The index o denotes amplitudes.) When B changes, U_{30} varies according to eq. (5) provided that I is kept constant. In this computer, hówever, I is regulated in such a way electronically, that U_{30} is automatically kept a constant. Hence, by combining eqs. (3), (4) and (5), we find

$$\mathfrak{I}_0 = \frac{\mathcal{U}_{30}}{K_H}\, \frac{1}{\sqrt{B^2 + \left(\frac{k}{K_H} R\right)^2}},$$

and by making

$$R = K_H\, B_0 / k, \qquad (6)$$

the output voltage at the hall plate becomes

$$\mathcal{U}_{10} = \mathcal{U}_{30}\, \frac{B}{\sqrt{B^2 + B_0^2}}. \qquad (7)$$

If U_1 is used to control any generator fulfilling eq. (2), the generated frequency follows B according to eq. (1).

Comparison of the eqs. (1), (6) and (7) shows, that the machine parameters ω_0 and B_0 can be varied independently by changing the level of U_{30} and the value of R, respcetively.

The Hall Electrode.

The Hall electrode must provide a sufficiently high voltage. The Hall coefficient must be independent of the magnetic field over the range from about 100 to 10 000 Oe within the desired limits of accuracy, and its temperature coefficient should be small.

For a 30 GeV proton synchrotron we have $B_o \approx 300$ Oe and, at injection, $B_i \approx 100$ Oe. The maximum guiding field will be about $B_m \approx 10\,000$ Oe. Hence, the ratio of the current at injection I_i, to the current at the end of the duty cycle, I_m, will be

$$\frac{I_i}{I_m} = \frac{\sqrt{B_m^2 + B_o^2}}{\sqrt{B_i^2 + B_o^2}} \cong 50.$$

Since $I \approx I_m$ after about one tenth of the total accelerating time, we may tolerate I_{io} to be as high as 100 mAmps, provided that the current does not flow during the entire time interval between accelerating cycles. For typical Germanium Hall samples of about 1 mm thickness, $K_H \approx 1$ µV/mAmp×Oe, thus $U_{10} \approx 10$ mV at injection, and increasing roughly by a factor of three during the accelerating cycle. The signal is, therefore, all the time well above the noise level.

Recent measurements of the Hall effect in Germanium indicate that the Hall coefficient is at room temperature generally slightly decreasing with increasing field. Still, the effect is quite small, provided there is a sufficient amount of impurities present in the sample material. A change of the Hall coefficient of ~ 1 ‰ for a field range from 0 to 10 000 Oe may be expected. The decrease of the Hall coefficient becomes noticable at fields of several thousand Oersteds. This systematic error, which is thus introduced into the computer, is, however, far from serious. It is at injection, and for a short time thereafter, that all the load is placed upon the accuracy of the computer, namely, during that time interval, in which insufficient bunching prevents the auxiliary beam controlled frequency correcting system to get hold on. The latter will work at fields above several hundred Oerstads and up to that limit the Hall coefficient may be considered independent of field within probably much better than 1‰.

The temperature dependence of the Hall coefficient is largely governed by the degree of impurities present in the probe material, and becomes less (around room temperature) with increasing concentration of lattice defects. Thus both conditions, constancy of the Hall coefficient and its low temperature coefficient call for relatively impure samples.

The connections to the Hall probe should be free of non-linear effects, and gold or indium wires should be used. Small non-linear effects will, however, cause no trouble, since it is possible to isolate the fundamental component of the ACvoltage by means of filters.

A typical computer.

Fig. 1 shows schematically the possible arrangement of a typical computer.

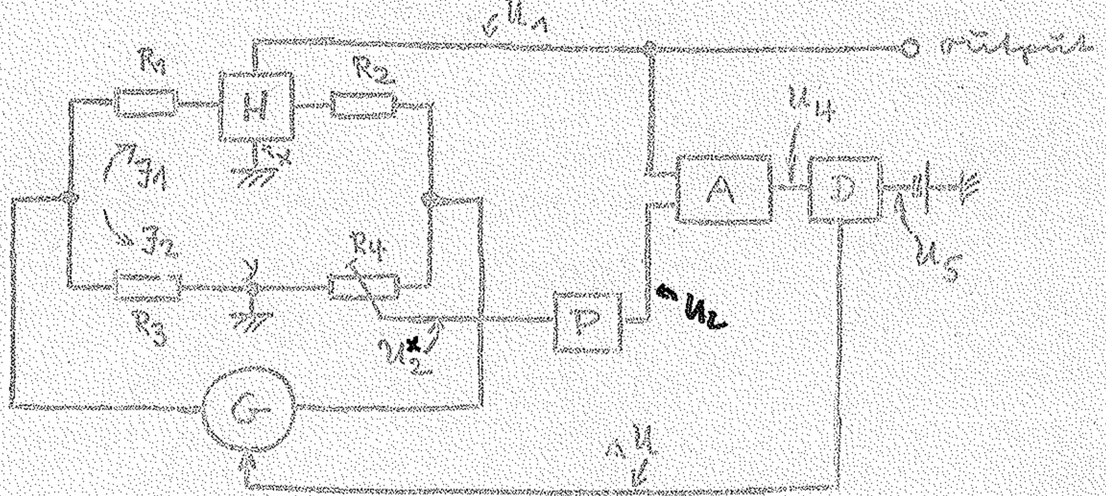

Fig. 1. A typical computer.

A symmetrical bridge network +), consisting of the resistors R_1 ... R_4 and the Hall electrode H, is fed from the generator G. The purpose of the network is to ~~bring~~ assure equal (zero-) potentials of the reference points x and y, from which U_1 and U_2^+, respectively, are measured. U_2^+ is tapped off either from R_3 or R_4. If the total resistances in both branches of the network are equal, $I_1 = I_2$ and eq. (7) applies directly. Inequality of the currents in both branches introduces a correc-

+) Means for the compensation of residual parameters and stray fields are not shown, they will, however, be necessary.

ting term in eq. (6), which influences the constant k. A variable ratio I_1/I_2 is not suited for correcting for the constants in eq. (1), because the ratio influences both, ω_∞ and B_0, simultaneously.

P is the phase shifter, which brings U_1 and U_2 in quadrature. The electronic device A serves for adding U_1 and U_2, and for amplifying and rectifying the sum voltage U_3. No restrictions need, in principle, be placed upon the amplitude dependence of both, amplification and rectification. If the output voltage from A, $U_4 = F(U_3)$ is kept constant, then, of course, U_{3o} is also a constant.

The voltage at the output of A, U_4, is compared with a standard voltage U_5 in the difference amplifier D. Its output forms the desired error signal ΔU, which controls the amplitude of the RF generator G.

The RF generator G is of the oscillator-amplifier type. For sufficient frequency accuracy, the oscillator should be quartz controlled. This is necessary to avoid phase errors between U_1 and U_2. (A phase difference of 0.1° from 90° causes a relative systematic error of approximately 10^{-4}.) The cascaded RF amplifiers are all controlled simultaneously by the error signal. The more stages are used, the less is the necessary amplification in the servo-loop.

The actual arrangement will be more complex. It will, in particular, contain circuits, which make the computer practically independent from fluctuations of the necessary supply voltages. Moreover, it may prove necessary to use two or more computers in cascade in order to obtain the rather high accuracy in the regulation of the current I. This will be discussed in forthcoming reports.

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Ch. Schmelzer,
W. Schnell.