Laboratori Nazionali di Frascati

LNF-56/27 (1956)

G. Ghigo, I. F. Quercia: REVERS FIELD STABILIZATION IN A D. C. - A. C. EXCITED MAGNET OF AN ELECTROSYNCHROTRON.

Estratto dal: CERN SYMPOSIUM PROCEEDINGS, VOL. 1, 475 (1956)

REVERSE FIELD STABILIZATION IN A D.C.-A.C. EXCITED MAGNET OF AN ELECTRON-SYNCHROTRON *

G. GHIGO and I. F. QUERCIA

Sezione Acceleratore, Istituto Nazionale di Fisica Nucleare, Roma

1. In the design of an electron-synchrotron much care must be given to the values of magnetic parameters at the injection. In fact the field in the gap at injection is only of a few gauss, and both the remanent field and eddy currents have a very large effect on the space distribution of the field. For keeping constant from cycle to cycle the field distribution it is very important to keep constant the value of the peak reverse field, and the value of rate of rise of the field at injection time.

In the project for 1 Gev Italian electron-synchrotron we shall excite the magnet with a 20 c/s sinusoidal current and with a bias direct current. Resulting magnetic field in the gap will of course be composed by an A.C. sinusoidal component and a D.C. component. As fig. 1 shows the peak reverse value of the field B_r, is just the difference between the peak value of A.C. component B_a, and the value of the D.C. component B_c. Suppose that we want a peak positive value of the field of 9260 gauss, and a peak reverse field $B_r = 200$ gauss : there results $B_a = 4730$ gauss and $B_c = 4530$ gauss.

If we can stabilize the D.C. current and the A.C. current feeding the magnet in such a way that independent variations of B_a and B_c will be limited to $\pm$ 0,1 % there still results a possible variation of B_r of about 5 %. Moreover this variation of B_r is accompanied by a change of about 2,5 % in the value of the rate of rise $\dot{B}$ of the field at injection.

Reaching an 0,1 % stability in the performance of the heavy machinery that supplies the magnet is not very easy, and asking for a higher degree of stability is very expensive, or nonsense.

For this reason we considered the possibility of approaching the problem in quite a different way. We started by the observation that what we need is some kind of stabilization of the reverse peak value of the magnetic field; we can let the A.C. magnetic field vary in a reasonable range if we are able to track the A.C. field with the D.C. field in such a way that the peak reverse value of the total field is maintained within allowed limits.

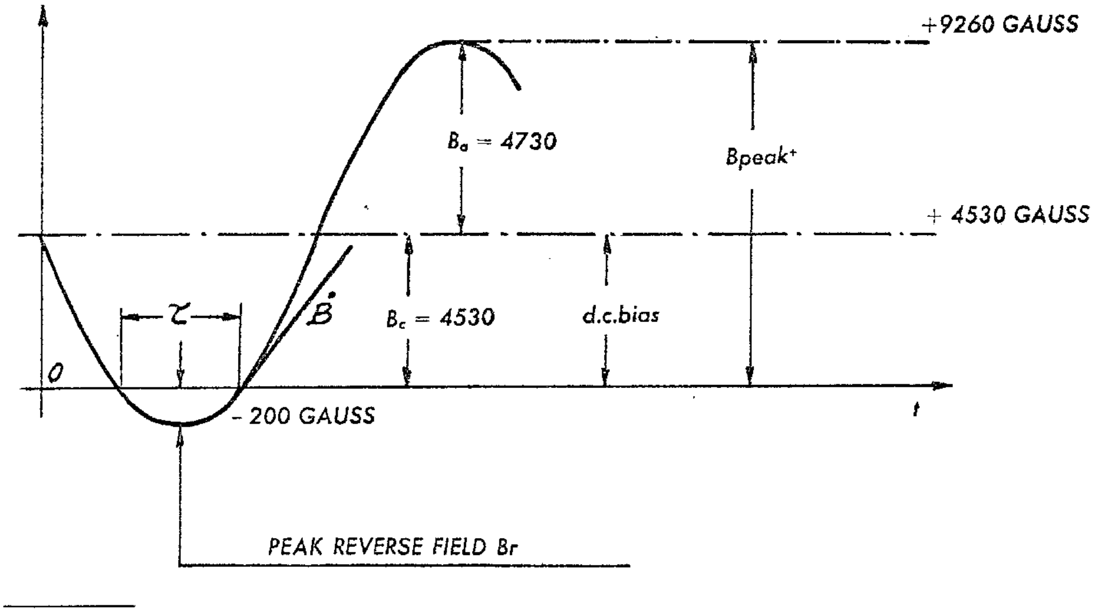

Fig. 1.

* This paper was presented in title only.

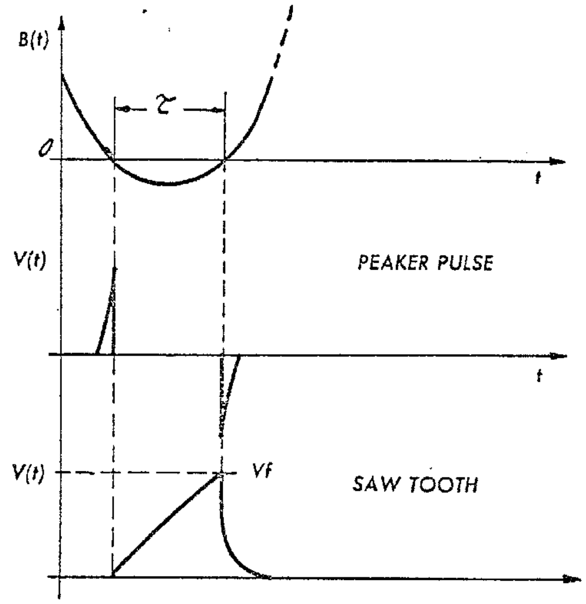

Fig. 2.

Of course the problem arises of measuring the value of the peak reverse field. Unfortunately we have to discard the most obvious way of measuring the instantaneous value of the current feeding the magnet: in fact for the measurement of the D.C. component of this current we need a drop of at least 1 or more volts, to which corresponds a power dissipation of some kilowatts because of the high values of the currents involved. For this reason we found it more convenient to use a device sensitive to the variation of the peak value of the reverse field.

2. The device consists of a probe containing a peaking strip surrounded by a pick-up coil. The probe is placed in the fringing field of the synchrotron magnet. As is well known (see for instance [1]) a voltage pulse is generated by the peaking strip in the pick-up coil, every time the magnetic field crosses the null value. Pulses change their polarity according to the sign of the time derivative of the magnetic field.

Following the wave forms referred to in fig. 2, the first positive pulse controls the start of a saw-tooth wave form generator, while the second negative pulse stops the saw-tooth. The peak value of the saw-tooth wave results as a function of the peak reverse value of the magnetic field.

Through a vacuum tube peak voltmeter, the peak value of the saw-tooth is compared with a reference voltage; the error voltage drives a power amplifier that controls the excitation current of the D.C. generator feeding the magnet. The block diagram of the apparatus results as in fig. 3. The work of the control loop is very clear: suppose the peak reverse magnetic field is increasing; the time τ between the two peaker pulses also increases; the peak of the saw-tooth wave is raised and the voltage V_f developed by the peak voltmeter is no more equal to the reference voltage V_r. The error voltage $(V_f - V_r)$ drives the current amplifier resulting in an increase dI_e of the excitation current of the D.C. generator. The D.C. bias of the magnet is raised, and the peak value of the reverse field is adjusted to the correct value.

3. In this paragraph we shall attempt a quantitative analysis of the working of the control loop. Because of unavoidable non-linearity of some parts of the loop, the analysis results to be only roughly approximated, but for very small deviation of involved quantities from their stationary values.

Let B_a be the peak values of the A.C. component of the magnetic field; B_c the value of the D.C. component of the magnetic field:

the peak reverse value of the field is simply:

$$B_r = B_a - B_c$$

If the A.C. field follows the law

$$B_a \cos \omega t$$

it is easy to show that the time interval τ between two crossings (see fig. 1) of the null value of the total field is given approximately by:

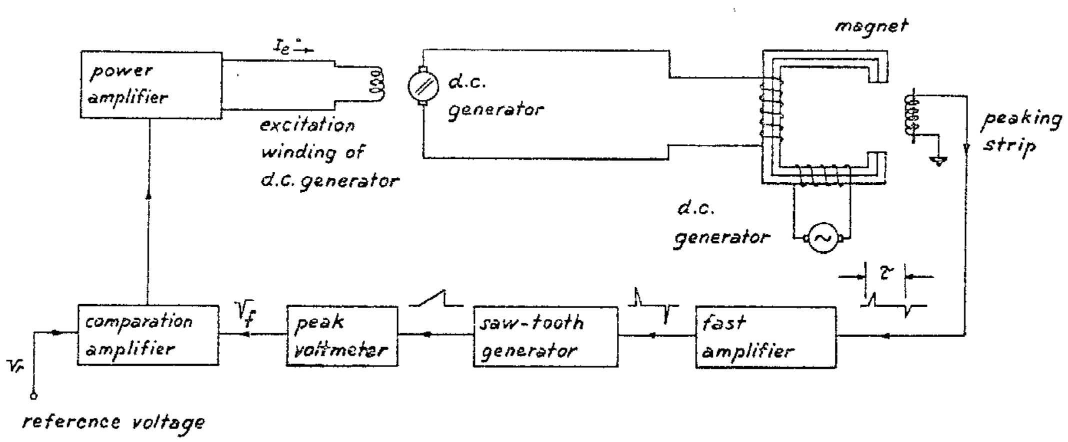

Fig. 3.

$$\tau \simeq \frac{2}{\omega} [2\, B_r/B_a]^{1/2}$$

if $\omega\tau \ll 1$.

We shall introduce the following parameter :

$$k = d\tau/dB_r = \frac{1}{\omega} [2/B_a]^{1/2} \cdot B_r^{-1/2},$$

which is a slowly decreasing function of B_r. Using a very crude approximation in the following we shall suppose that :

$$k = \text{const.}$$

Let now V_f be the output voltage of the peak voltmeter so that :

$$dV_f = b \cdot d\tau.$$

Let $Y \cdot dV_f$ be the variation of the excitation current of the D.C. generator due to a change dV_f of peak voltmeter output :

$$dI_e = Y \cdot dV_f.$$

If we indicate by dB_c the variation of D.C. field component following a change dI_e of excitation current, so that :

$$dB_c = z \cdot dI_e,$$

we can summarize the preceding relations in the following table :

$$\begin{cases} d\tau = kdB_r \\ dV_f = hd\tau \\ dI_e = YdV_f \\ dB_c = zdI_e. \end{cases}$$

From this set of relations by substitution we get :

$$dB_c = LdB_r$$

with :

$$L = khzY.$$

We shall call L the "loop gain" of the device. Remembering the definition of B_r by differentiation we can write down :

$$dB_r = dB_a - dB_c.$$

Substituting the value of dB_c and rearranging we obtain :

$$dB_r = dB_a/(1 + L)$$

This relation shows that the effect of feed-back loop is to decrease by a factor $1/(1+L)$ the variation of the peak reverse field due a change of the peak value of A.C. Field.

4. Of course, according to the general rules of feed-back loops, the value of the loop gain L is limited by the Nyquist stability criterion.

In our case through a part of the loop is carried intermittent information, with a repetition rate corresponding to the frequency of the A.C. generator supplying the magnet. This fact introduces an unavoidable delay time θ between two successive informations. Moreover we can suppose that the electromechanical part of the system introduces a very big lagging time constant T, so that we can consider the frequency response of the open loop to be of the dominant lag type.

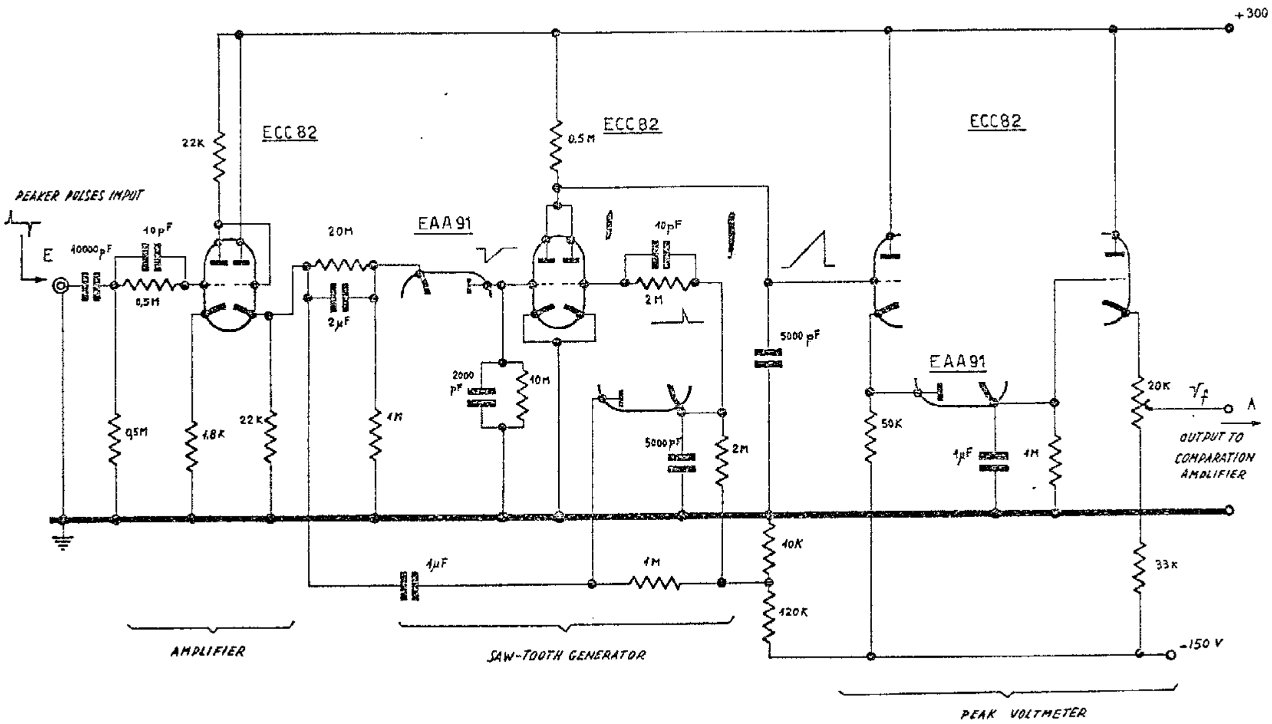

Fig. 4.

It can be demonstrated that a loop like this is stable if the zero frequency loop gain $L(0)$, is limited by the following relation :

$$L(0) < T/\theta.$$

The latter equation shows that we must choose a compromise between the stabilization factor $1 + L$ and the response speed of the loop. If we want to increase the stabilization effect of the system we must increase the lag time constant T; as a consequence we loose any control over fast transients in the value of the peak reverse field B_r.

5. We have applied the stabilization system described in the previous paragraphs to a model magnet of the 1 Gev electron synchrotron to be built in Frascati.

The magnet excitation coil was paralleled by a condenser bank in such a way as to resonate at 50 c/s.

The Q value of the resonating LC circuit was about 20. The A.C. excitation current was derived through a transformer directly from the mains.

The D.C. bias excitation current was supplied from a 13 kW generator driven by an asynchronous motor. The field of the D.C. generator, was supplied by a smaller 0,2 kW, D.C. generator. The field of this small D.C. generator was supplied from the electronic power amplifier to be described later.

Variations of the peak value of the A.C. field of the order of $\pm 10\%$ were observed, due to instability of both the voltage and frequency of the mains. In fact the A.C. current in the magnet was very sensitive to the value of the frequency as a consequence of the high Q value of the LC resonating circuit.

We had to operate the magnet with the following approximate values of the field :

Peak positive value of the field ~ 8.500 gauss. Peak reverse value of the field $B_r \sim 200$ gauss. It follows that the A.C. component of the field has a peak value of $B_a \simeq 4350$ gauss, and the D.C. component has a value of $B_c \simeq 4150$ gauss.

A change of only – 5 % of the B_a value causes the reverse field to disappar completely, with the consequence of changing drastically the remanent field in the iron of the magnet, and of course the value of $\dot{B}$ at injection field of 22,7 gauss.

As a sensitive element we used a Mu-metal wire of 0,05 mm diameter and about 40 mm. length. This peaking strip was surrounded in the middle part by a 400 turns pick-up coil. Pulses of about 60 mV induced in the pick-up coil, were amplified by a conventional fast amplifier of gain 100, and injected in the electronic device of fig. 4. The peak value V_f of the saw-tooth wave form was compared with a reference voltage V_r in the electronic device of fig. 5, and the resulting error voltage drove the two 807 tubes power amplifier.

The zero frequency loop gain $L(0)$ can be changed simply by changing the RC time constant of the saw-tooth wave generator. In fact the coefficient h defined in 4 is :

$$h = \text{const.}/RC$$

In order to choose the correct value of loop gain, supposing that the main lag time constant T is introduced by the chain D.C. exciter—D.C. Generator—Magnet, we measured

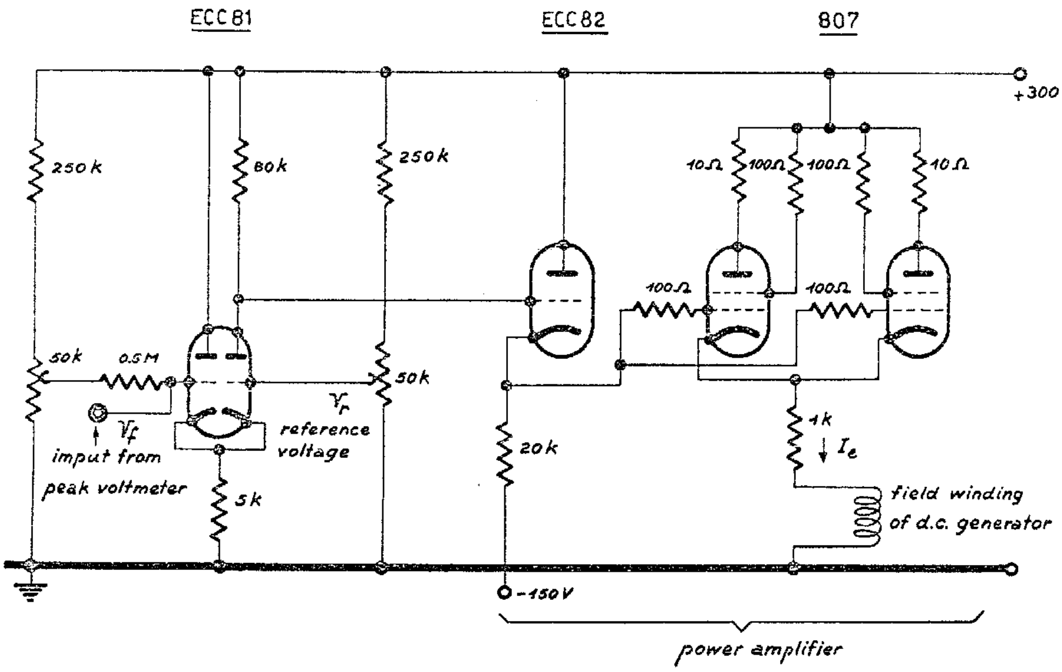

Fig. 5.

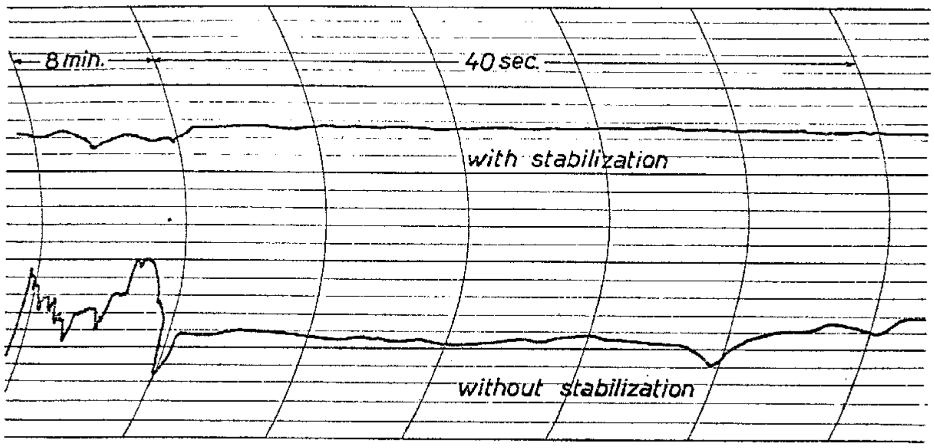

Fig. 6.

the rate of rise of the magnetic field in the gap due to a step pulse of current supplied by the power amplifier. We observed a rise time corresponding to $T \sim 0{,}9$ seconds. Because the delay between two successive information corresponds to $\theta = 1/50$ of a second, according to the discussion of 4., we decided to have a loop gain $L \simeq 30$. In the operating conditions we had the following set of the already defined parameters :

$z = 11$ gauss/mA; $h = 0{,}025$ V/μs; $k = 1/0{,}17 \cdot$ μs/gauss; $Y = 20$ mA/V

The loop gain results as :

$$L(0) = 32{,}5.$$

With this device the long term stability of the peak reverse value of B_r was observed to be about $\pm 10\%$.

Fig. 6 is a time record of the interval τ with and without the stabilization device.

Obviously the described results are to be considered quite preliminary. Now we are considering the possibility of applying the same technique to the stabilization of a bigger 1 : 1 scale model of the magnet of 1 Gev electron-synchrotron. In the next few months we hope to be able to know if the system is useful in the control of high power generators employed for the supply of our Synchrotron.

LIST OF REFERENCES

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