Laboratori Nazionali di Frascati

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

II°

" Field Stabilization, in a D.C.- A.C. Excited Magnet of a Synchrotron "

by

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- Summary - The shape of the magnetic field of an Electron-Synchrotron is quite critical at injection. If the machine is fed with an A.C. current and with a bias D.C. current, the shape of the field at injection is quite sensitive to the values of the peak A.C. current and of the D.C. current. A device is described that is sensitive to the difference between peak A.C. and D.C. current and which keeps this difference constant by controlling the value of the D.C. current. The apparatus was applied to model magnets of the I GeV Italian Electron-Synchrotron, and is planned for controlling the supply of the Synchrotron.

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

In the project for I GeV italian Electron-Synchrotron (4) we shall excite the magnet with a 20 c/s sinusoidal current and with a bias direct current. The resulting magnetic field in the gap will be of course composed of an A.C. sinusoidal component and a D.C. component. As Fig. I shows, the peak reverse value of the field B_r, is just the difference between the peak value of the 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: this gives $B_a = 4730$ gauss and $B_c = 4530$ gauss.

If we will be able to 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 by limi ted at ± 0.I%, the possible variation of B_r will still be about 5%. Moreover this variation of B_r is accompaned by a change of about 2.5% of the rate of the rise $\dot{B} = \frac{dB}{dt}$ of the field at injection.

To reach a 0.I% stability in the performance of the heavy machinery that supplies the magnet is not very easy, and to ask for a higher degree of stability is very expensive, or may be impossible.

For this reason we considered the possibility of approaching the problem in a quite different way.

We started from 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 mantained within allowed limits.

This of course leads to the problem of measuring the value of the peak reverse field.

The most obvious way to measure it, seems to be to measure the difference between the peak value of the A.C. current, and the value of the D.C. current.

Unfortunately the currents to be measured are so high that a voltage drop of I Volt corresponds to some Kilowatt of power, and we can not hope to be able to measure D.C. voltages of less than I Volt with an accurancy better than 10mV. In fact any electronic device for measuring D.C. voltages is affected by a drift of some millivolts which can not be easily suppressed. For these reasons we found it more convenient to leave the idea of measuring the components of the current feeding the magnet and to use a device sensitive directly to the peak value of the reverse magnetic 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 istance (I)) 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 shown in Fig. 2, the first positive pulse starts a saw-tooth wave form generator, while the second negative pulse stops the saw-tooth. The peak value of the saw-tooth wave results to be 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 is shown in Fig. 3. The control loop acts as follows: 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. It is easy to show that the effect of the device is to reduce the variation dB_r of the peak reverse field as consequence of a variation dB_a of the peak value of A.C. field, according to the formula:

$$dB_r = \frac{dB_a}{1+L}$$

Where L is the gain of the feed-back loop. (see for intance (2)). Of course, according to the general rules of feed-back loops (3), the value of the loop gain L is limited by the Nyquist stability criterion. In our case part of the loop carries an intermittent information, with a repetition rate corresponding to thefrequency 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 time lag T, so that we can consider the frequency response of the open loop to be of the "dominant lag" type (see e.g. (2)).

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

$$L(0) < \frac{T}{\theta}$$

The latter equation shows that we must choose a compromise between the stabilization factor I + L and the response speed of the loop.

If we want to increase the stabilization effect of the system, we must increase the time-lag T; as a consequence we loose any control over fast transients in the value of the peak reverse field B_r.

§ 4. We have applied the stabilization system described in theprevious paragraphs to a model magnet of the I GeV electronsynchrotron to be built in Frascati (4). The magnet excitation coil was paralleled by a conden

ser bank in resonance at 50 c/s.
The Q value of the resonating LC circuit was about 20. The A.C. excitation current was taken from a transformer directly from the mains.
The D.C. bias excitation current was supplied from a I3 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 thepeak value of the A.C. field of the order of ± IO% were observed, due the 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 $\sim$ 8.500 gauss.
Peak reverse value of the field $\sim$ 200 gauss. It follows that the A.C. component of the field has a peak value $B_a \cong$ 4.350 gauss, and the D.C. component has a value of $B_c \cong$ 4.I50 gauss.
A change of only - 5% of the B_a value causes the reverse field to disappear complety, with the consequence of changing drastically the remanent field in the iron of the magnet, and of course the slope of the

field at injection.

As 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 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 I00, 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 power amplifier (two 807 valves).

The zero frequency loop gain L (0) can be changed simply by changing the RC time constant of the saw-tooth wave generator.

In order to choose the correct value of loop gain, supposing that the main lag-time T is introduced by the chain: D.C. exciter - D.C Generator - Magnet, we measured 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 = 0,9 seconds. Because the delay between two successive informations corresponds to I/50 of a second, according to the discussion of § 3, we decided to have a loop gain $L\ (o) \cong 30$.

In the operating conditions we had a loop gain of:

$$L\ (o) = 32{,}5$$

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

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

§ 5. With some modification in the output power stage we have used the device described in the previous paragraphs for stabilizing the peak reverse field in a bigger model of our Synchrotron magnet. We obtained good results, and now we hope to be able with a similar device to control the field in the magnet of our Electron-Synchrotron.

Of course it is possible to use other quantities, then the time τ, for measuring and controlling the shape of the field at injection. For istance the Cornell Synchrotron Group developed a device (5) that samples the value of $\dot{B} = \frac{dB}{dt}$ at injection time, and controls the A.C. component of the current feeding the I GeV Synchrotron magnet.

We would like to emphasize that our device can find a wider application whenever it is necessary to control the relative values of a D.C. and an A.C. current.

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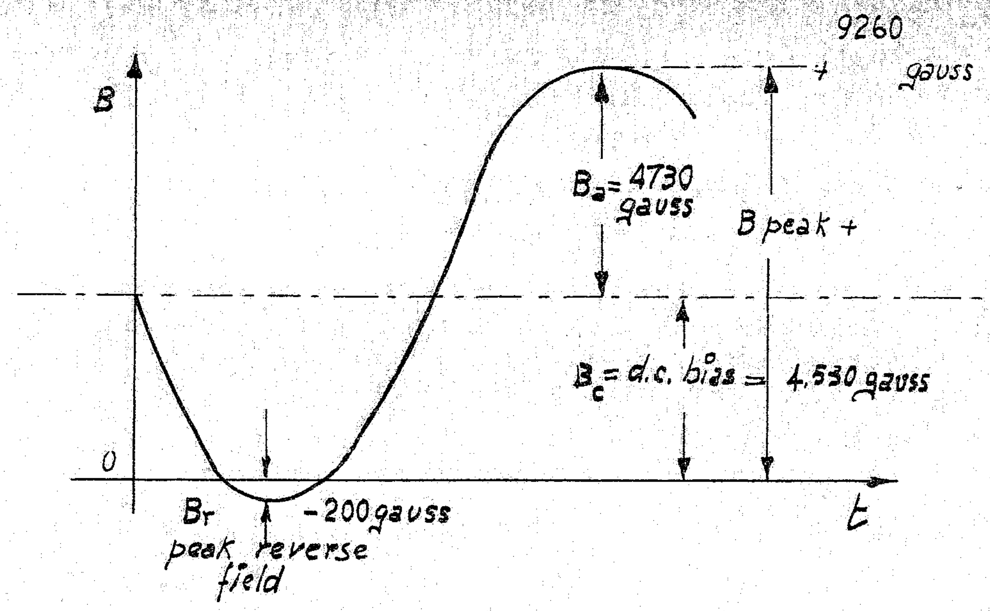
9260 gauss
B
B_a = 4730 gauss
B peak +
B_c = d.c. bias = 4.530 gauss
0
B_r peak reverse field
-200 gauss
t

FIG. 1

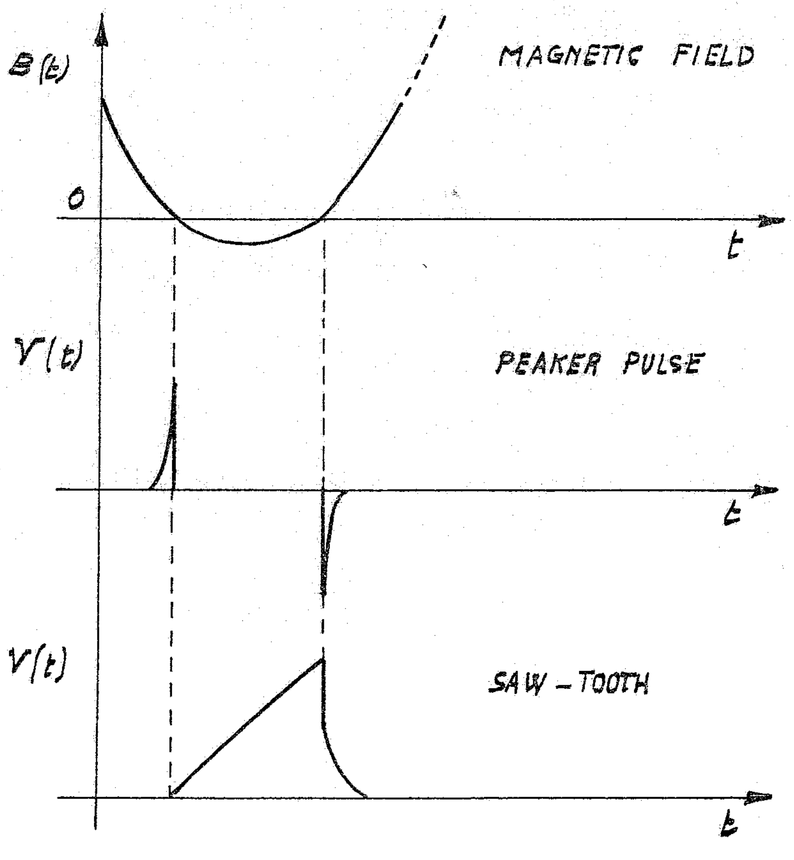
B(t)
MAGNETIC FIELD
0
t
V(t)
PEAKER PULSE
t
V(t)
SAW-TOOTH
t

FIG. 2

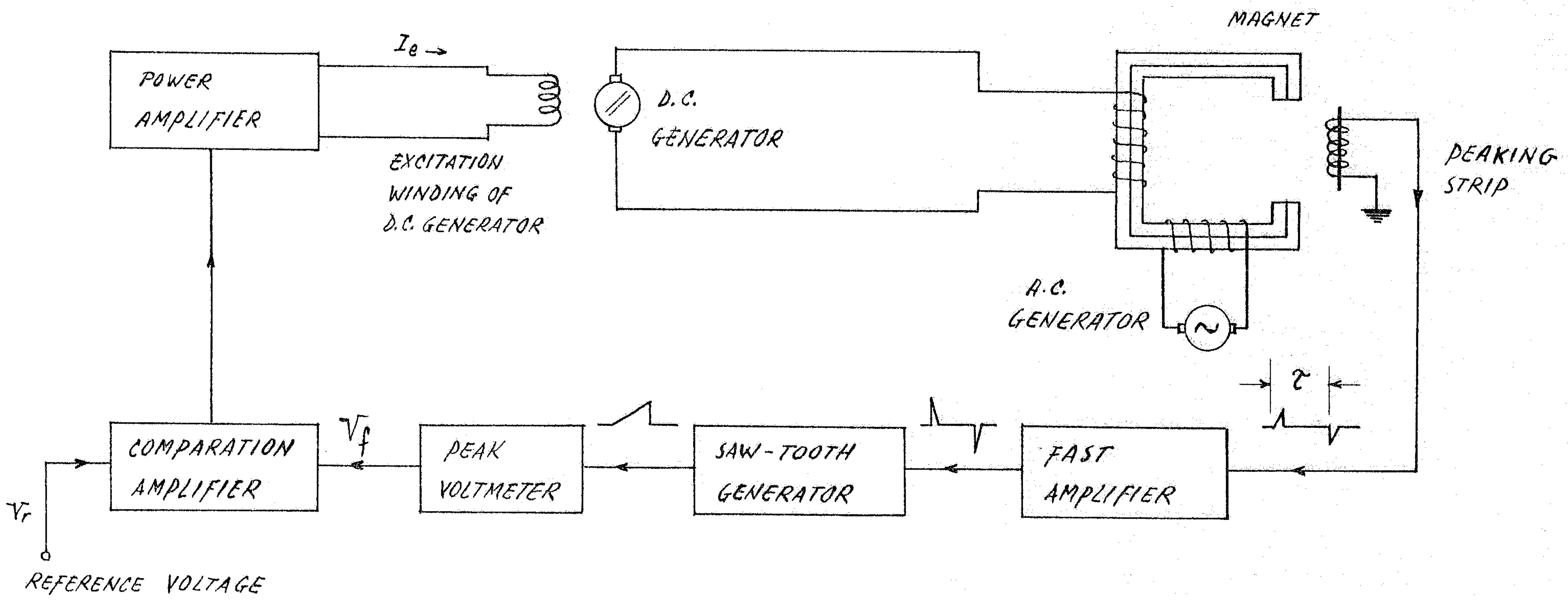
MAGNET
POWER AMPLIFIER
I_e →
D.C. GENERATOR
EXCITATION WINDING OF D.C. GENERATOR
PEAKING STRIP
A.C. GENERATOR
τ
COMPARATION AMPLIFIER
V_f
PEAK VOLTMETER
SAW-TOOTH GENERATOR
FAST AMPLIFIER
V_r
REFERENCE VOLTAGE

FIG. 3

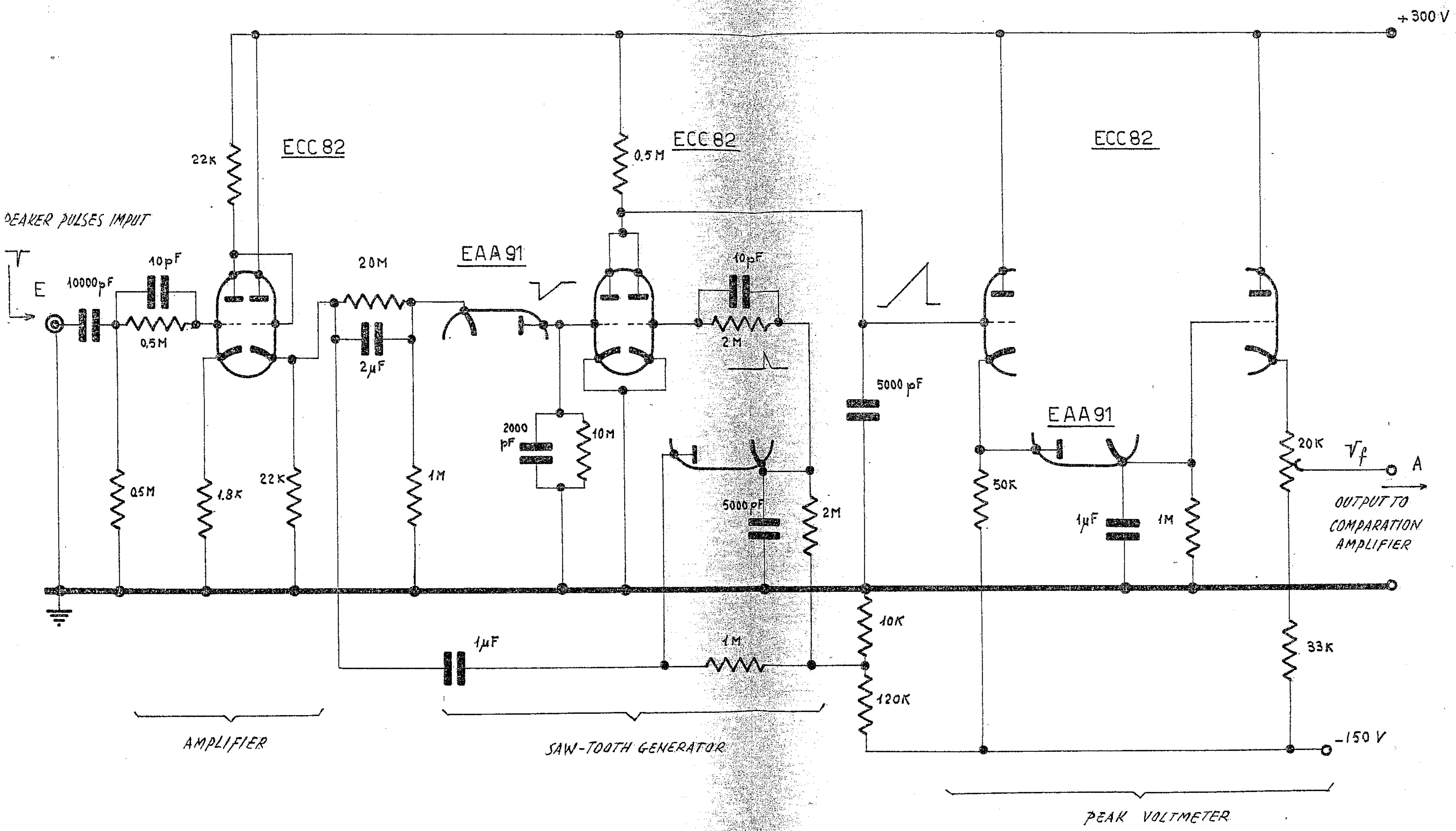
+300 V
PEAKER PULSES IMPUT
E
10000pF
10pF
0.5M
22K
ECC 82
0.5M
1.8K
22K
20M
2μF
1M
EAA 91
2000 pF
10M
0.5M
ECC 82
10pF
2M
5000 pF
2M
1μF
1M
5000 pF
10K
120K
ECC 82
EAA 91
50K
1μF
1M
20K
V_f
A
OUTPUT TO COMPARATION AMPLIFIER
33K
-150 V
AMPLIFIER
SAW-TOOTH GENERATOR
PEAK VOLTMETER

FIG. 4

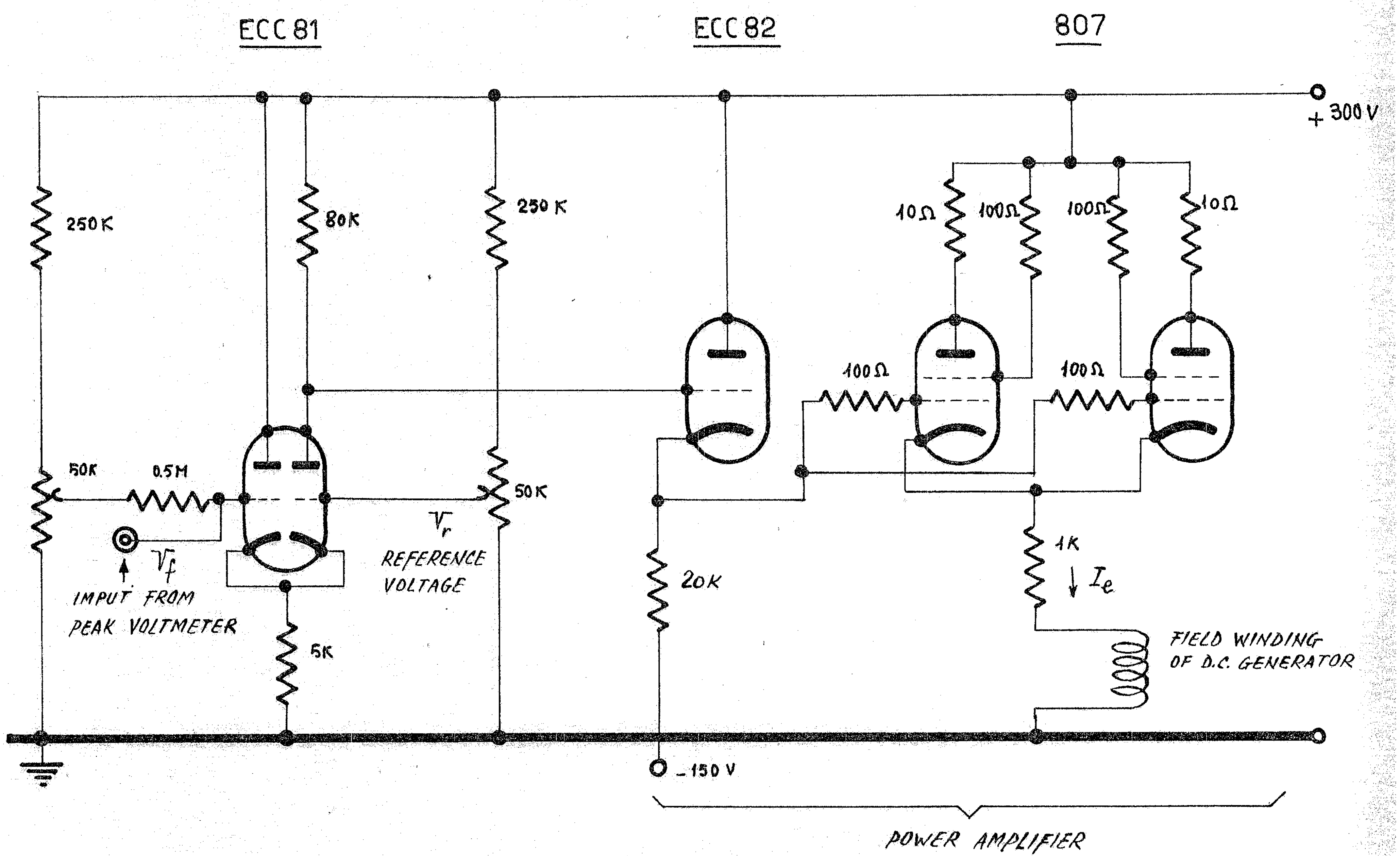
ECC 81
ECC 82
807
+ 300 V
250 K
80 K
250 K
10 Ω
100 Ω
100 Ω
10 Ω
100 Ω
100 Ω
50 K
0.5 M
50 K
V_r
REFERENCE VOLTAGE
V_f
IMPUT FROM
PEAK VOLTMETER
5 K
20 K
1 K
I_e
FIELD WINDING
OF D.C. GENERATOR
_ 150 V
POWER AMPLIFIER

FIG. 5

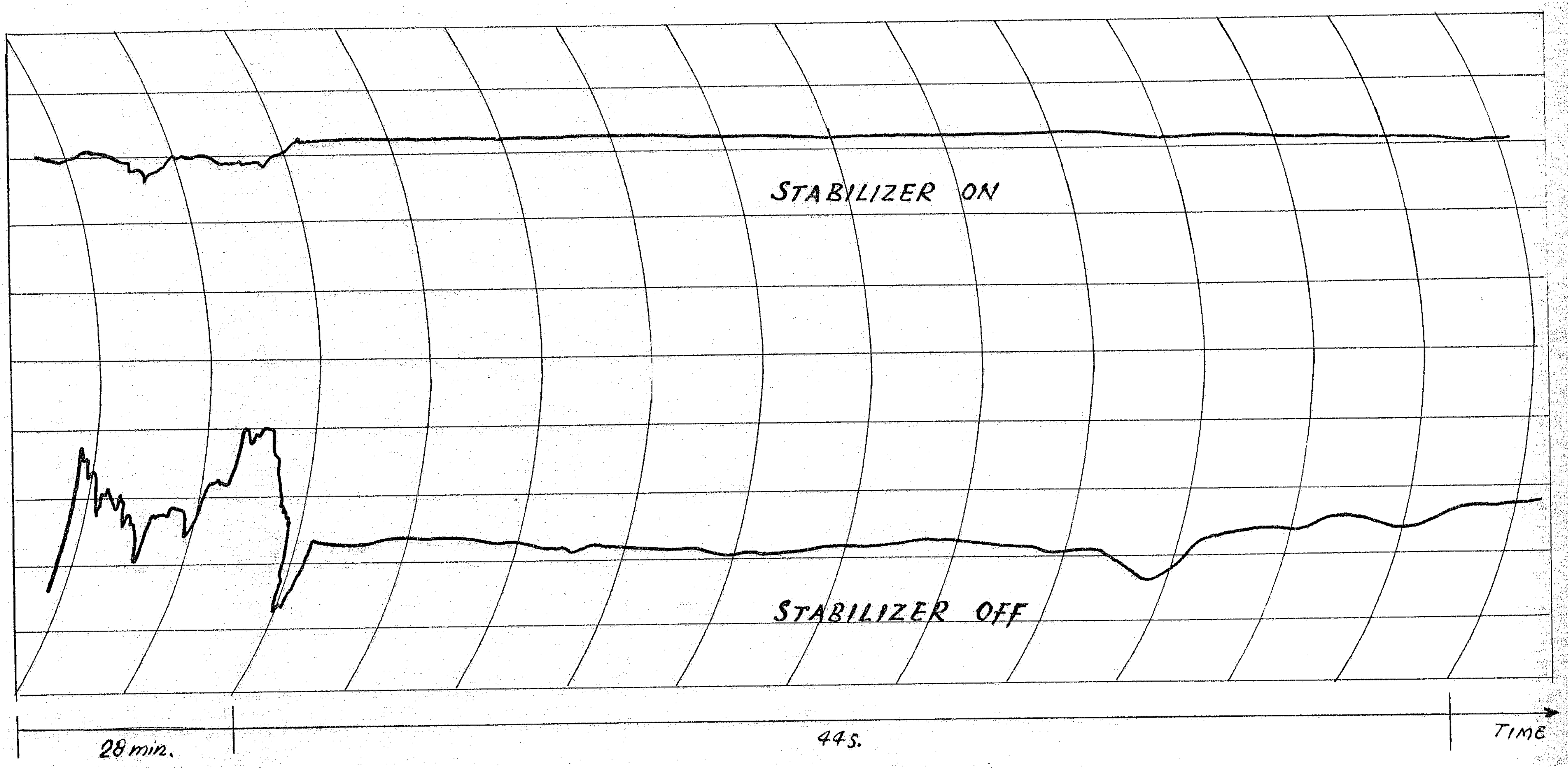

FIG. 6