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MASTER

Accelerator Department
Cosmotron Division

Internal Report

VJK-2
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COSMOTRON CURRENT MARKER

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Tests on the previous current marker (Accelerator Development Department, AGS Internal Report, JPP-10, 1960) indicated problems with noise pickup and stability of the feedback loop. It was decided at a design review meeting to redesign the feedback loop and shield the toroid to minimize capacitive pickup. To facilitate troubleshooting and maintenance, it was further decided to insulate the core from the magnet buss and have the associated circuitry operate at ground potential.

To review J. Palmer's paper (JPP-10, 1960), consider the following argument: If I_B in Figure 1 is supplied from constant current (high impedance) source and a high μ square loop core is placed inside the toroid, a voltage pulse will be induced in the toroid windings when H moves into the region where the core material is not saturated. A constant current (high impedance) source is necessary to minimize errors due to pulse loading and I_B drifts. H_c (see Figure 2) is the coercive force associated with core material. It contributes a timing error. A measurement of H_c was made in the following manner (shown in Figure 3). The input voltage is adjusted so that at zero crossover $\frac{1}{R} \frac{dV_1}{dt}$ is equal to the $\frac{dI}{dt}$ of the Cosmotron magnet. The delay before

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With these assumptions

$$E_0 = N_t \dot{\Phi}$$

$$\dot{\Phi} = kNBA = kNH\mu A = 420 \times 10^{-10} \mu$$

$$E_0 = N_t \dot{\Phi} = 7.5 \times 10^3 \times 4.2 \times 10^{-8} \times 1.4 \times 10^5$$

$$\approx = 44 \text{ volts}$$

E_0 = voltage induced in windings

N_t = number of turns on core (7500)

$\dot{\Phi}$ = total flux change/sec in core

$k = 4\pi \times 10^{-7}$ (M.K.S. system)

$N = 1$ turn

$H = 1.48 \times 10^4$

A = area of core
 22.6×10^{-7} meters²

$\mu = 1.4 \times 10^5$ linear approx. from curves

(2)

This means a square pulse of 44 volts will appear across the windings in the region of interest. The pulse duration should be in the order of 1.1 msec. Actually the pulse will be longer and have a maximum value at $B = 0$ since μ is not a constant but is a function of H .

Now consider the effect of R and C loading

In the equation

$$E_0 = N_t \dot{\Phi}$$

$$\dot{\Phi} = \dot{\Phi}_M - \dot{\Phi}_t$$

$\dot{\Phi}_M$ is result of magnet current

$\dot{\Phi}_t$ is result of load current

$\dot{\Phi}$ is redefined since it is a function of two variables.

$$E_0 = k N_t \mu A \left[\dot{H}_M - \dot{H}_t \right]$$

$$E_0 = k N_t \frac{\mu A}{L} \left[\dot{I}_M - N_t \dot{I}_t \right]$$

(3)

which reduces to $k N_c \frac{\mu A}{L} \dot{I}_M = N_t \dot{\Phi}$ (equation 2) for $\dot{I}_t = 0$

From the equivalent circuit

$$E_0 = \frac{q}{C} = I_R R$$

$$I_t = I_c + I_R = \dot{q} + I_R = \dot{E}_0 C + \frac{E_0}{R}$$

$$\dot{I}_t = \dot{E}_0 C + \frac{\dot{E}_0}{R}$$

Substitution in equation 3 gives

$$E_0 = \frac{k N_t \mu A}{L} \left[\dot{I}_M - N_t \left(\frac{\dot{E}_0}{R} + \dot{E}_0 C \right) \right]$$

Setting up in standard form

$$\ddot{E}_0 + \frac{1}{RC} \dot{E}_0 + \frac{1}{k_1 N_t C} E_0 = \frac{\dot{I}_M}{N_t C}$$

$$\text{where } k_1 = \frac{k N_t \mu A}{L}$$

Since $\dot{I}_M$ is a constant, the equation reduces to

$$\ddot{E}_0 + k_2 \dot{E}_0 + k_3 E_0 = k_4$$

$$\text{where } k_2 = \frac{1}{RC}$$

$$k_3 = \frac{1}{k_1 N_t C}$$

$$k_4 = \frac{\dot{I}_M}{N_t C}$$

(4)

The solution of equation 4 is

$$E_0 = Ae^{\frac{P_1 t}{2RC}} + Be^{\frac{P_2 t}{2RC}} + D$$

$$\text{where } P_1 = -\frac{1}{2RC} + \sqrt{\left(\frac{1}{2RC}\right)^2 - \frac{1}{kN_t^2 C}}, \quad P_2 = -\frac{1}{2RC} - \sqrt{\left(\frac{1}{2RC}\right)^2 - \frac{1}{kN_t^2 \mu AC}}$$

$$E_0 = e^{-\frac{t}{2RC}} \left(F \cos \left[\left(\frac{1}{2RC}\right)^2 - \frac{L}{kN_t^2 \mu AC} \right]^{\frac{1}{2}} t + G \sin \left[\left(\frac{1}{2RC}\right)^2 - \frac{L}{kN_t^2 \mu AC} \right]^{\frac{1}{2}} t \right) + K$$

for $R = 10^6$ ohms, $C = 2.5 \times 10^{-9}$ μ f.

$$E_0 = e^{-200t} (F \cos 866t + G \sin 866t) + K$$

Substituting boundary conditions of

$$E_0 = 0 \text{ at } t = 0 \text{ and } 1.6 \times 10^{-3} \text{ sec.}$$

gives

$$E_0 = Ge^{-200t} \left[.825 (\cos 866t - e^{-200t}) + \sin 866t \right]$$

Assuming $E_0 = 60$ volts @ $t = .8 \times 10^{-3}$ seconds, which is a reasonably valid assumption from no load pulse calculation and test considerations, yields

$$E_0 = 230 e^{-200t} \left[.825 (\cos 866t - e^{-200t}) + \sin 866t \right]$$

A plot of $E_0 = f(t)$ is shown in Figure 4. This curve is also modified by the fact that $\mu \neq$ constant in the region of interest.

System Controls

Toroid bias current (I_B) is adjusted by a helipot located in the Control Room. This current, once selected, is maintained by a feedback amplifier. An independent method of checking I_B is provided by a shunt which can be read on a digital voltmeter. This shunt is calibrated so that I_B is simply related to main magnet current. One millivolt is equivalent to 100 amperes.

The pulse output, generated when the core flips, is available on the patch panel. All system power is controlled by the M.G. Room and should remain on at all times.

System Operation (Refer Figure 6)

The magnet current rises at approximately 6.5 amperes per msec. I_B is selected and read out on the digital voltmeter. At t_1 , $I_B = I_M$ and the marker pulse is generated. Varying I_B will vary the time when $I_B = I_M$. Thus it is possible to plot magnet current as a function of time. Twelve amps should be added to this plot to compensate for core constants discussed earlier.

Feedback Loop

The servo system is shown in Figure 7. It consists of two temperature stabilized transistor amplifiers ($A_1 + A_2$) followed by tube amplifiers (A_3 , A_4 , and A_5). The output stage (A_5) consists of two 4-400A's in parallel driven by a 12AT7 cathode follower (A_4). The transistor amplifiers are self-contained units and either can be replaced as a unit. Input voltage drifts of these amplifiers are in the order of $20\mu V$, which is an order of magnitude smaller than allowable drifts due to design considerations. Each amplifier has a feedback loop around it to stabilize its individual gain. The gain bandwidth product of these units is 1.75×10^8 with an open loop gain of 4×10^3 . The loop gain of the complete system can be adjusted from 370 to 740 by means of a pot located between the two transistor amplifiers. The design was chosen so that the maximum allowable current drift of A_5 is $\pm .1$ per cent at a current of .26 amps in the toroid. This corresponds to a Cosmotron magnet current of 2000 amps. To keep these drifts to $\pm .1$ per cent the current drifts have to be less than .26mA. Perturbations in I_B (bias current) are caused by B+ fluctuations, grid drifts, and the core pulse. The plate to cathode gain is approximately 0.003; therefore the maximum allowable plate voltage change is .87V (10 Ω in cathode). A loop gain of 100 would wash out plate voltage changes of 90V, which is the magnitude of the core pulse; but a gain of 400 was chosen to compensate for tube changes.

Mechanical Changes

The core is insulated from the Faraday shield which was added to minimize capacitive pickup. The insulation has been checked up to 24kV. In addition to this, the Faraday shield, which is grounded, is insulated from the buss and has been checked for voltage breakdown up to 30kV. A temperature check of the winding indicates a rise of 25°C after two hours with one ampere going through the windings.

FIG. 1 TOROID LOCATION

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FIG. 2 BH CURVE

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FIG. 3 TEST SETUP

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FIG. 4 E₀ AS A FUNCTION OF TIME

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FIG. 5 SCHEMATIC OF SYSTEM

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FIG. 6 MAGNET CURRENT AS A FUNCTION OF TIME

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FIG. 7 BLOCK DIAGRAM OF SERVO SYSTEM

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