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DYNAMIC FIELD MEASUREMENT IN THE BEAM SWITCHING MAGNET.

In this report we would like to discuss the possible methods of measuring the magnetic field in the beam switching magnet. This magnet will switch the electron beam of the accelerator to different target areas. The pulse repetition rate is 360 cycles and the beam energy is 25 Bev *. The magnet pulser should be able to pulse the magnet with an accuracy of .1% and repeat the operation in less than 2 1/2 milliseconds. The magnetic field in the magnet rises sinusoidally and it has a peak value of 2070 gauss. Before we discuss the requirements for the field measuring device, we would like to sketch the necessary triggering signals to operate the pulse magnet.

Triggering of the Pulsed Deflection Magnet

According to our latest discussion with the Control and Instrumentation group the magnet pulser will receive timing and energy information signals in the form of programmed pulse trains. Figure 1. shows the three "energy information pulse trains" with the clock pulse train and a block diagram for the decoding system. The energy information pulse train is delayed compared to the corresponding clock pulses with .5-1ms which is needed to pulse the field in the beam switching to its peak value. In the decoding system the clock pulse will be delayed with the same amount (.5-1ms) and the coincidence signal will start to pulse the magnet. The field will rise in the magnet sinusoidally to its peak value of the order of 2100 gauss. To insure that each pulse will be sent to the predetermined

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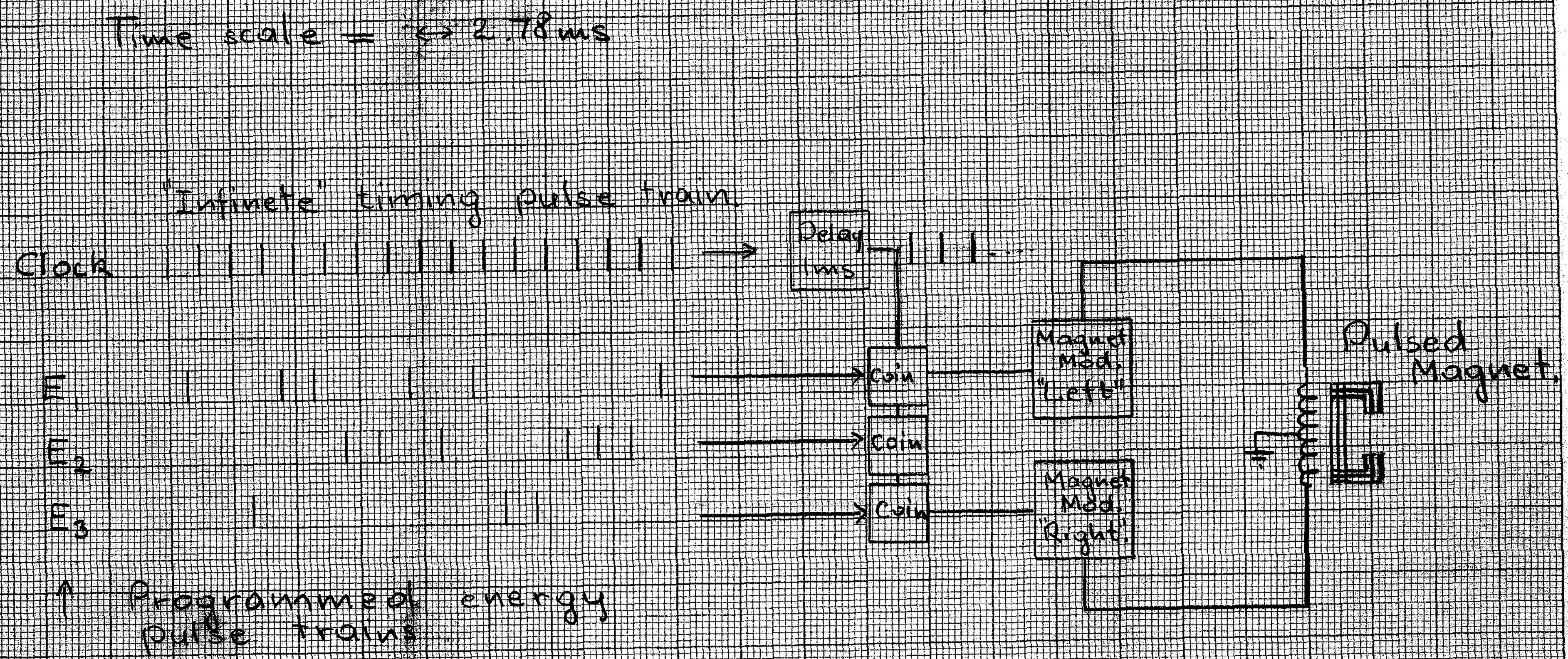
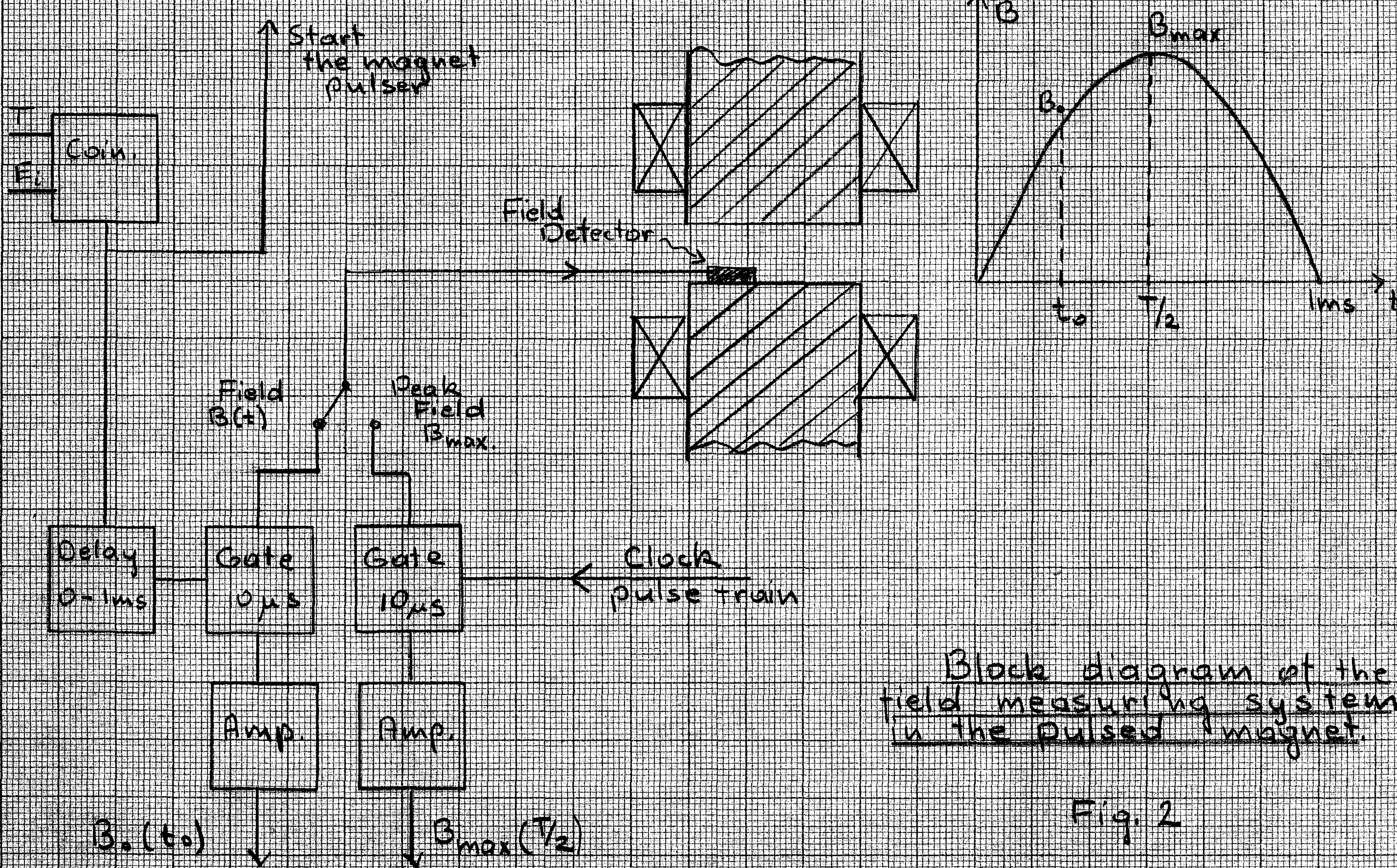


Triggering System for the Pulsed Magnet.

Fig. 1.



Block diagram of the field measuring system in the pulsed magnet.

Fig. 2

place or no pulse will come when the magnet is not ready, it is important to send a "ready" signal to the gun pulser. When the magnet is energized and able to accept the electron pulse, the ready pulse would open a gate for the gun keying pulse. Then in the pulse magnet one has to measure the field B_o after a preset time t_o. This signal can be used as a "ready" signal. However, one would like to measure the field at any time during the magnet pulse duration (1ms). Figure 2 shows the block diagram to obtain the "ready" signal and the maximum field value from the pulse magnet.

Now, we can summarize the requirements for the field detector which is placed in the gap (or near) of the beam switching magnet.

1 - The field measurement doesn't need to be an absolute measurement. R. Taylor suggested that a D.C. field coil on the pulse magnet would be very useful for field calibration and in the case when thepulse magnet fails.

2 - The detector should be able to measure the field from 500 to 3000 gauss at any time within the magnet pulse. The pulse sampling time (measuring time) is 10 microseconds.

3 - The frequency response of the detector should be in the frequency range of 0 - 1 Mc because during the 10μs measuring interval one would like to see structural details.

4 - The measurement accuracy, resolution stability, and reproducibility of 1 part in 10^3 is required.

5 - Small physical size and simple, rugged mechanical and electrical construction with no moving parts for ease of installation and operation even in a vacuum.

6 - Ability to be insensitive to nominal ambienttemperature fluctuations.

7 - Ability to operate in radiation environment.

The possible candidates for such a field detector are the following instruments:

I - Hall generator

II - Gated integrators

III - Electron magnetic resonance device.

I. (a) Hall generators are capable of continuous operation from 10 to 25000 gauss with less than 0.5% deviation from a linear relationship between output and magnetic field.

(b) Hall generators have attained the 1 part in 10^4 accuracy after calibration with our NMR gaussmeter, using special temperature compensating circuits.

(c) The Hall generator element, being a compound semi-conductor, has been observed* to undergo a change in output characteristics due to the effect of radiation.

(d) Since the average output sensitivity of the available Hall generators is about 15 mv/kg and they are low output impedance devices, they are free from noises and well suited for standard electronics.

(e) The frequency response of Hall generators are usually an order of magnitude lower than what is required here.

II. In principle the magnetic induction B at any point in a time varying field can be obtained by integrating the output voltage from a

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search coil placed in the field. The elecromotive force and the magnetic induction are given by

$$V = - N A \frac{d B}{d t}, \qquad \text{and} \qquad B = B_o - \frac{1}{N A} \int_{t_1}^{t_2} V \, dt$$

The product $N A$ is the ratio of magnetic flux to magnetic induction for the search coil in a uniform magnetic field.

The magnetic field in the pulsed magnet has a simple sinusoidal form

$$B(t) = B_o \sin \omega t$$

and the integral of the search coil output voltage for a quarter cycle gives

$$\int_0^{T/4} V \, d t = N A B_o$$

If one wants to sample the field then the integration should be extended only for the required sampling interval. Then

$$\int_{t_1}^{t_2} V \, d t = - N A B_o \left[\sin \omega t \right]_{t_1}^{t_2} \sim N A B_o \frac{\Delta T}{T/4}$$

where ΔT is the sampling time and T is the periodic time.

The integration in such a gated integrator can be performed by an operational amplifier or with an integrating D.C. circuit. The detailed study of these systems will be performed in the near future. Just to give an order of magnitude value for the induced voltage during $\Delta T = 10 \mu s$ for the staionary coil in the field we might estimate it from

$$V = - N A \frac{d B}{d t} \frac{\Delta T}{T} \approx 10^2 \times 10^{-3} \left(\frac{.2}{10^{-3}} \right) \frac{-10}{10^3} \sim .1 \text{ V}$$

This voltage has to be integrated and displayed in a recording device. Because after the integration with an operational amplifier the output voltage is

$$V_{out} = \frac{1}{R C} \int_{t_1}^{t_2} V_{in} \, d t \quad \text{when} \quad t_2 - t_1 = \Delta T$$

the R C time constant has to be small if one wants a large output voltage. For the integration time constant has to hold the following relation to $R C < \Delta T$ from which $R C \sim 10^{-5}$. Using this value the output voltage from this integrator

$$V_{out} \sim \frac{1}{R C} V_{in} \Delta T \sim V_{in} \sim .1 \text{ Volts}$$

III. An electron magnetic resonance magnetometer is capable of measuring changing magnetic fields to within an absolute accuracy of 0.1%. The magnetic field can range from 0 - 6000 gauss and field rise can be as high as then $\frac{5\ k\ G}{m\ sec}$.* The sensing element in these instruments is the electron spin resonance of 1 : 1 diphenyl - 2 picryl hydrazyl (D P P H). It has a Lande g value of 2.0008 ± 0.0002, a linewidth of 1.4 Gauss. The spin - spin relaxation time $T_2 = 2.4 \times 10^{-8}$ sec. The resonance frequency of D P P H is given by

$$\nu = (2.807 \pm 0.001)\ H \text{ in } M\ c.$$

where ν is the frequency in M c and H is the field in gauss. Fields of 500 to 2500 Gauss will resonate the D P P H in the frequency range of 1.4 to 7 k M c. With an electron magnetic resonance fluxmeter one would be able to measure the absolute value of the field at any predetermined time just by changing the oscillator frequency. At constant frequency the device would give a signal at a predetermined time if the field reached the required value. This would be a very convenient way to generate the "ready" pulse for the gun. Using a coincidence circuit between the E M R and the timing pulse one would be able to read the resonant frequency which corresponds to the peak magnetic field.

This device would serve as a very sensitive analyzing system for the pulse magnet modulators to investigate jitter and amplitude from pulse to pulse basis. Development of such an E M R device is under consideration

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* O. E. Spokas and M. Danos, Rev. Sci. Inst. June 1962

J. L. Stahlke, Nuc. Inst. and Methods 17 (1962) with the gated integrator as part of the instrumentation for the beam switching magnet.

The conclusion of this brief survey is that the E M R unit is the most adequate instrument for our application but the gated integrator using a fast calibration process would fullfill the requirements, too.