A WIDE AREA ELECTRON BEAM SCANNER

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Summary

A wide-area electron beam scanner, which utilizes a single three-phase electromagnet has been designed and constructed for use with Grumman's 3 MV Van de Graaff accelerator. The uniformity of the beam scan has been measured, and between radii of 1 and $4\frac{1}{2}$ inches has been found to be constant to within ± 10 percent (%).

Introduction

Unscanned accelerator-generator electron beams have limited utility for radiation effects experiments, because of their small cross sectional area. This restricts electron irradiations with unscanned beams to small numbers of specimens and to specimens whose area is small compared with the beam area. This restriction is particularly important in programs investigating semiconductor device behavior in radiation environments. These programs frequently require the uniform irradiation of large numbers of devices. Linear scanning systems provide only a partial answer to the above restrictions, and require extremely precise specimen alignment to insure uniform irradiation. The best solution to this problem requires the use of some type of wide-area (two-dimensional) electron beam scanning system. The scanning system which we have designed and constructed utilizes a single scanning magnet, which has been constructed identically to the field coil of a three-phase motor. The magnetic field generated herein sweeps the electron beam into a circle with constant angular velocity independent of the radius. Since the area swept per unit time increases with radius the beam deposits less energy per unit area per unit time at larger radii. By suitable modulation of the current in this magnet, the beam can be swept in the radial, r, direction as well, thus producing a uniform wide-area scan. It can be shown that the required radial modulation (for a thin beam and $\dot{r} << r\dot{\theta}$) is proportional to $t^{\frac{1}{2}}$. The electronic circuitry required to generate this waveform and to modulate the three-phase current flow was designed and constructed.

Analysis of Radial Modulating Function

Consider a circuitry scanned electron beam of small cross section, whose radial position is "slowly" changing at a rate given by $\dot{r}(\dot{r} << r\dot{\theta})$. After a time, dt, the area of the annulus impinged upon is given by:

$$dA = 2 \quad r\pi dr$$

Constant area per unit time is fulfilled by the condition that:

$$r \frac{dr}{dt} = \text{const.}$$

integration yields a radial time dependence given by:

$$r(t) = (\text{const.})t^{\frac{1}{2}}$$

This result shows that infinite radial sweep rate is required at the origin. In practice, a small region near the origin will fail to achieve uniform flux.

Electronics

System Design

The basic deflection unit consists of a 3-phase motor stator centered on the beam axis; under 3-phase excitation this stator produces a magnetic field vector at right angles to the beam direction, whose instantaneous azimuthal orientation rotates at the excitation frequency, producing a circular scanning pattern on the target. Uniform exposure over a circular annulus is achieved by slowly modulating the excitation current according to $t^{\frac{1}{2}}$.

The desired waveform is generated by a special function generator which modifies the output of a low-frequency triangle generator. The waveform is then amplified, DC-shifted, and converted to a low-impedance output driving the field windings of three Hall effect type solid-state modulators (Bell "Hall Pak"). At the same time, each modulator Hall effect current is supplied from a separate phase of a 3-phase, 400-cycle generator, resulting in three Hall output voltages, representing 3-phase, 400 cycle AC with a common $t^{\frac{1}{2}}$ modulation envelope on each phase. Finally, the three signals are fed through separate 400-cycle filters and amplified in separate 200 watt audio amplifiers to drive the 3-phase (star) windings of the beam deflection coils. A block diagram of the system is presented in Figure 1.

Function Generator Circuit

The waveform generator, whose schematic is shown in Figure 2, utilizes ten negatively biased diodes in a resistance network whose gain diminishes as each diode begins to conduct; a linear input signal, spanning the thresholds of all ten diodes, furnishes an output composed of eleven linear segments, with diminishing slope. Using uniform bias increments and appropriate resistance values, the output is made to approximate the continuous curve, $V = kt^{\frac{1}{2}}$. This waveform is then inverted, amplified, and adjusted to the proper DC level by the subsequent 6SN7 stage. (A "zero-set" pot accounts for the fact that the diodes conduct somewhat above zero volts bias).

Current Amplification and Hall Modulation Circuit

Since the field windings of the Hall effect modulators have an input resistance of only 5Ω, these inputs must be supplied from a low impedance source. This is accomplished by employing a transistorized current driver for each Hall modulator, supplying about 300 ma. of modulation signal to each field winding. The second input ("Hall current") signal is furnished from a separate phase of a 3-phase, 400 cycle generator, reduced to 3/4 volt amplitude by transformers. A schematic of one of these circuits is shown in Figure 3. Finally, by observing the modulated output signal on an oscilloscope, the DC level of input modulation signal is adjusted to give 100% modulation. This adjustment allows the deflected beam to reach the center of the scanned disc at the beginning and end of each radial sweep cycle.

Power Amplification Circuit

The millivolt Hall output signals are next amplified to several volts by three plate-tuned preamps that automatically reject undesirable harmonics produced in the 400 cycle generator. These pre-amplified signals are then amplified by three variable-gain, 200-watt, audio amplifiers (similar to "hi-fi" amplifiers) to supply the power for the "star" windings of the deflection magnet. Gains are carefully adjusted on each phase, to keep the scanned region circular.

Deflection Coils

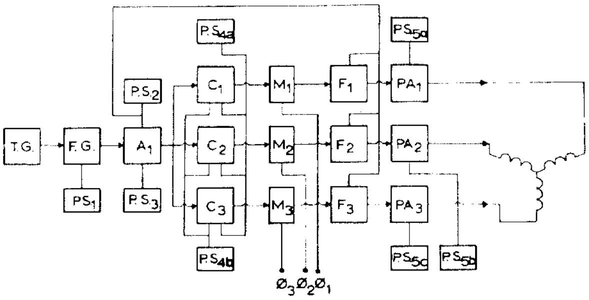
The deflection coils are the field windings of a 24-pole, 3-phase motor stator with a core length of about 4 inches and an inside diameter of 1½ inches. Coil impedances of 25Ω (at 400 cps) allow coil currents of about 3 amperes at 200 watts; external water cooling is employed for operation above 1 amp. A thin-walled stainless steel tube encloses the beam through the stator, to prevent excessive eddy current losses.

Measurement of Scan Uniformity

The system for measuring the beam uniformity, which is rather straightforward, consists of a number of Faraday rings connected to calibrated polystyrene condensers. The beam uniformity was determined by measuring the potential across these condensers, with a vacuum tube voltmeter. The Faraday rings were machined to insure normal incidence of the electron beam when placed concentrically on a 12-inch diameter plate at the end of a roughly conical chamber, some thirty inches (30") from the scanning magnet (see Fig.4). The ring diameters were 2", 5", 7", and 9" respectively, and the beam was aligned using a centered Faraday cup. The rings were connected to the polystyrene capacitors by cables through standard feed-throughs (see Fig. 5). Measurements were made at an energy of 2 MeV and at radial sweep rates of 0.1 and 1.0 cps. The beam was found to be uniform to within ±10 percent in the former case, and to within ±20 percent in the latter.

Conclusions and Recommendations

The feasibility of using a single three-phase electromagnet for wide-area electron beam scanning has been demonstrated. Future work will be directed towards improving beam uniformity, and towards increasing radial sweep rates. In addition, the suitability of this system for bremsstrahlung radiation will be investigated.



Key

TG - Low Frequency Triangle Generator
FG - Diode Function Generator
A1 - Function Generator Amplifier and DC Level Set
C1, C2, C3 - Transistorized Impedance Converter
M1, M2, M3 - Hall Modulator
F1, F2, F3 - 400 Cycle Filter and Amplifier
PA1, PA2, PA3 - 200 Watt Power Amplifier
PS1 - 15 Volt Power Supply
PS3 - Minus 150 Volts Power Supply
PS2 - 250 Volt Power Supply
PS4a - 6 Volt Power Supply
PS4b - Minus 6 Volt Power Supply
PS5a, 5b, 5c - Power Amplifier Power Supply
Ø 1, Ø2, Ø3 - 400 cycle 3-phase Input

Fig. 1. Block diagram of the G.A.E.C. Spiral Scanner.

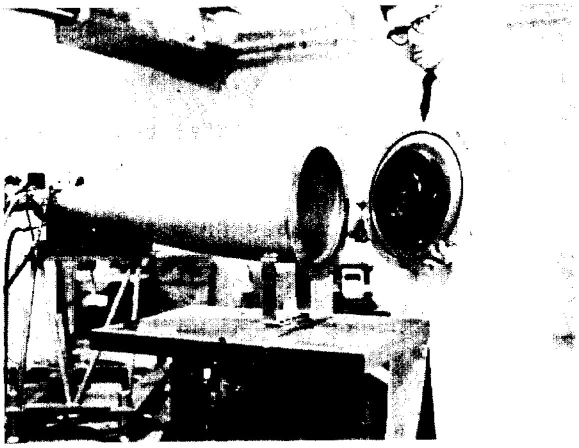


Fig. 4. Scanning Chamber with Faraday Ring Arrangement.

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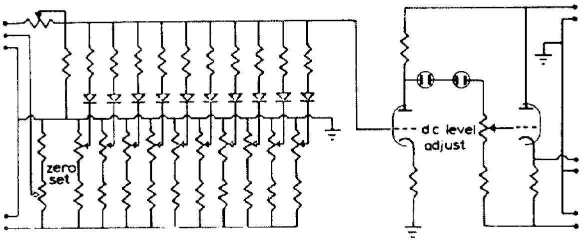

Fig. 2. Function Generator.

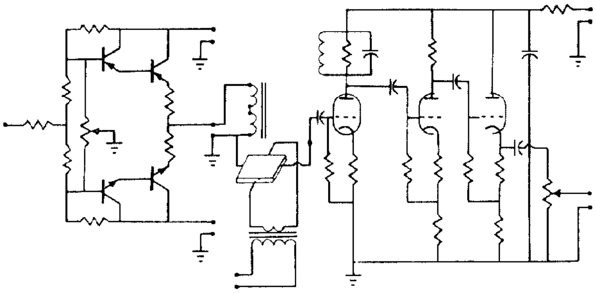

Fig. 3. Hall Modulator and 400-Filter Preamp.

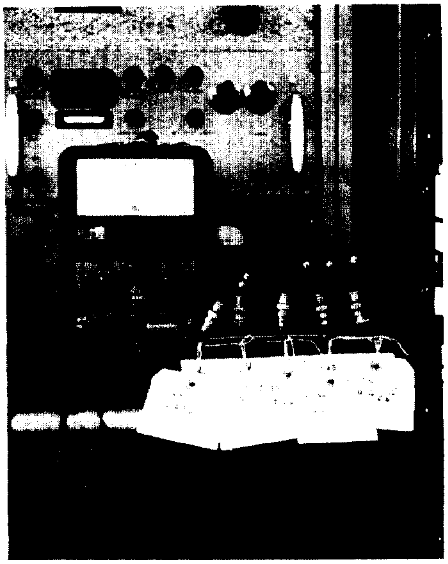

Fig. 5. Beam Measurement Instrumentation.