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SLOW BEAM RASTER SYSTEM AT CEBAF*

C. Yan, J. Beaufait, R. Carlini, C. Cuevas, W. Vulcan, R. Wines
CEBAF, 12000 Jefferson Avenue, Newport News, VA 23606, U.S.A.

July 7, 1994

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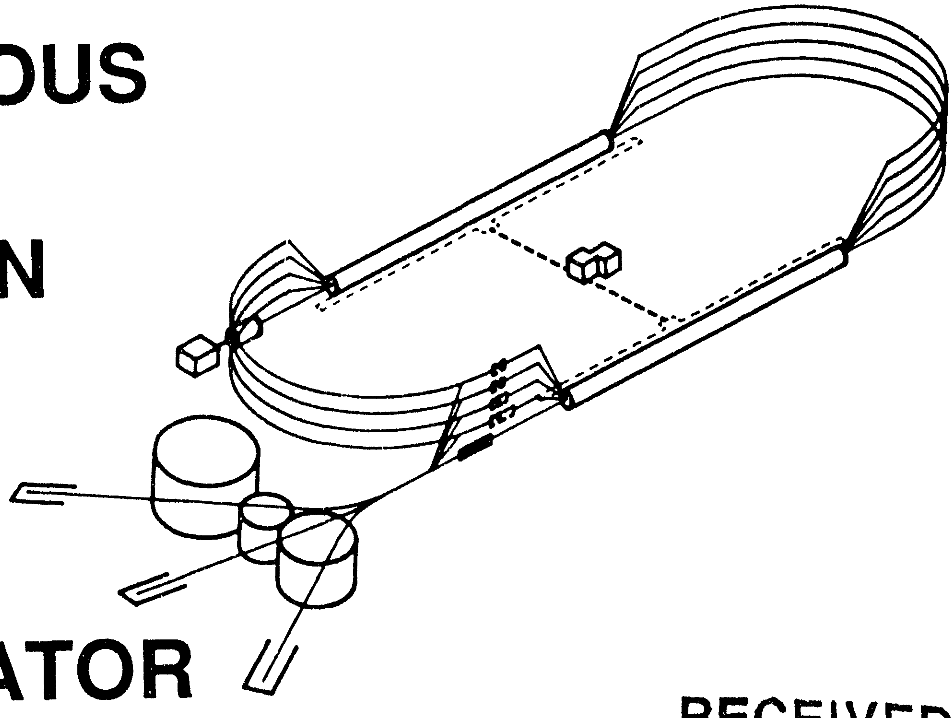

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The Southeastern Universities Research Association (SURA) operates the Continuous Electron Beam Accelerator Facility for the United States Department of Energy under contract DE-AC05-84ER40150.

Slow Beam Raster System at CEBAF *

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Abstract

A bedstead air-core raster magnet is being installed now, it will be used at CEBAF to scan the beam on the Hall C polarized target and the beam dump with fixed frequency 60 Hz in horizontal, 103.4 Hz in vertical. The x and y raster magnets are driven by Variac transformer and SUMITOMO inverter respectively. Both of them provide an approximately sine current waveform with peak current 20 A, corresponding to a maximum deflection angle 1 mr.

1 INTRODUCTION

The maximum beam power carried by 200 μA 4 GeV CEBAF beam will be 800 kW. The beam interaction with different materials was discussed in previous paper [1]. For an instantaneous spot size of 100 μm, the critical time constant for drilling a hole into the window by CEBAF 200 μA electron beam is about 100 μs. Also, any metal window material loses its strength after an energy deposition of 10^{18} ergs/gram by the beam. Therefore, the beam rastering speed and pattern have to be selected carefully to avoid long dwell times. Tentatively, an average beam spot size of 4×4 cm^2 at beam dump was adopted.

The Hall C polarized target will have a useful width and height of 2.5 cm. To make full use of it, the rastering of the beam on the target should cover at least 2.5×2.5 cm^2. Both of beam dump and polarized target require raster magnet having a maximum angular deflection 1 mr for 6 GeV electron beam. Table 1. gives rastering parameters required by different target materials.

2 RASTER MAGNET DESIGN BY TOSCA

Bedstead air core coils are selected as the raster magnets. The bedstead is made up of eight straight sections and eight 90 degree arcs. The cross section is rectangular, defined by its width in local x direction and thickness in local y direction. The TOSCA design specifications of slow raster coils are listed in Table 2.

The geometry of slow raster magnet is shown in Figure 1. The bedstead shape of the raster coil will generate larger uniform field region than flat coil, and keep the high order field components, mainly the sextupole component, as small as possible. The coil with constant perimeter ends

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Table 1: Parameters of slow raster magnet

Destination of rastering	Polarized Target	Beam Dump materials
Position(m)	142.59	200.65
Beam Current(μA)	0.1	200
Rastering Area (cm2)	2.5x2.5	4.0x4.0
Rastering Frequency(Hz)	60/103.4	60/103.4

Table 2: Specification of SR magnet

Design Parameter	Slow Raster
Central field (Gauss)	438.8
Bending angle at 6 GeV	0.84 mr
$\int Bdl$ (kG cm)	16.8
Field uniformity	10^{-2}
Effective length (cm)	38.34
Physical dimension (cm)	48
Inner radius (cm)	1.905
Number of turns	200
Ampere-turns (A-T)	4000
Current density (A/cm^2)	148
Stored energy (Joules)	6.944
Inductance (H)	34.7×10^{-3}
DC resistance (Ω)	0.916
RMS power (kW)	2.18
Type of conductors	Awg 6 square
Rastering frequency (Hz)	60/103.4

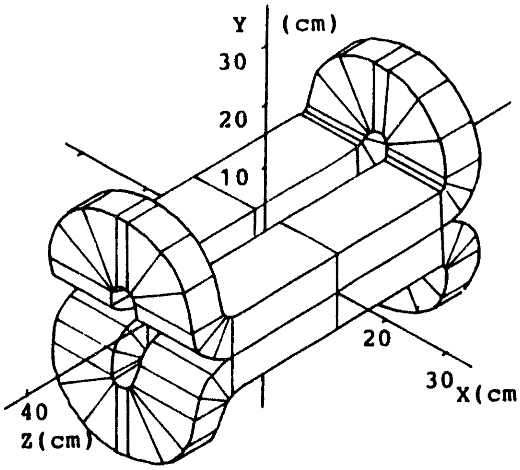

Figure 1: TOSCA layout of the slow raster raster magnet (SR).

has higher efficiency than bedstead coil, but it doesn't fit beam pipe geometry.

The bedstead air-core coils are manufactured by Applied Magnetic Products. The first slow raster magnet is shown in Figure 2.

3 DRIVERS FOR SLOW RASTER MAGNETS

The frequency ratio between horizontal and the vertical rastering is selected in such a way that a fast rolling pattern is generated, therefore, the density distribution over entire scanning area becomes uniform just after few cycles, it is much faster than TV scan pattern. The rastering pattern is illustrated in Figure 3.

Triangle waveform is originally preferable to drive the raster coil because there is no slow down area near each turning point. In fact, it is difficult to design a triangle current driver with ±20 A capability because of the large inductance of the coils. A Volt-Pac variable transformer (9T92A77) is used as 60 Hz, 20A current driver. Current waveform is obtained from LEM LA 55-P current sensor, which is a current transducer for the electronic measurement of currents (DC, AC and pulsed) with galvanic isolation between the primary (measured) and the analog output (control) signal. Its measuring range covers 0 to ±70A with turns reduction ratio 1:1000. The linearity is better than 0.15%, response time is better than 500 ns. The di/dt accurately followed is better than 200 A/μs, and its bandwidth is from 0 to 200 kHz (-1dB).

A pulse-width modulation (PWM) power amplifier (SUMITOMO AF504-011) is used to drive horizontal raster magnet at 103.4 Hz. The superiority of pulse-width modulation (PWM) power amplifier to linear amplifier technology is particularly striking when the need is to drive AC magnetic coils with high inductance and low

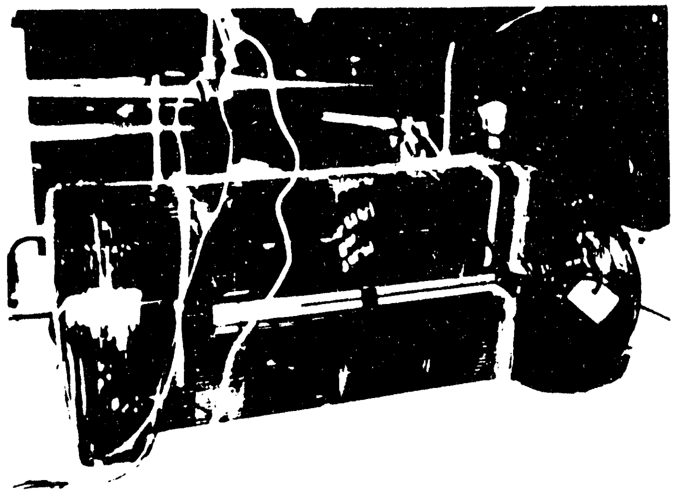

Figure 2: Slow raster magnet with current transducer and Hall probe mapping device

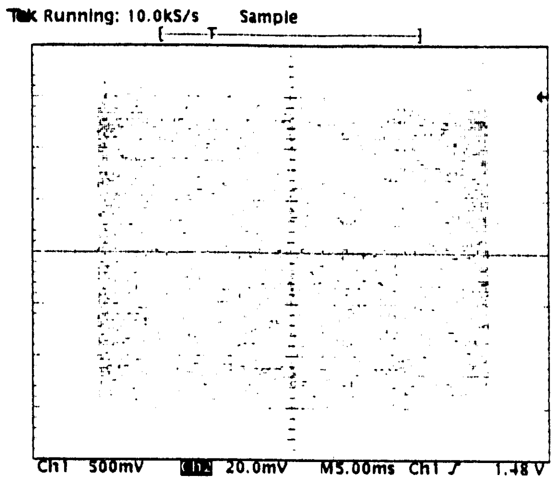

Figure 3: Rastering pattern of slow raster system

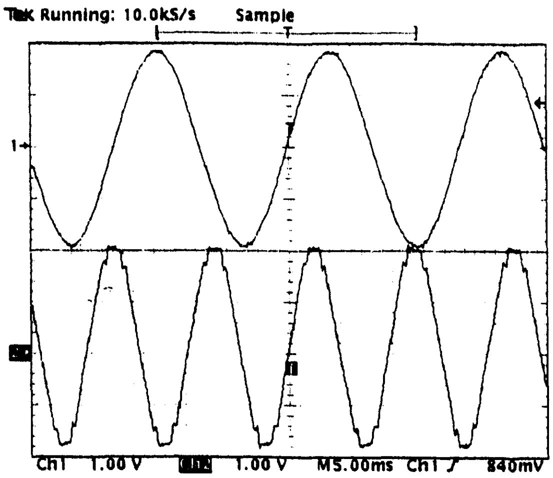

Figure 4: 60 Hz and 103.4 Hz current waveforms from LEM sensors

ohmic resistance, which is just the case of slow raster magnets. The current waveforms from LEM sensor are shown in Figure 4. At 103.4 Hz the output sine waveform is encompassed by stair shape wave modulated by a 3.7 KHz chop frequency. At each step there is a 270 μs plateau between two spikes and the length of flat top is 1.34 ms. This is the major drawback of PWM power driver. As the result of such highly distorted current waveform there is a density enhancement alone the horizontal boundary of 2-dimensional raster pattern.

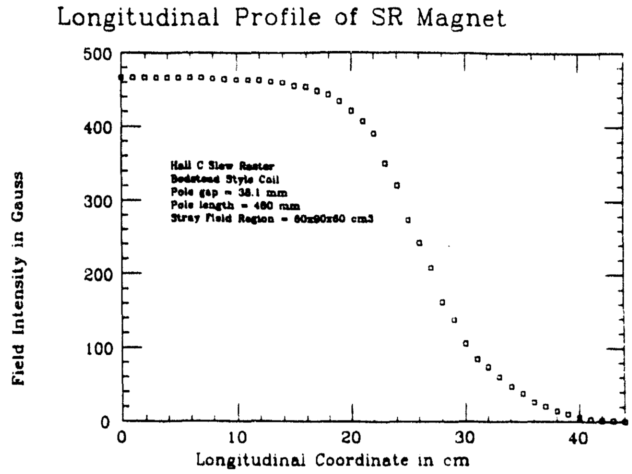

Figure 5: Longitudinal field profiles of slow raster magnet

4 DC AND AC FIELD MAPPING

A Sorenson DC power supply is used to drive magnet with DC current stability of 10^{-3}. A DTM-141 digital teslameter with a transverse Group3 Hall probe MPT-141 is used to measure transverse and longitudinal field distribution manually. The longitudinal field profiles are shown in Figure 5, dish line is TOSCA calculation and solid line is experimental curve. The TOSCA data is reproduced within 1% accuracy.

The excitation curve shown in Figure 6 is obtained by measuring central field versus varying current from 2A to 40A.

Lakeshore teslameter (true rms ac response 400 Hz) and F. W. Bell 4048 Gaussmeter (true rms ac response 12 KHz) are used to generate rms field mapping when two kinds of drivers power the magnet respectively. The stray field (below 10 Gauss) volume is about $80 \times 90 \times 60 cm^3$ when the central rms field is 440 Gauss.

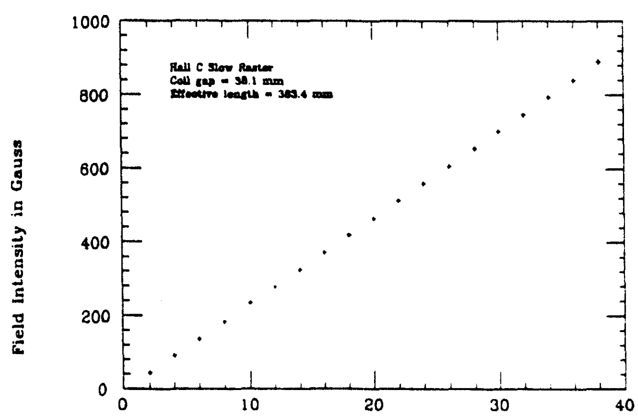

Figure 6: Excitation curve of slow raster

5 AC VIBRATION

Horizontal and vertical vibration sensors (L-10 Accelerometer, Martin products) are used to obtain quantitative analysis of magnet mechanical vibration caused by low frequency magnetic force generated by driving current in winding. The calibrated output voltage of L-10 is 0.7V/(inch/s) when terminated by 75 ohm, 0.8V/(inch/s)

Table 3: Vibration parameters at 60 Hz

Driving peak current (A)	20	30	40
Driving rms voltage (V)	198	296.2	385.9
Peak central field (Gauss)	467.6	697.2	907.0
Horizontal velocity (inch/s)	0.045	0.0725	0.105
Vertical velocity (inch/s)	0.233	0.366	0.463
Maximum amplitude (μm)	9.7	15.25	19.29

Table 4: Vibration parameters at 103.4 Hz

Driving peak current (A)	14.2	20	21.5	25.28
Horizontal velocity (inch/s)	0.037	0.053	0.063	0.076
Vertical velocity (inch/s)	0.207	0.295	0.327	0.384
Maximum amplitude (μm)	6.24	8.92	9.9	11.62

with open ends. Vibration amplitude at 60 Hz and 103.4 Hz with different driving current are listed in Table 3 and Table 4.

Even the vibration caused by AC field of slow raster is in the order of 20 μm, one should isolate raster magnet from other beam line elements, especially the wire scanners, by installing bellows at two ends of beam pipe of raster magnet and placing a μ-metal shielding cover over the scanner.

6 BEAM PIPE FOR RASTER MAGNET

The skin effect of alternate current in a solid conductor is its concentration in a thin layer at the periphery. The effect results from the internal and external distribution of flux lines. At 60 - 100 Hz frequency range, penetration depth is 6.5 - 8.5 mm. Even inside the stainless steel beam pipe the field is not effected by skin effect, the eddy current generated by low frequency alternative field causes large amount of power dissipation on the wall of beam pipe. The temperature of beam pipe increases rapidly (about 40^oK per minute) when the magnet is powered.

As a temporary replacement of ceramic pipe, an epoxy pipe is under testing now. Two flanges (one fixed, and one rotatable) are glued to the beam pipe by Torr-Seal high vacuum epoxy. After two weeks continuous pumping down by a set of ion pump and turbo pump, the pressure is 5×10^{-6}, that is still not good enough for normal vacuum operation. As soon as the ceramic duct is manufactured, it will be coated by very thin metal layer (few MΩ per inch^2), which is used to release extra charges produced by either beam polarization effect on the wall or scattered electrons, to prevent any accidential damage. The coated ceramic duct will be the permanent beam pipe of slow raster magnets.

7 REFERENCES

[1] C. Yan et al, Beam Raster System at CEBAF, CEBAF-PR-93-005, May 1993.

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