

BEAM RASTER SYSTEM AT CEBAF

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Abstract

A cascade raster system will be used to generate variable rastering pattern on polarized target, cryogenic hydrogen target, and the beam dump with adjustable frequency up to 10 kHz and variable deflection angle from 0.05 mr to 1 mr. Each raster consists of two air-core bedstead coils providing transverse and vertical scans. The magnets are energized by individual MOS power amplifiers being controlled by the scan generator which determines frequency, amplitude, and phase shift between the cascade rasters.

I. INTRODUCTION

A. Heating effect in the solid target

Assume that a beam current was 200 μA and the target periphery was kept fixed at the initial target temperature 20 K. The beam spot size is about 0.2 mm diameter. A thin molybdenum target of $2 \times 2 \text{ cm}^2$ was considered. The target thickness was 0.2 mm, which corresponds to about 0.15% radiation lengths (0.204 g/cm^2) for Molybdenum. In this case thermal conduction through the metal target material and the metal frame are considered as the major manner releasing the heat deposited by the beam and the black body thermal radiation can be eliminated. With the beam spot fixed at the center of the target, the steady state beam spot temperature reached 2500 K. If the beam scans the target with a sinusoidal motion having frequency 100 Hz and amplitude 9.6 mm in one direction, the steady temperature is about 300 K over the target area except the four vertex points of the motion [1]. A further simulation by [2] shows that if a fast two dimensional rastering ($f_1 = 2 \text{ kHz}$ and $f_2 = 0.1176 \text{ kHz}$) is applied to an aluminium target ($20 \text{ mm} \times 20 \text{ mm}$). The temperature rise on the target will be quickly saturated at Δt is below 70 K from an initial temperature 300 K after 1 second. For the iron target a temperature rise of 500 K occurs due to the worse thermal conductivity and the smaller specific heat.

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B. Heating effect in the cryogenic target

In the case of 10 cm liquid hydrogen target operating at 20 K the power dissipation due to the energy loss in the target cell by 200 μA beam is about 1 kW. Along the track of the beam the liquid hydrogen is overheated by the deposited energy of the beam and bubbles will be formed, therefore, a density variation is eventually generated. In order to minimize this bubble formation effect and reduce forced flow velocity to a reasonable level (1 to 10 m/s), the best solution is to make beam rastering. The global and local beam heating analysis by [3] shows a 18 kHz rastering with 2 mm amplitude is preferable.

C. Heating effect in the beam dump

As discussed by [4], for an instantaneous spot size of 100 μm , the critical time constant for drilling a hole into the window is 100 $\mu\text{seconds}$. Also, any window material loses its strength after an energy deposition of $10^{18} \text{ ergs/gram}$ by the beam. Therefore, the rastering speed and pattern has to be selected carefully to avoid long dwell times. Tentatively, a spot size of $4 \times 4 \text{ cm}^2$ at the dump was adopted. The spot size at the beam dump entrance can be increased nearly arbitrarily by using high speed magnetic rastering.

D. Rastering on the polarized target

The UVa 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 $2.5 \times 2.5 \text{ cm}^2$ [5]. An adjustable offset of rastering current is desirable for the beam alignment. In the polarized target experiment the current density is only 100 nA, it is reasonable to require 1 kHz rastering. The Møller polarimeter requires a linear rastering pattern on the iron target with amplitude of 2 mm instead of moving target [6]. The linear scan of the beam will effectively reduce the temperature rise of the target and keep the polarization at an higher level in the beam current range from 10 to 100 μA .

E. Rastering frequency and amplitude

Parameter	Cryogenic Target	Polarized Target	Beam Dump materials
Position(m)	146.25	146.25	200.65
Current(μ A)	200	0.1	200
Area (cm ²)	0.2x0.2	2.5x2.5	4x4
Frequency(kHz)	10-18	0.1-1	0.1
Operation	FR	FR+SR	SR

Table 1: Raster frequency and amplitude, FR:fast raster, SR:slow raster

Design Parameter	SR	FR
Central field (Gauss)	438.8	80.1
Bending angle at 6 GeV	0.84 mr	0.0588
$\int Bdl$ (kG cm)	16.8	1.2
Field Uniformity	10^{-2}	10^{-2}
Effective length (cm)	38.34	15
Physical dimension (cm)	48	25
Inner radius (cm)	1.905	1.27
Number of turns	200	20
Ampere-turns (A-T)	4000	240
Current density (A/cm ²)	148	100
Stored energy (Joules)	6.944	0.0167
Inductance (Henries)	34.7×10^{-3}	84×10^{-6}
DC resistance (Ohm)	0.916	3.02×10^{-3}
RMS power (kW)	2.18	0.528
Type of conductors	Awg 8	Litz
Rastering frequency (Hz)	60	10k

Table 2: Specification of SR and FR magnets

II. RASTER MAGNET DESIGN BY TOSCA

Two bedstead air core coils will be used as the raster magnets. The specification of the coil are listed in Table 2.

The geometry of the raster magnet is shown in Figure 1. The bedstead shape of raster coil will generate a larger uniform field region and keep the high order field components, mainly sextupole component, as small as possible. In order to reach a higher rastering frequency up to 10 kHz, neither iron nor laminate iron material can be used as the raster magnet. Ferrite magnet is also not preferable because its small hysteresis makes difficulty for phase control.

III. FREQUENCY CHARACTERISTICS OF RASTER COIL

A triangle waveform is selected to drive the raster coil. Based on the Fourier theorem, an arbitrary function $F(x)$ can be expressed

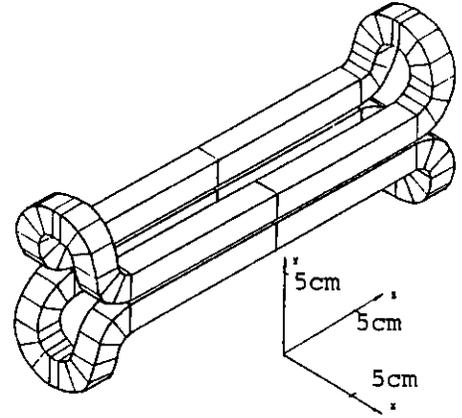


Figure 1: TOSCA layout of FR raster magnet

$$F(x) = \sum_{n=1}^{\infty} [A_n \sin n\omega_n x + B_n \cos n\omega_n x] \quad (1)$$

Where, $\omega_n = 2\pi f_n$, A_n and B_n is the amplitude of n-harmonic components, therefore, the amplitude of the n-harmonic = $\sqrt{A_n^2 + B_n^2}$ and the intensity of the n-harmonic = $A_n^2 + B_n^2$.

In the case of identical triangle waveform

$$y = \begin{cases} -T - x & -T \leq x \leq -T/2 \\ x & -T/2 \leq x \leq T/2 \\ T - x & T/2 \leq x \leq T \end{cases} \quad (2)$$

The Fourier expansion of the triangle waveform is

$$y = \frac{4T}{\pi^2} \sum_{n=1}^{\infty} \frac{(-1)^{n-1}}{(2n-1)^2} \sin \frac{(2n-1)\pi x}{T} \quad (3)$$

$$y = \frac{4T}{\pi^2} \left[\sin\left(\frac{\pi x}{T}\right) - \frac{1}{9} \sin\left(\frac{3\pi x}{T}\right) + \frac{1}{25} \sin\left(\frac{5\pi x}{T}\right) - \dots \right] \quad (4)$$

Therefore, the ratio of the amplitudes and the intensities of the first, the third, and the fifth harmonic components are $1 : \frac{1}{9} : \frac{1}{25}$ and $1 : \frac{1}{81} : \frac{1}{225}$ respectively.

The 20 kHz triangle waveform generated from Tektronix FG 501A 2 MHz function generator was experimentally analysed by HP network analyser. The frequency spectrum is displayed in Figure 2. The ratio of relative amplitudes of the fundamental frequency, the third and the fifth harmonic is as the same as the computation from Fourier analysis mentioned above.

Losses in a conductor due to the skin effect and proximity effect should be considered. The frequency range should cover 3-order harmonic for triangle driving waveform. For the FR raster magnet, a round Litz cable 660/36 is used to make the winding. For SR raster magnet, Litz cable is not necessary for the winding because at lower frequency 60 Hz the skin depth in copper conductors is 8.5 mm, Awg no. 6 cable can be easily used for winding.

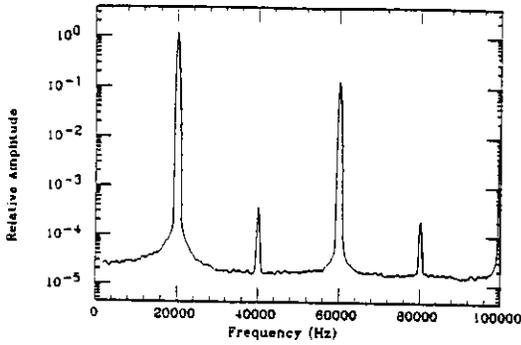


Figure 2: Frequency spectrum of triangle waveform from HP analyser

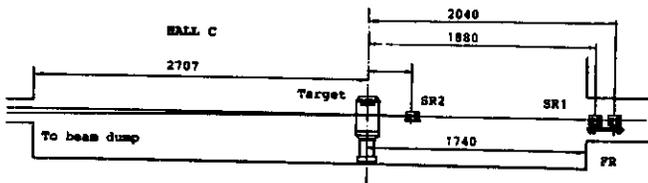


Figure 3: The raster system in Hall C beam line

IV. OPERATIONAL PERFORMANCE

The raster system is arranged as shown in Figure 3.

A fast raster system (FR) is placed just at the entrance of Hall C - in front of the first chicane magnet (BE). With a bending power 0.0588 mr at 6 GeV/c it is able to provide $2 \times 2 \text{ mm}^2$ rastering area on the cryogenic target. A combined SR raster system which is located in front of the FR raster scans the beam on the polarized target with rastering area $2.5 \times 2.5 \text{ cm}^2$. The second SR raster near the target chamber executes two functions: in the absence of polarized target it scans the beam to a safety size ($4 \times 4 \text{ cm}^2$) on the beam dump and in the operation of polarized target it derasters the beam with opposite phase in order to reduce the large amount background generated from scattered beam at the wall of beam pipes.

Each raster system consists of two pairs of bedstead coils, one for horizontal scan, another for vertical scan. Different rastering patterns have been simulated and compared by two dimensional oscilloscopic Lissajous figures. Instead of TV frame/line scan rate the best ratio (1.721) of the two rastering frequency was found, which gives the longest trajectory traversal and fast uniform distribution.

FR raster magnet is driven by PA03 MOS power amplifier (APEX micro technology). PA03 is an ideal driver for FR magnet due to its excellent features of high voltage,

high current, and high internal dissipation. SR magnet is driven by a resonance circuit, which consists of a π -type LC resonance circuits, impedance match network, and low frequency power amplifier. Both of those drivers are under construction.

Ceramic duct should be used as vacuum pipe of FR raster magnet. The ceramic vacuum duct avoids heating-up effect and the field attenuation due to eddy currents induced by alternative magnetic field. A very thin metal coating layer should be applied in the inner-wall of the duct conducting image current produced by beam.

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