CHICANE RASTER SYSTEM PROVIDES TRULY PARALLEL BEAM FOR PARITY AND OTHER EXPERIMENTS

C. Yan
Physics Division
Jefferson Laboratory

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1 Introduction

Since G_0 experiment requires a relatively high beam current on a cryogenic target, it is necessary to raster the beam across the surface to avoid excessive heating. Based on the operational experience with CEBAF Hall C liquid hydrogen targets the beam should be spread over an area of 0.2 cm^2. It is also necessary to synchronize the raster frequency with the helicity reversal rate to prevent unintended false asymmetries.

One of the geometric options of G_0 target location is to place G_0 target 12.5 meters upstream from original Hall C target position. The upgraded Hall C target raster system FR2 will generate a maximum angular deflection about 0.2 mr for a 4 mm rastered beam size. Because this relatively large beam angular deflection could generate a false measurement on the helicity in G_0 toroid spectrometer, a chicane type of beam raster/handling system is specially designed providing a truly parallel beam with approximately uniform raster density for G_0 experiment. This device will also be used as a permanent high quality beam transfer system for other Hall C experiments.

2 Hall C Target Raster System

2.1 Target raster magnet

The target raster magnet is a pair of bedstead air-core coils which are made of Litz 1650/38 cable. The inductance value of the magnet is about 88 μH while the quality factor changes from 180 to 204 at a frequency range from 1 kHz to 100 kHz. The core losses is greatly reduced by Litz cable windings. The Litz cable was self-bound by applying superglue on its nylon wrappings and no stuff material was used. During continuous experimental run from November 1995 to December 1997, no any change of electrical performance was found and the equilibrium temperature on the surface of the magnet didn't exceed 25 ^oC at the full loaded current $I_{pp} = 40A$. The major characteristics of FR magnet is shown in the following table.

Effective length (cm)	23.7
Gap (inch)	1.0
Turns	20
Winding type	Litz 1650/38 (Awg #6)
Inductance (μH)	88
Quality factor	120
$\int$ Bdl/I (Gauss cm/A)	81
Resonance frequency (kHz)	24.2
Good field area (cm^2)	1.0

2.2 Raster Power Resonance Loop

The series power resonance loop consists of raster air-core magnet, resonance capacitor bank and a toroid high frequency transformer, which transforms output impedance of Bogen amplifier from 4 ohm to extremely low impedance matching resonance loop. The output power cable is pulled through the central hole of Pearson 411 current probe. Pearson probe is a passive current pick-up sensor with broad frequency response (1 Hz - 20 MHz) and fast rise time (20 ns). 10 0.1 μF high voltage (1000 VAC) polypropylene snub capacitors are installed on a thick copper bus in parallel forming a air-cooled capacitor bank. The capacitor bank ensures the temperature rise at full current operation is less than 10 degree, keeping capacitance very stable for a long term operation. The quality factor of FR power resonance loop is above 100.

2.3 Raster Pattern Generator

Hall C target raster system was upgraded in the beginning of 1998. The TV type scanning electronics of original Hall C target raster FR1 (operated from 1995 to 1997) was replaced by a pseudo-spiral raster with special amplitude modulation which keeps rastering linear velocity along the track constant. To identify with original Hall C raster

FR1, we call the upgrade raster system as FR2. The new round shape raster pattern gives absolutely uniform raster density distribution when used together with linear pow amplifier, and an approximately uniform primary density distribution when used with power resonance mode drivers. The huge density enhancement at four vertexes of TV pattern due to the sinusoidal slow down behaviour near the turning points was greatly improved, see figure 5.

To avoid high harmonic distortion of the modulation waveform at the central region, one small hole is created in the center of raster area. Adjusting the symmetry of modulation waveform generates a 10% artificial density enhancement along both inner and outer boundaries in order to keep secondary density distribution uniform by increasing local thermal conduction and transverse convection rate through the boundaries between beam heating volume and cold cryogenic liquid.

The 24.2 kHz fundamental frequency is produced by WAVETEK function generator DDS 29. The 24.2 output sinusoidal signals are split into two channels: the first one is directly sent to power amplifier while the second one passes through a 90 degree phase shifter, then is sent to second amplifier. The $(t)^{1/2}$ modulation waveform is embedded into the second WAVETEK generator, which provides 47 Hz modulation output to the first WAVETEK. The block diagram of Hall C upgrade raster system FR2 is shown in figure 1.

The major performance of FR2 target raster system is listed in following table:

Maximum deflection power (mr)	1.94/p[GeV]
Maximum current amplitude (A)	80
Maximum raster amplitude (mm)	38.8/p [GeV]
Minimum raster amplitude (mm)	$(\mathrm{I}_{beam}[\mu\mathrm{A}]/200)^{1/2}$
Current calibration $\mathrm{I}_{pp1/2}$(A)	2.06p[GeV]$\Delta x_{1/2}$ [mm]
Fundamental frequency (kHz)	24.2
Modulation frequency (Hz)	47
Modulation waveform (%)	$(t)^{1/2}$
Symmetry of modulation (%)	0.01
Raster parameter control	EPICS

3 Chicane Optics

3.1 Chicane Raster Geometry

Like DC chicane magnets, a cascade FR2 raster magnets are configured as chicane raster system. The first FR2 raster sweeps beam with 24.2 kHz with pseudo-spiral pattern and the second FR2 raster system executes the same function but with inverse phase, then a parallel rastered beam is produced. The principle of operational function of chicane raster is shown in Figure 2.

The maximum deflection power of FR2 target raster is about 1.94/p[GeV/c] mr. At 4 GeV - the beam energy used for G_0 experiments, the maximum deflection angle is about 0.485 mr. To generate a parallel beam with 2 mm raster amplitude for $G-0$ and other Hall C experiments, the distance between the first FR2 and the second FR2 raster should be at least 4.12 m. The second FR2 raster magnets should be installed downstream right after G_{en} BE magnet. The chicane raster system will become a permanent device and it can also be used for G_0 experiment without any alternation.

3.2 Beam Transportation Through Chicane Raster

The final three quadrupoles 3C18, 3C19, and 3C20A on the second match section of Hall C beam line is used to transfer beam from Hall C 34.3 degree achromat to the target through the chicane raster. TRANSPORT code has been used to simulate the first and the second order beam focusing behaviour. The triplet plus chicane raster form a very flexible beam tuning system. Two tuning mode are optional for the diffrent uses.

1. The triplet transfers the beam with double focusing ($x/\theta = y/\phi = 0$) and double achromaticities ($x/\delta = \theta/\delta = 0$.) The beam is well focused into a 0.05 mm size with a tiny incident angle 0.01 mr. The chicane raster rasters the beam to r = 2 mm size.
2. By using achromatic point-to-parallel focusing ($\theta/\theta = \phi/\phi = x/\delta = \theta/\delta = 0$), an absolute zero incident angle beam with 0.4 mm size is delivered on the target. The chicane raster will uniformly raster the beam to r = 2 mm size.
3. In both cases, a fully achromatic transportation is achieved because of the absolute zero dispersion of the chicane raster system. The dispersions of raster chicane magnets FR2A and FR2B are compensated each other whenever in spite of raster amplitude. This function is ensured by the accurate phase control and field mapping datum.

The first order matrix elements of the triplet plus chicane raster transportation optics are given by the following table:

-0.71619	0.00000	0.00000	0.00000	0.00000	0.00222
-1.59949	-1.39627	0.00000	0.00000	0.00000	0.00000
0.00000	0.00000	-1.03791	0.00000	0.00000	0.00000
0.00000	0.00000	-1.25769	-0.96347	0.00000	0.00000
-0.00036	-0.00031	0.00000	0.00000	1.00000	0.00000
0.00000	0.00000	0.00000	0.00000	0.00000	1.00000

4 Chicane Raster Electronics

The configurations of two FR2 system electronics are identical. The complete chicane raster system uses only fundamental frequency 24.2 kHz, and only modulation generator. Two precision 180 degree phase shifters are inserted in front of Bogen amplifiers between system A and system B. The block diagram of chicane raster electronics is shown in Figure 3.

FR2 system has reliably been operating for Hall C experiments since February 1998. The experimental primary raster density distributions taken from Hall C data acquisition system are shown in Figure 4: a) the 3-D contour plot, b) the 2-D projection plot and c) top view of raster density distribution. The chicane raster will produce the same plots like these from single FR2 system. Comparing them with the 3-D plot of original Hall C TV type raster in Figure 5, the entire performance of FR2 is quantitatively much better than FR1.

The 24.2 kHz fundamental frequency could be synchronized with helicity reversal rate and the modulation frequency by phase lock function of the master generator. Frequency locking is achieved by using the clock output from the 'master' generator to drive the clock inputs of 'slaves'.

The EPICS control, BRM (Beam Raster Monitor) and FSD (Fast Shut Down) were already upgraded and operated for Hall C upgrade raster FR2 system during Jackson's run in 1998. They are effectively working in a very straightforward way. The true rms to DC converter converts the fundamental and modulation signals into certain DC level. For any arbitrary waveform, the ratio between input peak-to-peak value and the output DC level is a constant. By experimental calibration, the conversion coefficient can be found and programmed into the EPICS control software. A presettable window discriminator will detect the failure of FR2 system to fire FSD according to the trigger of upper and lower DC threshold.

Hall C has scheduled that after G_{en} experiment 1998, the second FR2B system will be installed downstream BE magnet (the second Hall C chicane magnet, which is reserved for polarized target experiments during 1999 to 2000.) and have chicane raster system ready for experiments in 1999 as well as for G_0 in 2000. There are already enough spare parts, including power resonance components, current probes, function generators, Litz winding FR magnets, in hands for the use of reproduction of the second unit FR2B immediately.

5 Conclusion

Chicane raster system could provide uniform beam rastering with zero incident angle. It combines advantages of achromatic chicane optics and properties of pseudo-spiral rastering. It is the best beam transportation system for all experiments in Hall C. With application of chicane raster system, a larger uniform raster area could be obtained without beam intrinsic structure. The high raster frequency 24.2 kHz will greatly help the cryogenic target reducing local heating effect, therefore a higher current operation will be available.

6 Reference

1. C. Yan, R. Carlini, S. Danagulian, "Target raster system for G_0", a brief report to G0 collaboration, January 28, 1998

2. C. Yan, Private communication with D. Beck, February 2,1998