LOCATION AND CORRECTION OF 60 HZ IN THE CEBAF INJECTOR*

R. Legg, D. Douglas. G.A. Krafft, and Q. Saulter, CEBAF, Newport News, VA 23612 USA

CEBAF produces a continuous electron beam with an emittance of 2-3 nm-Rad. Transverse low frequency magnetic oscillations act to dilute this emittance. These fields are typically associated with AC line conductors. The CEBAF injector is approximately 40 m long. To locate the source(s) of the beam motion, measured offsets were back propagated along the beamline using the DIMAD model. Field measurements were then made at the calculated field source positions and correlated with the measured offsets. Corrections and final beam measurements were made to verify the corrections.

I. CALCULATION OF SOURCE POSITION

The beam motion at different points along the beam line can be related by the equation:

$$k = (d1/d2)(\cos\Psi_2/\cos\Psi_1)/((\beta_1/\beta_2)/(\gamma_1/\gamma_2))^{0.5}$$

Where d1 and d2 are the measured beam motions at points 1 and 2 along the beamline. β is the calculated betatron function, γ is the measured relativistic term for the beam and Ψ is the calculated betatron phase advance at the points of measurement along the machine.

K is the variation in the normalized emittance. When k is greater than one it indicates that the observed transverse motion is greater than that to be expected from a motion being simply propagated by the lattice along the beam line. Where k equals one the beam motion is simply propagating along the beam line according to the lattice function. Where k is less than one there is the suggestion of an unknown damping function or experimental error.

The magnitude of the observed motions, the energy and the calculated β's are tabulated in Table 1 for the three measurement points, 0.5, 5 and 25 MeV. The betatron functions along the beamline were calculated using a DIMAD model of this particular machine configuration. This model uses the experimental values to back-propagate betatron functions upstream of the diagnostic instrumentation used.

The 60 Hz motion at the A4 aperture in front of the quarter cryounit was measured by positioning the beam partially on the aperture, desync'ing the pulser from the 60 Hz line frequency and observing the oscillations in intercepted current on the aperture. This technique assumes that the spot is round and that, because of the emittance defining aperture upstream, the current density is uniform across the spot. Given these assumptions, this technique is very sensitive, allowing motions of only .02 mm to be measured. The measurements at the 5 and 25 MeV points were made by desync'ing the beam 20 Hz from the line frequency and then cycling the harp. The harp's travel time across the pipe is slow enough, 10-15 sec, that the 20 Hz beat frequency generated looks like a multiple maxima of the beam intensity on the harp trace and can be quantified by comparing it to a trace taken with the beam line sync'd.

The measured transverse beam motions along the beamline, d_1/d_2, the calculated $(\cos\Psi_2/\cos\Psi_1) / ((\beta_1/\beta_2) / (\gamma_1/\gamma_2))^{1/2}$ parameters and their ratios are tabulated in Table 2. The last column in Table 2 plots the k from the first equation above. The values are very close to one.

These results suggest a source before the A4 aperture which is being propagated down the machine or a distributed effect with the bulk of the disturbance before the 5 MeV point. The region of the injector most sensitive to stray low frequency magnetic fields is the 15 cm long acceleration region between the cathode and anode in the gun. The momentum goes from 0 to 0.34 MeV/c in this distance and is difficult to shield because the acceleration is electrostatic and the structures are dielectrics. To quantitize the problem low frequency field measurements were made using a milliGauss meter, placing the probe where the cathode normally sits while turning the high potential deck electronics ON and OFF. The measurements indicated a total field of 13 mG in the horizontal plane of which 10 mG was accounted for by several AC fans in the CAMAC crate on the hot deck.

* Work supported by U.S. D.O.E. contract #DE-AC05-84ER40150

Diagnostic	E, MeV	Line Sync'd	β, m	d, mm	FWHM, mm	γ	Ψ, rad
A4, aperture	0.5	no	52	0.6	-	2	0
harp	5.55	yes	27		1.17	11	0.12
harp	5.55	no	27	0.2	1.34	11	0.12
harp	25.1	yes	55		0.69	50	0.4
harp	25.1	no	55	0.13	0.82	50	0.4

Table 1

ΔE	$\cos\Psi_2/\cos\Psi_1$	d1/d2	$((\beta1/\beta2)/(\gamma1/\gamma2))^{0.5}$	k
0.5 -5.5	1.01	3.0	3.25	0.93
5.5 - 25	1.08	1.53	1.49	1.11
0.5 - 25	1.09	4.62	4.86	1.03

Table 2

The total vertical AC magnetic field was measured at 3.5 mG. The calculated beam motion for the horizontal field at the second emittance defining aperture was 255 microns. The experimental result measured was 360 microns.

II. EXPERIMENTAL VERIFICATION

To verify the correlation between the field measurements and the beam motion measurements a test was performed measuring the observed beam motion with the AC fans in the CAMAC crate ON and OFF. The vertical motion of the beam with the fans ON was 250 +/- 20 microns. With the fans OFF the motion dropped to 50 +/-20 microns. The correlation of the ratio of the observed beam motions, 50/250 microns, to the ratio of the transverse AC fields, 3.3/13.3 mG, was 0.81 +/- 0.4. The large error term is due to the 20 micron resolution of the position measurement.

After shielding several of the power supply transformers on the hot deck the measured fields were further reduced to 0.5 mG in the horizontal plane and 1.6 mG in the vertical plane at the the cathode. The experiments at the 0.3 MeV/c and 0.8 MeV/c regions were repeated to verify reduction of the transverse beam motion. The data along with the calculated beam properties are given in Table 3. The data suggest another, smaller source of transverse beam motion between the measurement points. An extensive search for such fields failed. The other possibilities were an error in the measurements, an unknown or incorrect phase advance, magnification of the beam motion by spherical aberration in some optical element or momentum changes caused by low frequency oscillations in the rf control systems causing beam steering. Beam steering effects from small momentum changes are seen regularly when using the real-time bunchlength diagnostic.

To test this, a simple experiment was performed in which the signal from the cavity used to measure the arrival time of the micropulses was monitored with the gun pulser AC line synchronous. The pulser was then reset to a pulse rate of 58 Hz but the beam was shut off. A measurement of the signal was made for a baseline noise figure and the beam was restored. A second measurement was made and the arrival time monitor showed a 1.8 picosecond variation from macropulse to macropulse. This would correspond to an AC modulation in the buncher amplitude at -24 dB. Corrective tuning of the amplitude loop was taken and further tests are pending.

After all modifications were made in the thermionic gun region, the beam motion at the end of the injector was remeasured by measuring σ_x and σ_y using a harp scanner with a 0.3 mm/second insertion velocity. The gun pulser was then set to a 50 Hz repetition rate and a second harp scan made. The 10 Hz beat frequency coupled with the slow harp speed, causes the measured sigmas to have a hashy outline that grow larger as the beam motion increases. The difference between the RMS sigmas with the beam pulser line synchronous and at some arbitrary frequency is the motion due to the line synchronous transverse magnetic fields. The data is presented in table 4.

The synchronous and non-synchronous data are essentially the same indicating little or no transverse AC beam motion.

III. CONCLUSIONS

The transverse AC magnetic field sources in the CEBAF injector were traced using experimental beam motion measurements and back propagated machine model parameters. The sources were quantified experimentally using direct field measurements and beam motion measurements. The sources of the fields were corrected to be a factor of 20 lower in the horizontal plane and a factor of 2.5 lower in the vertical. The correction was verified using direct field measurements Beam motion experiments also show a factor of four reduction in the 0.8 MeV/c region and a reduction below the 50 micron resolution on the CEBAF harp scanners in the 5.5 MeV/c region.

Beam Momentum	Horizontal Beam motion measured, mm	Vertical Beam Motion measured, mm	γ	β, m	Ratios of motion
0.3 MeV/c	-	0.03	1.2	3	
0.8 MeV/c	-	0.15	1.98	21	2.8
0.3 MeV/c	0.03	-	1.2	3	
0.8 MeV/c	0.1	-	1.98	14	2.3

Table 3

line sync'd σx, mm	line sync'd σy, mm	non-line sync'd σx, mm	non-line sync'd σy, mm	Δσx, mm	Δσy, mm
2.26	3.66	2.25	3.5	-0.01	-0.16

Table 4

IV. REFERENCES

[1] R. Legg and Q. Saulter, CEBAF TN #94-030, 1994

[2] R. Legg and D. Douglas, CEBAF TN#93-075, 1993