

## Reducing North Linac Betatron Matching Sensitivity to Injector RF Phasing Errors

D. Douglas

### Abstract

We discuss the sensitivity of the injector-to-north-linac betatron match to injector RF phasing errors and suggest a means of reducing it.

### Overview

During recent running periods, significant variability has been observed (over periods of hours to days) in the beam spot size in the 45 MeV matching region and at the front end of the north linac. This variability has been associated with slow drifts in the RF phase set point of the injector cryounit [1]. In this note, we review the source of this sensitivity, and suggest a means of reducing it.

The focusing properties of CEBAF cavities have been discussed elsewhere [2]. Here, we simply note that these cavities produce extremely strong RF phase-dependent focusing at low energies. Figure 1 shows the  $M_{21}$  ( $M_{43}$ ) matrix element for a CEBAF cavity with 2.5 MeV energy gain as a function of RF phase offset from crest and injection energy. At injection energies of 0.5 MeV (at the level of the CEBAF injector cryounit), the focal length on crest is on the order of 5 m; this varies dramatically (and in fact changes from focusing to defocusing) as the phase changes over a few tens of degrees.

Operationally, this effect leads to two problems. Firstly, when all injector cavities are crested, the beam is badly overfocussed, leading to transverse beam blowup. Secondly, RF phase drifts at the degree level lead to significant changes in focussing, causing downstream changes in beam envelope functions and giving rise to unacceptable betatron mismatches.

The first problem, the strength of the focusing, has historically been countered through use of the so-called "Serenio condition" [3], which is the backphasing of the first cryounit cavity by 7.5°. From Figure 1, we see that this moves the inverse focal length of the first cavity (with injection energy of 0.5 MeV) to a value near zero. The effect of this choice of phase setpoint is therefore to reduce the focussing from the first cavity, thereby avoiding beam overfocusing at low energy and allowing propagation of a well-contained beam through the entire injection. The focusing of the remaining cavities in the injector provide excellent beam envelope control

through the rest of the system. Beam envelopes through the injector for a variety of phase values are shown in Figure 2. The choice of -7.5° clearly leads to ideal downstream beam envelope behavior.

The second problem, that of the impact of focussing variations, is the subject of the following discussion.

### Effects of Focusing Variations

The problem at hand is to control the sensitivity of spot size to changes in upstream focusing due to RF phase variations. The relative change in beam envelope function due to a focusing error  $\Delta k_l$  at a location with beam envelope function  $\beta_e$  is as follows [4].

$$(\Delta\beta/\beta)_o = -\Delta k_l \beta_e \sin 2\psi_{o-e}$$

Here, the "o" and "e" subscripts refer to "observation" and "error" points, respectively.

Given this expression, we realize the issue at hand is to understand how to reduce  $(\Delta\beta/\beta)_o$  to the smallest possible levels throughout the north linac. The sinusoidal term is a function of the betatron phase advance from error to observation point, and will vary as we move down the north linac; it, therefore, is not globally controllable. (Moreover, at points where  $\Delta\beta/\beta$  is zero because  $\sin 2\psi$  vanishes,  $\Delta\alpha$  is generally nonzero because it depends on  $\cos 2\psi$  as well as  $\sin 2\psi$ . The error source term,  $\Delta k_l$ , is simply the inverse focal length of the cavity, and is the source of the RF phase dependence. From Figure 1, the only way of reducing this dependence is by lowering  $\partial(\Delta k_l)/\partial\phi$  through an increase in injection energy to at least a few MeV, or to more tightly control the RF phase. The only remaining available control parameter is  $\beta_e$ ; it is clearly possible to reduce the downstream error at all locations by simply reducing the beam envelope function at the error point.

We therefore conclude that dependences of transverse beam size on RF phase variations can be reduced by minimizing, to the lowest practical levels, the beam envelope function at the lowest energy injector cavities.

### Method for Reducing Phase Dependences

A method for reducing phase dependences now presents itself. At the cryounit itself, the beam envelope function should be reduced as much as possible though



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modifications to the warm injector setup [5]. This will reduce the downstream impact of focusing errors due to shifts in phase of the cryounit cavities. Recall that the Sereno condition gives excellent beam behavior (small betatron function, and therefore weak coupling to focusing errors due to shifts in RF phase) at all locations but the cryounit. We therefore suggest using the 5 MeV matching quadrupoles to transform the beam phase space exiting the cryounit (after the modification outlined above), to an injection condition at the entrance of the first module equivalent to the envelopes provided by the Sereno condition. These values are  $\beta_{x,y} = 10$  m,  $\alpha_{x,y} = -2.5$ . The quadrupoles required for the match can be computed once the beam envelopes at the exit of the cryounit are established (through the use of PARMELA and/or an emittance measurement).

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### References

- [1] C. Sinclair, J. Bisognano, unpublished.
- [2] As examples, see G. Krafft, CEBAF-TN-0051; G. Krafft, *et. al.*, CEBAF-TN-90-0287; G. Krafft, CEBAF-TN-91-069; Z. Li "Beam Dynamics in the CEBAF Superconducting Cavities", Ph.D thesis, College of William and Mary, 1995.
- [3] After N. Sereno; this condition was developed during early injector precommissioning operations, most notably, the injector recirculation experiment N. Sereno, "Experimental Studies of Multipass Beam Breakup and Energy Recovery Using the CEBAF Injector Linac", Ph.D thesis, University of Illinois, 1994.
- [4] D. Douglas *et. al.*, "The Collins' Scheme for the Local Correction of Chromatic Aberrations Due to Insertions", LBL Internal Note LBL-911, LBL-17984, June 1984.
- [5] Typical values for beam envelope functions at the front of the cryounit, from back-propagated emittance measurements, are 10 to 100 m. A reduction to a value of 1 m would therefore reduce the error sensitivity by one or two orders of magnitude.

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Figure 1: Cavity inverse focal length as a function of RF phase and injection energy.

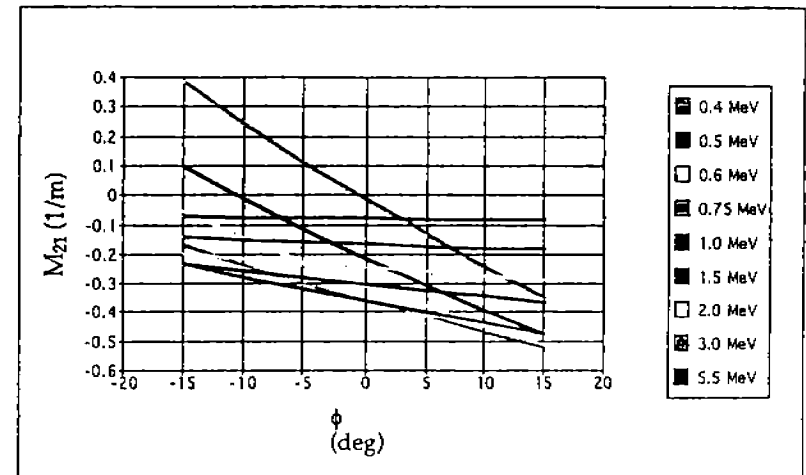
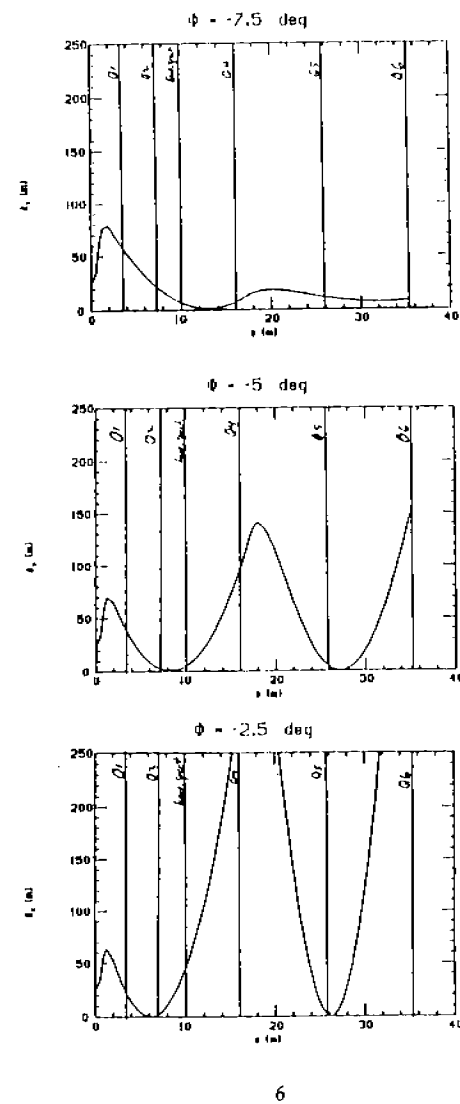
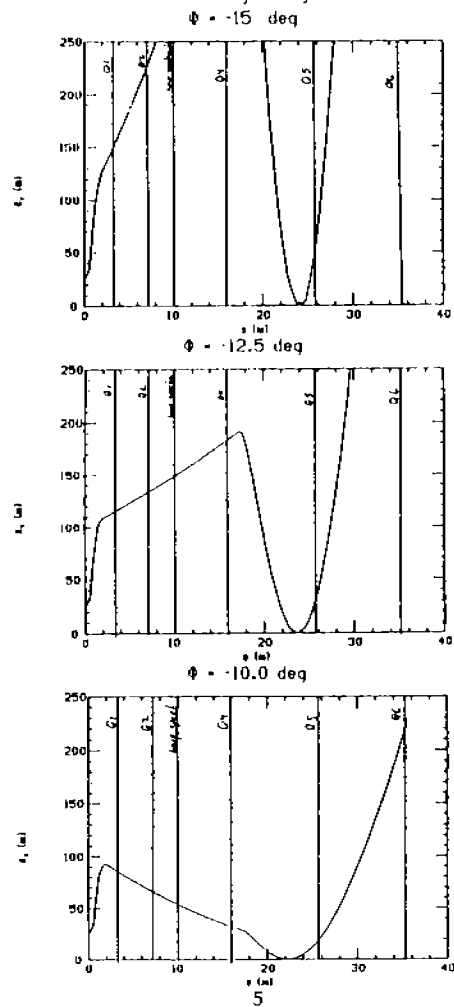


Figure 2: Beam envelope functions through injector for various choices of phase in first cavity of cryounit.



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