SLAC-TN-16-005

SINGLE PASS COLLIDER MEMO CN-327

AUTHOR: M. Sands

DATE: June 11, 1986

TITLE: MATCHING OF BEAM ENERGY TO ARCS**

A procedure is proposed for matching the energy of the Arc to the energy of the Linac.

Define a magnification,M, of the magnet movers as follows: Assume every magnet mover* is displaced by the distance X_{mov}, then the periodic trajectory will pass through each BPM with a displacement x_1. Define the ratio to be M.

$$x_1 = MX_{mov} \tag{1}$$

Let E_a be the 'natural' energy of the arc as determined by actual geometry and fields. Define $\triangle E$ to be the difference of the beam energy E_b from the arc energy:

$$\triangle E = E_b - E_a \tag{2}$$

I maintain that the arcs will work best if $\triangle E = 0$. I propose here a procedure for 'tuning' E_b or E_a to make $\triangle E = 0$.

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*Note: X_{mov} is MOVER displacement, not the average magnet motion

**Work supported by Department of Energy contract No. DE-AC03-76SF00515.

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This material is based upon work supported by the U.S. Department of Energy, Office of Science, under Contract No. DE-AC02-76SF00515.

An energy off-set ΔE will produce a periodic trajectory whose displacement at each BPM in an ideal arc would be

$$x_2 = \eta_m \frac{\Delta E}{E_a}, \tag{3}$$

where η_m is the value of the off-energy function at the BPM.

Let's define X_{mov} to be zero at the surveyed position of the magnets. (Note that it is the nearest fit to the surveyed orbit that determines the 'natural' arc energy E_a). If we now steer the beam through the arc with the 'wrong' energy, the movers will be adjusted so that $x_1 + x_2 = 0$, which means that

$$MX_{mov} = -\eta_m \frac{\Delta E}{E_a} \tag{4}$$

So, if we know the mover offset X_{mov} we know ΔE.

Now let the beam be steered through the arc in the way usually assumed. There will be random adjustments of the movers away from zero, and there may be, in addition, some systematic mover displacement if ΔE is not zero. If all such adjustments are small (namely, as expected) the energy deviation ΔE will be given by Eq.(4) with X_{mov} replaced by its average value $\langle X_{mov} \rangle$. That is

$$\frac{\Delta E}{E_a} = -\frac{M}{\eta_m} \langle X_{mov} \rangle \tag{5}$$

Given $\langle X_{mov} \rangle$ this equation can be used to determine the adjustment of the Linac energy or the Arc magnet excitation to bring ΔE to zero.

Once there is the best match between the Linac and the whole arc, the same procedure can be used to look at the energy match of each achromat (or selected group of achromats). If $\langle X_{mov} \rangle$ is not zero for a particular achromat, the achromat trim supply can be used to bring it to zero if desired.

Of course, once the energy has been reset (to correct for the measured ΔE) the arc should be re-steered with the new energy, and the new value of $\langle X_{mov} \rangle$ determined to see that it is indeed near zero, that is, below some pre-arranged value like $5\mu m$ or so.

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I am told that $\eta_m = 35 \times 10^{-3} m$. Bill Weng has calculated M for the actual effect of a magnet mover and finds that $M = 1.26$. So the important ratio is

$$\frac{\eta_m}{M} = 28 \times 10^{-3} m$$

So a relative energy off-set of 10^{-3} gives an average magnet mover displacement of $28\mu m$.

The uncertainty δX in the measurement of the <u>average</u> $\langle X_{mov} \rangle$ is given by the expected uncertainty δX_i in the knowledge of the position of an individual magnet divided by the square-root of N the number of movers in the sample. Let me take a conservative estimate for δX_i of $25\mu m$. For the whole arc $N = 230$, so the error in the determination of $\langle X_{mov} \rangle$ would be about $2\mu m$. And the error in the measurement of $\Delta E/E$ would be less than 10^{-4}.

For one achromat $N = 10$ and the error in the measured energy-match of a single achromat would be about 5×10^{-4}.

* * *

We may ask what would be the effect of systematic errors in either the zero-positions of the magnets or in placement of the BPM's.

Since the 'natural' energy of the arc is defined here to be the energy determined by the <u>actual</u> magnet positions (with $X_{mov} = 0$), any 'systematic displacement' of the magnets (with respect to some ideal curve) merely re-defines the 'natural' arc energy.

A systematic off-set of the BPM position by the amount Δx_p will mean that the proposed procedure will generate a mis-match $\Delta E'$ between the linac and arc given by

$$\frac{\Delta E'}{E} = \frac{\Delta x_p}{\eta_m}$$

Say that $\Delta x_p = 25 \times 10^{-6}$, then $\Delta E'/E = 7 \times 10^{-4}$. But the important point is that after energy matching to make $\langle X_{mov} \rangle = 0$ and resteering, the magnets are now correctly placed for the proper energy match ...as we would wish ...and the energy mis-match $\Delta E'$ is well within the energy window of the achromat.

This note has developed out of discussions with K. Brown, T. Fieguth, G. Fischer, A. Hutton, J. Murray, R. Servranckx and W. Weng.

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