A FAST TECHNIQUE OF MEASURING EQUILIBRIUM ORBIT WARPS IN THE ZERO GRADIENT SYNCHROTRON (ZGS) AT INJECTION*

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Summary

The difference signals from radial pi induction electrodes[1] located in the eight straight section boxes of the ZGS are used to determine equilibrium orbit warps. A 1 μs, debunched linac beam is injected in the ZGS ring and the eight coasting beam signals are analyzed. Since the effective electrode centers and inflector magnet positions are known, one can obtain orbit positions around the ZGS ring. The zero crossing times of all eight coasting beam bow-tie patterns are entered into our CDC-924A computer. The computer graphically displays orbit warps via CRT terminal.[2] An additional feature to be described is that betatron tunes at injection can be very easily obtained from the coasting beam patterns.

Introduction

Knowledge of equilibrium warps and how they are distributed around the ZGS ring is essential for a systematic tuneup. The technique described in this paper was born out of necessity to aid in a successful turnon after the titanium vacuum chamber[3] and pole face winding[4, 5] installation in the ZGS. Very early in the tuneup phase it was essential that the ZGS ring be properly tuned to successfully coast injected beam. The orbit warps were determined, and corrections were made using the KICKER computer program[2] with little difficulty. It was also essential that the injection betatron tunes be set properly and made reasonably flat.

The coasting beam signal from one location in the ZGS ring provided the necessary information so that the pole face windings and dc tune magnets (BM-100's) could be set for proper injection tunes.

Discussion

A 1 μs, debunched beam is injected in the ZGS ring and injection timing adjusted for maximum coasting time. Using a debunched beam is most advantageous to prevent spatial smearing of the coasting beam pulse due to energy spread. This problem is most noticeable after beam has coasted past the vacuum chamber center and effectively destroys detection of radial betatron motion. The 1 μs injected beam fills half of the ZGS ring circumference and as the coasting orbit shrinks, it provides a periodic pulse input for radial induction electrode pickups.

Injection timing is set such that the radial betatron motion is minimum, but sufficient to miss the inflector magnet on successful orbits. Minimizing the radial betatron amplitude makes the detection of zero crossings on the coasting beam bow-tie patterns easier to measure. Figure 1 shows the radial induction electrode and associated electronics. Since beam is injected when the equilibrium orbit is near the outside of the electrode and the main magnet field is ramping upward in magnitude, it is easy to visualize the beam pulse spiraling inward at the rate $\Delta R/\Delta T$:

$$\frac{\Delta R}{\Delta T} = \frac{R\,\Delta B}{(\nu_x)^2 B\,\Delta T} \qquad (1)$$

R = ZGS radii.

$\frac{\Delta B}{\Delta T}$ = Rate of rise of the main magnetic field.

ν_x = Radial betatron tune.

B = Average field strength around the ZGS ring.

The differential amplifier output will look like a bow-tie as a function of coasting beam time. Immediately after injection, the coasting beam pulse traverses under the outside edge of the electrode, which causes the differential amplifier's ouput to be positive, as shown in Fig. 2. Notice that the beam area is mostly under electrode B and very little of A is covered. The amplifier's output is proportional to the difference of the two electrode halves shadowed by the beam, and beam intensity.

$$V_o = -KG\,(A-B) \qquad (2)$$

V_o = Output voltage.

K = Beam intensity factor.

A = Noninverting signal input.

B = Inverting signal input.

G = System gain transfer function set by amplifier's feedback loop and electrode sensitivity.

As the coasting orbit shrinks inward, the differential amplifier's output V_o changes in magnitude and direction because the effective areas of electrode halves (A and B) are a function of equilibrium orbit radii. Figure 3 shows an actual photograph of the resultant bow-tie pattern. Notice that radial betatron motion has been made very small, as previously explained.

If the coasting time to crossover (see Fig. 2) is measured at all eight straight sections around the ZGS ring, the data can be used to compute orbit warps. Equation (3) is used to calculate orbit warps on the basis of a known $\Delta R/\Delta T$ (see Eq. [1]) and the

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measurement of T_1. (See Fig. 2.) Corrections must be made for inherent orbit offsets at some ring straight sections.

$$R_o = \frac{\Delta R}{\Delta T}\left[T_1 - \frac{\Delta T}{\Delta R} X_n\right]. \qquad (3)$$

R_o = Orbit warp in inches.

$\frac{\Delta R}{\Delta T}$ = See Eq. (1).

T_1 = Coasting time to crossover on bow-tie picture.

X_n = Effective displacement from radial electrode centerline to inflector magnet edge at straight section n. This term is corrected when used at ZGS short straight sections where the BM-100 magnets are located. These magnets produce a +2.5 in (outward) orbit bump. The radial electrode must be placed at either the upstream or downstream end of the magnets. Different corrections are required, depending on which end the radial electrode is placed.

Note that a "zero warp" reference time is generated by the term ($\Delta T/\Delta R\ X_n$). Any deviation from this time in T_1 will result in a warp when multiplied by $\Delta T/\Delta R$. Equation (3) works because the outside wall of the coasting aperture is determined by a known physical stop, the inflector magnet. Specific corrections for electrode placement and BM-100 effects are well known. The computer program KICKER[2] has all corrections available for use in calculating orbit warps. The degree of sophistication in examining orbit warps and achieving rapid correction is only possible due to the computer program. The computer displays, via CRT terminal, orbit warps corresponding to each ZGS straight section. These data are presented in a fashion that one can easily determine what correction is needed from the ZGS kicker coils. Actual orbit corrections, in inches, are entered in the computer and processed. The computer displays required kicker coil currents and informs the operator of any changes in injection parameters due to the new kicker coil currents.

Measurement of Betatron Tunes

Injection tunes are measured by analyzing the betatron motion on the coasting beam signals. Large radial betatron oscillation amplitude must be present for easy interpretation of the coasting signal. Injection timing is delayed until the radial betatron amplitude is sufficient for analysis. Figure 4 shows the first 100 µs of a bow-tie pattern. Radial betatron oscillations are clearly evident and can be used to calculate the radial tune ν_x. The number of beam orbits per betatron oscillation period does, in fact, define ν_x as shown:

$$\nu_x = \frac{N-1}{N} \qquad (4)$$

N = Number of beam orbits per betatron oscillation period.

Since beam coasting time is related to vacuum chamber radii (see Eq. [1]), it is possible to measure radial tune as a function of radii. Usually, the beam orbits are averaged over three radial betatron oscillation periods for more accuracy in calculating N for Eq. (4). This technique yielded rapid coasting tune profiles when the ZGS was started up with titanium vacuum chambers. By simply rotating the electronic insert at the four quadrant position electrodes[1] by 90°, one can observe the vertical betatron oscillations and obtain a vertical tune profile of ν_y.

Electronics Considerations

The most important factors to consider in designing this induction electrode amplifier system were bandwidth and common mode rejection as a function of frequency.

Bandwidth considerations involved minimizing the baseline differentiation of bow-tie patterns, and insuring sufficient speed to reproduce the beam pulse rise time.

Any baseline differentiation is due to insufficient low frequency response. Figure 1 shows two FET's connected as source followers. The very high input impedance of FET source followers is used to obtain sufficient low frequency response in conjunction with the induction electrode capacitance. Simply stated, Eq. (5) determines the minimum (-3 dB) frequency response of the electrode and follower combination.

$$f_1 = \frac{1}{2\pi R_1 C_1} \qquad (5)$$

f_1 = Lower frequency response (-3 dB).

R_1 = Input impedance of FET source follower.

C_1 = Electrode capacitance.

The source follower input impedance is the only parameter available to adjust low frequency response because electrode capacitance is fixed. While one can pad the electrode with fixed capacitance to boost low frequency response, this is done at the expense of sensitivity.

Individual adjustment of the source follower gain is provided to facilitate adjustment of common mode rejection. A trimmer capacitor can be connected from either FET source to ground to optimize high frequency common mode rejection. For good operation, it is only necessary to pass the highest frequency represented by the coasting beam pulse rise time, in this case 3.5 MHz. The lower frequency response is set for 250 Hz which, as explained, is necessary to minimize differentiation of the bow-tie baseline.

Acknowledgments

R. Konecny determined the best FET circuit parameters and assembled eight of the amplifier boards, with the help of W. Chyna. M. Knott developed the KICKER[2] computer program, which makes the whole concept useful as a rapid-tuning aid.

References

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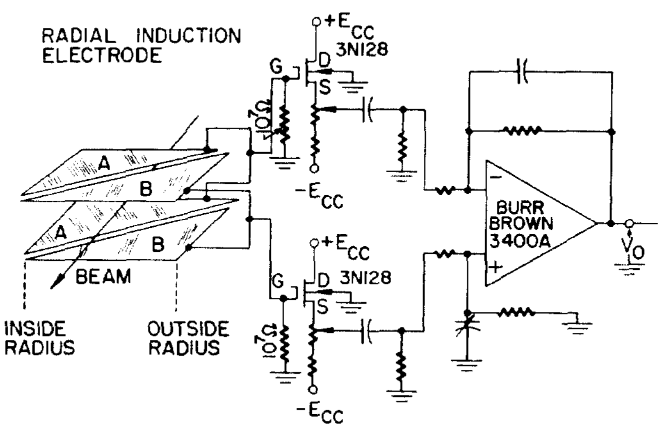

Figure 1.

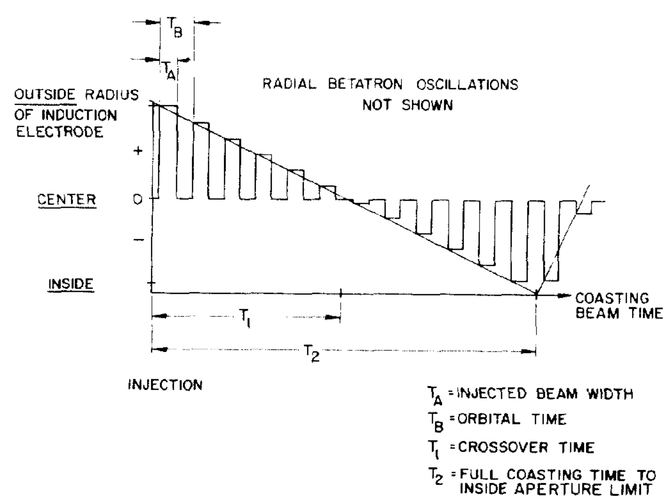

Figure 2.

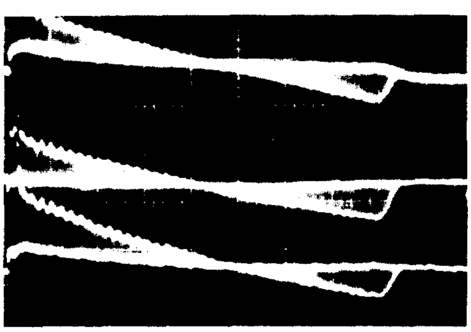

Figure 3.

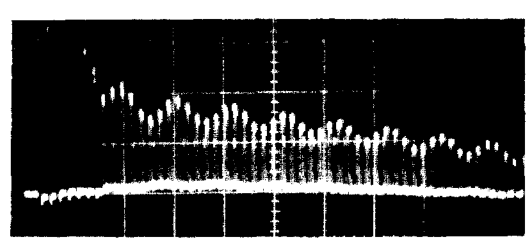

Figure 4.