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COMPUTERIZED MEASUREMENT OF INJECTION TUNES
AT THE ZERO GRADIENT SYNCHROTRON

J. M. Bogaty and A. V. Rauchas

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J. M. Bogaty and A. V. Raugas
Argonne National Laboratory
Argonne, Illinois 60439

Summary

Half of the Zero Gradient Synchrotron (ZGS) ring is filled with a 1.0 microsecond, debunched beam pulse from the linac. As the main magnetic field rises, particle orbits spiral inward. The difference signal from a pi induction electrode is used to obtain radial position data of the coasting beam as a function of time. A sharp cutoff bandpass filter passes betatron tune frequency components to a computing counter. The computing counter uses a resident software program to calculate tune values in real time. Data is available immediately which allows corrections to be made on line.

Discussion

When turning on a new ZGS operating program, a systematic tune up is followed. Injected beam parameters are set using the L-3 segmented Faraday screen. Then one microsecond debunched beam is injected in the ZGS ring and allowed to coast inward as the main magnetic field rises. To the observer, at one location in the ring, the average orbit radius shrinks as coasting time progresses. Orbit position, taken as a function of coasting time, relates to the radial betatron tune as follows:

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

where

R = ZGS radius

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

ν_x = radial betatron tune

B = average field strength around ZGS ring.

Orbit motion is detected by using the difference signal from a radial pi induction electrode. The differential amplifier output is proportional to orbit position and beam intensity. As the schematic in Fig. 1 shows, beam outside the electrode centerline will appear as positive pulses. As the orbit becomes smaller the amplifier output diminishes until a null is obtained at the electrode centerline. Beam inside the centerline will cause negative output pulses that grow in amplitude as the orbits continue to shrink. Fig. 2 shows a graphical representation of the coasting pattern expected. This idealized response is shown without radial betatron motion for reasons of clarity.

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Betatron oscillations modulate the "bow tie" pattern as shown in Fig. 3, an actual picture of coasting beam. The radial tune can be calculated from Fig. 3 by counting the number of beam orbits per betatron oscillation period.

$$\nu_x = \frac{N-1}{N} \quad (2)$$

where

N = number of beam orbits per betatron oscillation period.

This graphic procedure has drawbacks because the number of orbits must be counted with great accuracy over at least three betatron oscillation periods. One has difficulty determining the number of beam orbits to $\pm 1/4$ turn. Even averaged over three betatron periods, this uncertainty amounts to an appreciable tune deviation. Increasing the number of betatron periods averaged means that fine detail in the tune contour can be lost. Also, the graphic method is time consuming because polaroids of the coasting signal have to be taken over 100 μ s increments of the total coasting time. Given a coasting time of 500 μ s means that at least five polaroids are required. Then someone has to sit down and count beam orbits for tune calculations. A better method for obtaining data is to extract those frequency components from the coasting signal that are directly related to the tune and then input them to a computer for calculation.

In terms of orbit frequency and radial tune, the following equation describes the radial modulation present on "bow tie" polaroids:

$$f_t = f_o (1 - \nu_x) \quad (3)$$

where

f_t = frequency of radial beam motion due to the betatron tune

f_o = particle orbit frequency

ν_x = radial betatron tune

solving equation (3) for ν_x

$$\nu_x = 1 - \frac{f_t}{f_o} \quad (4)$$

This equation can be solved by computer easily and quickly for ν_x .

The tune limits considered in this system range from 0.500 to 0.900. This corresponds to a frequency band of 55.5 kHz to 277 kHz. Strong signals are present due to the particle orbit frequency and must be filtered out. A twenty pole bandpass filter was designed which just encompasses the desired tune frequencies while rejecting the orbit component. Fig. 4 shows a block diagram of the complete system.

A computing counter system is used to measure the betatron frequency and to calculate and display the coasting tune. The system is made up of a Hewlett Packard 5360A computing counter and a Hewlett Packard 5375A keyboard. It allows real time solution of equations. This system has been used for many years for the measurement and computation of accelerated tunes,³ but was not used for coasting tunes because of the different frequency components in the complex pi induction electrode signal. The filter eliminates the undesired components from the signal and the remaining betatron frequency component is amplified and used as an input for the computing counter. The counter's ability to accurately measure the frequency from a single cycle of the input signal allows fast, multiple point tune measurements without loss of detail encountered by using the manual counting method. The software is written to solve equation (4). Although the counter has the ability to also sample the orbit frequency (f_o), to maintain measurement speed the orbit frequency is assumed to be constant for the whole coasting time. This assumption introduces an insignificant error in the tune measurement. The computing counter system allows internal storage of two different programs, so either the coasting tune or

accelerated tune program can be easily selected without reprogramming.

Conclusion

The old method of coasting tune measurement was slow and depended heavily on human interpretation of the results. The present method has greatly simplified the whole process and eliminated the human factor. Coasting tune measurements can now be made much faster and with more accuracy. This allows for more accurate adjustment of the coasting tune and decreases the time spent reaching the operating beam intensity on a new ZGS magnet program.

References

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Fig. 3.
"Bow tie" coasting beam pattern
showing radial betatron oscillations.

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Fig. 4.