BETATRON TUNE PROFILE CONTROL IN THE ZERO GRADIENT SYNCHROTRON (ZGS) USING THE MAIN MAGNET POLE FACE WINDINGS (PFWs)*

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Summary

The original PFW controls provided only a limited correction for eddy current effects on the ZGS guide field. The present control system provides not only dynamic eddy current correction, but also additional complex corrections such as tune shift, median plane tilt and octupole fields. These corrections can be continuously tailored to specific requirements during the acceleration cycle. The electrical and operational characteristics of the system will be discussed along with the use of a computer program which calculates and graphically displays the resulting tune profile.

Evolution of Present Control System

The PFWs were installed primarily to correct for the sextupole field errors produced by eddy currents in the titanium vacuum chambers and magnet iron. Fig. 1 is a cross section of the vacuum chamber showing the location of PFWs. The driving voltage for the windings was proportional to the rate of change of the magnetic field (d) and was altered by five separate controls:

1. Master gain control (G1, 0 < G1 < 1.0),
2. Time constant controls which matched the eddy current correction with measured eddy current rise times in the vacuum chambers (τ1, 0 < τ1 < 0.1s) and magnet laminations (τ2, 0 < τ2 < 0.01s),
3. Proportional control (A) which varied the ratio of the two time constant corrections,
4. Median plane control (B1) which changed the ratio of the currents in the top windings to the currents in the bottom windings and provided a median plane tilt.
5. Gain control for each winding (Gij, 0 < Gij < 1.0), which set the amount of eddy current correction in each winding, to produce a constant gradient across the chamber.

An additional function for remnant field correction was provided with its own master gain (G2), balance (B2) and individual winding gain controls (G2j). This correction was found unnecessary and was never used as originally intended. The original control system is shown in Fig. 2.

After installation, betatron tune measurements indicated that a fixed gain was inadequate to correct the tunes at all energies. The need for maintaining flat tunes became critical for the acceleration of polarized protons to high energies. An attempt at modifying the drive voltage with a triggered level change permitted only a single correction and required recalibration for each new magnet program. A digital control system promised the required versatility and provided a convenient interface with the ZGS programmer for further system expansion.

This ease of expansion became apparent when a method for radial damping of the beam was developed, requiring the PFWs to produce an octupole field across the chamber. At a later date, an additional function was added to produce a quadrupole field and thereby shift the betatron tunes.

Present System Description

Eddy Current Correction

This function remained basically the same except that a programmable attenuator replaced the passive master gain control (G1) and provided a dynamic eddy current correction during the whole acceleration cycle. The range of control remained from full off to full on with 1 part in a 1000 resolution.

Median Plane Tilt

The ratio control (B1) was made programmable to provide dynamic median plane control. The resolution was increased by a factor of 20 with a maximum current change of 10% to both the upper and lower windings for a net effect of 20% at any radial position.

Octupole Function

This function was added during the latter part of 1975. It proved to be so successful in damping the beam radially that the radial damper was taken out of service. The function was generated by making use of the available but unused remnant field correction circuitry. The master gain control (G2) was made programmable and the balance control (B2) was eliminated so that the corresponding upper and lower windings received an equal correction. The individual winding gain controls were set to produce a vertical betatron tune profile such that

\[
\Delta v^2 = -0.0004/\text{in}^2
\]

where

\[ v = \text{vertical betatron tune and} \]
\[ r = \text{distance from the chamber centerline (inches).} \]

Since the normal direction of current flow in the PFWs on the inside is opposite to the direction of flow on the outside windings, for the above mentioned...
octupole polarity, currents were added to the inside windings and subtracted from the outside windings.

Tune Shift Function

This function was added shortly after the octupole function to offset a small tune shift created by the octupole correction. The ability to adjust the tune level proved to be helpful in adjusting the ZGS stability. The function was implemented by adding a programmable function generator which changed the current in the windings by an equal amount. The correction was applied to selected windings, equally spaced across the vacuum chamber. Subsequent tune measurements indicated the function was able to shift the tune with no aberrations. The controls were made bipolar so that the tune could be shifted in either direction. A positive command word value increases current on the inside windings and decreases current on the outside raising the radial tune ($v_r$). The range of control was set for a maximum correction of one ampere.

Each of the functions is controlled from the ZGS programmer by a unique command "word" with an associated "value." The value determines the amount and polarity of the correction and the system is calibrated so that the operator is aware of the current change in the individual winding. The ZGS programmer allows an operator to easily add, delete or change any command value at any time during the ZGS cycle. Normally, during a tune up of the ZGS for a new magnet program, the initial values for the functions are determined from measurements of the coasting tune. When the required coasting tune is established, beam is accelerated and tune measurements at several energies are made to determine the time and magnitude of any additional corrections. Further tuning of the PFW functions is done with regard to beam intensity, size, stability and extraction efficiency.

Computer Assistance and Monitoring

The current in each of the PFWs is sampled once each ZGS cycle by the Control Data 924-A computer. The measured currents are compared to maximum and minimum limits for each winding previously entered into the computer. If any of the currents exceed the limits, an audio alarm and visual CRT display on the operator's desk notify him of the abnormal condition. This has proved to be a far superior system compared to the old monitoring systems.

A computer program "POLEFACE," developed by the ZGS Accelerator Physics and Computer Control Groups, assists the operator in setting up the beta-torsion tune correction functions. The computer samples the PFW currents at the magnetic field of interest and displays on a large screen CRT the normalized vertical tune. The measured tune vs. radial position data is entered into the computer which displays it on the CRT together with opposite fit points required to flatten the tune. The operator enters hypothetical currents into the computer which recomputes the data and displays the resulting tune profile. When the required tune condition is established in the computer, the corresponding changes are made in the actual PFW controls. Fig. 3 shows the CRT display during eddy current correction. The numbered points are the measured tune values and the dotted line is the correction required to produce a flat tune. Fig. 4 shows a typical octupole correction applied to the flattened tune and Fig. 5 shows the addition of a tune shift to the previous conditions.

Conclusion

The new control system for the PFWs, in part responsible for the record breaking beam intensities now being achieved at the ZGS, has greatly simplified betatron tune corrections with improved resolution and repeatability. The monitoring and control system with a typical winding route around the ZGS ring is shown in Fig. 6. Computer monitoring of all PFW currents and functions has provided an increased diagnostic capability and improved operator confidence in system stability. All of these factors combine in making ZGS tuning a much easier and more rewarding effort.

References

Fig. 2. Original Control System

Fig. 3. Sextupole Correction

Fig. 4. Octupole Correction

Fig. 5. Quadrupole Correction

Fig. 6. Measurement and Control System