# POLE FACE WINDING (PFW) EQUIPMENT FOR EDDY CURRENT CORRECTION AT THE ZERO GRADIENT SYNCHROTRON (ZGS)*

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## Summary

The titanium vacuum chambers installed in the ZGS this past summer were equipped with PFW's. In this paper, the operation and monitoring of the windings used to flatten the guide field in the ZGS will be described. The physical and electrical characteristics of the system will be discussed along with a computer program which calculates the magnetic field shape in the vacuum chamber as a function of PFW current and other machine parameters.

## Physical Arrangement

The ZGS has eight vacuum chambers in its ring. Figure 1 is a cross section of one of these chambers showing the position of the PFW's. Windings from different chambers occupying the same position in a pole face are series connected in one of the two ways shown in Fig. 2. Those windings which enclose a small area of the pole face are connected eight in series and powered by a single regulator. Those windings enclosing a large area of the pole face are connected four in a series in order to reduce the forward voltage on the output transistors of the current regulator. The two regulators required in this configuration have the same output current. The entire PFW system has 84 regulators controlling the current in 56 windings.

## The Current Regulators

Current controls were built into the system which independently counteract the effects of the remnant magnetic field, the eddy currents in the titanium chambers, and the eddy currents in the main magnet laminations. The corrective currents for these effects are given below.

### Remnant Field

The remnant field opposes the fields caused by the eddy currents. Since PFW current is unidirectional, the total current in the PFW's is reduced by $CI_i$ A where $(0 \le C \le 1.0)$ and $I_i$ is variable for each winding.

### Titanium Chamber Eddy Currents

A current of $A \frac{dB}{dt} X_i\left(1-e^{-t/\tau_1}\right)$ flows in each winding

where $0 < \tau_1 < 0.1$ s

$0 \le A \le 1.0$

$B$ = magnetic field in the main magnet

$X_i$ = variable for each winding

$t$ = 0 when the magnet field begins to rise

### Eddy Currents in the Magnet Laminations

A current of $(1-A)\frac{dB}{dt} X_i\left(1-e^{-t/\tau_2}\right)$ flows in each of the windings where $0 < \tau_2 < 0.1$ s and all other terms are as before.

### Median Plane Shift

In addition to the above controls, the current in each top winding is multiplied by D $(0 \le D \le 1.0)$ while the current in each bottom winding is multiplied by $(1-D)$. In this manner, the magnetic center of the vacuum chamber can be shifted.

The total current through the $i^{th}$ PFW located on the top of the chamber is then

$$I_T = D\left\{-CI_i+\left(\frac{dB}{dt}X_i\right)\left[A\left(1-e^{-t/\tau_1}\right)+(1-A)\left(1-e^{-t/\tau_2}\right)\right]\right\}$$

Current ceases to flow in the windings when the magnet reaches full field.

## Computer Program

A computer program has been written that predicts the effect of the PFW currents on the vertical betatron tune. The PFW currents are read into the computer (Control Data Corp. 924A) which calculates and plots on a large CRT screen the tune values as a function of radial position in the chamber. This program, together with a device that automatically measures the vertical tune at different positions across the vacuum chamber,[1] enables us to quickly establish a flat tune in the ZGS. First, the predicted PFW currents[2] are read into the computer and the expected tune plotted on the CRT screen. The actual measured tune is then plotted on the same screen. Hypothetical changes in the PFW currents are then read into the computer in an attempt to compensate for any deviations from the desired tune. The computer calculates and plots the new tune configuration on the CRT screen. If the tune change produced is satisfactory, the actual current changes are made in the PFW's. After only a few repetitions of this process, a zero magnetic field gradient is established. Figure 3 shows the CRT screen during the program's operation. The desired tune is indicated by the horizontal dashed line, the measured tune by the angled line.

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## Monitors

When the ZGS resumed operation in October 1972, it became immediately apparent that our ability to accelerate beam was extremely dependent on having the correct currents in the PFW's. A small current change in even one of the windings resulted in a significant lowering of beam intensity. An oscillating current of 5 kHz in a winding near the center of the chamber resulted in the loss of most of our beam, even though the current through the winding was only a few amps. In order to spot deviations from the normal current distribution in the windings as quickly as possible, the output voltage of every current regulator shunt was monitored. Using a multiplexer, these 84 voltage values were simultaneously displayed on an oscilloscope as a series of steps. This enabled a machine operator to quickly identify a regulator that was oscillating or grossly in error. In addition, all of these voltages were destructively stored in the control computer every ZGS cycle, and a printout was available on command. The institution of this monitoring system saves much valuable time in diagnosing PFW problems.

In addition to the above monitors, an error detector was built into the system. This detector samples the voltage across a precision shunt connected in series with each winding. This signal is then compared to the drive signal. If the current through any winding differs from what the drive signal demands by more than 5%, an alarm is sounded in the control room. This monitoring system alone was inadequate in that neither loss of drive signal nor current oscillations were detected.

## Conclusion

The PFW's have proved to be very effective in modifying the magnetic field inside the vacuum chambers of the ZGS. Figure 4 shows the vertical tune variations in the ZGS as a function of magnetic field before and after the installation of the new chambers. The dashed lines indicate conditions in the "old" ZGS at various radii, while the solid line indicates present conditions at all radii. The magnitude of the PFW currents needed to establish this flat tune is somewhat less than was predicted,[2] 6 A being the maximum current through any winding. We have great confidence in our ability to use the monitors, tune detector, computer, and current controls to effect a flat guide field in the ZGS.

## References


[1] C. W. Potts, Argonne National Laboratory, An Instrument for Measuring Betatron Resonant Frequencies, 1971 Particle Accelerator Conference, Chicago, Illinois, March 1-3, 1971, IEEE Transactions on Nuclear Science, Vol. NS-18, No. 3 (June 1971), pp. 382-386.

[2] E. Crosbie, T. Khoe, E. Berrill, T. Hardek, and R. George, Argonne National Laboratory, Measurement of the Titanium Vacuum Chamber Eddy Current Fields and Pole Face Winding Corrections for the Zero Gradient Synchrotron (ZGS), 1971 Particle Accelerator Conference, Chicago, Illinois, Mar. 1-3, 1971, IEEE Transactions on Nuclear Science, Vol. NS-18, No. 3 (June 1971), pp. 1000-1001.


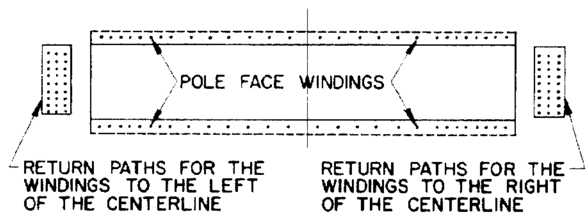


Fig. 1 Vacuum Chamber Cross Section

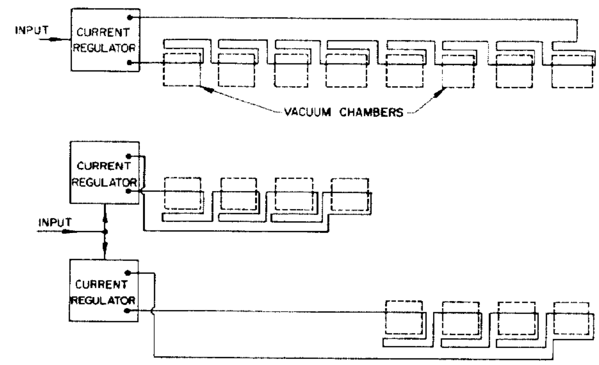


Fig. 2 PFW Interconnections

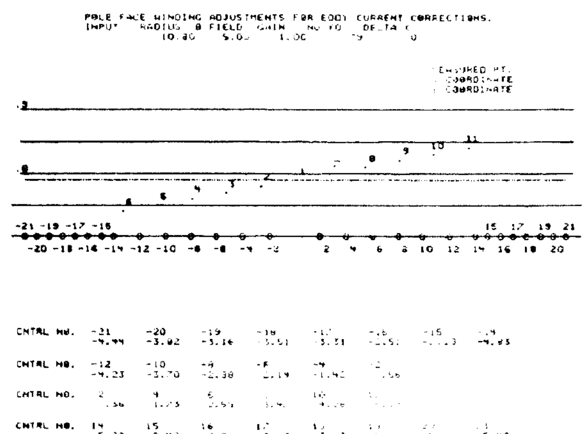

Fig. 3 CRT Display

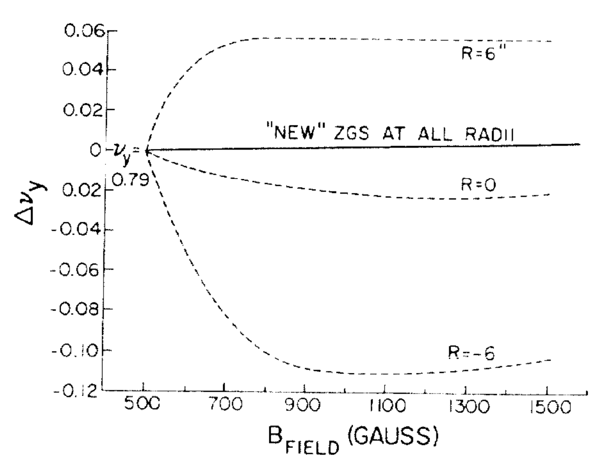


Fig. 4