THE PROGRAM USED TO RETUNE THE ZERO GRADIENT SYNCHROTRON (ZGS) AFTER THE INSTALLATION OF A NEW VACUUM CHAMBER AND POLE FACE WINDINGS*

R. L. Kustom
Argonne National Laboratory
Argonne, Illinois

I. Introduction

During the summer of 1972, the ZGS main ring magnets were completely dismantled and a new vacuum chamber was installed. The old chambers, which employed copious quantities of epoxy, had suffered extensive radiation damage and had to be replaced in the interests of maintaining a sound vacuum system. In addition, the new chambers contained radially distributed pole face windings in order to facilitate simultaneous two-thirds resonant extraction into two extracted proton lines and to help eliminate unfavorable field components which might have an effect on usable beam aperture and, eventually, on the acceleration of polarized protons.

Prior to the installation period, considerable effort on the part of the accelerator staff was devoted to developing techniques and equipment which could be used to return the ZGS to high energy physics in the shortest possible time. Naturally enough, invention was stimulated by anticipated problems. The equilibrium orbits were expected to be drastically altered since every magnet block had to be removed to install the new vacuum chamber; and the retuning of the magnets was expected to be complicated by the addition of 84 radially distributed pole face windings with time-varying, independent amplitude-controlled currents. Furthermore, after such a long shutdown of the accelerator, the task of setting the injection parameters for optimum capture was likely to be time consuming, if past experience repeated. Another major concern before the installation was how strongly the new chamber would deleteriously affect thresholds and rise times of the resistive wall instability.

The philosophy of the retuning program was to develop measuring techniques and equipment which would give quantitative indication for the adjustment of critical machine parameters in the shortest reasonable time. The details of the components will be presented by respective authors in many other papers at this Conference. I intend here to present the collective application of the various ideas and equipment.

The sequence of adjusting parameters was as follows:

1. Determine the correct current settings for the single-turn orbit correction coil (kicker coils) on each of the octants.

2. Determine the proper current distribution in the pole face windings and the time constants in the function generator for the best match to the eddy current distribution and, consequently, obtain a zero gradient octant.

3. Determine proper currents in the homogenous, gradient, and parabolic coils in the dc magnets in the short straight sections.

4. Set the injection time of the linac beam.

5. Set energy ramp and energy spread of injected beam for optimum capture and acceleration.

6. Adjust currents in 50 MeV transport line for optimum beam transfer and matching.

7. Optimize beam steering program with RF controls and adjust vertical and radial dampers to minimize resistive wall effect.

8. Adjust radial positions and currents of extraction magnets for external beam operation.

II. Magnet Adjustments

Distortions in the equilibrium orbit of the ZGS are minimized with single-turn coils (kicker coils) available on each octant. In order to measure the distortions in the orbit, a new FET amplifier was designed[1] to work with the pi-shaped position electrodes[2] present in each straight section. Using a 1 μs chopped beam, an RF signal was produced, which with a 17,800 G/s magnet ramp would correspond to about a 450 μs coasting beam. If there were no orbit distortions, the signal on the position electrodes (see Fig. 1) would be symmetrically distributed. The relative time from injection to zero crossing in individual straight sections is a direct measure of the relative symmetry of the equilibrium orbit. This measurement was used in conjunction with a computer program[3] to obtain the correct current settings.

Determination of the proper current distribution in the pole face windings and the proper time constants in the function generator[4] was expected to consume the most retuning time. An automatic tune-measuring instrument[5] was developed which allowed rapid measurement of betatron tune as a function of field and radius. The device was designed to work with $\sim 3 \times 10^{11}$ circulating protons so that very little beam was required at early stages of the retuning program. Complete betatron tune maps as a function of radius at ten different field levels were completed in 10-12 h. A computer program was developed to determine required changes in individual pole face winding currents to produce the desired tune correction. Trial and error techniques had to be employed to adjust the two time constants of the function generator which drives the pole face windings. Essentially,

*Work performed under the auspices of the U. S. Atomic Energy Commission.

tune maps were made at several field levels to predict the correct time constants. The homogenous, gradient, and parabolic coils of the dc tune-correcting magnets were set to values which were calculated to compensate for the tune alterations due to remanent field at injection. Only minor adjustments were made in these currents.

III. Injection Matching

Once adequately flat tunes were achieved and equilibrium orbit distortions minimized, attention was directed towards adjusting the injected beam parameters for optimum acceleration. A system of segmented Faraday cups[6] (SFC) was placed in the ring so that it was possible to take measurements of horizontal and vertical beam distribution at the inflector (L-1 straight section), vertical distribution 90^o away from the inflector (L-2 straight section), and horizontal distribution 180^o away from the inflector (L-3 straight section). FET switches were used to unclamp the individual SFC's from ground for any given 10 µs interval of the injected beam. A sample-and-hold electronic system interrogated the charge distribution after 10 µs and displayed the result on a CRT display unit. Second turn was prevented by stopping plates in order to avoid confusing the data. (See Fig. 2.) This technique permitted measurements of the injected beam to be made with full dynamic loading on the linac.[7]

The SFC in the L-3 section was situated very close to where the image of the injected beam would refocus ($\nu_x \pi$ rad where $\nu_x \simeq 0.84$) provided that the injected beam was monochromatic in energy. Radial beam width measured by the L-3 SFC was in fact quantitatively related to energy spread of the injected beam. Furthermore, the energy ramp of the linac was measured by progressively delaying the 10 µs window throughout the injected pulse. Injection timing was available in the same measurement.

Quadrupoles and bending magnets of the 50 MeV transport line were adjusted with the use of the information on horizontal and vertical beam size provided by the SFC's in L-1 and the vertical beam size provided by the L-2 SFC. In the latter case, the vertical beam distribution is a quantitative measure of the divergence of the injected beam in the vertical plane since the L-2 section of the ZGS is close to 90^o in betatron phase from the inflector.

IV. Damper Adjustments

Quantitative measurements on the resistive wall instability were not part of the preparatory effort for turnon after the chamber installation. Instead, new radial and vertical damper amplifiers were built. In both instruments, more power was made available and more flexible control of gain and delay incorporated, in the event the threshold for the resistive wall instability was decreased and the rise time of the instability increased by the presence of the new vacuum chamber.

V. Results of Retuning Program

The installation of the titanium vacuum chambers and the pole face windings was completed by the first week of September 1972. The total installation period was four months and one week. The retuning program began on the 18th of September.

Adjustment of the equilibrium orbits with the kicker coils using the "bow-tie" electronics and the KICKER2 computer program took < 8 h. In order to get some accelerated beam for tune measurements, the SFC's were used to adjust the injection timing and other linac parameters. Within the first 24 h of the retuning program, 3.5×10^{11} protons/pulse were accelerated to 12.5 GeV and tune measurements were begun.

The total amount of time devoted to tune adjustment was four days. A fair fraction of this time was lost because a few instabilities within pole face winding amplifiers occurred and had to be eliminated. By September 24, the early tunes were sufficiently close to the desired values to start injection matching. Figure 3 compares the early betatron tunes before and after the installation and retuning.

On the morning of September 24, 1972, the ZGS consistently accelerated stable beams over 1×10^{12} protons/pulse. The use of the SFC's in the L-1, L-2, and L-3 sections proved to be extremely useful; and accelerated beams as high as 2.4 to 2.5×10^{12} protons/pulse were achieved within two days.

The threshold of the resistive wall instability was found to be no lower with the new chamber, and perhaps somewhat higher. In any event, tuning of the vertical damper was no more difficult than during an ordinary turnon period.

The last several days of the retuning program were devoted to extraction studies.

The ZGS was operated for high energy physics on October 2, 1972. This date was one month in advance of the date which was projected on the long-range schedule. The circulating intensity and operating efficiency were essentially the same as before shutdown, even though during the first few weeks of operation the preaccelerator voltage had to be operated 20-40 kV below the optimum value. Figures 4 and 5 are the weekly summaries of average intensity and efficiency before and after the installation. The lower intensity recorded during the first four weeks of operation was primarily due to the lower preaccelerator voltage. Higher average beams resulted after the HV column was repaired.

VI. Acknowledgments

This paper obviously represents the efforts of the whole of the Accelerator Division and many participants from the High Energy Facilities Division. I am honored to act as spokesman on behalf of J. Bogaty, A. Brescia, Y. Cho, G. Concaildi, E. Crosbie, L. DeBall, M. Knott, R. Martin, J. Martin,

E. Parker, C. Potts, L. Ratner, A. Rauchas, D. Schmitt, D. Suddeth, R. Timm, and all other members of the Accelerator and High Energy Facilities Divisions whose efforts are described in this paper.

VII. References

[1] J. M. Bogaty, Argonne National Laboratory, A Fast Technique of Measuring Equilibrium Orbit Warps in the Zero Gradient Synchrotron (ZGS) at Injection, 1973 Particle Accelerator Conference, San Francisco, California, March 5-7, 1973.

[2] C. W. Potts and F. R. Brumwell, Argonne National Laboratory, The Zero Gradient Synchrotron (ZGS) Closed Orbit Position Monitoring System, 1971 Particle Accelerator Conference, Chicago, Illinois, March 1-3, 1971, IEEE Transactions on Nuclear Science, Vol. NS-18, No. 3 (June 1971), pp. 918-919.

[3] M. J. Knott and E. A. Crosbie, Argonne National Laboratory, Computer-Based Visualization and Manipulation of Orbit Warps in the Zero Gradient Synchrotron (ZGS), 1973 Particle Accelerator Conference, San Francisco, California, March 5-7, 1973.

[4] 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, March 1-3, 1971, IEEE Transactions on Nuclear Science, Vol. NS-18, No. 3 (June 1971), pp. 1000-1001.

[5] 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.

[6] R. L. Kustom, C. W. Potts, R. B. Wehrle, F. R. Brumwell, E. F. Parker, Argonne National Laboratory, A New Diagnostic System for Studying the Injector and Injection at the Zero Gradient Synchrotron (ZGS), 1973 Particle Accelerator Conference, San Francisco, California, March 5-7, 1973.

[7] E. F. Parker, Argonne National Laboratory, Recent Measurement of the ZGS Injector Beam Characteristics, 1972 Proton Linear Accelerator Conference, Los Alamos, New Mexico, October 10-13, 1972, LA-5115 (November 1972), pp. 63-66.

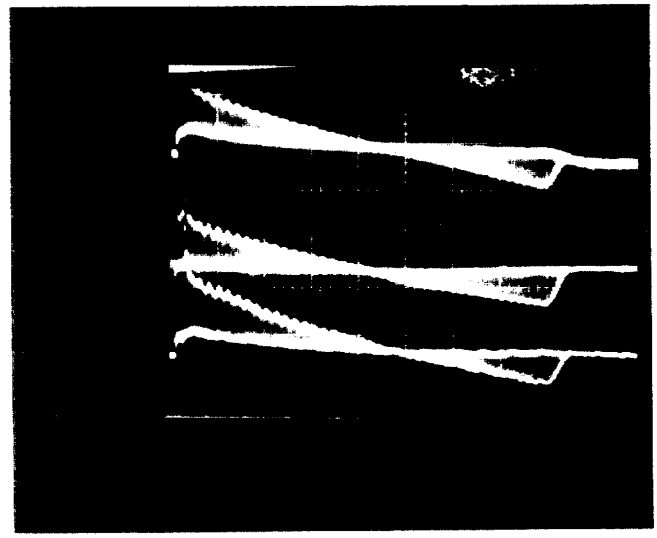

Fig. 1 Typical "Bow-Tie" Signals from which Orbit Warps were Measured

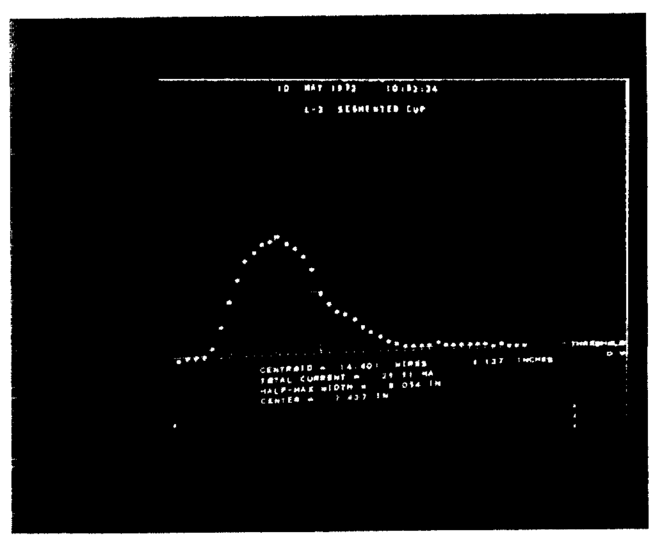

Fig. 2 Typical Injected Beam Distribution as Measured on L-3 SFC

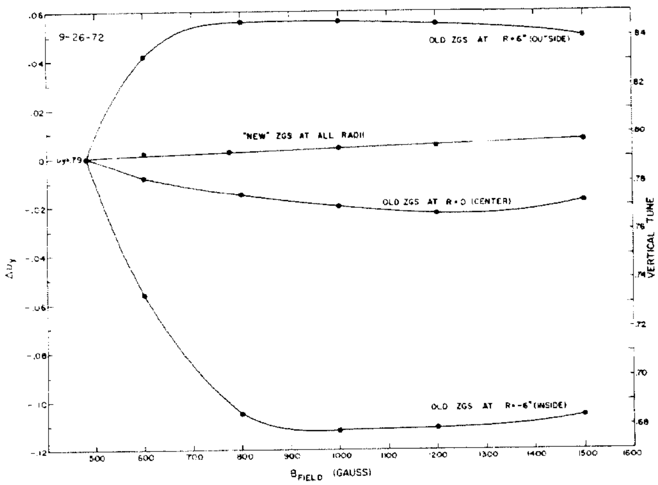

Fig. 3 Comparison of Tunes Before and After Installation and Retuning Program

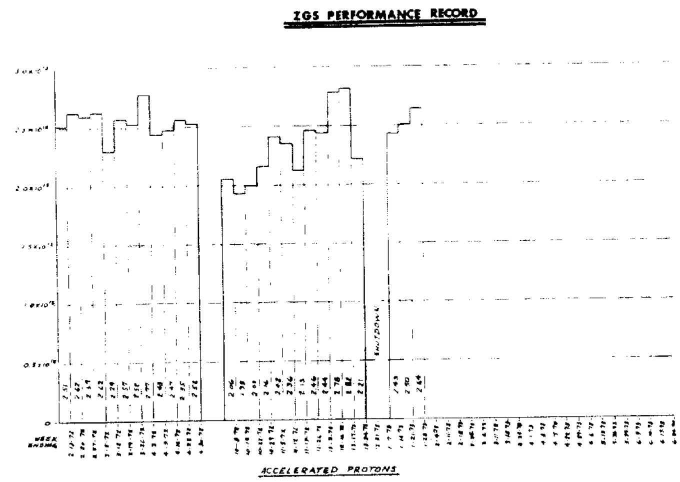

Fig. 4 Average Weekly Intensity of ZGS Before and After Shutdown for Titanium Vacuum Chamber Installation

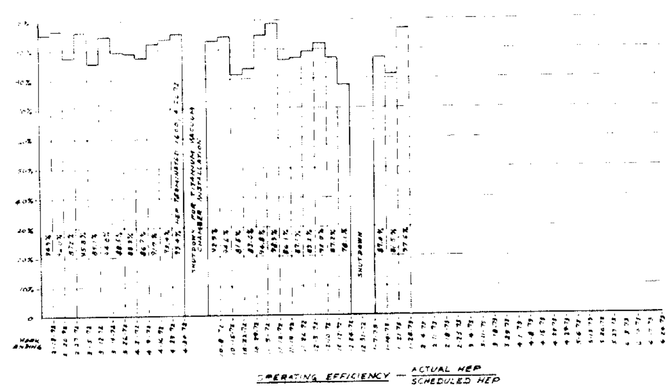

Fig. 5 Average Weekly Operating Efficiency of ZGS Before and After Shutdown for Titanium Vacuum Chamber