PERFORMANCE CHARACTERISTICS OF THE ZGS*

R. L. Martin
Argonne National Laboratory
Argonne, Illinois

Summary

The ZGS intensity has recently been increased. The main factors involved were removing the limitations imposed by the coherent vertical instability and partial correction of tune variations occurring during acceleration. With the higher intensities we observe a growth in the radial size of the beam. This phenomena is discussed briefly. Slow extraction from the ZGS on a "front porch" field over a wide range of momenta has been successful and the fast extraction efficiency has been increased to 50%.

Discussion

The intensity of the ZGS had been limited for some time to a maximum of 6×10^{11} protons per pulse and an average of 4×10^{11} protons per pulse by, among other factors, the vertical resistive wall effect[1] and the limitation of the equipment to damp this coherent vertical instability. The limitation was removed in September 1966 and a big increase in intensity was achieved. At the same time, the pulse-to-pulse intensity variations were somewhat reduced. Figure 1 is a histogram of the intensity distribution of 1000 pulses which represent approximately one hour of running time on the ZGS. For this period the average intensity was 1.7×10^{12} and the full width at half maximum of the intensity distribution was 5% of the average intensity.

At the present time we typically inject a 50 MeV beam of 20 mA for 100 μs, coast approximately 5×10^{12} protons per pulse, capture into acceleration buckets 3×10^{12}, and accelerate to full energy 1.5×10^{12} protons per pulse. The loss of captured beam occurs early in the acceleration cycle.

The coherent vertical instability due to resistive wall effects was first encountered in the ZGS in April of 1964 at a threshold intensity of 3×10^{11} protons per pulse. Circuits to damp this instability were installed shortly thereafter and have undergone a series of modifications since that time.[2] The first such system was patterned after the one in use at the time on the Cosmotron[3] and had a narrow bandpass (10 kHz) operating at the frequency of the $1 - \nu_v$ mode (ν_v = number of vertical oscillations per revolution). After a period of trial it became clear that the vertical oscillations of the eight RF bunches within the ZGS ring were not always in phase with each other and the system worked properly on only about half of the pulses. In order to apply a correction signal for each RF beam bunch independently a wide-band system is required, in addition to a variable delay line, to maintain synchronism of the applied damping signal with the appropriate RF bunch at a point 3/4 of a vertical oscillation wavelength (one machine revolution) downstream of the pickup electrode. An earlier version of this system, with a 20 V output capability of the final amplifier, damped the instability reliably to an intensity of 6×10^{11} protons per pulse in August 1965. The final version is shown in schematic form in Fig. 2. The final amplifier of the present system has an output capability of ± 135 V and a band width of 100 MHz. A pair of matched switchable delay lines is used. The master line determines the appropriate times for switching both delay lines simultaneously, thereby eliminating the necessity of programming the switching times and making the system independent of adjustments of the radial position of the beam at any time during acceleration. The delays are switched approximately 240 times during the pulse. Adequate synchronism of the applied signal with the appropriate beam bucket throughout the pulse was achieved in August 1966. It is felt that this success is the largest single factor in obtaining the intensity increase.

Another factor in the improvement of the performance of the ZGS was in the partial correction of the changes in betatron oscillation frequency (tune) which occur during the acceleration pulse. These changes are due to two effects. First, the eddy current in the vacuum chamber walls and magnet iron cause distortion of the radial profile of the magnetic field. The other effect is the intentional skewing in the ZGS of the high energy orbits toward the inside in short straight sections and outside in long straight sections. This orbit skewing facilitates beam extraction with stationary dc extraction magnets. The short straight sections contain dc tuning magnets which are used to adjust the tunes at injection, as well as for centering or shaping the injection orbits. The effects of the dc magnets on the tunes, therefore,

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

vary during acceleration. To compensate for these effects, coils were wound on the end guards of each octant in the long straight sections to give approximately a sextupole correction field. Figure 3 shows the correction in the radial tilt of the vertical tune achieved by pulsing these coils. The radial tilt of the tunes is reduced, although the vertical tune still decreases sharply from its initial value during early acceleration due to the orbit skewing. The possibility of partially compensating for the latter effect, also with the end guard coils, is being investigated.

With the present higher intensity beams a new phenomena has developed. Above a reasonably well defined intensity threshold the radial width of the beam at full energy increases. While this increase in radial beam size does not normally lead to beam loss, it makes beam manipulation for targeting more difficult and often leads to some loss of smoothness in the beam spill. Measurements of beam width which illustrate this effect are shown in Fig. 4. The threshold for radial beam growth is about 6×10^{11} protons per pulse, twice that for the coherent vertical instability. For intensities above this threshold the radial width of the beam varies considerably from pulse to pulse so that the measured points in this intensity region are more widely scattered. This pulse-to-pulse variation is possibly related to the independent growth of individual RF bunches. Under these conditions one often observes early targeting from only one of the eight bunches in the ring. The threshold is somewhat sensitive to the radial position of the beam, particularly during the interval of 100-200 ms after the start of acceleration. A possible cause of this phenomena is the radial coherent throbbing instability induced by the resistive wall effect and discussed elsewhere at this conference.[4] However, this is not yet certain and the study is continuing.

Protons have been extracted from the ZGS at a number of momenta from 5.0 to 13.4 GeV/c without substantially affecting other users of the beam. During the pulse when the desired momenta is reached the magnetic field is held constant for a period of 300 ms (called the "front porch") while a portion of the beam is extracted for a particular experiment. At the end of this time the field is increased to its full value and the normal flat-top applied for durations up to 500 ms for other users of the beam. In one physics experiment more than 50 different values of "front porch" field were used with little time lost in shifting values. The procedure will be described in more detail in a paper[5] to be published with the proceedings of this Conference.

The efficiency of fast extraction from the ZGS has been significantly improved by a method described in another paper[6] at this conference. Extraction efficiencies of 50% are achieved for durations of about 40 μs.

Acknowledgment

The study and improvement of the performance of the ZGS is the collective work of a large number of members of the Particle Accelerator Division in collaboration with the MURA Group.

References

1. L. J. Laslett, V. K. Neil, and A. M. Sessler, "Transverse Resistive Instabilities of Intense Coasting Beams in Particle Accelerators," Rev. Sci. Instr. 36, 436-448 (1965)

2. J. H. Martin, R. A. Winje, R. Hilden, and F. E. Mills, "Damping of the Coherent Vertical Beam Instability in the Argonne ZGS," Fifth International Conference on High Energy Accelerators, Frascati, Italy, September 1965

3. M. Q. Barton, J. G. Cottingham, and A. Tranis, "Damping of a Resistive Wall Beam Instability in the Cosmotron," Rev. Sci. Instr. 35, 624-627

4. M. J. Lee, F. E. Mills, and P. L. Morton, "Throbbing Beam Instabilities in Particle Accelerators and Storage Rings," 1967 U.S. National Particle Accelerator Conference Paper No. E-14

5. L. G. Ratner, T. deParry, A. M. Glowacki, "ZGS External Proton Beam," 1967 U.S. National Particle Accelerator Conference Paper No. F-9

6. A. Yokosawa, J. H. Martin, T. B. Novey, and S. Suwa, "A New Scheme of Beam Extraction of the Argonne ZGS," 1967 U.S. National Particle Accelerator Conference Paper No. F-10

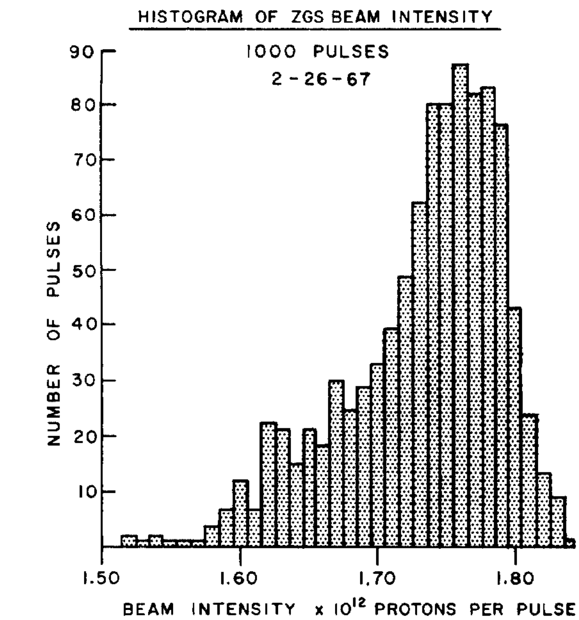

Fig. 1 Intensity Distribution of 1000 Pulses of the ZGS Beam

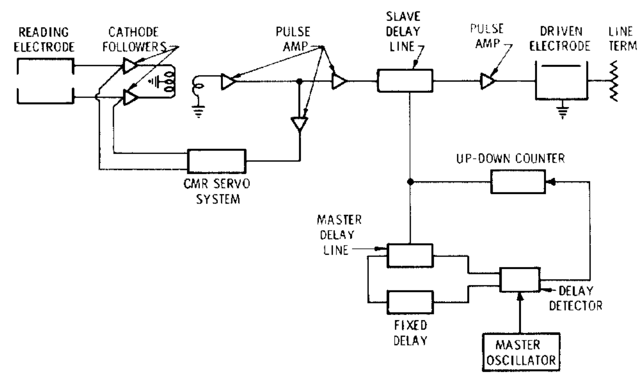

Fig. 2 Schematic of the Vertical Instability Damper System

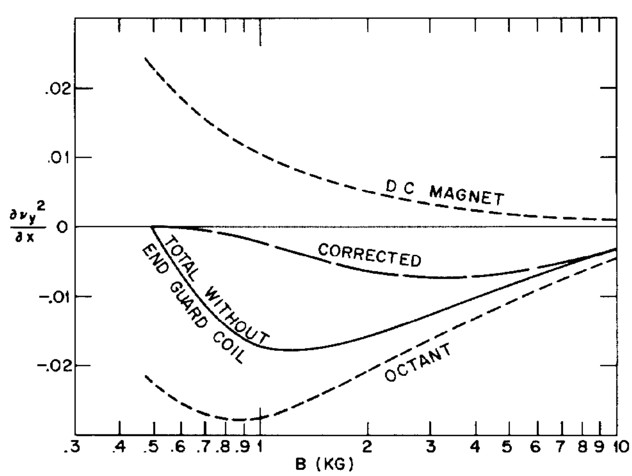

Fig. 3 Radial Variations of the Vertical Tune, ν_y, as a Function of the Magnetic Guide Field Strength. The Curve Labeled "Corrected" is the Effect Including Pulsing of the End Guard Coils.

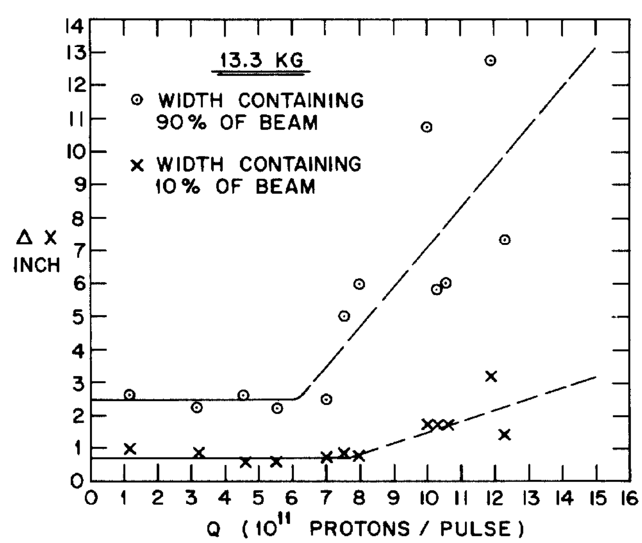

Fig. 4 Radial Width of the Internal ZGS Beam at 13.3 kG as a Function of the Intensity of the Accelerated Beam