A resonant extraction scheme utilizing the $v_r = 1$ integral resonance has been successfully used at the ZGS. The system consists of a full sextupole magnet used to drive the unstable protons radially inward toward a 1.5-mm septum magnet located three octants ($\approx 0.3$ betatron wavelengths) downstream. The thin septum magnet jumps the protons radially inward across the thick septum of the regular extraction magnet two octants further downstream. This magnet drives the beam outward into the extraction chain one octant later. Due to the scalloping of ZGS orbits at high energy, it is not necessary to plunge any of these magnets.

Introduction

The ZGS operates with the radial tune ($v_r$) higher than the vertical tune ($v_z$). For this reason, it is necessary to raise $v_r$ from its value of 0.84 to 1.0 to achieve a resonance growth rather than lower it to the more commonly used $2/3$ resonance. With the addition of pole face windings which are scheduled to be installed later this year, we plan to operate our extraction system at the $v_r = 2/3$ point. Using the $v_r = 1$ resonance, we presently extract into one of the two external proton beam lines (EPB II). It appears feasible to do simultaneous extraction to two external beam lines when operating on the $2/3$ resonance and this mode will be attempted.

Fig. 1 Layout of ZGS Ring Showing Extraction System Components

System Layout and Components

As shown in Fig. 1, the ZGS utilized two short and two long straight sections to accomplish extraction. A full sextupole magnet is located in the first long straight section (L-1), a 1.5-mm thin septum magnet in the second short straight section (S-2), a 3.0-cm thick septum in the S-3 straight section, and a series of three magnets in the L-4 section finally directs the beam into EPB II.

For operation at $v_r = 2/3$, a second sextupole will be placed in L-3, a second thin septum in S-4, and the beam will then be extracted with magnets in S-1 and L-2 into EPB I.

The field shape of the sextupole magnet is shown in Fig. 2. The thin septum magnet (Fig. 5) is a 3-1/2-in horizontal by 2-in vertical aperture magnet with a two-turn edge cooled copper sheet coil. This magnet is more fully described in another paper given at this Conference. The rest of the extraction magnets have been described at a previous conference.

Fig. 2 Field Plot of Full Sextupole Magnet. Normal Operation is at 3/4 of Above Excitation.

System Operation

The full sextupole magnet consists of two windings (dipole and sextupole) which are separately energized. These two windings are energized with opposite polarity so that the full sextupole field with net zero $\mathbf{B}_d$ at the center is produced as seen in Fig. 2. The circulating beam is parked at the center radius, or slightly radially inward, and then the magnet is energized. Rise times are matched so that there is very little beam movement during this process. Depending on the radial size of the beam, however, about 4% of the circulating beam is lost during this turn-on. Once the magnet is at the correct field level, the beam is driven radially outward into the sextupole field to produce a radially coherent growth which drives the protons inward at the location of the thin septum. The movement of the beam can be controlled by a fast bumper magnet located in L-3 by the RF system, adding more dipole component from the resonance magnet, or by sloping the flattop field of the synchrotron.
Combinations can be used to reduce movement of phase space during extraction.

For fast extraction, a combination of RF and beam bumper has provided a 50-μs (full width at base) extracted beam with up to 70% efficiency. Normal operating efficiency averages about 65%. Spill times with this efficiency have also been achieved from 50 μs up to several hundred milliseconds with the use of the RF drive. For the longer spills, it is necessary to use a feedback signal from the extracted beam to control the RF. A 200-ms slow spill is shown in Fig. 3. This is an extracted beam signal with about 1.2 x 10^{12} protons. The beam shape is shown in Fig. 4. This 1-1/2-in wide by 1-in high spot contains 100% of the extracted beam.

For the longer spills, it is necessary to use a feedback signal from the extracted beam to control the RF. A 200-ms slow spill is shown in Fig. 3. This is an extracted beam signal with about 1.2 x 10^{12} protons. The beam shape is shown in Fig. 4. This 1-1/2-in wide by 1-in high spot contains 100% of the extracted beam.

Fig. 3  Slow Beam Spill of 1.2 x 10^{12} Protons. Horizontal Scale 50 ms/division.

Fig. 4  Extracted Beam Spot. 100% of Beam is Contained in 1 1/2 in Width by 1 in Height.

Fig. 5  Photograph of Thin Septum Magnet. Normal Operation is at a Current Density of 103,000 A/in^2.

Our losses from 100% efficiency have been determined from a series of gold foil irradiations. These indicate that there is a 12% loss due to incoherent vertical growth of the beam. Computer calculations of the effects of the ν_r = 1 operating point indicate that this is to be expected. Additionally, we have found that about 10% of the beam is wiped out on aperture limits because of the position of the extraction magnets. These magnet displacements will soon be corrected and should bring our efficiency up to about 80%. Then, besides the initial 4% turn-on loss, the septum intercepts about 5% of the beam which agrees with an average jump distance of about 1.5 in.

<table>
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<tr>
<th>Loss</th>
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<td>0-4%</td>
<td>Magnet turn-on</td>
<td>May be corrected by closer matching of rise times of dipole and sextupole coils</td>
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<tr>
<td>12%</td>
<td>Vertical growth</td>
<td>May be corrected by operating at ν_r = 2/3</td>
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<td>10%</td>
<td>Magnet alignment</td>
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<td>5-9%</td>
<td>Septum thickness and jump distance</td>
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References
