ENGINEERING DESIGN OF THE AGS FAST BEAM EXTRACTION SYSTEM*

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Summary. The equipment described deflects the accelerated beam of the AGS into a tangential pipe, providing an external beam with essentially the same structure and intensity as the original.

1. Introduction

This paper is a condensed version of a Brookhaven National Laboratory report which contains comprehensive details of the components forming the AGS beam extraction system.[1] The three-step ejection process used in the AGS is fully described in Ref. 2, which also includes quantitative details of the deflected orbits. The basic arrangement is shown in Fig. 1. Three magnets are spaced three-quarter betatron wavelengths apart. The septum magnet and ejector magnet have a relatively slow field rise time and are energized before ejection. Both magnets are designed so that the conductors separate areas of almost zero field from areas of high field. The equilibrium orbit lies on the zero field side thus permitting normal acceleration as the field is developed in the extraction magnets. The two septum magnets are withdrawn during injection so the magnets do not reduce the horizontal aperture of the AGS. They are rammed into position using hydraulic pistons. The first magnet in the chain, the fast kicker, is a ferrite magnet with a full aperture to permit normal injection in the AGS without moving the magnet. The kicker starts the ejection by deflecting the proton beam into the high field area of the septum magnet. The field rise time in the kicker is less than the bunch-to-bunch spacing of particles within the AGS, thus if correctly phased to bunch position the kicker will move the beam into the high field area of the septum without loss of particles. The field in the kicker is maintained for 2.7 microseconds, thus causing all bunches to be ejected. The general specification for the magnets is shown below in Table I.

2. Ferrite Magnet and Pulser

The pulsed field requirements of the fast kicker magnet correspond to the current waveform associated with a line-type modulator. Thus the current must flow in magnets in series with the matched terminating resistor. The inductance of the magnets should not cause a radical change in the discharge current waveform. The basic circuit is shown in Fig. 2. To achieve the desired 200 nanosecond rise time the magnet is split into four sections switched by two 7890 hydrogen thyratrons. The parallel capacitor across the terminating resistor improves the field rise time by causing the discharge circuit to become critically damped. The field rise is synchronized to bunch position by deriving a trigger from the synchrotron rf accelerating voltage. The general characteristics of the fast kicker are shown in Table II.

TABLE I

	Fast Kicker	Septum	Ejector
Length, in.	60	84	84
Aperture, in.	2 x 5	½ x 1¼	0.8 x 2
Septum Thickness, in.	none	0.06	1.0
Field Range, Gauss	200-500	500-2000	5000-15000
Stability	±1%	±0.5%	±0.2%
Rise Time	200 nsec	6 msec	2.2 msec
Duration	2.7 μsec	200 msec	oscillatory
Current Avail., max.	2500 A	2000 A	7500 A
Construction	Ferrite Picture Frame	One turn septum	Four turn septum

TABLE II

Field rise time:	<200 nsec
Field flat-top:	3 microsec.
Field ripple:	<2% p-p
Total deflecting force:	750 gauss meters
Flux density in gap:	500 gauss
Peak pulse power:	200 MW
Average pulser power:	300 W
Max. charging voltage:	40 kV
Peak current per tube:	5000 amps
Number of tubes:	2
Number of p.f.n.'s:	2
p.f.n. impedance:	4 ohms
Number of magnets:	4
Magnet gap size:	5" x 2" x 15"

*Work carried out under contract with U.S. Atomic Energy Commission.

3. Septum Magnet and Power Supply

3.1 Magnet

The septum magnet is a laminated (.025 thick) soft iron core "C" structure, eighty-four in. long. It has a clear aperture 0.5 in. high by 1.87 wide and overall cross section dimensions 2.156 by 2.375 in. It is energized by a single turn coil of 4.2×10^{-3} ohms at 20°C and 8.1 microhenries inductance. It has a maximum design field of 2000 gauss at 1600 amperes. The magnetic field is developed in about 6 milliseconds which is quite long compared to the time per revolution of the circulating protons (approximately 2.5 microseconds). In its operating position the septum magnet just grazes the edge of the unperturbed accelerated beam in the AGS. Consequently, it is necessary to terminate the magnetic field as sharply as possible. This is accomplished by carrying the return of the energizing current in a thin septum, .045 in. thick, placed across the opening of the slot in the "C" shaped core. Calculated fringe field patterns as a function of septum shape, position, and allowed clearances for insulation, are shown in Fig. 3. Also shown for comparison, is the fringe field of the magnet as actually built and operated for the first year.

3.2 Power Supply

The power supply is a closed loop current regulating servo, the regulating element is a bank of 200 power transistors connected in parallel. This bank and the driver stages are mounted on a water-cooled plate. The loop is closed by comparing the voltage across a shunt with a reference and amplifying the error signal. This is a typical type zero regulator. Current variation due to load changes, ripple and other causes must be held to within ± 0.5%. The power supply is located some 80 ft. from the magnet, outside the AGS tunnel. This is done to prevent deterioration of the power transistors due to radiation damage. The lead and magnet resistance is 7.7 milliohm (magnet cold) and the load inductance is ≈20 microhenries. The current available is 700 to 2000 amps in three ranges. Separate ranges are used to minimize dissipation in the transistor bank by selecting taps on the collector supply power transformer. The frequency response of the supply is determined mainly by the low pass characteristic of the power transistors, two lead-lag networks stabilize the supply which has a closed loop 3 db point of 500 cps, thus compensating for 360 cps power supply ripple. The supply is turned on just before ejection by means of a programmed reference signal. The current rise time is kept to 6 milliseconds to prevent large error signals in the controller. The supply contains a fairly complex fault protection system because of the limited thermal capacity of the septum magnet itself.

4. Ejector Magnet and Power Supply

4.1 Magnet

Like the thin septum magnet, the ejector magnet is an open "C" core, 84 in. long with a clear aperture 0.8 in. high and 2.00 in. in radial extent. The laminations are 0.015 in. thick; the effective frequency of the field build-up being 100 cps. The maximum design field is 15 kG at 6000 amperes, with normal operating field at 30 BeV ejection approximately 12.5 kG. The energizing coil is a four-turn hollow conductor winding of 4.1×10^{-3} ohms at 20°C and an inductance of 0.15 millihenries. The field is terminated in a current septum placed in the mouth of the aperture slot.

Field measurements showed negligible fringe field up to 12 kG in the working aperture. Between 12 kG and 15 kG the fringe field at the centerline of the unperturbed beam rises from essentially zero to a maximum of 350 gauss due to saturation of the core. At the 12.5 kG operating level no fringe field effects on the beam have been observed and consequently no attempt has been made to compensate for the measured fringe field. The use of hollow conductors will permit a current flat-top at 15 kG of at least 150 milliseconds which would again permit use of the same magnet for slow extraction of the AGS proton beam.

4.2 Power Supply

The power supply consists of a 16,000 μF capacitor connected to the magnet by ignitrons. When the ignitrons are triggered the capacitor resonates with the magnet inductance to produce a damped sinusoid current waveform. The ignitrons extinguish after one full cycle, thus the charging supply must restore to the capacitor only the energy lost due to resistive dissipation during the cycle. The beam is ejected when the current reaches a peak during the first half cycle. The permissible tolerance for pulse-to-pulse variation of the ejector field is ± 0.1% from all causes. The field tolerance is met by controlling the voltage to which the bank is recharged. The discharge frequency is approximately 100 cps. A simplified circuit of the power supply is shown in Fig. 4.

The charging supply consists of a single-phase monocyclic constant current network feeding a step-up transformer and full-wave rectifier. When the capacitor voltage matches a reference, a shunt load tube diverts the charging current and leaves the bank recharged to the reference level. This is a simple and very economical method of achieving a precise charging level.

5. Hydraulics

Both the septum and ejector magnets are plunged hydraulically using identical basic systems which differ only in piston stroke and rating of the mechanical deceleration value. A schematic of the basic circuit is shown in Fig. 5. In the septum configuration the moving assembly weighs 200 lbs. and is plunged 3-5/8 in.; the ejector assembly weighs close to 2000 lbs. and is plunged 2-5/8 in. Both motions are accomplished in approximately 250 milliseconds with maximum velocities of about 22 in. per second and maximum acceleration loads of approximately 4 gravity. A schematic of the mechanical assembly is shown in Fig. 6.

The septum assembly has been cycled some 2×10^6 times including initial tests. Both systems have been cycled 1.2×10^6 times in the AGS ring. The basic system does suffer from an initial shock when the main four-way control valve is first opened. We presently propose to improve the shock characteristic of the system by replacing the present pump, accumulator, and control valve portions of the circuit with a programmed variable delivery, servo controlled, swash plate pump.

6. Vacuum

Each of the plunging systems is housed in an aluminum box of about 40 cu. ft. capacity. Each assembly requires three sliding seals. The sliding seals each consist of three chevron rings forming two annuli about each of the sliding shafts. The outer annulus is kept flooded with a diffusion pump oil held under fore-vac pressure and the inner annulus, which faces the vacuum, is also held under fore-vac pressure. Pressures of 1 to 2×10^{-6} torr are maintained using pumping systems of 265 liters per second at the pump port of the septum box, and 425 liters per second at the pump port of the ejector box, which has a larger gas load due to the epoxy coil insulation. From estimated gas loads and observed pressures calculate the total dynamic gas leakage of the seal assemblies at 30 cycles per minute to be:

3.4×10^{-3} torr-liters/sec - Ejector assembly

2.4×10^{-3} torr-liters/sec - Septum assembly

References

1. "The AGS Fast Beam Extraction System" by E.B. Forsyth and C. Lasky, BNL Report #910, T-373.
2. "External Beam - I" by G.K. Green, BNL Accel. Dept., Internal Report GKG-6.

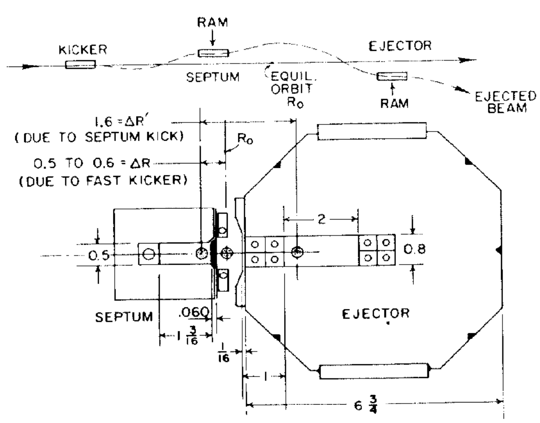

Fig. 1. General arrangement of fast beam extraction system.

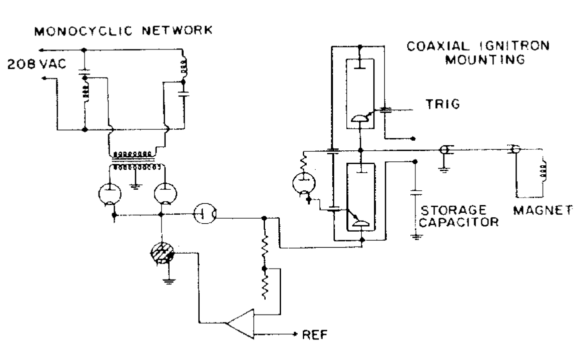

Fig. 4. Simplified circuit of ejector magnet power supply.

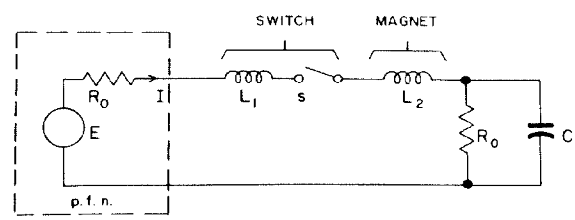

Fig. 2. Equivalent circuit of lumped magnet discharge system.

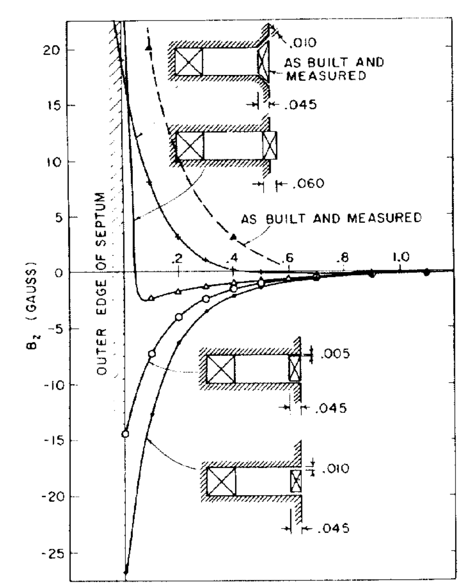

Fig. 3. Computed fringing field of thin septum as a function of septum shape and location and insulation thickness. B_0 = 2000 Gauss.

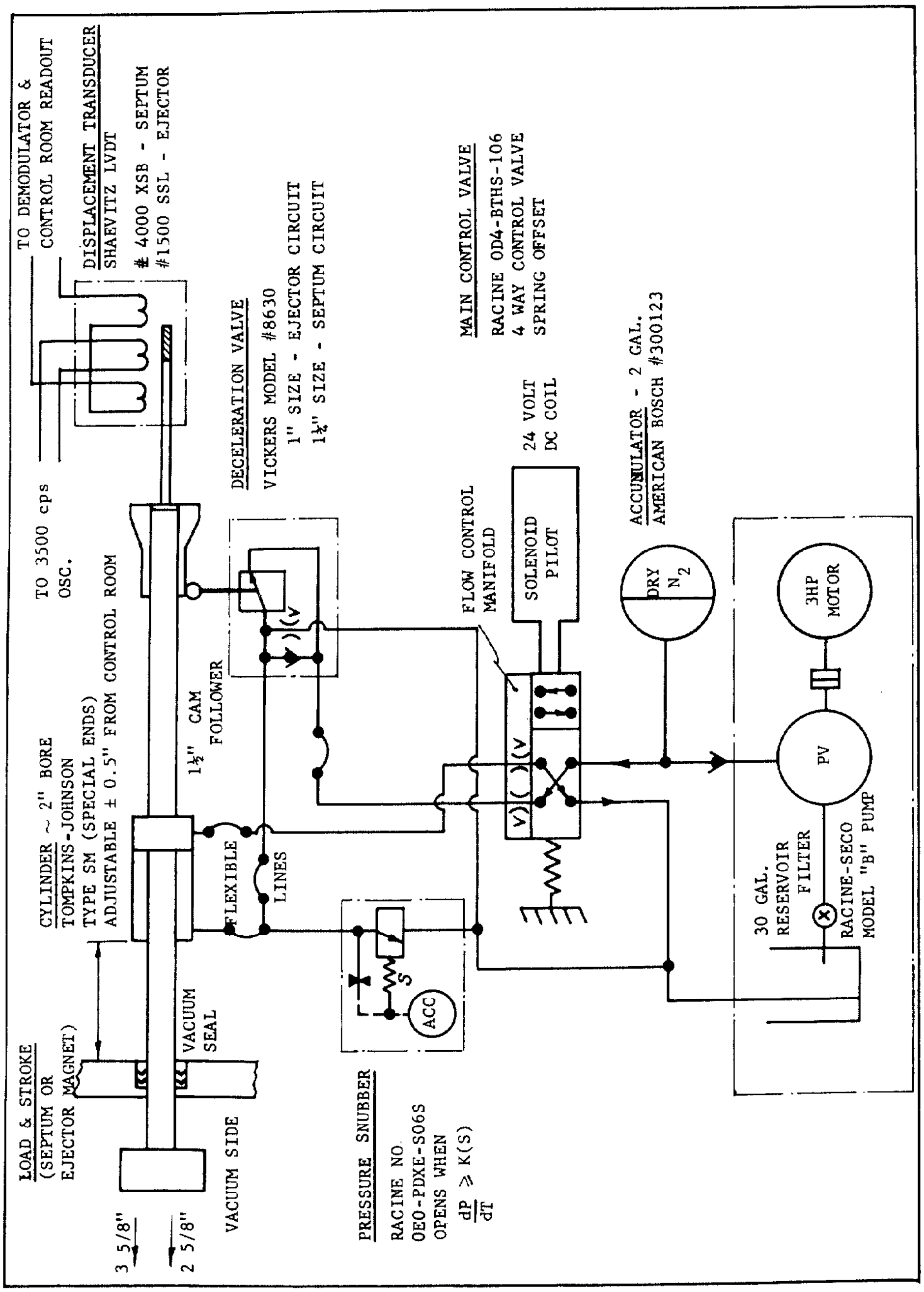

Fig. 5. Schematic of hydraulic plunging circuit.

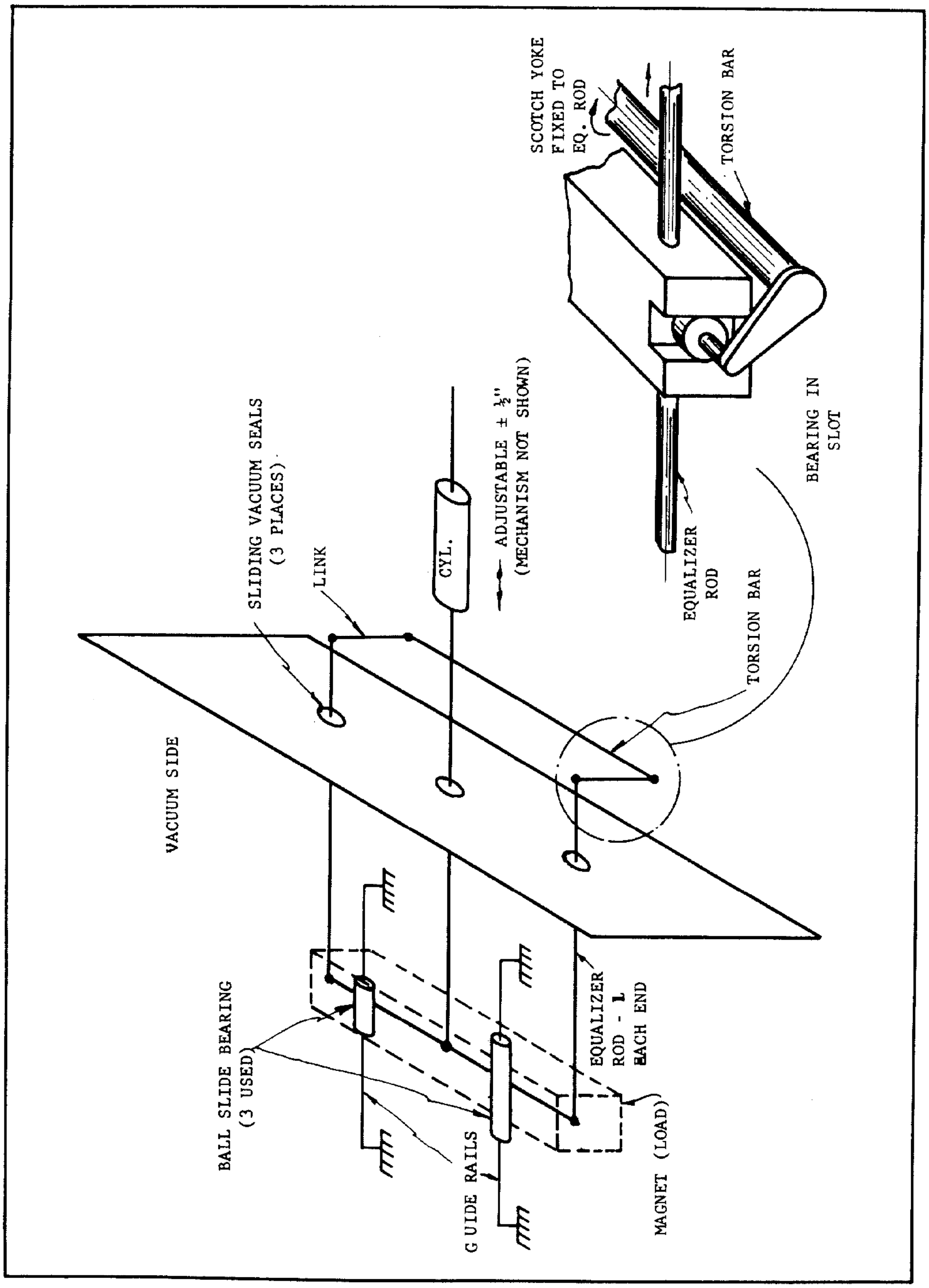

Fig. 6. Schematic of mechanical linkage.