

THE AGS FAST KICKER MAGNET SYSTEM*

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Summary

A new fast extraction system from the AGS will be implemented to improve the neutrino beam and to serve for ISABELLE injection. The fast kicker for the system is of an open C-type design with a field strength of 1.25 kG at 2650 amperes. The pulser system is a mismatched, discharge type PFN which is capable of delivering a pulse of 3000 amperes peak current at 30 kV d.c., with a 2.7 μ sec pulse width, 170 nsec rise time, and flat top ripple within $\pm 1\%$. It also serves as a prototype for an ISA injection magnet, and is to be operated in UHV in the 10^{-11} Torr range. Special measures to achieve this goal are also discussed.

Introduction

To prepare the AGS as an injector for ISABELLE and to improve the beam quality for the existing neutrino program, a new fast extraction system of the AGS is proposed. It consists of a new fast kicker located at H5 straight section (s.s.) followed by an ejector located at H10 s.s. Such an arrangement results from the desire to locate both the kicker and the ejector magnets close to horizontal β_{max} with phase separation of an odd multiple of $\pi/2$. Furthermore, since it is vertical β_{min} at H5 s.s., it requires fewer ampere-turns to give the same amount of bending. To further reduce the gap size of the kicker, a C-type open magnet is adopted and a $3/2 \lambda$ local orbit deformation will be created to move the beam into the gap before turning on the kicker. The orbit bump will also serve to bring the beam closer to the ejector to reduce the amount of deflection required from the kicker. A schematic diagram for the extraction components in the ring and the orbits in the extraction area is shown in Fig. 1.

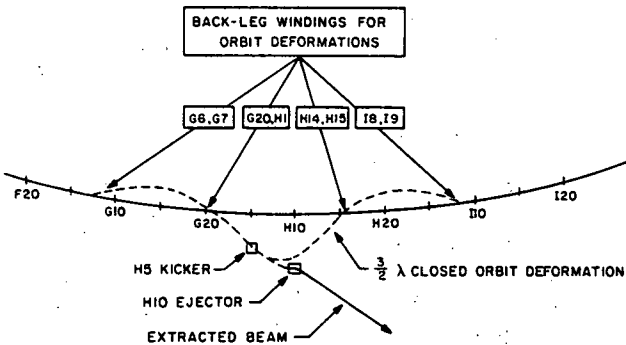


Fig. 1. Layout of the extraction orbits.

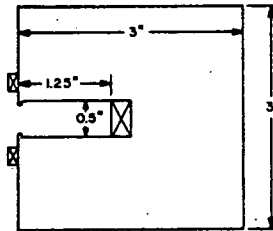
One of the special features of this kicker is that it has to serve as a prototype magnet for the ISABELLE injection kicker in the confirmation of vacuum requirement. The ISA injection kicker has to be operated in ultra high vacuum environment,

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typically in the 10^{-11} Torr range. This stringent requirement gives rise to a series of special considerations for the treatment of materials used and the assembly procedure followed. This article gives a comprehensive description of the design requirements, fabrication processes, and performance results of the new H5 kicker and its pulsing system.

Design Requirements

For the purpose of design, we assume that at extraction momentum of $p = 29.4$ GeV/c, the AGS beam has an emittance $\epsilon_x = \epsilon_y = 1.5 \times 10^{-6}$ m-rad and that the maximum momentum spread allowed is $\Delta p/p = \pm 0.12\%$. For the given betatron function and the phase advance between H5 s.s. and H10 s.s., the design parameters for the H5 kicker can be summarized in Fig. 2.¹



LENGTH	69 cm.	FIELD	1.25 kG
DEFLECTION	1.13 mrad.	APERTURE	0.5"(V) x 1.25"(H)
RISE TIME	150 n sec.	PULSE WIDTH	2.7 μ sec.
FLAT RIPPLE	$\pm 1\%$	VOLTAGE	26.5 kV
CURRENT	2650 amp	INDUCTANCE	1.4 μ H

Fig. 2. Design of the kicker.

The pole shape at the opening of the gap has been adjusted to maximize the good field region in the median plane, and the size and placement of the return coil has been chosen to minimize the inductance of the circuit and hence reduce the driving voltage on the PFN.²

The design of the pulser follows from the structure of the AGS beam. The revolution time of the AGS beam at 29.4 GeV/c is 2.7 μ sec and there are twelve bunches in the AGS beam, the bunch separation from center to center is 224 nsec and more than 180 nsec from edge to edge. Taking into account of the inevitable jitters of the switch tube and the control circuit, the kicker rise time should be about 170 nsec with a flat top duration of no less than 2.6 μ sec. Followed by a fall time of about 500 nsec, thus the overall pulse width required is about $T = 3.25 \mu$ sec.

The total inductance and capacitance of the PFN are determined as usual by the impedance Z_0 and pulse width T in the following way,

$$T = 2\sqrt{Lc}, \quad Z_0 = \sqrt{L/c}$$

In principle the total number of sections n is a matter of choice, but it usually is chosen to give

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the required rise time and to facilitate the minimization of the flat top ripple which is set to be less than $\pm 1\%$ to limit the emittance blow-up of the extracted beam to be less than 25%. A schematic diagram of the construction of the pulser circuit is shown in Fig. 3.

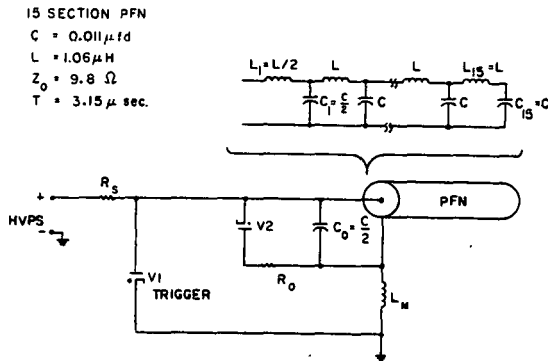


Fig. 3. Design of the PFN.

It is basically a pulse forming network (PFN) discharging into a mismatched load. This technique allows operation of the pulser at approximately half the voltage required by a matched, resistively terminated PFN of the same current rating. On the other hand, if a matched construction is preferred, it is possible to keep the voltage constant simply by reducing the characteristic impedance by half. But the price to pay then is twice the capacitance and stored energy.

The switch tube V1 is a deuterium filled thyatron which discharges the 15 section PFN into the H5 magnet coil. Capacitor C_0 is selected to resonate with the inductance of the H5 magnet, the thyatron, and that from the stray circuit to ensure proper rise of the current. Resistor R_0 is a damping resistor to control transient ringing. Another switch tube V2 is used to prevent the high negative voltage left on the PFN at the end of the pulse from damaging the main switch V1.

For test and evaluation purposes, another important design consideration is the requirement that this kicker should be able to operate in ultra high vacuum condition, typically in the few 10^{-11} Torr range. This imposes a number of special considerations on the choice and preparation of materials, the assembly procedure, and provisions for bakeout during service which will be discussed in the next section.

Special Considerations and Procedures

A) Vacuum System

To operate the H5 kicker in a vacuum of few 10^{-11} Torr range, the magnet and its vacuum tank are designed and prepared in accordance with the following criteria. 1) The ferrite utilized has to be machined with water and fired at 600°C in air to reduce its outgassing rate, vacuum firing the ferrite (not done in this case) should reduce the outgassing further, 2) the stainless steel for the vessel and magnet supports are cleaned, degreased, and then vacuum fired at 900°C , 3) the only other material used in the magnet are OFHC copper and ceramic which are also carefully prepared, 4) the magnet has to be assembled in a clean area in accordance with normal UHV practice, 5) the magnet, its supports, and the conductors are designed to withstand the 300°C bakeout required after each

leakage, and finally 6) an ultra high vacuum ceramic feedthroughs are specified for the magnet.

B) Requirements on the Materials Used

We have used Ceramic Magnetics production CMD5005 ferrite for the kicker magnet core. The choice is based on the considerations for favorable permeability curve, high resistance for reduced eddy current effect, high density to reduce outgassing, and high frequency application. The capacitor used in the construction of the PFN is specially ordered to be a low inductance, high voltage, and low leakage pulse capacitor. It also has to be radiation resistive and operational under 100% reverse voltage.

Owing to the requirement on the stability of the PFN waveform, the power supply is specified to have output voltage stability of 0.1% at maximum, maximum output voltage drift of 0.05% per hour, and ripple and noise of less than 0.02%.

The switch tubes used are EEV CX1154 or EG&G HY 3301 of 3000 ampere and 40 kV rating. The jitter is estimated to be 5 nsec and the switch time is about 100 nsec. Since the design of the charging system requires that the PFN be placed as close to the magnet as possible, the performance of the high voltage switch under the radioactive environment is of a considerable concern. A test program is initiated to understand the false firing rate in the AGS tunnel in the extraction area which typically has radiation background of 0.5-1 R/hr during operation. The results indicate that there is no correlation between false firing of the tube and the radiation background, and the mis-firing can be attributed to the transient effects in the AGS tunnel which is estimated to be one false firing per million pulses. In the actual operation there will be cover for the PFN to isolate the tube from those transient effects to improve the reliability of the tube.

C) Tuning of the PFN

For given total inductance and capacitance of a PFN, the rise time is improved as the number of sections increased. However, the rise time of the load current pulse also depends on the inductance of the load as well as the stray inductances of the loads and the switch tube. Although the stray inductances could not be completely eliminated, modifications can always be made, after the equipment becomes operational, on the locations and ratings of some of the capacitors and inductors to improve the rise time.

Practical experiences indicate that it is not always desirable to obtain a very fast rise since, in general, a shorter rise time results in a ripple of higher amplitude at the top of the pulse.³ While tuning the PFN it was observed that a rise time of 160 nsec was achievable by using a low value, 8 ohms or less, of the resistor R, in parallel with the first coil L_1 . However, it produced a large overshoot in the current and subsequently flat top ripples which could not be reduced to within acceptable limits. Since the resistance can only be changed by discrete amounts, exact optimization is not possible. Presently, we are using a 10 Ω resistor in parallel with a four-turn coil to provide a rise time of about 170 nsec. We also tried a three-turn coil for L_1 which was equivalent to a reduction of R_1 , however, the overshoot was unacceptable although the rise time had improved.

Because of the multiple mutual coupling between different sections, a theoretical estimation of the

flat top ripple is very difficult. The effects of the inductance in each section on the ripple have been empirically determined and the ripple has been minimized through several iterations. In the end, it is clear that the residual ripples are due to the oscillations in each section of the PFN. This implies that the capacitance of the coil itself has to be taken into account. To further reduce the ripples, resistors are introduced in parallel with each coil to create a damped R-L-C circuit. Several values of the resistors have been tried for each coil to achieve the required flat top ripple of $\pm 1\%$.

Test, Measurement, and Performance

Shown in Fig. 4 is the ferrite core and conductor arrangement of the H5 kicker, in Fig. 5 is the kicker in the vacuum vessel hooked to the PFN and power supply for test in the laboratory.

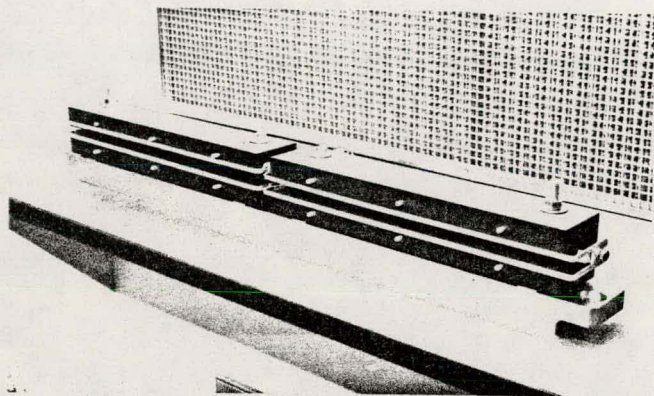


Fig. 4. Construction of the kicker.

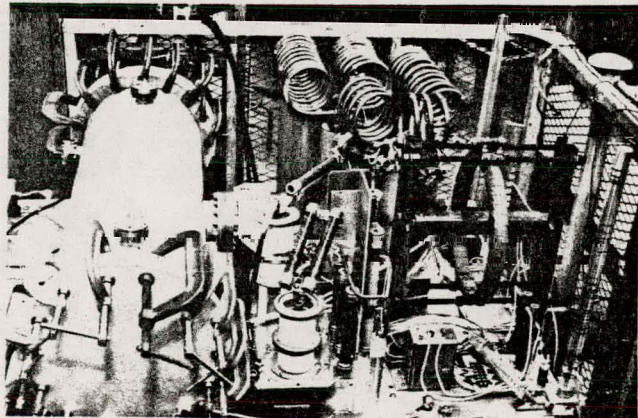


Fig. 5. Assembly of the kicker and PFN.

The pumping system for the ultra high vacuum test consists of a 270 l/sec turbomolecular pump with a UHV valve, a 60 l/sec ion pump, and a Ti sublimation pump with a surface area of 3200 cm². To record the system's pressure, two ionization vacuum gauge are used in the magnet tank and a mass spectrometer is used to determine the partial pressure of the residual gases. Vacuum bakeout of the magnet tank is achieved by wrapped heater wires controlled by an automatic program controller which regulated the tank temperature rise to a rate of 20°C/hr, up to 300°C.

A final equilibrium pressure of 5×10^{-11} torr has been achieved. Analysis shows that the pressure of the methane gas (CH₄) and noble gases accounts for about 30% of the total pressure of the system and

there is also a large amount of hydrogen outgassing which contributes another 30% of the pressure. Given the pumps used in the test, the equilibrium pressure is consistent with the outgassing rate of 2×10^{-13} , 3×10^{-12} , 4×10^{-12} , and 4×10^{-12} Tl/s cm² for stainless steel, ferrite, copper and ceramic, respectively. We find that the 60 l/sec ion pump alone is too small to deal with the noble gas component and would most likely be inadequate for an ISA design. If the pressure of the residual gas is reduced by faster pumping speed and the hydrogen outgassing rate is reduced by better handling of the materials used in the system, a vacuum in the low 10^{-11} Torr range is certainly achievable.

The system has undergone the test of 300,000 pulses at 3000 ampere and 30 kV d.c. The waveform of the current passing through the conductor are recorded by a precision current transformer as shown in Fig. 6. It is clear that a rise time of 170 nsec, ripple of less than $\pm 1\%$, and pulse width of 2.6 μ sec has been achieved.

In order to understand the relationship between the field generated in the gap to the charging current through the coil and the field distribution in the gap, a magnetic measurement system has been set up. Two pairs of pick-up coils are stretched along the magnet to measure the field in both vertical and horizontal plane. Another short coil of 2.7 cm is used to measure the fringe field at the end. The measurements indicate that the fringe fields extend outside the gap of about 2 cm and at the end of about 5 cm. Fortunately, there is no beam passing by the kicker when the kicker is energized; therefore, no correction is necessary. The shape of the field follows the current as predicted by the design.⁴

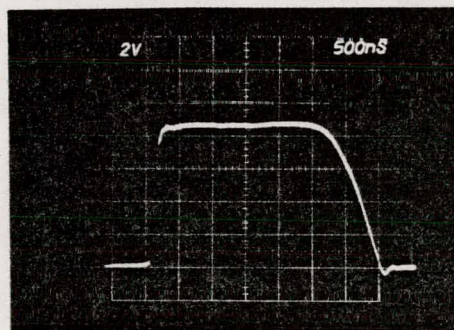


Fig. 6. Current waveform recorded.

Acknowledgments

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