THE AGS FAST KICKER MAGNET SYSTEM[*]

W.T. Weng, J.G. Cottingham, H. Foelsche, W. Frey, S. Ghoshroy, C. Schmidt and J. Tuozzolo

Accelerator Department
Brookhaven National Laboratory
Upton, New York 11973

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 sys-
tem 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 μsec pulse width, 170 nsec rise
time, and flat top ripple within ± 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 dis-
cussed.

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 $\pi/2$. Further-
more, 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 kick-
er, a C-type open magnet is adopted and a 3/2 λ 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 extrac-
tion components in the ring and the orbits in the
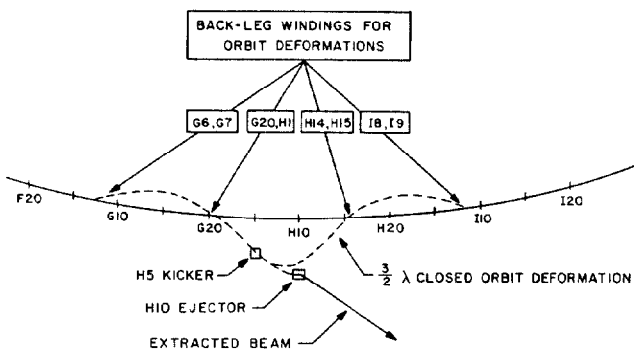extraction area is shown in Fig. 1.

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,

typically in the 10^{-11} Torr range. This stringent
requirement gives rise to a series of special consid-
erations 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 $\varepsilon_x = \varepsilon_y = 1.5 \times 10^{-6}$ 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]
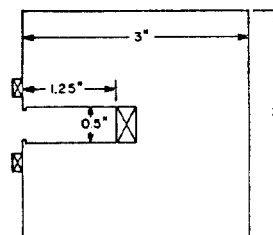
LENGTH	89 cm	FIELD	1.25 kG
DEFLECTION	1.13 m rad.	APERTURE	0.5"(V) x 1.25"(H)
RISE TIME	150 n sec.	PULSE WIDTH	2.7 μ sec.
FLAT RIPPLE	± 1%	VOLTAGE	26.5 kV
CURRENT	2650 amp	INDUCTANCE	1.4 μ H

Fig. 2. Design of the kicker.

The pole shape at the opening of the gap has been ad-
justed 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 struc-
ture of the AGS beam. The revolution time of the AGS
beam at 29.4 GeV/c is 2.7 μsec 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 inevit-
able jitters of the switch tube and the control cir-
cuit, the kicker rise time should be about 170 nsec
with a flat top duration of no less than 2.6 μsec.
Follwed by a fall time of about 500 nsec, thus the
overall pulse width required is about T = 3.25 μsec.

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

---

the required rise time and to facilitate the minimiza-
tion of the flat top ripple which is set to be less
than ± 1% to limit the emittance blow-up of the ex-
tracted beam to be less than 25%. A schematic diagram
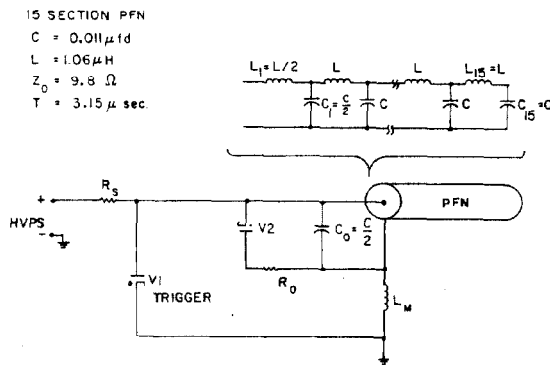of the construction of the pulser circuit is shown in
Fig. 3.

Fig. 3. Design of the PFN.

It is basically a pulse forming network (PFN) dis-
charging 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 thyra-
tron 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 thyratron,
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 impor-
tant 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 sup-
ports 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 ef-
fect, 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 re-
sults 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 opera-
tion 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 operation-
al, on the locations and ratings of some of the capa-
citors 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. Present-
ly, 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 prallel 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 ± 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.
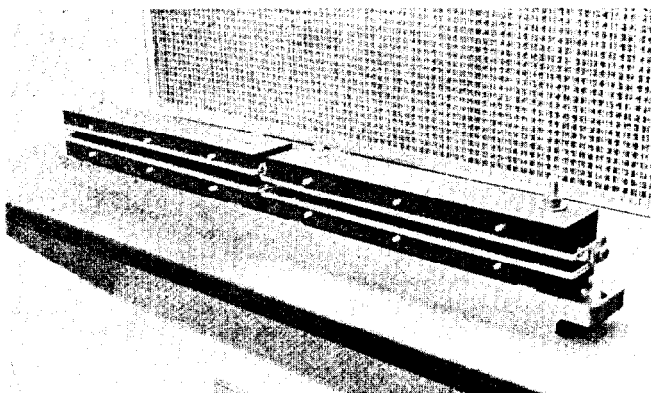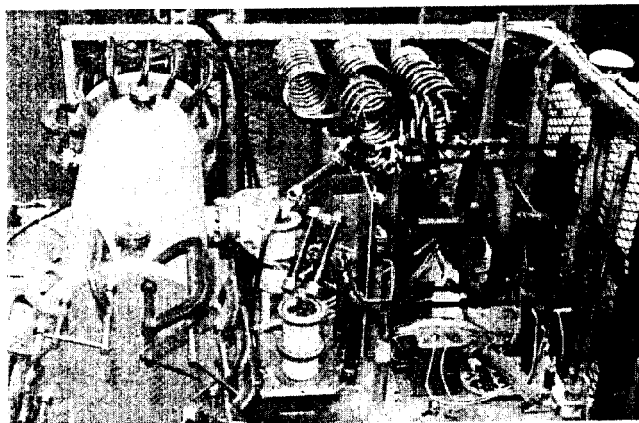

Fig. 4. Construction of the kicker.

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 cm^2. 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 magnt 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 (CH_4) 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 3×10^{-12}, 4×10^{-12}, and 4×10^{-12} Tℓ/s cm^2 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 ± 1%, and pulse width of 2.6 µsec 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]
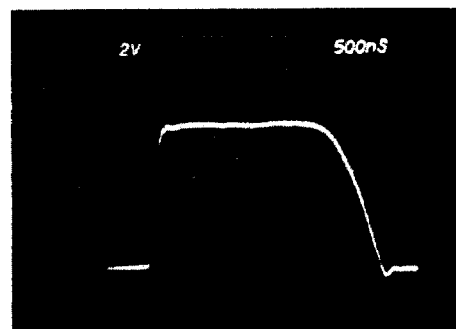

Fig. 6. Current waveform recorded.

Acknowledgments

References

1. W.T. Weng, The New AGS Fast Extraction System, BNL 51310, Sept. 1980.
2. J.G. Cottingham, BNL AGS Div. Tech. Note No.154, May 1971.
3. G.N. Glasoe, J.V. Lebacqz, Pulse Generator, Dover, New York, 1965.
4. R. Nawrocky, private communication, 1981.