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A 3kG KICKER MAGNET SYSTEM FOR THE TEVATRON BEAM ABORT SYSTEM

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Summary

We report on the design of the prototype kicker magnet system to be used in the abort channel of the Tevatron at Fermilab. The magnet has a peak field of 3kG, a 10-90% rise time of 1.5μ s, and the field is greater than 90\% of peak for 21µsec. The kicker magnetic energy is stored in a capacitor and resonantly discharged into the magnet inductance. When the magnet is completely charged a thyratron-ignitron combination is used to clip the recharge of the capacitor and circulate the current in the magnet.

Introduction

The high-field superconducting magnets of the Tevatron require that the beam abort system be highly efficient (\geq 99% at 2×10¹³ ppp) in extracting the beam from the ring. This requirement, together with the limited space available in the lattice for extraction elements, implies that kicker magnets with exceptionally high fields, 3kG, must be utilized. Extreme kicker rise-time need is alleviated by having a 1.8µs gap in the circulating beam; only 12 out of a possible 13 Booster cycles are utilized at injection into the Main Ring. The kicker system will consist of four 1.9mlong modules. The details of the abort system design are given in Ref. 1; the external beam dump² and its instrumentation³ are described elsewhere in these proceedings.

Magnet

A cross section of the magnet is shown in Fig. 1. The magnetic return path consists of 0.002", 3% silicon steel, tape wound cores. This material is less expensive than ferrite and allows for a larger maximum field. Calculations show that the energy loss due to eddy currents and hysteresis are a few percent."

eddy currents and hysteresis are a few percent." Samples of both 0.001" and 0.002" tape cores were tested with an oscillatory current drive of 110kHz and no measurable phase lag of the field vs current was seen in either sample.

The 1-1/2'' tape width gives an average voltage drop, lamination to lamination of $\sim 1/2$ the maximum vendor guaranteed value of one volt. Assuming 50kV across the magnet, the average voltage drop across each lamination is 0.38 volts. The normal interlamination coating supplied by the industry was overcoated with a methylate coat, after slitting, to give an added safety factor.

The core segments are epoxy potted into the aluminum strong back and machined in the gap area. This makes possible a very close tolerance in the gap width. At the inner pole tip edge, the machined radius guarantees the maximum electric field will be on the outer surface of the conductor. Silicon rubber is used in the space between the conductor and cores. The silicon rubber impregnation is the last step in building the magnet, which takes full advantage of the good electrical properties ($E_{max} = ~550V/mil$) of the rubber.

The vacuum beam tube is a slip cast ceramic tube, elliptical in cross section, made of 99.5% Al₂O₃, with metalized ends and flanges brazed on. The inner surface of the tube is coated with a conductive coating (R_s ~50.0 Ω /sq) of indium oxide, In₂O₃, to bleed off the

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Figure 1. Magnet cross section: a) aluminum strong back; b) 0.002" tape wound core; c) ceramic beam tube; d) copper conductor; e) silicon rubber.

surface charge and yet have a negligible effect on the magnetic field.⁵

Calculations have been done on the magnet field quality⁶ and are presented in Fig. 2. This is a dc type calculation but it is expected to be very close to the measured value as a function of time. From this same calculation we expect the inductance of our 1.9 meter module to be $2.4-2.5\mu$ H and to obtain 3kG as the peak field we will need a peak current of approximately 20k amps.



Figure 2. B_x in magnet where 100% = 3kG.

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Electrical

The simplified block diagram of the pulsing system is shown in Fig. 3. The power supply will track the Tevatron beam energy keeping the capacitor Cl charged to the correct potential such that if an abort is needed, Sl can be closed. The energy in Cl is transformed into current as is characteristic of LCR underdamped circuits. When the voltage on S2 goes positive this switch is closed shunting Sl, Cl, and R2, allowing the current to circulate in the magnet and S2. The current rise is given by the equation

 $i \approx I_m sin\{(2\pi/9.24\mu s)t\}, 0 < t < 2.3\mu s$ (1)

The resistance of S2, the transmission line, and the magnet will be made small enough such that the current will drop only 10% in 21µsec. Calculations show that this is possible but if not, another avenue is available to us. We could increase L1 at the expense of a smaller C1 with a corresponding higher voltage. This is not very appealing but possible.

The power supply will charge Cl through Rl, the transmission line and the magnet. Cl will be made up from six $0.1\mu f$ capacitors⁷ in parallel. Their peak voltage will be approximately 50kV. Two manufacturers have supplied us with capacitors to test.

S1 and S2 will be high voltage, high current thyratrons. S1 must hold off 50kV dc, conduct a peak current of 20k amps, and have a peak di/dt of 17k amps/ µsec. S2 does not have to hold off dc voltage but has the sum of voltage across C1, R2, and S1 during the rise-time of the current. S2 must conduct the 20k amps but it will be paralleled with an ignitron to pick up the current after 5-10µsec. S2 must also attain 60k amps/µsec at a very low anode voltage. We are just now starting to evaluate the EG&G HY-5333, a developmental three gap deuterium filled ceramic thyratron. We now believe that this tube will work for both S1 and S2.

The transmission line will be made up of six RG-220 cables approximately 30' long. The region of the cable braid will be filled with SF_6 gas to enhance cable lifetime. C2 and R3 are added to damp frequencies characteristic of the length of the line (≈ 4 MHz). With C2 = 0.01µf and R3 = 8.3 ohms, there is only a small effect on the final current in the magnet.

The value of R2 is not decided as of yet. The best estimate has been taken from a computer simulation of the rise of the current in S1 and its transfer to S2. The main purpose of R2 is to cause the anode of S2 to go positive before C1 is completely discharged.

Two results are obtained with the insertion of R2. The first is that the reverse voltage on S1 is

smaller when the current is totally transferred to S2. Second is that the turn-on of S2 is softened (smaller di/dt). For example:

| | R2 = 0 | $R2 = 0.3\Omega$ |
|---------------------|-------------|------------------|
| V _{Cl max} | -9kV | -lkV |
| di/dt S2 | 120k amp/µs | 60k amp/us |

The addition of R2 has many good effects such as increased life of the thyratons and only minor ill effects such as a small increase in initial capacitor voltage.

Conclusion

The prototype of both pulser and magnet are currently under construction. Many of the computer simulations must be verified with measurement on these prototypes.

The main aspects of this circuit are not new, just the time scale at which the current transfers to S2 must be addressed very carefully. Test indicates that this will not be a problem.

Our present magnet design can readily go to 5kG. If the tape thickness was changed to 0.001" the risetime could be improved by a factor of four. Both modifications would require appropriate pulser changes.

References

- Design Report, 1979 Superconducting Accelerator, Fermilab (1979).
- J.Kidd, et al., "A High Intensity Beam Dump for the Tevatron Beam Abort System," paper presented at this Conference.
- E.Harms, et al., "Instrumentation for the Tevatron Beam Abort Dump," paper presented at this Conference.
- 4. S.C.Snowdon memo to F.Turkot, September 24, 1980.
- E.Tilles, "Conductive Coating for Ceramic Beam Tubes," IEEE Transactions NS-18, June 1971.
- 6. S.C.Snowden, LINDA run DBLRKICK 103180-1330
- 7. Fermilab Engineering Specification 1750-ES-103803.

Figure 3. Simplified electrical schematic of Abort Kicker System.

