Pulsed Dipole Magnets for the Muon Collider[*]

E. Willen
Brookhaven National Laboratory, Upton, NY 11973

ABSTRACT

Pulsed conventional magnets for rapid acceleration and storage of the muons in a muon collider are discussed.

I. INTRODUCTION

Because of their short lifetime, muons in a muon collider[1] must be accelerated more quickly than possible with conventional accelerators. Magnets that are ramped up quickly in field as the muons gain energy in multi-pass linacs could be used for accelerating the muon beam. Such a pulsed magnet scheme appears feasible for the 250 GeV machine option; the parameters appear less favorable for a 2 TeV machine. Pulsed magnets for the storage ring of the collider are also a possibility.

II. ACCELERATOR

A. Magnet Design

A particular design for a pulsed dipole magnet with parameters chosen to be practicable is shown in Fig. 1. The figure shows a quarter of the magnet; four turns of multistrand copper formed into a trapezoidal shape are used in each of two required coils. The turns are placed in an approximate cos θ current distribution to maximize the field and minimize unwanted harmonics. An iron yoke contributes substantially to the field and provides mechanical support. Cooling requirements are modest and can be satisfied by circulating water in pipes (not shown) passing through the yoke.

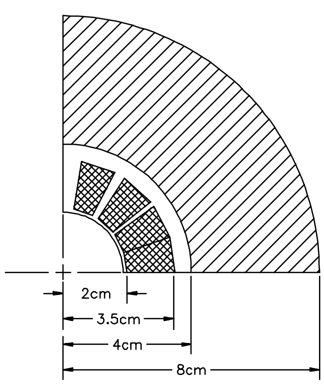

Figure 1: A quarter-section view of a pulsed magnet for the muon accelerator.

The magnet shown in Fig. 1 produces a field of 4 T at a current of 29.5 kA. The conductor cross sectional area is 1.275 cm^2. For a magnet length of 10 m, the inductance is 0.37 mH and the resistance is 19 mΩ. Assuming 250 GeV at 90% of full field, a total of 146 such dipoles is required.

B. Accelerator Parameters

Assuming two linacs with an accelerating gradient of 9 MeV/m, and a dipole filling factor of 70% in the arcs, the time required to accelerate the muons from 25 GeV to 250 GeV is 360 μs. The power to drive the magnet during this acceleration time can come from the discharge of the stored energy in a capacitor bank. A design with such an LRC power supply, producing the waveform shown in Fig. 2, has a quarter period of 550 μs. Note that the required acceleration is not linear but rather must follow the field increase in the magnets. The voltage required is 31.2 kV and the required storage capacitance is 340 μF. Each magnet has its own power supply and it is triggered to discharge in synchronization with the acceleration cycle. After a quarter cycle, the energy is recovered by the power supply in the next quarter cycle with an efficiency of ~80%. The required voltage (31.2 kV) is uncomfortably high. It can be reduced by connecting some or all of the turns in the magnet in parallel, fed from several subsections in the power supply. Power supplies with power output similar to that required here operating at voltages ~5 kV are used at accelerators to inject beam or to capture antiprotons[2].

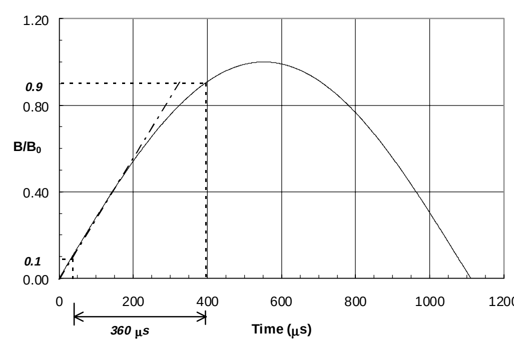

Figure 2: Waveform of field produced by the magnet, powered with an LRC power supply. The dot-dash line shows, for reference, a linear ramp.

During a half cycle, the heat deposited in the coils is 9400 J. This gives an estimated temperature rise per cycle in the coils of 0.13 °C. At a repetition rate of 2 Hz, the average power dissipated in each magnet due to this resistive heating

[*] Work performed under the auspices of the US Department of Energy

is 19 kW. For the entire machine (144 dipole magnets), the power dissipated in these magnets at 2 Hz is 2.7 MW. Table I summarizes the parameters for this particular design. The calculations used to obtain these values are approximations and further work will be needed to refine the results.

Table I: Accelerator magnet parameters.

	Units	Values
Coil inner radius	cm	2
Magnet length	m	10
Field	T	4
Current	kA	29.5
Stored energy	kJ	160
Inductance	mH	0.37
Coil resistance	mΩ	19
Ramp time, 10% to 90%	μs	360
Power supply voltage	kV	31.2
Storage capacitance	μF	340
Magnet heat per cycle	J	9400
Magnet temperature rise per cycle	°C	0.13
Power into magnet @ 2 Hz	kW	19

III. COLLIDER

A similar design approach using pulsed magnets can be considered for the collider ring. Here, the magnet current need not rise quickly, but the magnet must have a constant flattop current for ~5 ms. A possible design is shown in Fig. 3. With two layers of turns, a field of 6 T can be achieved. Assuming a dipole filling factor of 0.7, the time for 1000 orbits is 4.2 ms. A current of 24.9 kA and a voltage of 1.1 kV is required to maintain the current in the magnet. The average power in each magnet at 2 Hz is 452 kW. For the entire ring, with 44, 10 m long magnets, the average power at 2 Hz is 39.4 MW. Table II summarizes the parameters for such a design.

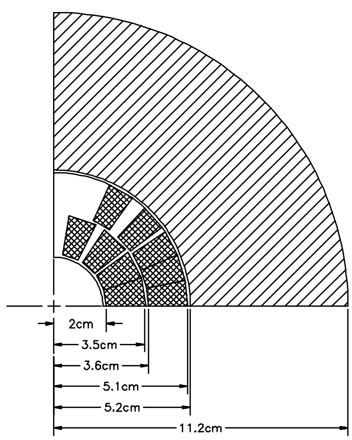

Figure 3: Collider ring pulsed magnet.

Table II: Collider magnet parameters.

	Units	Values
Coil inner radius	cm	2
Magnet length	m	10
Field	T	6
Current	kA	24.9
Stored energy	kJ	360
Inductance	mH	1.2
Coil resistance	mΩ	44
Power supply voltage	kV	1.1
Power into magnet @ 2 Hz	kW	452

ACKNOWLEDGMENT

Robert Palmer suggested the possibility of using pulsed magnets in the muon accelerator and collider.

[1] R. Palmer et al, "Muon Collider Design", BNL 62949 (March 1996)

[2] R. Winje and K. Bourkland, IEEE Trans. Nuc. Sci., NS-22, No.3 (1975), 1242