PROTON DRIVER POWER SUPPLY SYSTEM

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Abstract

This paper describes magnet power supply system for a proposed Proton Driver at Fermilab. The magnet power supply system consists of resonant dipole/quadrupole power supply system, quadrupole tracking, dipole correction (horizontal and vertical) and sextupole power supply systems. This paper also describes preliminary design of the power distribution system supplying 13.8 kV power to all Proton Driver electrical systems.

$$I(t) = I_{dc} - I_{ac}\cos(2\pi 15 t) + 0.125 I_{ac}\sin(2\pi 30 t)$$

1 INTRODUCTION

Power supply system for dipoles and quadrupoles is designed to provide current to the magnets of the form:

Adding second harmonic (30 Hz) to the fundamental of the magnet current reduces dB/dt in the magnets during acceleration. A 12.5% second harmonic component results in 25% reduction of dB/dt.

Since all magnets are designed to operate at 16 GeV, all magnet power supply system components interfacing Proton Driver magnets must be designed to operate at 16 GeV. These include interconnecting bus, terminals, LCW water system, bucking chokes, power supplies, controls and regulation systems. Infrastructure (service buildings, equipment pads) and 13.8 kV power distribution system are also designed to accommodate 16 GeV configuration. Energy storage devices (resonant cell chokes and capacitors) for the dipole/quadrupole resonant network are designed to operate at 12 GeV and can be fully utilized in 16 GeV configuration.

2 SUBSYSTEMS

2.1 Dipole/Quadrupole Resonant Power Supply Subsystem

The choice of magnet resonant network configuration is influenced by three factors: the need to avoid drawing a large reactive power from the a.c. line, reliability, and cost.

A circuit in Figure 1 satisfies the basic requirements. The diagram shows two resonant cells near the power supply. Dipoles, quadrupoles F and quadrupoles D are connected in series. Power supplies are inserted in series with magnets near virtual ground of the distributed resonant circuit. Each power supply is a source of a.c. and d.c. power (similar to Fermilab Booster). Dividing the resonant system into 30 resonant cells permits notable

decrease in the system voltage to ground. Equivalent cell magnet (L_m), capacitor banks (C and C_1), and chokes (L_{ch}, and L_1), form a resonant cell with two series resonant frequencies: 15 Hz and 30 Hz.

Owing to its series connection, the distributed resonance circuit provides a basic uniformity in magnets currents. It is necessary to ensure that the a.c. potentials of the corresponding points in the network attain a similar value. This is achieved by matching equivalent cell magnet inductances, close tolerances of each resonant cell components and auxiliary windings in chokes L_{ch} connected in parallel with each other.
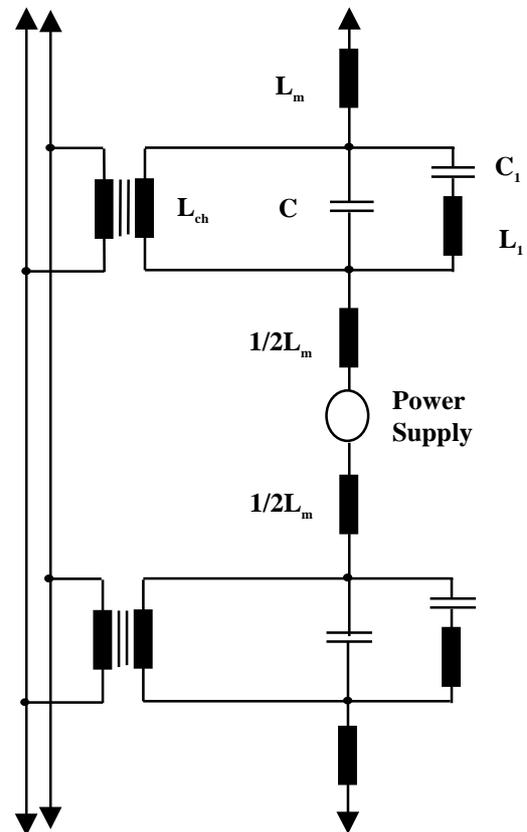
Figure 1: Dipole/Quadrupole Resonant network.

Calculations of d.c. resistances and d.c. losses have been scaled from Fermilab Booster. All system parameters will be verified when a prototype resonant cell becomes available. The dipole/quadrupole power supply subsystem parameters are shown in Table 1.

Table 1: Dipole/Quadrupole Subsystem Parameters

Parameter	12 GeV Mode	16 GeV Mode
Irms	3,000 A	4,000 A
Total a.c. voltage	247,000 V	324,000 V
Total d.c. voltage	1,500 V	1,900 V
Number of resonant cells	30	30
Voltage to ground, peak	4,400 V	5,700 V
Total losses	4.1 MW	8.9 MW
Number of power supplies	3	3
Power supply current, peak	4,900 A	6,400 A
Power supply voltage, peak	±900 V	±1,200 V

2.2 Quadrupole Tracking and Correction Power Supply Subsystem

The quadrupole correction peak current requirements at given frequencies are set by the required tune compensation or tracking compensation, whichever is higher. It is assumed that only frequencies up to 7th harmonic (105 Hz) will be required to provide sufficient quadrupole field gradient correction (tracking compensation and tune control). Table 2 gives quadrupole tracking and correction power supplies system requirements. Tracking correction has been calculated using dipole and quadrupole saturation curves. Tune compensation requirements are predicted values needed for tune compensation.

Table 2: Quadrupole Tracking Subsystem Requirements

Freq [Hz]	Tracking [±%]	Tune [±%]	Requirement [±%]
15	0.53	2.00	2.00
30	0.36	0.20	0.36
45	0.21	0.10	0.21
60	0.09	0.10	0.10
75	0.02	0.10	0.10
90	0.03	0.10	0.10
105	0.03	0.10	0.10

Due to space requirements the quadrupole correctors are planned to be integrated in the quadrupole magnets. The estimated induced voltage from the main bus is 8.5 kV per quadrupole family.

The primary windings of the bucking choke are connected in series with quadrupole trim windings, while the secondary windings are connected in series with the main coils. The mutual inductance of the bucking choke must be equal in value (but opposite in sign) to the sum of mutual inductances of the quadrupole main/trim coil transformers for proper operation.

2.3 Dipole Horizontal Correction Subsystem

Horizontal orbit correction is accomplished using trim coils wound on the dipole magnet cores. Each dipole magnet is supplied with two sets of trim coils having an equal number of turns. They are connected in series but with opposite magnetic senses so that no net voltage is induced across them by the main coil current. The common connection point between the two trim coils is then connected together with the common points between the other trim coils as shown in Figure 2. Each trim set is driven by an independent programmable power supply. The effect of energizing a single trim set is to cause a local horizontal orbit shift without altering the beam orbit path length. Subsystem parameters are shown in Table 3 below.
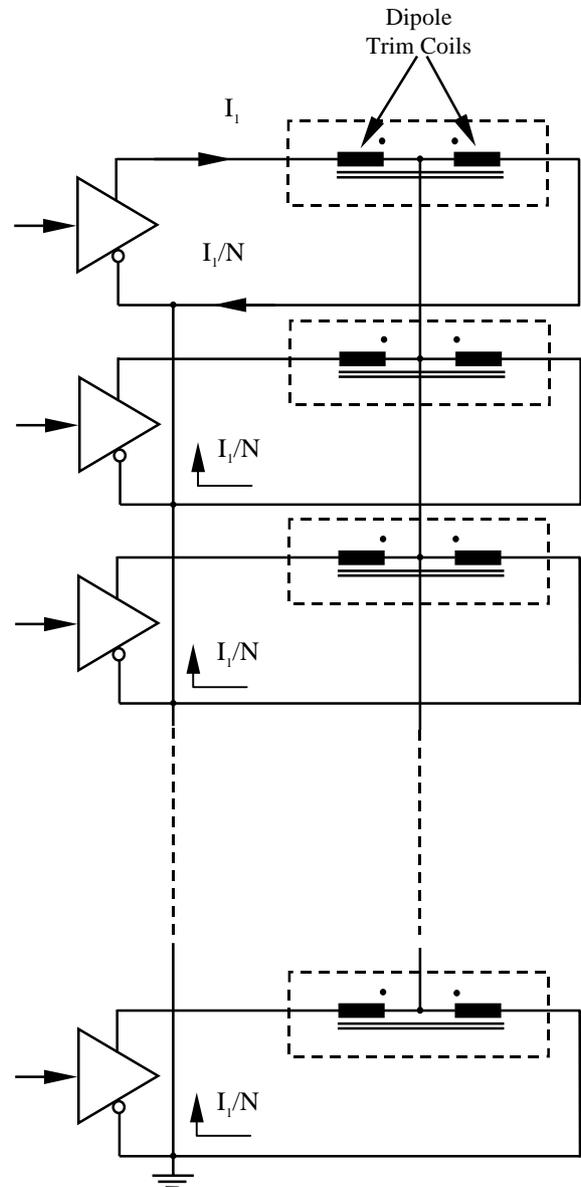
Figure 2: Dipole Horizontal Correction System Principle

Table 3: Dipole Horizontal Correction System Parameters

Parameter	12 GeV Mode	16 GeV Mode
Irms	210 A	280 A
Number of Power Supplies	48	48
Power Supply Current, peak	360 A	480 A
Power Supply Voltage, peak	±40 V	±50 V

2.4 Dipole Vertical Correction Subsystem

Separate corrector magnets situated at specific points in the ring accomplish vertical orbit correction. The vertical corrector magnets are driven with programmable power supplies similar to those used for horizontal correction. Subsystem parameters are shown in Table 4 below.

Table 4: Dipole Horizontal Correction Subsystem Parameters

Parameter	12 GeV Mode	16 GeV Mode
Irms	230 A	310 A
Number of Power Supplies	36	36
Power Supply Current, peak	300 A	400 A
Power Supply Voltage, peak	±450 V	±600 V

2.5 Sextupole Power Supply Subsystem

The sextupole power supply system consists of 3 independent circuits with distributed power supplies: SF loop, SD loop, and a stray field compensation loop. Table 5a describes subsystem parameters for 12 GeV mode of operation and Table 5b gives subsystem parameters for 16 GeV mode of operation.

Table 5a: Sextupole Power Supply – 12 GeV Mode

Circuit	SF	SD	Comp.
Number of sextupoles per circuit	24	24	
Irms	960 A	1,400 A	440 A
Induced voltage per circuit, peak	1,350 V	1,900 V	25 V
Number of power supplies	2	3	1
Power supply current, peak	1,800 A	2,700 A	900 A
Power supply voltage, peak	±700 V	±700 V	±30 V

Table 5b: Sextupole Power Supply – 16 GeV Mode

Circuit	SF	SD	Comp.
Number of sextupoles per circuit	24	24	
Irms	1,300 A	1,900 A	600 A
Induced voltage per circuit, peak	1,800 V	2,600 V	33 V
Number of power supplies	2	3	1
Power supply current, peak	1,800 A	2,700 A	900 A
Power supply voltage, peak	±1,000 V	±1,000 V	±33 V

2.6 Power Distribution Subsystem

At this stage of the project, it is assumed that the existing site power distribution system will not able to meet Proton Driver power demand. To meet Proton Driver power requirements, a new substation as well as existing facilities will be utilized. Table 6 gives power requirements of the power distribution system. To take advantage of the existing 345 kV equipment, the substation will be located inside existing Kautz Road Substation.

Table 6: Power Distribution Requirements

Subsystem	Peak MVA	RMS MVA
RF	40.0	10.0
Dipole/Quad	18.0	16.1
Sextupole	11.7	8.5
Quad Correction	5.0	4.4
Vert. Dipole	10.0	8.9
Hor. Dipole	0.8	0.7
Vacuum	1.8	1.8
Conventional	1.5	1.5
Total	88.8	51.9

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3 REFERENCES

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