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DESIGN SPECIFICATIONS FOR A LARGE-VOLUME, DC TO 60 Hz, 0.1 TESLA (PEAK) MAGNET FOR PRIMATE EXPERIMENTATION

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This report presents preliminary design specifications and cost estimates for a magnet that would be suitable for both DC and AC field studies with large species of mammals, including nonhuman primates and human subjects. The basic features of this magnet are the following:

(1) A homogeneous field of variable strength up to 0.1 T can be produced over a 2 ft x 2.5 ft x 4.5 ft (20.25 ft^3) volume.

(2) The magnet iron is laminated to minimize eddy current losses when operating in the AC mode.

(3) The power supply is designed to allow controlled frequency variation over the range 0 - 63 Hz, a feature that would permit the detection of frequency thresholds and/or frequency windows for physiological effects such as visual magnetophosphenes.

LAMINATED MAGNET DESIGN

The magnet configuration has been chosen to produce a uniform horizontal field perpendicular to the body axis of exposed primate subjects. The gap width is 2 ft (the distance between coil modules), the depth is 2.5 ft and the height is 4.5 ft. These dimensions would accommodate the entire torso and head regions of large primates (including man), and would permit moderate exercise routines to be performed by a subject within the confines of the magnet gap. A schematic representation of the magnet indicating the physical dimensions of its major components is shown in Fig. 1.

The magnet coil assembly consists of two mirrored pairs of hollow copper conductors, each with 14 turns (N = total turns = 56). The peak field strength has been chosen to be 0.1 T, to achieve which a total of 4.947×10^4 amp-turns are required. The current, I, needed for this value of amp-truns is 883 A. At the peak field strength of 0.1 T, the total magnetic flux, ϕ, is 0.141 webers. For operation at 0.1 T with the magnet dimensions as specified in Fig. 1, the electrical parameters for the coil modules are the following:

-- Inductance: $L = N \phi/I = 8.94$ mH

-- Resistance: $R = \rho bN/A = 1.893 \times 10^{-2} \Omega$ (ρ = resistivity; b = conductor length; A = conductor cross-sectional area)

-- Time constant: $\tau = L/R = 0.47$ sec

-- Maximum stored energy: $U = LI^2/2 = 3.486 \times 10^3$ J

-- Maximum DC dissipated power: $P_{max} = I^2R = 1.73 \times 10^4$ W

-- Maximum AC dissipated power: 56 kW (53 kW conductor losses and 3 kW core losses)

When the magnet is driven at the peak field level of 0.1 T and the maximum frequency f = 63 Hz, the reactance and peak voltage characteristics are the following:

-- Inductive reactance: $X_L = 2\pi fL = 3.54 \Omega$

-- Total reactance: $Z = \sqrt{R^2 + X_L^2} = 3.54 \Omega$ (the resistive reactance is negligible compared to the inductive reactance)

-- Peak Voltage: $\varepsilon_{peak} = IZ = 2.95 \times 10^3$ V

Magnet cooling is accomplished by water flow through the central region of the hollow copper conductors (Fig. 1). For the maximum AC conductor-dissipated power of 5.3×10^4 W, the total water flow rate must be 16 g.p.m. to maintain the temperature of the inner conductors of the coil modules within 6 ^{o}C of the inlet temperature (15 ^{o}C). The maximum required water pressure is approximately 60 p.s.i.

POWER SUPPLY DESIGN

The basic conceptual design of the power supply shown in Fig. 2 requires the use of a variable capacitor to drive the magnet at a desired resonant frequency. When operating under ideal wattless power conditions, the capacitance, C, would satisfy the resonant condition: $C = 1/(4 \pi^2 f^2 L)$. In practice, the circuit consisting of the variable capacitor bank and the magnet is relatively lossless. However, the magnet losses from coil resistance and eddy currents must be compensated by the use of a cyclo-converter (DC to 15 Hz) or an alternator (10 - 63 Hz) in parallel with the variable capacitor bank. These components of the circuit also serve to supply leading or lagging current in order to resonate the magnet at a chosen frequency, i.e. they serve to "fill in" the discrete intervals in capacitance.

The detailed specifications for the power supply components are shown in Fig. 3. The design of the capacitance bank is based on the requirement that the energy in the capacitors must equal the maximum stored energy in the magnet, $U = 3.486 \times 10^3$ J. Using this value of U and the peak applied voltage $\varepsilon = \sqrt{2} \times 2300 = 3253$ V, the required capacitance $C = 2U/\varepsilon^2 = 659\ \mu F$. The associated capacitative reactance $X_C = 1/(2 \pi f C) = 3.83\ \Omega$ at 63 Hz.

The capacitor kVA rating can be calculated from the peak current, I = 883 A, required to drive the magnet at a maximum field level of 0.1 T.

If banks of four 600 V series-connected capacitors are used to provide the required capacitative reactance, then the circulating power is (883 A) x (2.4 kV)/ $\sqrt{2}$ = 1.5 x 10^3 kVA. In order that the full capacitor rating cannot be exceeded, the capacitor rating specified in the power supply design (Fig. 3) is 3 x 10^3 kVA, i.e. twice the anticipated maximum power requirement.

COST ESTIMATE FOR MAGNET AND POWER SUPPLY (based on 1979 material and labor costs)

--	Laminated Magnet:	
A.	Materials:	
	Coil	15 K$
	Core (including lamination materials, stack fixture and frame)	20 K$
B.	Labor:	
	Engineering (mechanical, electrical, drafting and magnet testing)	36 K$
	Fabrication and assembly	41 K$
C.	Total + 20% contingency	134.4 K$
--	Power supply:	
A.	Existing equipment (no cost): alternator, DC motor, field power supply, exciter	
B.	New equipment items:	
	Two SCR power supplies	86 K$
	Tachometer generator and frequency control	3 K$
	Alternator current control	4.5 K$
	Cyclo-converter control	6 K$
	Capacitor bank (3000 kVA, 60 Hz) and switching links	35 K$
	Inductor	1.5 K$

C. Power Systems:

Power switching	7.5 K$
Distribution system (to and from electric substation)	30 K$

D. Labor:

Engineering (electrical)	5 K$
Fabrication and installation	10 K$

E. Total + 20% contingency	226.2 K$

FIGURE LEGENDS

Figure 1. Schematic diagram of two cross-sectional views of the laminated magnet.

Figure 2. Schematic representation of the magnet and power supply circuit.

Figure 3. Block diagram of the power supply components required for operation in the variable frequency range 0 - 63 Hz with a peak field level of 0.1 T.

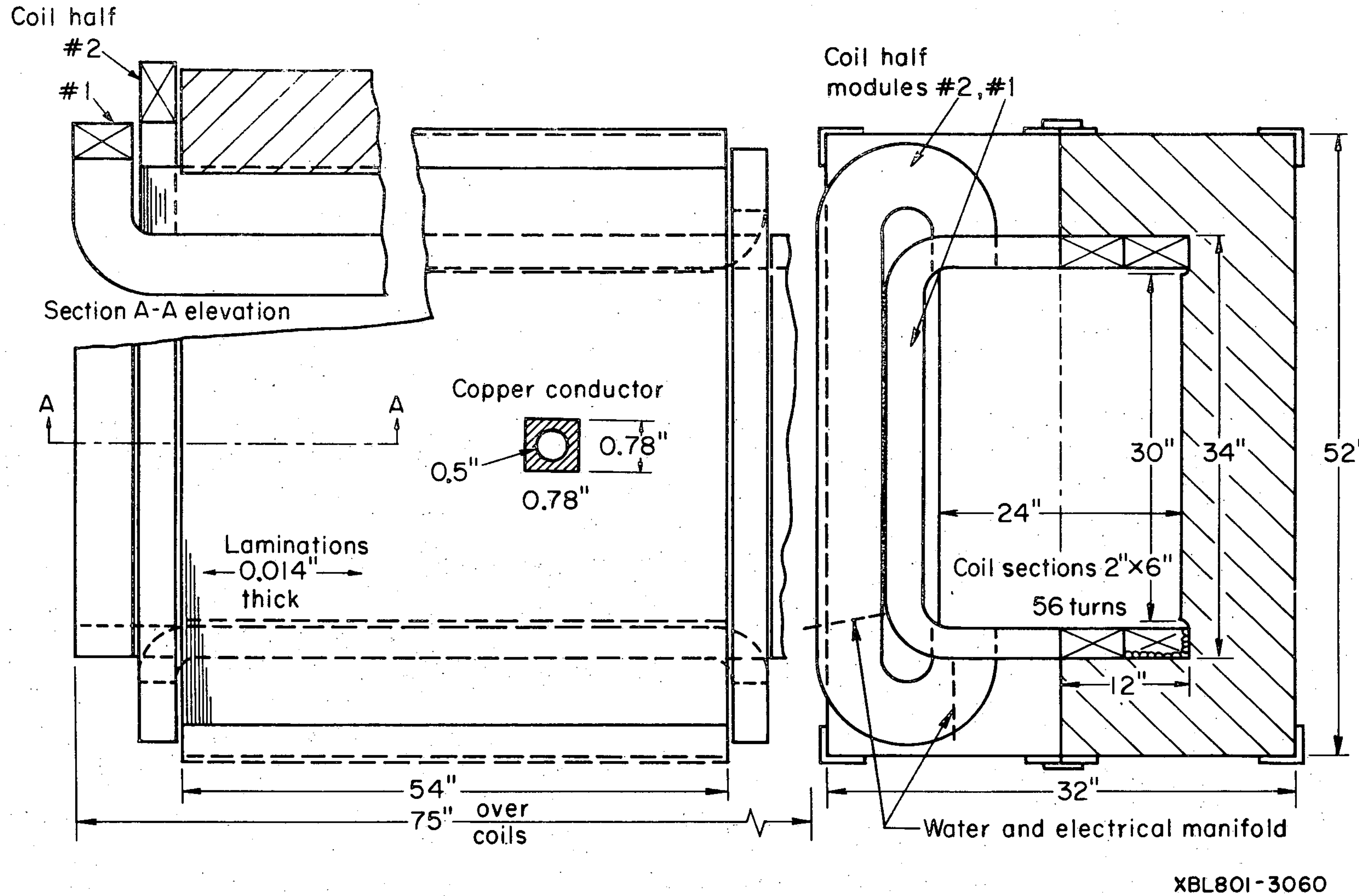
Coil half
#2
#1
Section A-A elevation
A
A
Copper conductor
0.78"
0.5"
0.78"
Laminations
0.014"
thick
54"
75" over
coils
Coil half
modules #2, #1
30"
34"
52"
24"
Coil sections 2"×6"
56 turns
12"
32"
Water and electrical manifold
XBL801-3060

FIGURE 1

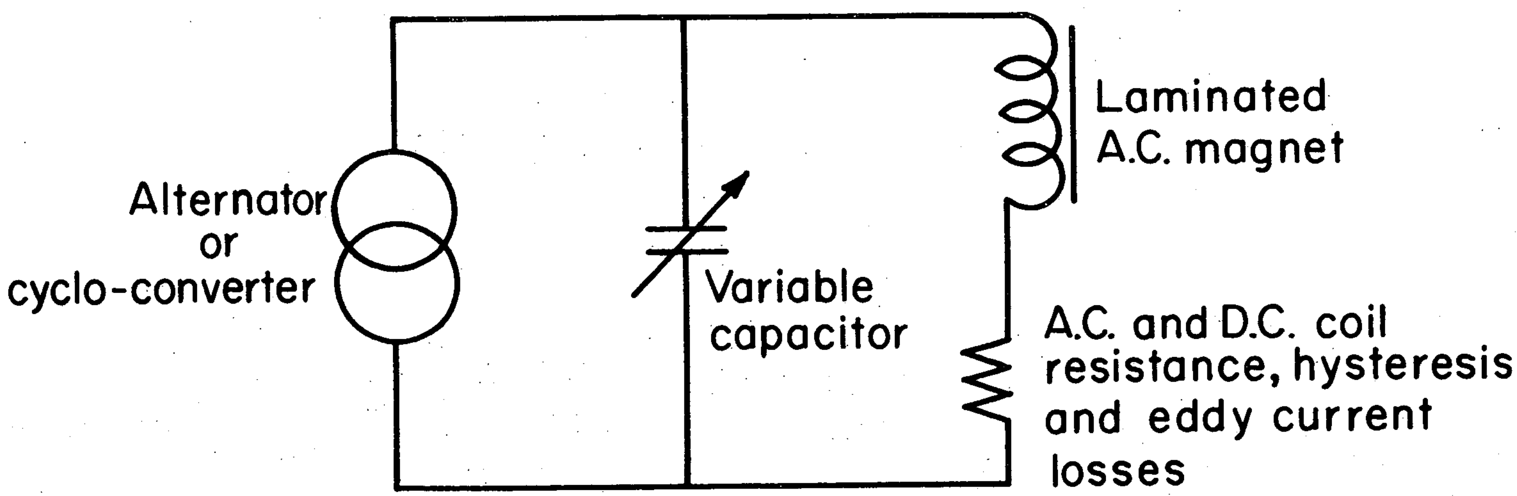

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FIGURE 2

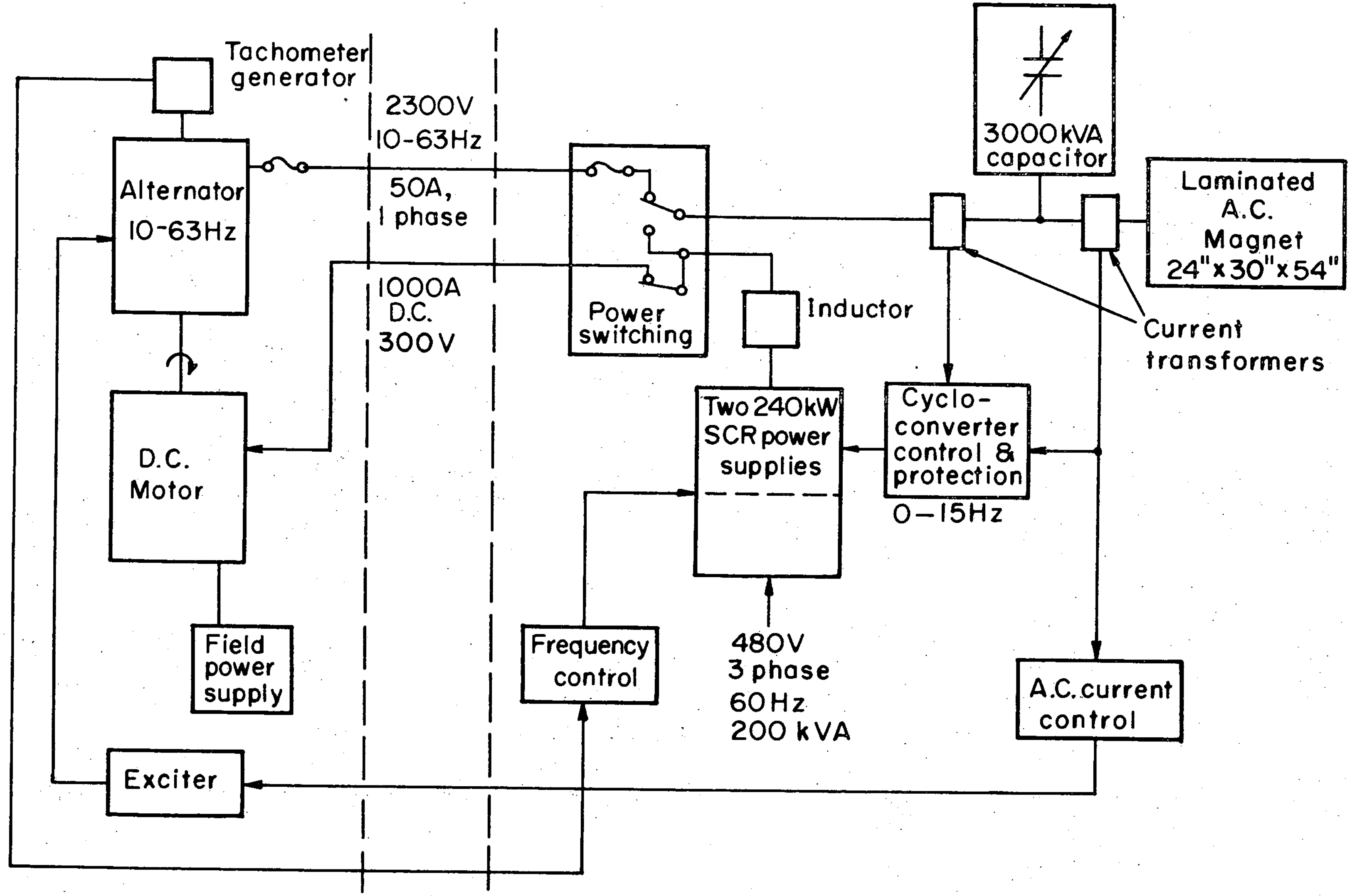

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FIGURE 3

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