Title

NEUTRAL BEAM INJECTOR SYSTEM DEFLECTION MAGNET DESIGN PARAMETERS AND NOTES

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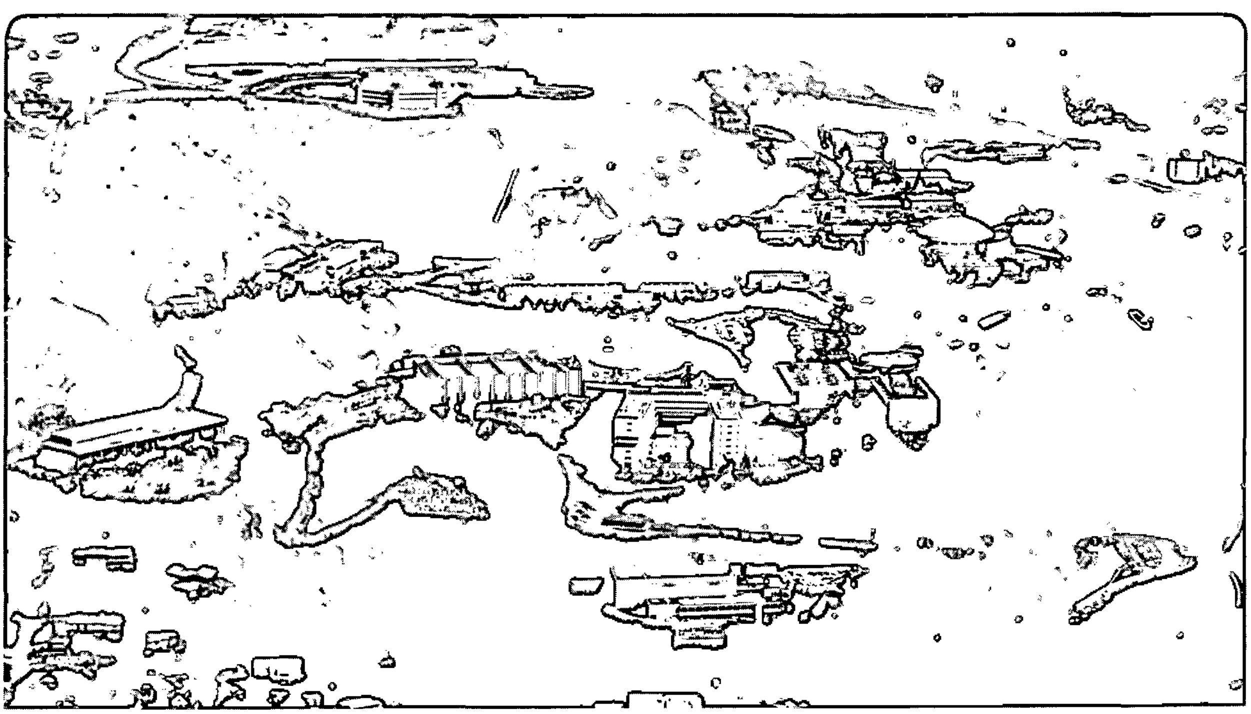

LAWRENCE BERKELEY LABORATORY - UNIVERSITY OF CALIFORNIA
ENGINEERING NOTE

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PROGRAM — PROJECT — JOB

NBSTF/TFTR

NEUTRAL BEAM INJECTOR SYSTEM DEFLECTION MAGNET

TITLE

DESIGN PARAMETERS AND NOTES

Rev. Sept. 15, 1978

Introduction

This note is to record some of the present parameters for the 3-channel ion deflection magnet for the TFTR neutral beam injection system. The magnet is to be positioned inside the vacuum chamber and to accept beams from each of the three sources. The + charged ions are to be deflected upwards to ion dump collector plates at the top of the vacuum chamber. The source is to be rated for 120 KV Deuterium and the magnet is to deflect the full energy D^+ ion by 60°. The other ions species all have much less beam power than the 120 KeV D^+ and are deflected by approximately 43.6° (120 KeV D_2^+), 52.8° (80 KeV D_2^+), 86.1° (60 KeV D^+), and 119.6° (40 KeV D^+).

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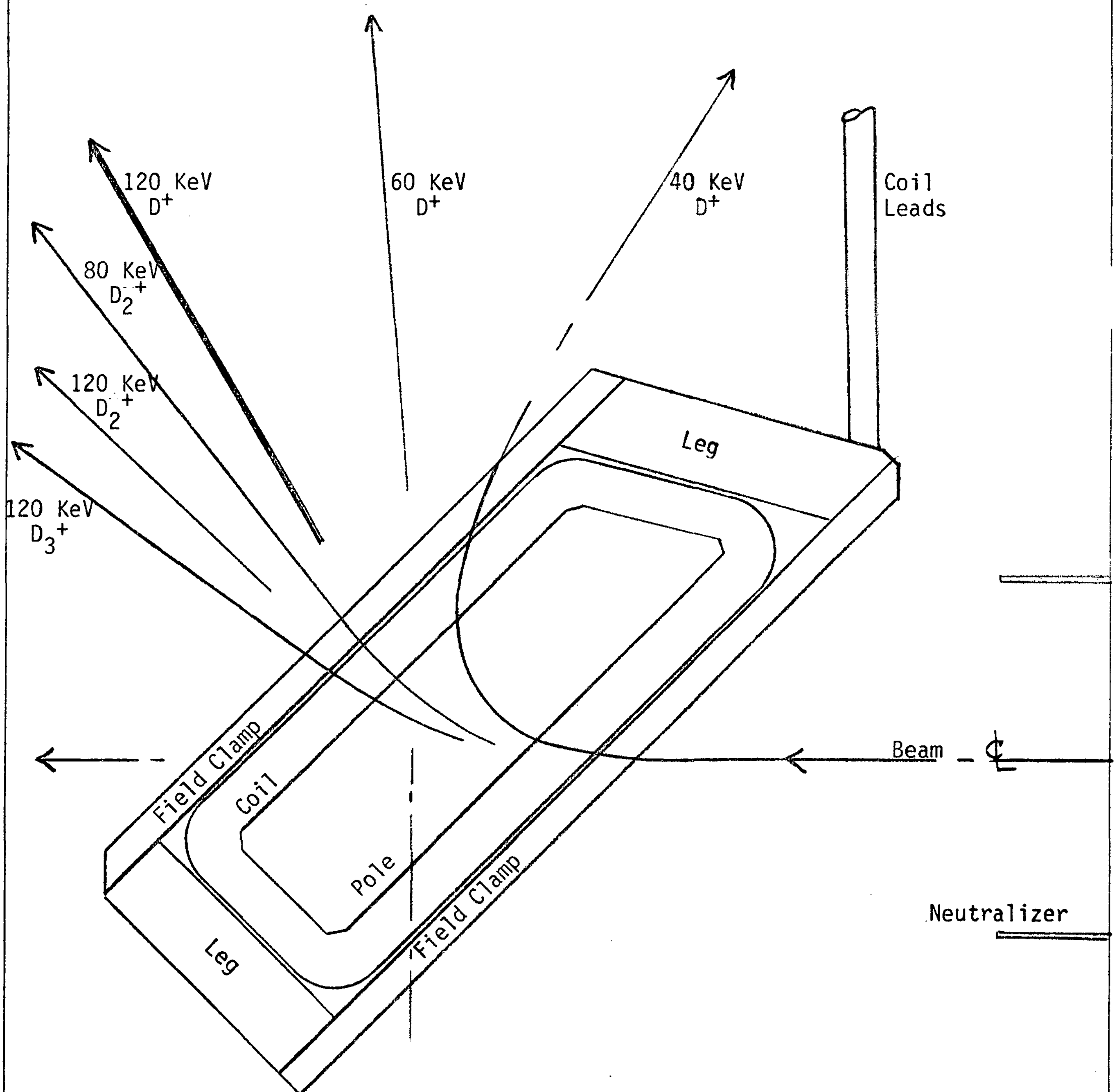

Ion Deflection Magnet and Ion Paths

Elevation View, Scale 1/10

Magnet Position

Inclined 45° to incident horizontal beam.

Located 306.5 cm from source ref. (as per B. Court dwg. LLL 5/16/77).

Gap separation 43.356 cm (17.069") center to center.

Beamline (and magnetic gap) convergence angle 4.03926°.

Aperture Requirements

Clear poletip gap 6.50"

Poletip length 9.0"

Poletip width 32" entrance, 37" exit actual; inclined 45° to beam.

3 separate gaps; each with independently controlled coil set.

3 Gap Properties

Separating webs to be between the 3 gaps to isolate the system into 3 essentially separately controllable magnets. The webs will be thick enough to shunt at least up to 30% of the flux around the adjacent gap. Thus, could have 2.0, 1.3, 2.0 Kg simultaneously in the 3 gaps by adjusting each of the 3 coils independently. The magnet will have a common yoke (3" thick) and common legs (approximately 4" thick). In addition, field clamps will be located at entrance and exit of each gap to further isolate the effects of each gap from each other and to cut off the fringing field sharply.

Field Levels

From Beam Tracing program results, a 60° deflection of 70.7 Kg-cm stiff beams (120 KeV D^+) requires total flux of 6.83 x 10^4 g-cm (case BEAM005, 6/30/77). POISSON fringing field run for typical cross section with field clamps requires a central midpoint field level of 2.20 kg, and an ideal coil strength of 14,600 (each) Ampere-turns (case MTFR3C 6/23/77) to produce this required total flux. The design field level will be 2.50 Kg nominal.

Coils

The coils are to be canned separately in stainless steel boxes similar to the CTR test magnet. The six pairs of coil leads will be contained in stainless tubes and extend vertically upward to make the vacuum chamber penetration on the top lid.

The coils will be each 21 turns of square hollow copper conductor (0.467" x .467" with 0.275" diameter LCW cooling hole) and will be a vacuum impregnated epoxy assembly. The mean length of each turn is approximately 100".

2.5 Kg should require 16,591 Amp turns. The coil design for 10% more current will allow for saturation effects, etc.

$$I_{des} = \frac{16591 \times 1.1}{21 \text{ turns}} = 869 \text{ Amps}$$

$$\text{Current density in copper} = \frac{869 \text{ A}}{.157 \text{ in}^2} = 5535 \text{ A/in}^2$$

$$\text{Conductor length} = 21 \times \frac{100}{12} \text{ ft} + \underset{\text{(leads)}}{25 \text{ ft}} = 200 \text{ ft}$$

$$R = \underset{(\Omega/\text{ft @ } 40°\text{C})}{57 \times 10^{-6}} \times 200 \text{ ft} = 11.4 \times 10^{-3}$$

$$V_{Coil} = IR = 11.4 \times 10^{-3} \times 869 = 9.9 \text{ volts}$$

(V_{gap} = 19.8 volts; 2 coils in series)

$$P_{Coil} = IV = 869 \times 9.9 = 8.609 \text{ Kw}$$

(P_{gap} = 17.2 Kw), $P_{3 \text{ gaps}}$ = 51.65 Kw total magnet

For 50 psi Δp water pressure and 200 ft long, assume approximate flow of 1 gpm thru .275" hole,

$$\Delta T = \underset{°\text{C/Kw}}{3.8} \times 8.6^{\text{Kw}} = 32.7°\text{C}$$

for T_{in} = 20°C; T_{out} = 53°C.

Conductor mean temp might be 40 - 50°C

<u>D. C. Power Supply requirements</u>: 900 - 1000 A; 20 - 25 V each

<u>LCW Water requirements</u>: approximately 6 GPM total, $\geq$ 50 psi Δp

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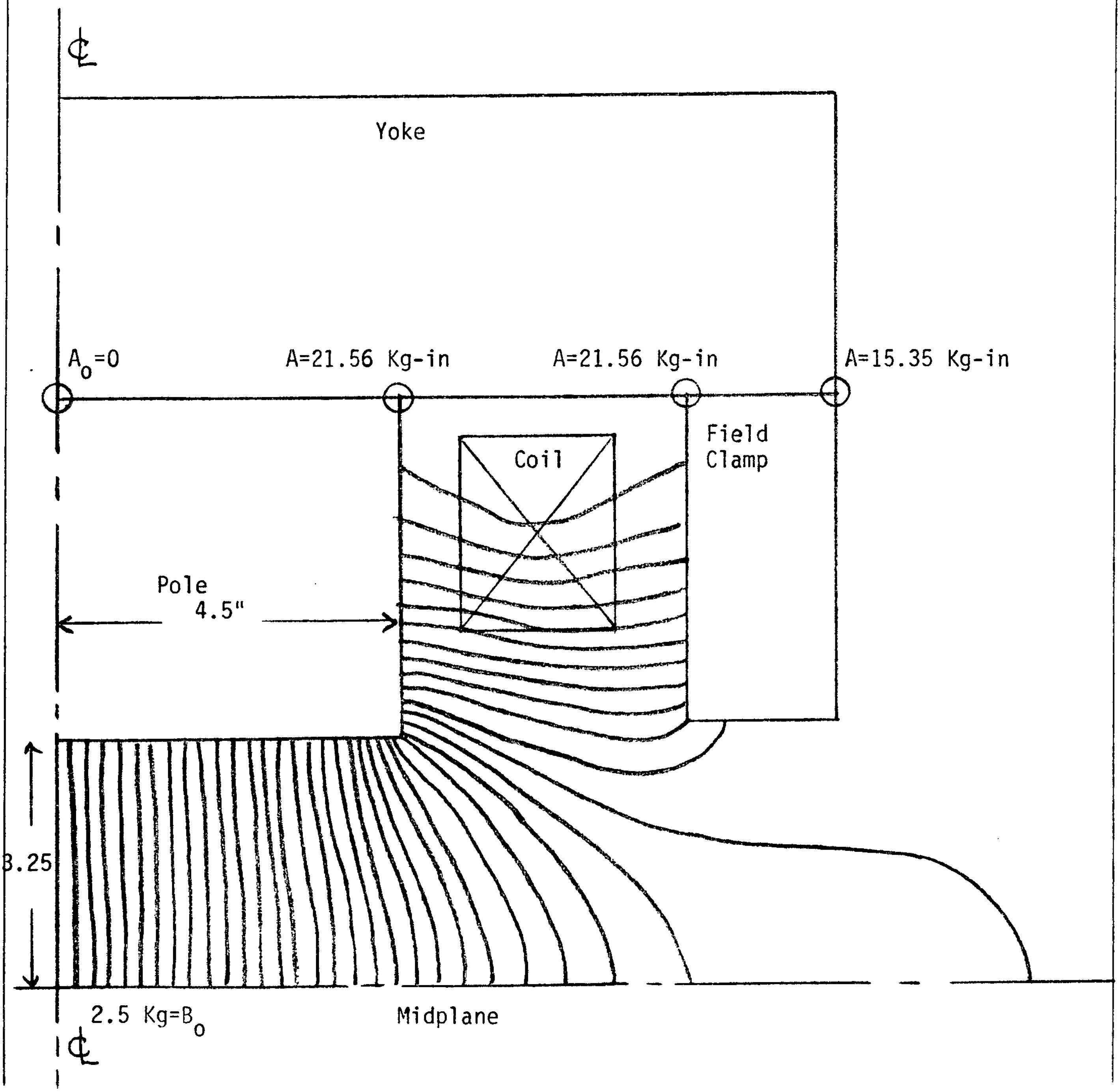
Note: All power connections, as well as all water connections are made outside vacuum vessel. The inside of the coil can is at air (not under vacuum) and there are no water connections or manifolds inside. Each coil is interlocked with a flow switch (0.75 gpm minimum) and a thermal switch (approximately 60°C).

Flux Distribution in Steel

Fringing field run for a cross section through the field clamp. (Actually shown1/2 size, for top gap only). Field plot for other "2-Dimensional" cross section is shown on next page.



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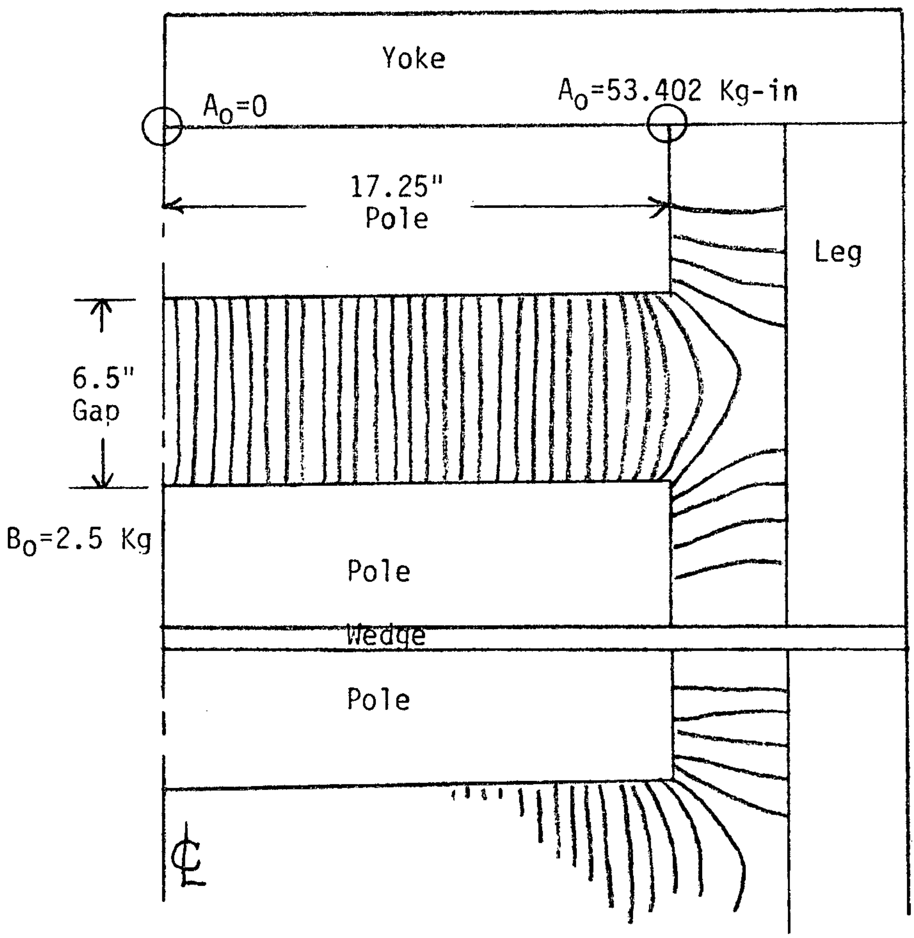
With 2.5 Kg in center of gap, vector potential (flux) at pole root corner is 21.56 Kg-in. 2D-flux at field clamp base (21.56 - 15.35) = 6.21 Kg-in.

Field level at pole base would be $\frac{21.56 \text{ Kg-in}}{4.5 \text{ in}}$ = 4.75 g = 1.916 x B

Flux plot showing field lines in the gap is shown below.

The magnet poletip is 34.5" wide (average) and 9" deep.

This run is for a 2-dimensional cross section and assumes magnet "long" in the other direction. This also shows only the top of the 3 gaps, assumes all gaps are uniformly excited.



The case assumes infinite steel permeability and is to get an idea of the flux distribution.

For a 2.5 Kg central field, the vector potential at the pole root corner is approximately 53.4 Kg-in; The 2-D field level at the pole base (for a "Long" magnet) would be 53.4 Kg-in/17.25 in. = 3.09 Kg = 1.238 x B, where B is the central gap field level 2.5 Kg.

Field Level at Base of Pole

The total flux at the polebase is combined from both views shown on pages 5 and 6. The total "3-dimensional" field level, B_{avg}, is approximated as

B_{avg} = 1.916 x 1.238 x B_o or B_{avg} = 2.37 x B_o = 5.93 Kg for B_o = 2.5 Kg design

The total flux at polebase = 5.93 x 9" x 34.5" = Φ_o Kg-in^2

Flux = 1841 Kg-in^2 passing through polebase

Yoke

Assume all flux from the pole base enters the yoke and must be carried to the legs. (Actually, this is pretty conservative - only the flux through the gap is carried to the leg; the remainder circulates through the pole-yoke-field clamp-coil circuit shown on page 5, and never reaches the leg). For a total flux of 1841 Kg-in^2; and a yoke cross section of 3" thick x 18.4" wide, the maximum field level is 1/2 (1841)/(3" x 18.4") = 16.67 Kg since the flux splits and half goes towards each leg.

Field Clamp

The flux passing through the root of the top (and bottom) field clamp through the yoke is (21.56 - 15.35) = 6.21 Kg-in as shown on page 5. (The center field clamps are combined with a "dividing wedge" and are treated separately.) Field clamps are approximately 4.25" high and 47" or 57" long on the exit or entrance sides, respectively. If the clamps are 1" thick, the maximum field level should be 6.21 Kg-in/1" = 6.21 Kg.

Dividing Wedge

The dividing wedge isolates the 3 gaps from each other. Also for conditions when the gaps are operating at different field levels, as much as 30% of the air gap flux must be diverted through the wedge to the field clamp and/or return leg. Approximately 70% of the polebase flux (0.71 x 1841 = 1310 Kg-in^2) passes through the air gap, and the remainder enters the field clamp (See page 5). The wedge is to divert up to 30% of this (0.3 x 1310 = 393 Kg-in^2) and carries it either directly to the leg, or carries it outward to the middle field clamps which then help carry it to the return legs. The perimeter of the wedge at the pole is 2 x 9" + 2 x 34.5" = 87 in, and if the average wedge cross section is 2", the average "outward" field in the wedge

is 393/(87" x 2") $\approx$ 2.25 Kg. Assume that $\frac{2 \times 34.5 \text{ in}}{87 \text{ in}}$ x 393 Kg-in^2 = 312 Kg-in^2

is diverted to the field clamps (half to each one) and the remainder (71 Kg-in) is carried directly to the legs. The center field clamps must be able to help carry this flux to the legs; the field level would be 1/2 (.5 x 312)/(1" x 8.5") = 9.2 Kg if clamps are only 1" thick and 8.5" high.

For convenient operation, the wedge and field clamps should be able to carry all the flux entering the pole base so that any one of the gaps can be operated alone (also initially, 3 power supplies may not be available). For the wedge to carry all the flux, the average field level would be 1841/(87" x 2") = 10.6 Kg; still very comfortable. Now, however, the portion carried to each field clamp is $\frac{34.5}{87}$ x 1841 = 730 Kg-in^2

This portion reaches the field clamp, and 70% of it (only the "air gap" portion - the remainder loops back from field clamp to pole through the coil) must be carried to each leg, and if the field clamps are 2" thick the highest field level would be 0.71 x 0.5 x 730/(2" x 8.5") = 15.24 Kg. This is an acceptable valve and a 2" thick field clamp is reasonable. For this consideration, then, the "wedge"-field clamps will be sized for 2" thick, and the top and bottom clamps will remain 1" thick.

Return Legs

The return legs are sized to carry the "air gap" portion of the pole base flux. (The remainder of the pole base flux loops through the yoke-field clamp-coil circuit.) The legs have slightly different minimum cross sections (4" x 12" and 4" x 15.75"), but combined have a total of 111.0 in^2. The average field level, then, would be 0.71 x 1841 Kg-in^2/(111.0 in^2) = 11.8 Kg.

Approximate Weights of Each Component

1.	Pole - 6 each	2,346 lbs
	9" x 34.5" x 4.5" x .28 lb/in^3 = 391 lb ea	
2.	Yoke - 2 each	1,638
	3" x 53" x 18.4" x .28 = 819 lb	
3.	Legs - 3 each, 3 each	1,848
	4" x 15.5 x 16.5 x .28 = 286	
	4" x 15.5 x 19 x .28 = 330	
4.	Field Clamps	
	2 x 1" x 4.25" x 48 x .28	114
	2 x 1" x 4.25" x 58 x .28	138
	4 x 2" x 4.25" x 48 x .28	457
	4 x 2" x 4.25" x 58 x .28	552
5.	Wedge, 2 each	1,210
	2 x 20.4 x 53 x .28 = 605	
6.	Coils, 6 each	2,340
	390 each	
	Approximate Total	10,643 lbs

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