Title
Bump Magnets BH1

Author
Caylor, R

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LAWRENCE BERKELEY LABORATORY - UNIVERSITY OF CALIFORNIA ENGINEERING NOTE	CODE PE0103	SERIAL M5148A	PAGE 1 OF 11
AUTHOR R. Caylor / DEPARTMENT M.E.	LOCATION Berkeley	DATE March 20, 1978	
PROGRAM — PROJECT — JOB PEP			
INJECTION			
TITLE BUMP MAGNETS BH1			

'A' Rev. 5/29/79 R. Reimers, first three pages revised and retyped ⚠ RMR

The required magnet parameters and design calculations for the #1 Bump magnets are summarized below. The detailed design calculations are given in the appendix of this report. The magnets will be physically located at positions 8B274BH1 and 10A274BH1 in the PEP ring in accordance with the 11/78 printout and show on PEP drawing SA-204-235-22.

1. REQUIRED MAGNET PARAMETERS

A.	Bend angle	θ	3 milliradians max.
B.	Beam stiffness	$B\rho$	667.2 kilogauss meters
C.	Beam Energy	E	20 GeV
D.	BL product	$\int Bdl$	2 kilogauss meters
E.	Field Uniformity	$\Delta B/B$	$\leq \pm 0.3\%$ for $\lvert\Delta x\rvert \leq 70$ mm from ℄
F.	Effective length	L_{eff}	2 meters
G.	Entrance and exit pole angle	-	Normal to beam
H.	Excitation	-	DC
I.	Power supply required	-	53 amps, includes 5% above 20GeV level
J.	Gap	g	105 mm

2. DESIGN CALCULATION

2.1 Magnetic Design

Dipole field	997 Gauss
Pole width	300 mm
Effective length	2,006 mm
Est. Efficiency	98%
Magnet ampere turns	8,495
Est. yoke field = 200/38 x 1000	5,263 gauss
Stored energy	402 joules
Iron length along beam ℄	1901 mm

2.2 Engineering Design @ 20 GeV

2.2.1 Coil

Conductor:	5.82 mm x 5.82 mm copper, solid (.229" x .229")
Conductor Cross Sectional Area:	31.8 mm^2
Average turn length:	4.73 meters
Number of turns per magnet:	168
Conductor length per magnet	795 meters
Coil resistance per mag. @ 20°C:	.430 ohm
Coil resistance per mag. @ 82°C:	.536 ohm
Conductor Weight per magnet:	506 lbs
Coils/magnet	2 each

2.2.2 Magnet Current, Power, and Time Constant

Current @ 20 GeV	50.7 Amps
Voltage @ 81.8°C (per magnet)	27.2 Volts
Power (Peak) @ 81.8°C	137 Watts
Current density @ 20 GeV	1.59 $Amps/mm^2$
Inductance	.313 henrys
Time constant @ 20°C	.73 Seconds

2.2.3 Magnet Cooling (Air-cooled)

Max. Iron Temp.	78°C
Max. Coil Temp.	82°C

2.2.4 Core

Material	AISI 1010 Steel
Core Weight	2880 lbs
Total Magnet Weight	3400 lbs

3. DOCUMENTATION

	PO/JO	Drawing	Specification
Steel	3797002	-	-
Conductor	3791702	-	-
Core	036582,036397	204-235-01	LBL M584
Coil	6206802	204-235-07	LBL M580
Assy	036629	204-235-21	LBL M582

4. SCHEDULE

Assembly will begin on June 7, 1979 with LBL (Main, Nelson) measurement and installation at PEP immediately following. SLAC beam tubes will be fitted there by the vacuum group.

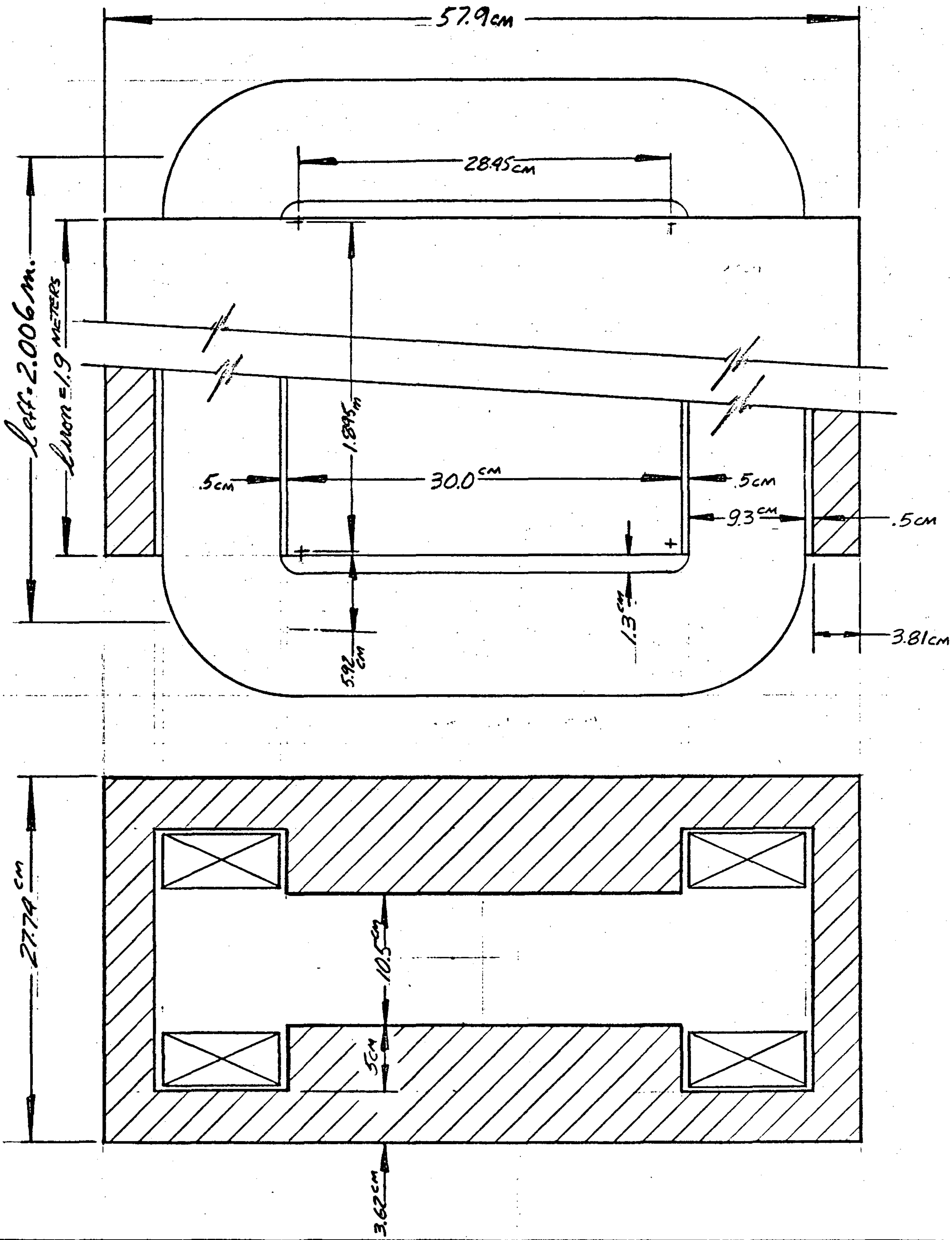
5. COSTS

Projected direct costs (excluding design, inspection, measurement, and shipment to SLAC);

	Unit	Unit Cost	Qty	Matl. Cost	Labor Cost	Total $	PO/JO	Date
Conductor, solid, copper	lb	1.40	1100	1540	-	1540	3791702	77
Coil fabrication	ea	630	4	-	2520	4926 (a)	6026802	79
Core steel (Incl. grind 2 surf)	lb	.32	5840	1871	-	1871	3797002	77
Core fabrication	ea		2	-	2000	2000	036582	79
Misc. hardware	-	-	-	-	800	800	036506	78
Assembly	ea		2	-	2000	2000	036629	79
TOTAL FABRICATION						13,137		

$/LB = 13,137/6800 = $1.93/lb

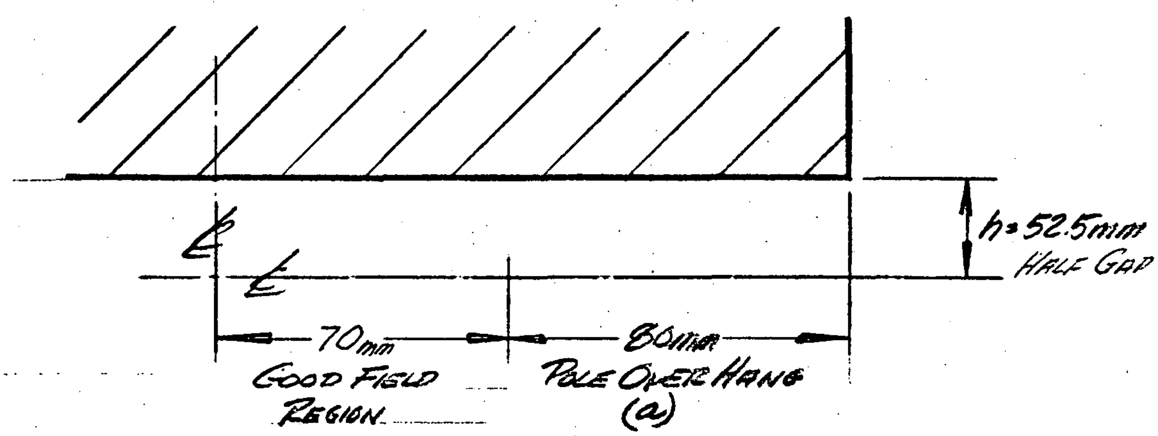
(a) Includes $2,406 prorated tooling charge


57.9cm
28.45cm
ℓ_{eff} = 2.006 m.
ℓ_{iron} = 1.9 METERS
1.895m
.5cm
30.0cm
.5cm
9.3cm
.5cm
1.3cm
5.92cm
3.81cm
27.74cm
10.5cm
5cm
3.62cm

APPENDIX

2. DESIGN CALCULATIONS

2.1 MAGNETIC DESIGN



ALLOWABLE $\frac{\Delta B}{B} \leq .003$ @ ± 70 mm from ℄ (from physicist)

FOR NON OPTIMIZED POLE:

$$\kappa = \frac{a}{h} = .75 - .36 \ln\left(100 \times \frac{\Delta B}{B}\right)$$

$$= .75 - .36 \ln(100 \times .003)$$

$$= \underline{1.183}$$ $\frac{a}{h}$

$$a = h\kappa = 52.5 \times 1.183 = 62.13 \text{ mm}$$

MAKE OVERHANG 80mm

POLE WIDTH

$$w_p = 2(70 + 80) = \underline{300 \text{ mm}}$$ w_p

CHECK $\frac{\Delta B}{B}$: $100\frac{\Delta B}{B} = \exp(-2.77(x - .75))$

$= \exp\left(-2.77\left(\frac{80}{52.5} - .75\right)\right)$

$= .117$

$\frac{\Delta B}{B} = \frac{.117}{100} = \underline{1.17 \times 10^{-3}}$ OK — $\frac{\Delta B}{B}$

$B = \underline{997 \text{ GAUSS}}$ — B

MAGNET EFFICIENCY = 98% EST — η

EFF WILL BE MEASURED & GIVEN IN REISSUED NOTE

MAGNET AMPERE TURNS:

$NI = \frac{2.02 B g}{\eta} = \frac{2.02 \times 997 \times 10.5\text{cm} \times .3937 \text{ in/cm}}{.98}$

$= \underline{8,495 \text{ AMP TURNS}}$ — NI

STORED ENERGY

$U_s = \frac{1}{2\mu_0}\int B^2 dV$

$= \frac{10^7 \times \bar{T}_{ES}^2}{2 \times 4\pi} 2m[(.105m \times .3m) + (.093m \times .205m)]$

$= \underline{402.4 \text{ JOULES}}$ — U_s

2.2 ENGINEERING DESIGN

2.2.1 COIL

AVERAGE COIL LENGTH

$l_{avg} = 2 \times 1.895_m + 2 \times .2845_m + 2\pi \times .0592_m$

$= \underline{4.731 \text{ METERS}}$ — l_{avg}

NUMBER OF TURNS

$$N = 84 \text{ TURNS/COIL}$$
$$= 168 \text{ TURNS/MAGNET}$$

N

CONDUCTOR LENGTH/MAGNET

$$L = N l_{avg} = 168_{TURN} \times 4.731 \text{ METERS}$$
$$= 794.8 \text{ METERS}$$

L

RESISTANCE

$$R_{20°C} = 8.521 \times 10^{-4} \Omega/\text{LB}$$

$$R_{20°C} = 8.521 \times 10^{-4} \Omega/\text{LB} \times 794.8\text{m} \times \frac{39.37 \text{ IN/M}}{12 \text{ IN/FT}}$$
$$\times \frac{194}{1000} \text{LB/FT} = .4310 \,\Omega/\text{MAG}$$

$R_{20°C}$

WEIGHT COPPER

$$W_{CU} = 84 \text{ TURNS/COIL} \times 4.731 \text{ METERS/TURN} \times \frac{39.37 \text{ IN/M}}{12 \text{ IN/FT}}$$
$$\times \frac{194}{1000} \text{LBS/FT} = 253 \text{ LBS/COIL}$$
$$= 506 \text{ LBS/MAG}$$

W_{CU}

2.2.2 MAGNET CURRENT, POWER, AND TIME CONSTANT

CURRENT

$$I = \frac{NI}{N} = \frac{8495 \text{ AT}}{168_{TURNS}} = 50.6 \text{ AMPS}$$

I

VOLTAGE

$$E = IR = 50.71_{AMPS} \times .431_{OHMS} = 21.86 \text{ VOLTS} @ 20°C$$

E

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POWER

$$P = I^2 R = \overline{50.71}^2_{\text{AMPS}} \times .4310_{\text{OHMS}}$$

$$= \underline{1108 \text{ WATTS}} \ @ 20°C \qquad \underline{P}$$

CURRENT DENSITY

$$A_{\text{COND}} = 31.8 \overline{mm}^2$$

$$I_A = \frac{50.71 \text{ AMPS}}{31.8 \overline{mm}^2} = \underline{1.59 \text{ AMPS}/\overline{mm}^2} \ @ 20 \text{ GeV} \qquad \underline{I_A}$$

INDUCTANCE

$$L_m = \frac{2 U_s}{I^2} = \frac{2 \times 4024 \text{ JOULES}}{\overline{50.71}^2_{\text{AMPS}}}$$

$$= \underline{.313 \text{ HENRYS}} \qquad \underline{L_m}$$

MAGNET TIME CONSTANT

$$t = \frac{L_m}{R} = \frac{.313 \text{ HENRYS}}{.4310 \text{ OHMS}}$$

$$= \underline{.73 \text{ SECONDS}} \qquad \underline{t}$$

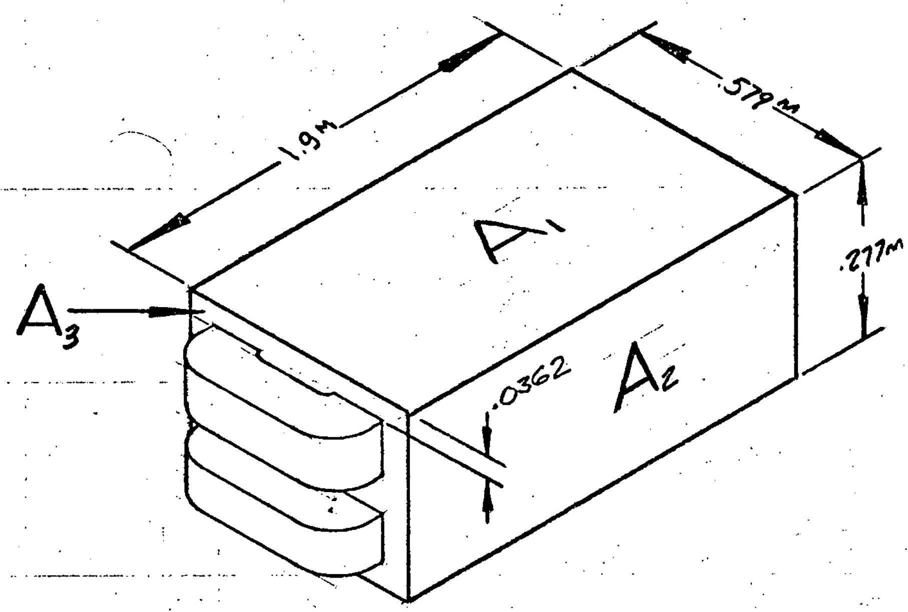
2.2.3 MAGNET COOLING

MAXIMUM COIL TEMP.

ASSUME $T_{COIL} = 80°C$

$RESISTANCE_{80°C} = R_{20}\left(\frac{234+T_{COIL}}{234+20}\right) = .431\left(\frac{314}{254}\right) = .533\,\Omega$ $R_{80°C}$

$POWER_{80°C} = I^2R = \overline{50.71}^2 \times .533 = 1371\,WATTS$ $P_{80°C}$

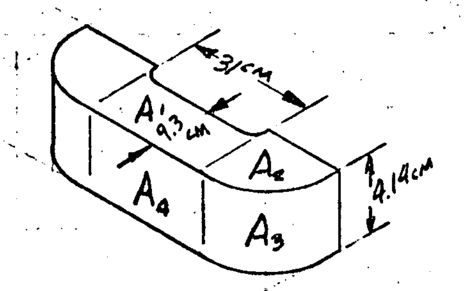


IRON SURFACE AREA (A_I): $A_I = 2A_1 + 2A_2 + 4A_3$

$= 2(1.9 \times .579) + 2(1.9 \times .277) + 4(.579 \times .0362) = 3.336\,M^2$ A_I

$= 5172\,IN^2$

COIL SURFACE AREA (A_c)



$A_c = 4A_1 + 8A_2 + 8A_3 + 4A_4$

$= 4(31 \times 9.3) + 8\left(\frac{\pi \times 9.3^2}{4}\right) + 8\left(\frac{2\pi \times 9.3}{4} \times 4.14\right) + 4(31 \times 4.14) = 2693.8\,CM^2$ A_c

$= 417.54\,IN^2$

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POWER DENSITY

$$Q = \frac{P}{A_I + A_C} = \frac{1371 \text{ WATTS}}{33360_{CM^2} + 2694_{CM^2}}$$

$$= \underline{.0380 \text{ WATTS}/CM^2} \qquad \underline{Q}$$

$$= \underline{.245 \text{ WATTS}/IN^2}$$

FROM GRAPH ENG NOTE M5077 Pg 7, $e = .6$

$$T_{IRON} = \underline{78 \ ^\circ C} \qquad \underline{T_I}$$

$$P = h A_{CON} (T_{COIL} - T_{IRON})$$

WHERE $h = \underline{.0542 \text{ WATTS}/CM^2 - C^\circ}$ $\underline{h}$
FOR .010" MYLAR + .005" INSULGREASE (EN M5077)
AND A_{CON} = AREA OF COIL IN CONTACT W/IRON

$$A_{CON} = 4(9.3_{CM} \times 190_{CM}) = \underline{7068 \ CM^2} \qquad \underline{A_{CON}}$$

$$T_{COIL} = T_{IRON} + \frac{P_{80}}{h A_{CON}} = 78.2 + \frac{1371_W}{.0542_{W/CM^2} \times 7068_{CM^2}}$$

$$= \underline{82 \ ^\circ C} \qquad \underline{T_{COIL}\ (80^\circ)}$$

RECALCULATE W/ T_{COIL} NOW 82 °C

RESISTANCE

$$R_{81.78} = R_{20}\left(\frac{234 + T_{COIL}}{234 + 20}\right)$$

$$= .431\left(\frac{316}{254}\right)$$

$$= \underline{.536 \text{ OHMS}} \qquad \underline{R_{82\ ^\circ C}}$$

POWER

$$P = I^2 R = \overline{50.71}^2_{AMPS} \times .536_{OHMS}$$

$$= \underline{1378 \text{ WATTS}}$$ $P_{81.75°C}$

$$Q = \frac{P}{A_I + A_c} = \frac{1378}{33360 + 2694}$$

$$= \underline{.0382 \text{ WATTS}/CM^2}$$ $Q_{81.75°C}$

$$= \underline{.247 \text{ WATTS}/IN^2}$$

FROM GRAPH EN M5077 Pg 7, e=.6

$$T_{IRON} = \underline{78.\ °C}$$ T_{IRON}

$$T_{COIL} = T_{IRON} + \frac{P_{82}}{h A_{CON}}$$

$$= 78. + \frac{1378}{.05425 \times 7068_{CM^2}} = \underline{82\ °C}$$ T_{COIL}

2.2.4 CORE

WEIGHT $W_{STL} = .0173\ LBS/CM^3 \times 190_{CM} \times$

(INNER & OUTER LEG) $20.5 \times (2 \times 3.81)$

PLUS TOP & BOTTOM YOKE $57.9 (2 \times 3.62)$

PLUS POLE TIP $30 (2 \times 5)$

$$\doteq \underline{2,880 \text{ LBS}}$$ W_{STL}

TOTAL MAGNET WEIGHT

$$W_T = W_{CU} + W_{STL}$$

$$= 506 + 2880 \cong \underline{3400^{LBS}}$$ W_T

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