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**Title**

Bump Magnets BH1

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**Author**

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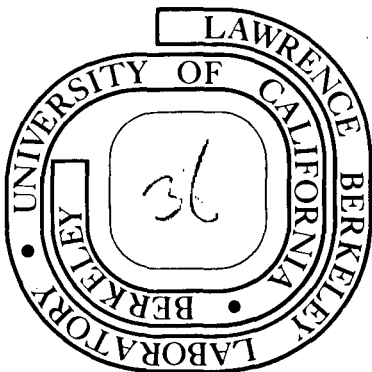
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**ENGINEERING NOTE**

CODE

SERIAL

PAGE

PE0103

M5148A

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AUTHOR

DEPARTMENT

LOCATION

DATE

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M.E.

Berkeley

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  $\triangle$

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	$\theta$	3 milliradians max.
B. Beam stiffness	$B_p$	667.2 kilogauss meters
C. Beam Energy	$E$	20 GeV
D. BL product	$\int B dl$	2 kilogauss meters
E. Field Uniformity	$\Delta B/B$	$\leq \pm 0.3\%$ for $ \Delta x  \leq 70$ mm from $\mathcal{E}$
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 CALCULATION2.1 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 = $200/38 \times 1000$	5,263 gauss
Stored energy	402 joules
Iron length along beam $\mathcal{E}$	1901 mm

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**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 <sup>2</sup>
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 <sup>2</sup>
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**

	<u>PO/JO</u>	<u>Drawing</u>	<u>Specification</u>
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

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**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

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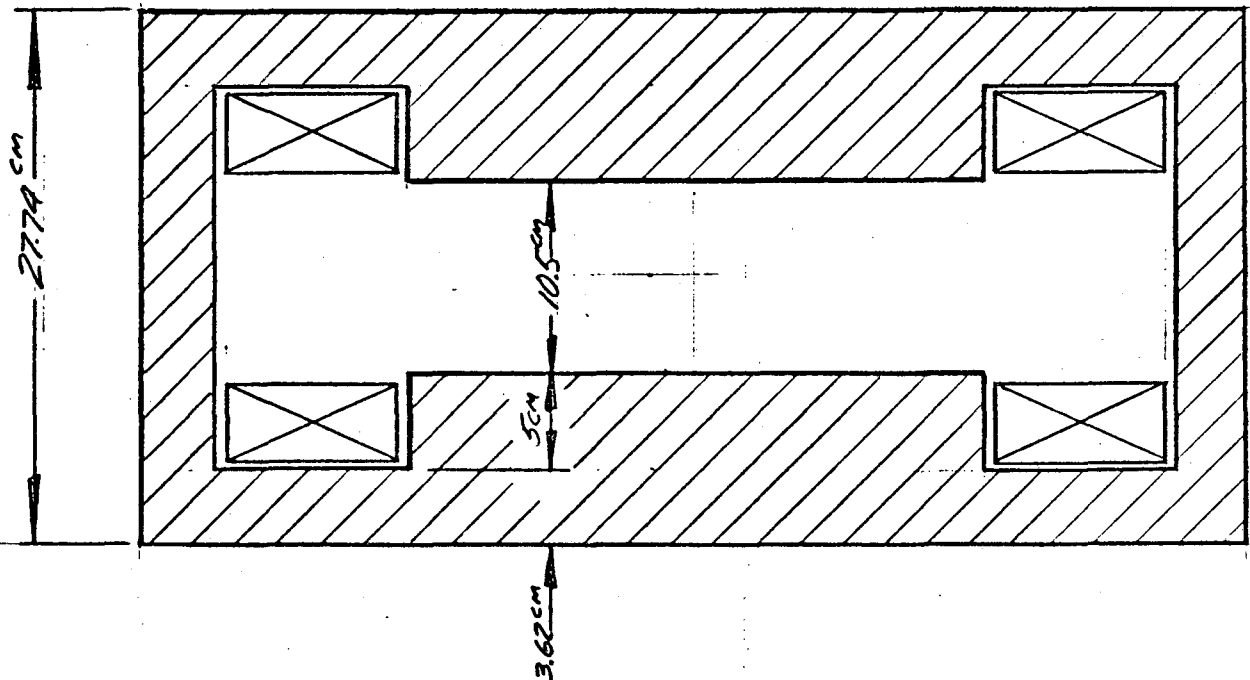
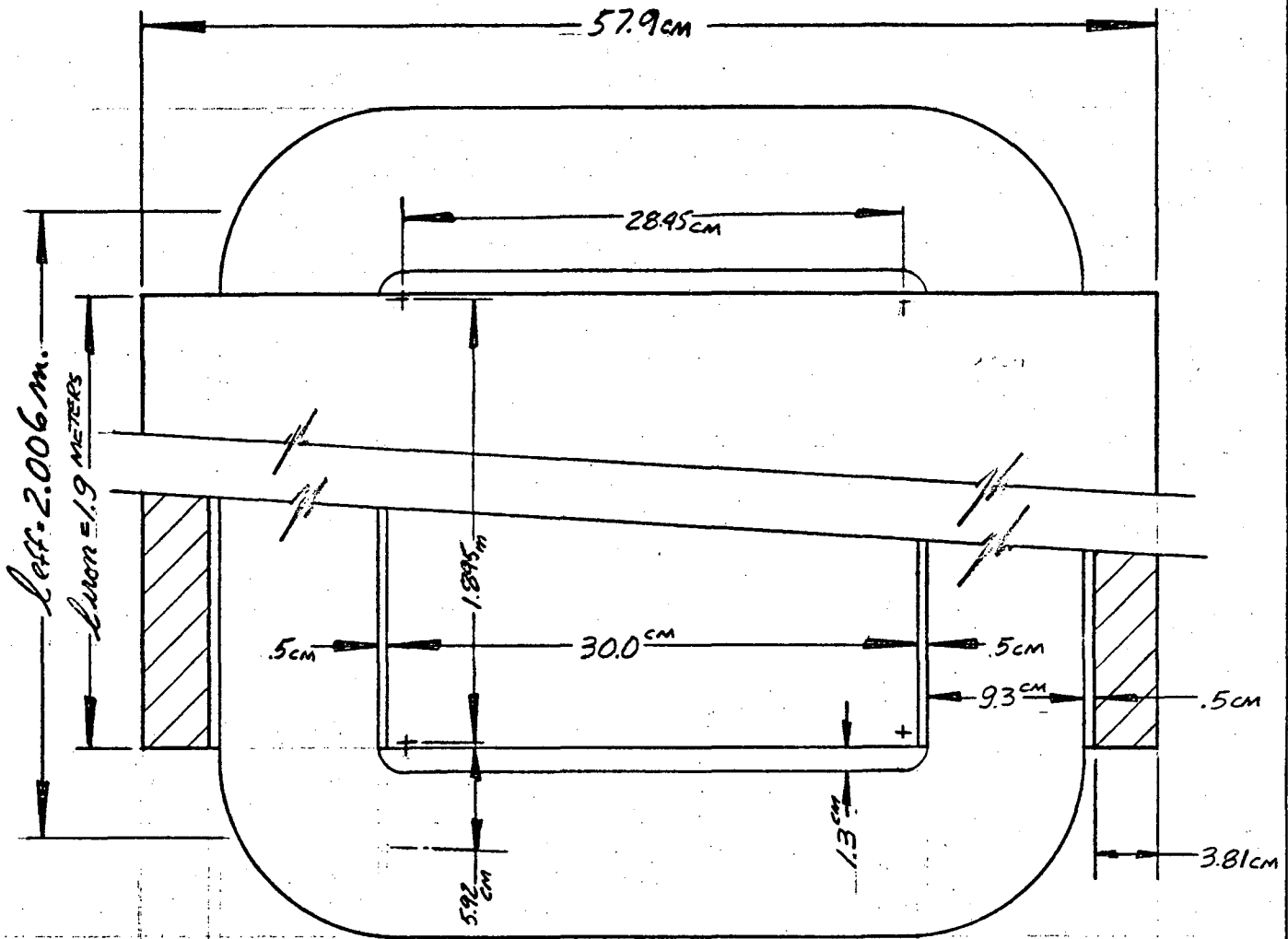
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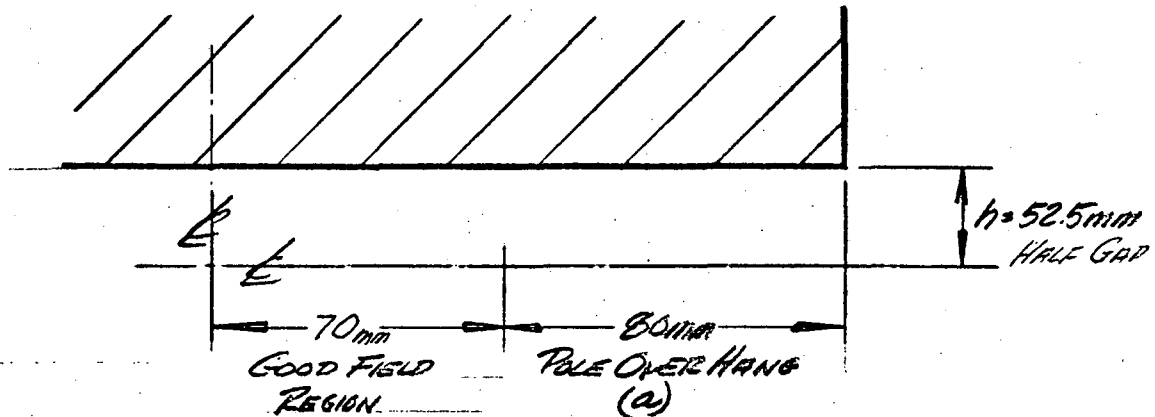
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APPENDIX2. DESIGN CALCULATIONS2.1 MAGNETIC DESIGN

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

FOR NON OPTIMIZED POLE:

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

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

$$= \underline{1.183}$$

$$\frac{a}{h}$$

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

MAKE OVERHANG 80mm

POLE WIDTH

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

w<sub>p</sub>



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$$\begin{aligned} \text{CHECK } \frac{\Delta B}{B} &: 100 \frac{\Delta B}{B} = \exp(-2.77(x-.75)) \\ &= \exp(-2.77\left(\frac{80}{52.5} - .75\right)) \\ &= .117 \\ \frac{\Delta B}{B} &= \frac{.117}{100} = \underline{1.17 \times 10^{-3} \text{ OK}} \end{aligned}$$

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

MAGNET EFFICIENCY = 98% EST  
EFF WILL BE MEASURED & GIVEN IN  
REISSUED NOTE

MAGNET AMPERE TURNS:

$$NI = \frac{2.02 B_0}{\mu} = \frac{2.02 \times 997 \times 10.5 \text{ cm} \times .3937 \frac{1}{\text{cm}}}{.98}$$

$$= \underline{8.495 \text{ AMP TURNS}}$$

STORED ENERGY

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

$$= \frac{10^7 \times \mu_{\text{FE}}}{2 \times 4\pi} 2m \left[ (.105m \times .3m) + (.093m \times .205m) \right]$$

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

## 2.2 ENGINEERING DESIGN

### 2.2.1 COIL

AVERAGE COIL LENGTH

$$L_{\text{avg}} = 2 \times 1.895m + 2 \times .2845m + 2\pi \times .0592m$$

$$= \underline{4.731 \text{ METERS}}$$

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NUMBER OF TURNS

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

NCONDUCTOR LENGTH/MAGNET

$$L = N \lambda_{\text{coil}} = 168 \times 4.73 \text{ METERS} \\ = 794.8 \text{ METERS}$$

LRESISTANCE

$$R_{20^\circ\text{C}} = 8.521 \times 10^{-9} \Omega/\text{LB}$$

$$R_{20^\circ\text{C}} = 8.521 \times 10^{-9} \Omega/\text{LB} \times 794.8 \text{ m} \times \frac{59.37 \text{ IN/M}}{12 \text{ IN/FT}} \\ \times \frac{194 \text{ LB/FT}}{1000} = \underline{.4310 \Omega/\text{MAG}}$$

R<sub>20°C</sub>WEIGHT COPPER

$$W_{\text{Cu}} = 84 \text{ TURNS/COIL} \times 4.73 \text{ METERS/TURN} \times \frac{59.37 \text{ IN/M}}{12 \text{ IN/FT}} \\ \times \frac{194 \text{ LB/FT}}{1000} = 253 \text{ LBS/COIL} \\ = \underline{506 \text{ LBS/MAG}}$$

W<sub>Cu</sub>2.2.2 MAGNET CURRENT, POWER, AND TIME CONSTANTCURRENT

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

IVOLTAGE

$$E = IR = 50.71 \text{ AMP} \times .431 \text{ OHMS} = \underline{21.86 \text{ VOLTS}} \\ @ 20^\circ\text{C}$$

E

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

$$= \underline{1108 \text{ WATTS @ } 20^\circ\text{C}}$$

PCURRENT DENSITY

$$A_{\text{CROSS}} = 31.8 \text{ MM}^2$$

$$I_A = \frac{50.71_{\text{AMPS}}}{31.8 \text{ MM}^2} = \underline{1.59 \text{ AMPS/MM}^2} \quad @ 20^\circ\text{C}$$

I<sub>A</sub>INDUCTANCE

$$L_M = \frac{2U_s}{I^2} = \frac{2 \times 402.4_{\text{Joules}}}{50.71_{\text{AMPS}}^2}$$

$$= \underline{.313 \text{ HENREYS}}$$

L<sub>M</sub>MAGNET TIME CONSTANT

$$t = \frac{L_M}{R} = \frac{.313_{\text{HENREYS}}}{.4310_{\text{OHMS}}}$$

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

t

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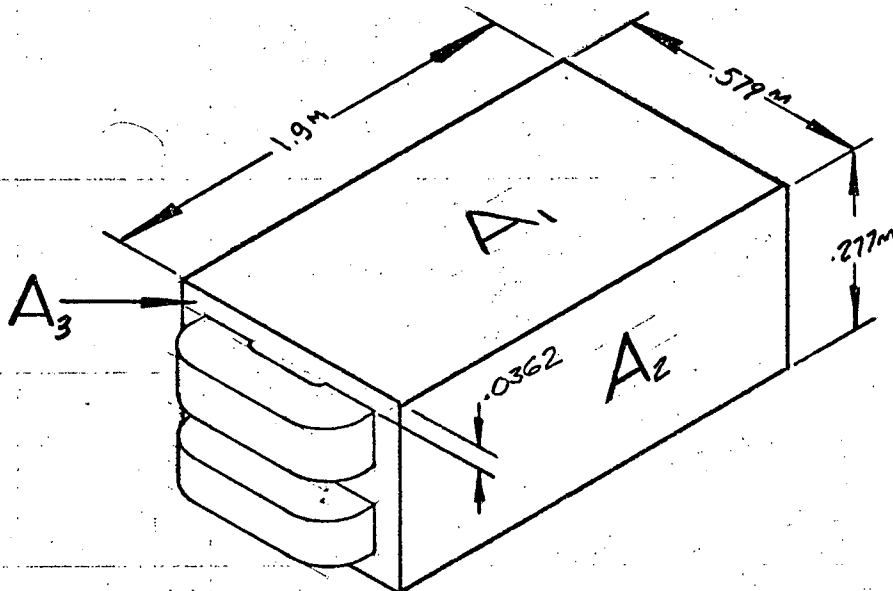
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2.2.3 MAGNET COOLINGMAXIMUM COIL TEMP.ASSUME  $T_{\text{coil}} = 80^\circ\text{C}$ 

$$\text{RESISTANCE}_{80^\circ\text{C}} = R_{20} \left( \frac{234 + T_{80}}{234 + 20} \right) = .43 \left( \frac{314}{254} \right) = \underline{533 \Omega} \quad R_{80^\circ\text{C}}$$

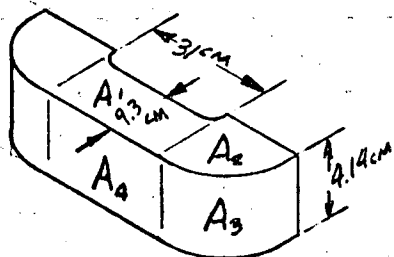
$$\text{POWER}_{80^\circ\text{C}} = I^2 R = 50.71^2 \times 533 = \underline{1371 \text{ WATTS}} \quad P_{80^\circ\text{C}}$$



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

$$= 2(1.9 \times 579) + 2(1.9 \times 277) + 4(579 \times 0.362) = 3336 \text{ m}^2$$

$$= \underline{5172 \text{ in}^2} \quad A_I$$

COIL SURFACE AREA ( $A_C$ )

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

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

$$+ 4(31 \times 4.14) = 2693.8 \text{ cm}^2$$

$$= \underline{417.54 \text{ in}^2} \quad A_C$$

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POWER DENSITY

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

$$= \underline{.0390 \text{ WATTS}/\text{cm}^2}$$

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

QFROM GRAPH ENG-NOTE M5077 Pg 7,  $\alpha = .6$ 

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

T<sub>FE</sub>

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

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

h

CONTACT w/IRON

$$A_{\text{CON}} = A (9.3_{\text{cm}} \times 190_{\text{cm}}) = \underline{7068 \text{ cm}^2}$$

A<sub>CON</sub>

$$T_{\text{COIL}} = T_{\text{IRON}} + \frac{P_0}{h A_{\text{CON}}} = 78.2 + \frac{1371_{\text{W}}}{.0542 \times 7068_{\text{cm}^2}}$$

$$= \underline{82 \text{ }^\circ\text{C}}$$

T<sub>coil</sub> (82°)RECALCULATE  $T_{\text{COIL}}$  NOW 82 °CRESISTANCE

$$R_{81.75} = R_{20} \left( \frac{234 + T_{\text{COIL}}}{234 + 20} \right)$$

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

$$= \underline{.536 \text{ OHMS}}$$

R<sub>82 °C</sub>

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

$$= \underline{1378 \text{ WATTS}}$$

P  
81.75°C

$$D = \frac{P}{A_s + A_c} = \frac{1378}{33360 + 2694}$$

$$= \underline{.0382 \text{ WATTS/CM}^2}$$

Q  
81.75°C

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

FROM GRAPH ENM5077 PG 7, c. 6

$$T_{\text{IRON}} = \underline{78.^\circ \text{C}}$$

T<sub>IRON</sub>

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

$$= 78. + \frac{1378}{.05485 \times 7068_{\text{CM}^2}} = \underline{82.^\circ \text{C}}$$

T<sub>coil</sub>2.2.4 CORE

$$\underline{\text{WEIGHT}} \quad W_{\text{STL}} = .0173 \frac{\text{LBS}}{\text{CM}^3} \times 190_{\text{CM}} \times 0$$

$$\text{(INNER \& OUTER LEG)} \quad 20.5 \times (2 \times 3.81)$$

$$\text{PLUS TOP \& BOTTOM YOKE} \quad 57.9 (2 \times 3.62)$$

$$\text{PLUS POLE TIP} \quad 30 (2 \times 5)$$

$$\underline{= 2,880 \text{ LBS}}$$

W<sub>STL</sub>TOTAL MAGNET WEIGHT

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

$$= 506 + 2880 \underline{= 3400 \text{ LBS}}$$

W<sub>T</sub>

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