1. Introduction

Protons are to be extracted from extraction port 2A to deliver beam to an external ISAC facility. An earlier report[1)] presented designs for the 27.5° vault dipoles. This report presents a design for the ±30° switching dipole that is required on the beamline.

2. Design parameters for the switching magnet

The TRANSPORT calculations for the beamline require a magnet with an effective length 1.246 m that is capable of producing a field of 15.3 kG for 500 MeV protons. We design the magnet for a maximum energy of 512 MeV and field of 15.5 kG. We also add the following additional parameters.

B_g	=	Maximum magnetic field	=	15.5 kG
g	=	Maximum air gap	=	10.16 cm
θ	=	Maximum bend angle	=	30.0°
s	=	Length of the central trajectory	=	1.246 m

We first calculate the basic parameters of the magnet.

$$\rho_0 = \text{radius of curvature of the central trajectory} = \frac{s}{\theta} = \frac{(180.0)(1.24595)}{(30.0)(\pi)} = 2.379589 \text{ m} = 93.685 \text{ in.}$$

$$\boxed{\text{Radius of curvature of the central trajectory} = \rho_0 = 2.380 \text{ m} = 93.695 \text{ in.}}$$

We take the effective straight-line length of the magnet to be

$$l_e = 2\rho_0 \sin\frac{\theta}{2} = 2(2.37959)(0.25882) = 1.23177 \text{ m} = 48.49472 \text{ in.}$$

$$\boxed{\text{Straight-line effective length of the magnet} = l_e = 1.232 \text{ m} = 48.495 \text{ in.}}$$

and assume that the the iron length, l_i, is obtained from

$$l_e = l_i + g$$

so that

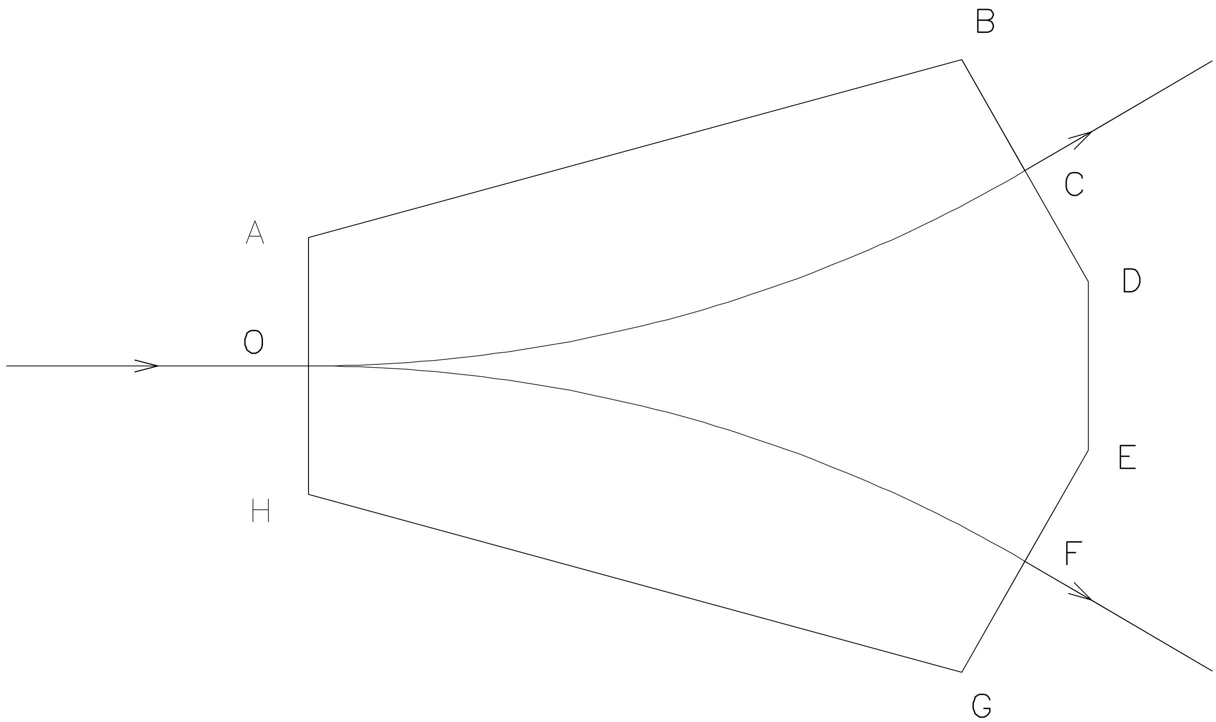
$$l_i = l_e - g = 1.23177 - 0.1016 = 1.13017 \text{ m} = 44.495 \text{ in.}$$

$$\boxed{\text{Iron length of the magnet} = l_i = 1.130 \text{ m} = 44.5 \text{ in.}}$$

3. Pole width and geometry

We assume a pole geometry as indicated in the figure on the next page. The beam enters at the mid-point of the pole (O in the diagram) and exits at an angle of ±30° at the points C and F in the diagram. The (straight-line) lengths $\overline{OC}$ and $\overline{OF}$ are then each 44.500 inches in length.

The deviation, Δ, of the central trajectory from a line drawn through the points of entry and exit is found from the relation



Geometry of the pole of the switching magnet.

$$\Delta = \rho_0 \left[1 - \cos\frac{\theta}{2}\right] = 2.37959(1 - 0.96593) = 0.08108 \text{ m} = 3.19223 \text{ in.}$$

Maximum deviation of central trajectory from straight line = Δ = 0.081 m = 3.192 in.

We allow for a maximum beam width, x, of 10.16 cm and assume a 0.625 in. (15.875 mm) chamfer, c, at 45° to the each pole edge. Because the field is relatively uniform in an H-frame magnet, we take the pole width, W_{iron}, to be

$$W_{iron} = 2\,g + \Delta + x + 2\,c = 2(4.000) \text{ in.} + 3.192 \text{ in.} + 4.000 \text{ in.} + 2(0.625) \text{ in.} = 16.442 \text{ in.}$$

Pole width = $W_{iron} = \overline{\mathrm{AH}} = \overline{\mathrm{BD}} = \overline{\mathrm{EG}}$ = 16.500 in. = 0.419 m.

Then the lengths of the sides $\overline{AB}$ and $\overline{HG}$ are

$$\overline{\mathrm{AB}} = \overline{\mathrm{HG}} = \overline{\mathrm{OC}} - 2\,\frac{W_{iron}}{2}\sin 15 = 44.500 - (16.500)(0.258819) = 40.22949 \text{ inches} = 1.0218 \text{ m.}$$

$\overline{\mathrm{AB}} = \overline{\mathrm{HC}}$ = 40.230 inches = 1.022 m.

From simple geometry we obtain the length $\overline{\mathrm{DE}}$ = 8.74548 in.

$\overline{\mathrm{DE}}$ = 8.745 inches = 0.222 m.

4. Ampere-turns per coil

The required Ampere-turns per coil are calculated from the relation

$$NI \text{ per coil} = \frac{1}{2}\left[1.1\,\frac{B_0\,g}{\mu_0}\right] = \frac{1}{2}\,\frac{(1.1)(1.550)(0.1016)}{4\pi\times 10^{-7}} = 68,925 \text{ A-t}$$

where we have allowed for a 10% flux leakage. We take

$$\boxed{NI \text{ per pole} = 69{,}000 \text{ Ampere-turns}}$$

and generate the following table

I (Amperes)	100	200	300	400	500	600	700	800	900	1000
N (turns)	690	345	230	172	138	115	99	86	77	69

Because a (relatively) inexpensive 600 A, 100 V power supply is available, we choose

I	=	575 Amperes
Coil configuration		10 turns wide by 12 turns high

5. Coil design

We assume a current density of 3000 A/in^2 = 4.65 A/mm^2 and calculate the required conductor area from

$$\text{Conductor area} = \frac{600\ A}{3000\ A/\text{in}^2} = 0.2000 \text{ in.}^2 = 129.03 \text{ mm}^2$$

This is satisfied within 10% by Anaconda 0.5790 in. conductor; its parameters are listed as

OD	0.5790	in.	14.707	mm
ID	0.3230	in.	8.204	mm
Copper area	0.2457	in.^{2}	158.516	mm^2
Cooling area	0.08194	in.^{2}	52.864	mm^2
Mass	0.9495	lb/ft	1.413	kg/m
Resistance at 20° C	33.15	$\mu\Omega$/ft	108.760	$\mu\Omega$/m
k (British units)	0.01320			

We assume that each conductor is double-wrapped with insulation that is 0.007 in. (0.178 mm) thick with a tolerance of 0.0015 in. (0.038 mm). Then the *total* insulation per conductor has:

Minimum thickness	4(0.007 − 0.0015) in.	=	0.022 in. = 0.559 mm
Nominal thickness	4(0.007) in.	=	0.028 in. = 0.711 mm
Maximum thickness	4(0.007 + 0.0015) in.	=	0.034 in. = 0.864 mm

The tolerance of the outer dimension of the conductor is listed as 0.004 in. = 0.100 mm so that the dimensions of a *wrapped* conductor are:

Minimum	0.579 in. + 0.022 in. − 0.004 in.	=	0.597 in. = 15.16 mm
Nominal	0.579 in. + 0.028 in.	=	0.607 in. = 15.42 mm
Maximum	0.579 in. + 0.034 in. + 0.004 in.	=	0.617 in. = 15.67 mm

We further allow

a) a gap between layers of 0.010 in. (0.254 mm) maximum
b) for keystoning, assume 0.010 in. (0.254 mm)
c) a 4-turn ground wrap of 0.007 in. (0.178 mm) tape

Then the *width* of the coil is obtained from the following considerations.

	Maximum		Minimum	
	in.	mm	in.	mm
Wrapped conductor	6.170	156.718	5.970	151.638
Gapping (9x0.10)	0.090	2.286		
Ground wrap (4x0.178x2)	0.056	1.422	0.056	1.422
Total (mm)	6.316	160.426	6.026	153.060

The average coil width is 6.171 in. = 156.7 mm. We take

Maximum coil width	=	6.350 in.	=	0.161 m.
Nominal coil width	=	6.200 in.	=	0.158 m.

The *height* of the coil is

	Maximum		Minimum	
	in.	mm	in.	mm
Wrapped conductor	7.404	188.062	7.164	181.966
Gapping (11x0.010)	0.110	2.794		
Keystoning (12x0.010)	0.120	3.048	0.060	1.524
Ground wrap (4x0.178x2)	0.056	1.422	0.056	1.422
Total (mm)	7.690	195.326	7.280	184.912

The average coil height is 7.485 in. = 190.1 mm. We take

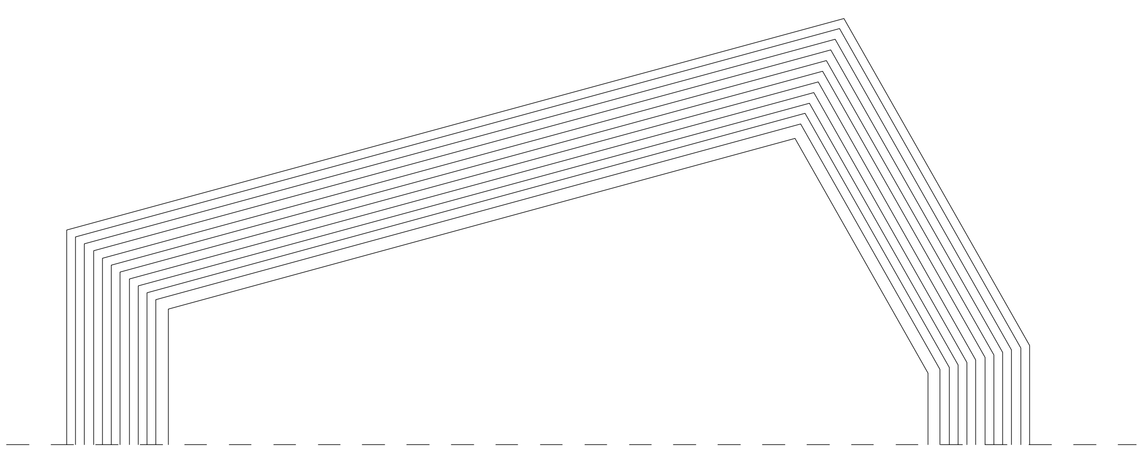
Maximum coil height	=	7.750 in.	=	0.197 m.
Nominal coil height	=	7.500 in.	=	0.191 m.

We take the conductor dimension D to be

$$\begin{aligned} D &= \text{Nominal dimension} + 4(\text{Insulation thickness}) + \text{Turn separation} \\ &= 0.607 \text{ in.} + 0.028 \text{ in.} + 0.010 \text{ in.} \\ &= 0.645 \text{ in.} = 16.38 \text{ mm} \end{aligned}$$

and further assume a pole-coil gap of $G = 0.75$ in. = 19.05 mm.

To simplify calculation we now assume that the coil is wound such that at each corner the direction of winding changes along the bisector of the angle between the two pole edges as shown in the diagram below.



The assumed method of coil winding.

Then the outer side of the n^{th} conductor is a distance

$$D_n = n\,D + G + 4(\text{insulation thickness})$$

from the edge of the pole. The length of the long, angled section of the winding is

$$L_{long} = L_{iron} + 2\,D_n \tan(75/2),$$

with $L_{iron} = \overline{\text{AB}}$ of section 3, that of the angled section along the pole width is

$$L_{angle} = W_{iron} + D_n[\tan(75/2) + \tan(30/2)],$$

that along the entry face is

$$L_{entry} = W_{iron} + 2\,D_n \tan(75/2),$$

and that along the straight portion of the exit face is

$$L_{exit} = y + 2\,D_n \tan(30/2)$$

where $y = \overline{\text{DE}}$ of section 3. Thus the length of the n^{th} turn is

$$\begin{aligned} l_n &= 2[L_{long} + L_{angle}] + L_{entry} + L_{exit} \\ &= 2\,L_{iron} + 3\,W_{iron} + y + D_n\,[8\tan(75/2) + 4\tan(30/2)] \end{aligned}$$

and the length of an N-turn layer is

$$L_N = \sum_{n=1}^{N} l_n = N\{2\,L_{iron} + 3\,W_{iron} + y + [G + 4(\text{insulation}) + (N+1)D][8\tan(75/2) + 4\tan(30/2)]\}$$

In our case with

$$\begin{aligned} L_{iron} &= 40.230\text{ in.} \approx 1021.8\text{ mm} \\ W_{iron} &= 16.500\text{ in.} \approx 419.1\text{ mm} \\ G &= 0.750\text{ in.} \approx 19.1\text{ mm} \\ D &= 0.645\text{ in.} \approx 14.1\text{ mm} \\ \text{Insulation} &= 0.007\text{ in.} \approx 0.2\text{ mm} \end{aligned}$$

we find that the length of a 10-turn layer is 1,700 in. [43,180 mm] = 141.7 ft [43.18 m]. We take

$$\boxed{\text{Length of 10-turn layer} = 145\text{ ft} \approx 44.2\text{ m}}$$

and the length per coil becomes

$$\boxed{\text{Length per coil} = 1{,}750\text{ ft} = 535\text{ m.}}$$

Because two coils are required per dipole, then

Total length per dipole	3,500 ft	≈	1,070 m
Allow 10% for winding losses	350 ft	≈	107 m
Total	3,850 ft	≈	1,177 m

Then order

$$\boxed{\text{Total length of copper} = 3{,}900\text{ ft} \approx 1{,}200\text{ m}}$$

of conductor of mass 0.9495 lb/ft for a total mass of

$$\boxed{\text{Total mass} = 3{,}710\text{ lb} \approx 1{,}680\text{ kg.}}$$

5.2 Power requirements

At 20°C, the resistance of the coil is:

$$R_{20^\circ} = 33.15\times10^{-6}\ \Omega/\text{ft}\times1750\ \text{ft} = 0.05801\ \Omega$$

We assume an ambient temperature of 20°C, an inlet water temperature of 30°C and an outlet water temperature of 70°C (thus allowing a 40° C coolant temperature rise). Then the mean coil temperature will be 50°C.

With a 30°C rise above ambient of the coil we then have:

$$\begin{aligned} R_{hot} &= R_{20^\circ}[1+(\text{Temp. coeff}/^\circ\text{C})dT(^\circ\text{C})] \\ &= 0.05801[1+(0.00393)(30)] \\ &= 0.06485\ \Omega \text{ per coil} \end{aligned}$$

Thus, at a current of 575 A, we obtain

$$\text{Voltage per coil} = 37.29 \text{ Volts}$$

Therefore, allowing for a 10% lead loss, we choose a power supply that has:

$$\boxed{\begin{array}{lcll} I & = & 575 & \text{A minimum} \\ V & = & 82.5 & \text{V minimum} \\ P & = & 47.5 & \text{kW minimum} \end{array}}$$

5.3 Cooling requirements

In these calculations we use the British system of units.

The power required per coil is:

$$\text{Power per coil} = I^2 R_{hot} = (575)(575)(0.06485) = 21.44 \text{ kW}.$$

The required flow rate is given by:

$$\begin{aligned} v\ (\text{ft/sec}) &= \frac{2.19}{\Delta T(^\circ\text{ F})}\times\frac{P(\text{kW})}{\text{Cooling area (in}^2)} \\ &= 0.37121\times P(\text{kW}) \end{aligned}$$

for $\Delta T = 72°\text{F} = 40°\text{C}$ and $A = 0.08194\ \text{in}^2 = 52.864\ \text{mm}^2$. Choosing $v = 2.50$ ft/sec to define the maximum power dissipation per water circuit we have:

$$P_{max} = \frac{(2.50)(72)(0.08194)}{2.19} = 6.375 \text{ kW/water circuit}$$

from which we calculate the number of cooling circuits per coil (excluding lead loss) as

$$\begin{array}{lclcl} P & = & \text{Total power per coil} & = & 21.44 \text{ kW} \\ \text{Number of circuits} & = & P\ /\ P_{max} & = & 3.36 \end{array}$$

We take

$$\boxed{\text{Number of cooling circuits per coil} = 6 \text{ or } 3}$$

This requires a flow rate of $v = 1.326$ ft/sec for 6 water circuits or $v = 2.653$ ft/sec for 3 circuits.

The volume of flow required for 6 circuits is

$$\begin{aligned}\text{Volume/circuit} &= 2.6\, v\,(\text{ft/sec}) \times \text{Cooling area}\,(\text{in}^2) \\ &= 2.6(1.326)(0.08194) = 0.2826 \text{ IGPM}\end{aligned}$$

and for 3 circuits

$$\begin{aligned}\text{Volume/circuit} &= 2.6\, v\,(\text{ft/sec}) \times \text{Cooling area}\,(\text{in}^2) \\ &= 2.6(2.653)(0.08194) = 0.5652 \text{ IGPM}\end{aligned}$$

Thus we have the following volumes of flow. For 6 water circuits

Volume per cooling circuit	=	0.283 IGPM	=	1.285 ℓ/min	=	0.339 USGPM
Volume per coil	=	1.696 IGPM	=	7.707 ℓ/min	=	2.036 USGPM
Volume per magnet	=	3.391 IGPM	=	15.415 ℓ/min	=	4.073 USGPM

and for 3 water circuits

Volume per cooling circuit	=	0.565 IGPM	=	2.568 ℓ/min	=	0.678 USGPM
Volume per coil	=	1.696 IGPM	=	7.709 ℓ/min	=	2.037 USGPM
Volume per magnet	=	3.391 IGPM	=	15.423 ℓ/min	=	4.075 USGPM

5.4 Pressure drop

The pressure drop is given by

$$dP = k\, v^{1.79} \text{ psi/ft}$$

with k a function of the cooling area. In our case with $k = 0.0132$ we obtain for 6 water circuits

$$\Delta P = (0.0132)(1.326)^{1.79} = 0.0219 \text{ psi/ft} = 0.0719 \text{ psi/m}$$

and the total pressure drop across one of six cooling circuits is:

Pressure drop over one of six cooling circuits = 0.0219 psi/ft $\times$ 290 ft = 6.35 psi.

For 3 water circuits we have

$$\Delta P = (0.0132)(2.653)^{1.79} = 0.0757 \text{ psi/ft} = 0.0248 \text{ psi/m}$$

and the total pressure drop across one of three cooling circuits is:

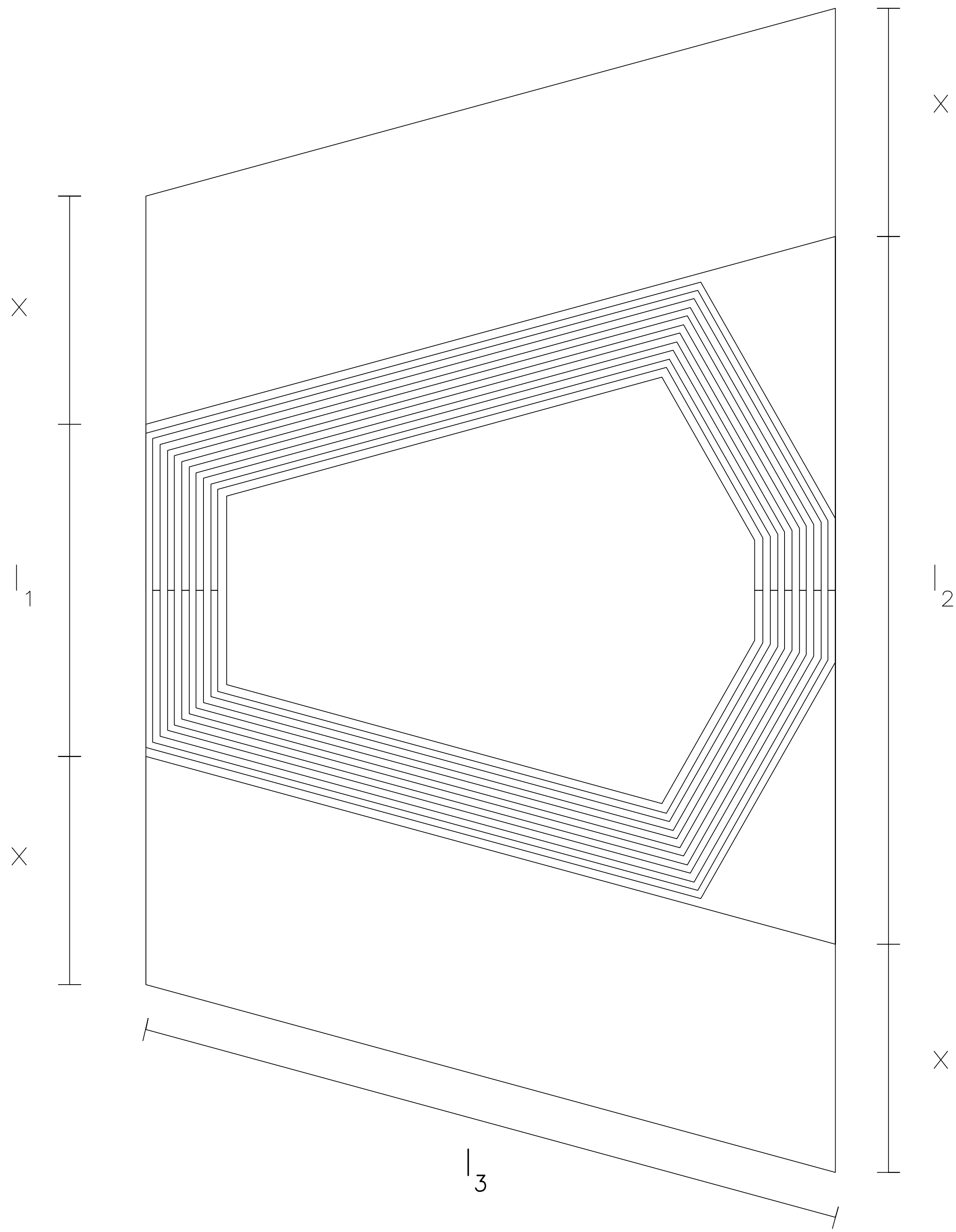
Pressure drop over one of three cooling circuits = 0.0757 psi/ft $\times$ 580 ft = 43.91 psi

The decision as to how many cooling circuits are required will be made during the detailed engineering of the coil.

5.5 Iron dimensions

We propose to construct the top and bottom yokes of pieces of iron that completely cover the pole and coil. This is illustrated in the figure at the top of the next page. Thus the top and bottom yokes are trapezoids whose parallel sides are of lengths $l_1 + 2x$ and $l_2 + 2x$. The spacers are parallelograms with sides l_3 and x. The length x is to be determined from the consideration that we want the flux to distribute itself equally in the spacers.

We begin by calculating the flux over the pole face. The pole area is found by dividing the pole into



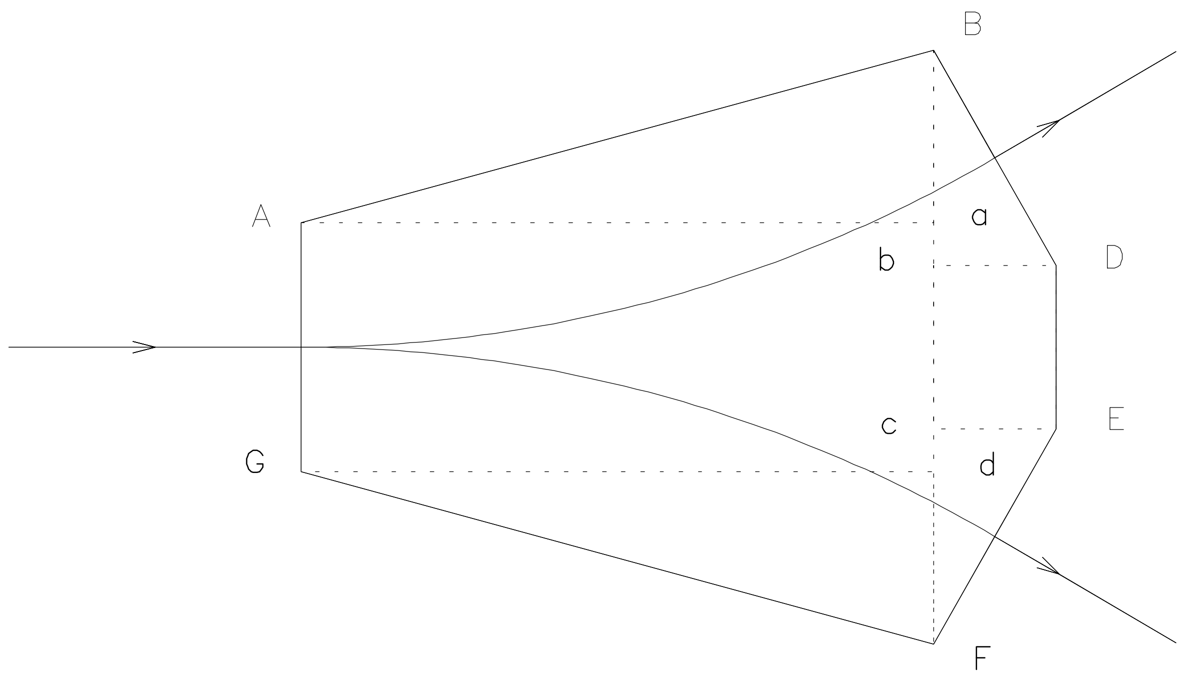
Proposed design of the yoke of the ±30° switching magnet.

rectangles and triangles as shown in the diagram on the next page. Then the pole area is

$$\begin{aligned}\text{Pole area} &= 2[\text{area of } \Delta\text{AaB} + \text{area of } \Delta\text{BbD}] + \text{area of rectangle AadG} + \text{area of rectangle DbcE} \\ &= 2\left[\frac{1}{2}(Aa)(aB) + \frac{1}{2}(Bb)(bD)\right] + (AG)(Aa) + (DE)(bD)\end{aligned}$$

From section 3 we have $\overline{AB} = 40.230$ in., the pole width $\overline{AG} = \overline{BD} = 16.500$ in. and $\overline{DE} = 8.745$ in. Thus we have

$$\begin{aligned}\text{Pole area} &= (\overline{AB}\cos 15)(\overline{AB}\sin 15) + (\overline{BD}\cos 30)(\overline{BD}\sin 30) + (\overline{AG})(\overline{AB}\cos 15) + (\overline{DE})(\overline{BD}\sin 30) \\ &= (40.230)(0.965926)(40.230)(0.258819) + (16.500)(0.866025)(16.500)(0.500000) \\ &\quad + (16.500)(40.230)(0.965926) + (8.745)(16.500)(0.500000) \\ &= (38.859196)(10.412290) + (14.289419)(8.250) + (16.5)(38.859196) + (8.745)(8.250) \\ &= 1235.824 \text{ in.}^2\end{aligned}$$



Pole divisions for the calculation of the pole area.

Pole area = 1,240 in.^{2} = 0.800 m^2.

Then the magnetic flux across the pole is

$$(BA)_{pole} = (15.5 \text{ kG})(1240 \text{ in.}^2) = 19,220 \text{ kG-in.}^2 = 1.240 \text{ T-m}^2.$$

Pole flux = 19,220 kG-in.^{2} = 1.240 T-m^2.

To this we add the flux through the coil slot. We estimate the areas by considering the trapezoids formed in our assumption of the coil-winding method. In the table below, the lengths of the short sides of the trapezoids are known for construction; those of the long sides are obtained by scaling from a diagram. We assume the altitudes of the trapezoids are the maximum coil width plus two pole-coil separations = 7.85 in. *except* for the entry and short exit-side trapezoids where we assume a height of the maximum coil width plus one pole-coil separation = 7.10 in.

Element	Short side (in.)	Long side (in.)	Height (in.)	Area (in.^{2})
Entry end	16.500	29.100	7.100	161.880
Long side	40.230	51.000	7.850	358.078
Long side	40.230	51.000	7.850	358.078
Exit end	16.500	24.500	7.850	160.925
Exit end	16.500	24.500	7.850	160.925
Short end	8.745	12.300	7.100	74.710
Total				1074.596

$$\boxed{\text{Area of coil slot} = 1{,}100 \text{ in.}^2 = 0.710 \text{ m}^2}$$

To estimate the flux through the coil slot we again assume that the field is zero at the inner edge of the yoke and rises to $0.6B_g$ at the pole edge. (This is not true, of course, at the entry and exit edges.) Thus the average field in the coil-slot is $0.3B_g$ and the flux trough the coil slot is estimated to be

$$\text{Coil slot flux} = 0.3(15.500)(1,100) \text{ kG-in.}^2 = 5,115 \text{ kG-in.}^2 = 0.330 \text{ T-m}^2.$$

$$\boxed{\text{Coil-slot flux} = 5{,}115 \text{ kG-in.}^2 = 0.330 \text{ T-m}^2.}$$

and the total flux through the gap region is

$$\begin{aligned}
\text{Total flux} &= \text{Pole flux} + \text{Coil-slot flux} \\
&= 19,220 \text{ kG-in.}^2 + 5,115 \text{ kG-in.}^2 \\
&= 24,335 \text{ kG-in.}^2 = 1.570 \text{ T-m}^2.
\end{aligned}$$

We take

$$\boxed{\text{Total flux} = 24{,}500 \text{ kG-in.}^2 = 1.580 \text{ T-m}^2.}$$

The length of the dipole along the longitudinal symmetry line is estimated from

$$\begin{aligned}
\text{Dipole length} &= \text{Pole length} + 2(\text{Pole-coil gap} + \text{Maximum coil width}) \\
&= \overline{AB}\cos 15 + \overline{BD}\sin 30 + 2(0.750 \text{ in.} + 6.350 \text{ in.}) \\
&= 38.859 \text{ in.} + 8.250 \text{ in.} + 2(7.100 \text{ in.}) \\
&= 61.309 \text{ in.}
\end{aligned}$$

$$\boxed{\text{Longitudinal length of the dipole} = L_{long} = 61.310 \text{ in.} = 1.557 \text{ m.}}$$

and that along the outer yoke edge is

$$\text{Length of outer edge} = \frac{L_{long}}{\cos 15} = 63.473 \text{ in.} = 1.6129 \text{ m.}$$

$$\boxed{\text{Length of outer edge of the dipole} = 63.500 \text{ in.} = 1.613 \text{ m.}}$$

We average these to obtain an average length of 62.405 in. and use this average length to obtain the thickness of the yoke. With the requirement that one-half of the total flux pass through each half of the top and bottom yokes we find, with t_y the yoke thickness and B_y the yoke field,

$$(\text{Cross-sectional area of yoke})(\text{Field in yoke}) = 62.405\, t_y\, B_y = \frac{24,500}{2} \text{ kG-in.}^2$$

or

$$t_y\, B_y = 196.298 \text{ kG-in.}$$

We obtain the thicknesses of the spacers in a similar manner. The length of the outer edge of the spacer was determined above to be 63.500 in. Again requiring that one-half of the total flux pas through each spacer and with $x = t_s$ the length of the other side of the spacer and B_s the field in the spacer, we find

$$(\text{Area of spacer})(\text{Field in spacer}) = 63.5\, B_s\, t_s \sin 75 = \frac{24,500}{2} \text{ kG-in.}^2$$

or

$$x\, B_s = t_s\, B_s = 199.719 \text{ kG-in.}$$

Because the field-thickness product is essentially the same for the top and bottom yokes and the spacers, we choose to make them of equal thicknesses. Taking that product as 200 kG-in., we form the following table.

$B_y = B_s$ (kG)	10	11	12	13	14	15
$t_y = t_s$ (in.)	20.000	18.182	16.667	15.385	14.286	13.333

We choose

$$\boxed{\begin{array}{lllllll} B_y & = & B_s & = & 11.429 \text{ kG} & = & 1.143 \text{ T} \\ t_y & = & t_s & = & 17.500 \text{ in.} & = & 0.445 \text{ m} \end{array}}$$

We are now in a position to estimate the amount of iron required. Estimating the lengths of the the parallel sides of the top and bottom yokes to be 64.100 in. and 97.100 in., we find their areas to be

$$\begin{aligned} \text{Area of top or bottom yoke} &= (\text{Average length of parallel sides})(\text{Longitudinal length}) \\ &= \frac{1}{2}(64.100 \text{ in.} + 97.100 \text{ in.})(61.310 \text{ in.} \\ &= 4941.505 \text{ in.}^2 \end{aligned}$$

$$\boxed{\text{Area of top or bottom yoke} = 4945 \text{ in.}^2 = 3.190 \text{ m}^2}$$

The area of each spacer is

$$\begin{aligned} \text{Area of spacer} &= (\text{Short side})(\text{Long side})\sin(\text{Contained angle}) \\ &= (17.500 \text{ in.})(63.5 \text{ in.})\sin 75 \\ &= 1073.385 \text{ in.}^2. \end{aligned}$$

$$\boxed{\text{Area of spacer} = 1075 \text{ in.}^2 = 0.694 \text{ m}^2}$$

Then we have

Component	Area (in.^{2})	Height (in.)	Volume (in.^{3})
Top yoke	4,941.505	17.500	86,476
Spacer	1,073.385	21.930	23,539
Pole	1,235.824	9.000	11,122
Total			121,137

Thus the total volume of iron required is 2(129,137) in.^{3} = 242,274 in.^{3}.

$$\boxed{\text{Total volume of iron required} = 245{,}000 \text{ in.}^3 = 141.782 \text{ ft}^3 = 4.0148 \text{ m}^3.}$$

At a density of 7900 kg/m^3, the total mass required is 31,717 kG = 69,936 lb.

$$\boxed{\text{Mass of iron} = 70.00\times10^3 \text{ lb} = 31.75\times10^3 \text{ kG.}}$$

In the above, the height of the pole was calculated from

$$\begin{aligned}\text{Height of poles} &= \text{Maximum coil height} + \text{Chamfer} + 0.590 \text{ in.}\\ &= 8.965 \text{ in.}\end{aligned}$$

(The 0.590 in. addition is from arbitrarily allowing an additional 15 mm to the height.)

$$\boxed{\text{Height of poles} = 9.0 \text{ in.} = 0.229 \text{ m.}}$$

The height of the spacers is then

$$\begin{aligned}\text{Height of spacers} &= 2(\text{Pole height}) + \text{Gap}\\ &= 2(9.000) \text{ in.} + 4.000 \text{ in.}\\ &= 22.0 \text{ in.}\end{aligned}$$

$$\boxed{\text{Height of spacers} = 22.0 \text{ in.} = 0.559 \text{ m.}}$$

The table on the next page presents a summary of these calculations.

6. Discussion

This note has presented a conceptual design for a ±30° switching magnet for beam line 2A. It must be stressed at the outset that a number of the estimates presented here are exactly that—estimates.

The amount of copper required for the coils was estimated without taking into consideration the amount necessary for the bends required during fabrication. Although it is not felt that this estimate is grossly out-of-line, it could easily be off by 10%. Thus the amount of copper required for the coils must be determined in the detailed engineering of the coil.

Power supply requirements for the magnet should still be satisfied by the available power supply, however. In the final analysis it may, however, be necessary to use 6 cooling circuits rather than the 3 circuits that have been suggested.

There may be a better method by which the upper and lower yokes and the spacers could be constructed. Their dimensions given here have been obtained from rough calculations only; exact dimensions will come from the detailed engineering work.

There should also be a two-dimensional (at least) study of the field distribution if the design given here is followed. This would yield an estimate of the effect at the exit of the dipole of extending the yoke in the manner suggested here.

Summary of $\pm 30°$ switching magnet design parameters for Anaconda 0.5790 conductor

Yoke:	Entry width	64.100 in.	1.628 m
	Exit width	97.100 in.	2.466 m
	Iron length	61.310 in.	1.557 m
	Iron thickness	17.500 in.	0.445 m
	Coil-slot width	7.850 in.	0.199 m
	Side-yoke height	22.000 in.	0.559 m
	Side-yoke short side	17.500 in.	0.445 m
	Side-yoke long side	63.500 in.	1.613 m
Pole:	Width	16.500 in.	0.419 m
	Height	9.000 in.	0.229 m
	Length along center-line	47.109 in.	1.197 m
	Chamfer at 45°	0.625 in.	0.159 m
Iron:	Total mass	70.00×10^3 lb	31.75×10^3 kg
Coil:	Anaconda conductor		
	Conductor OD	0.579 in.	0.0147 m
	Conductor ID	0.323 in.	0.0082 m
	Nominal coil width	6.200 in.	0.1575 m
	Nominal coil height	7.500 in.	0.1905 m
	Total coolant flow (3 ccts.)	4.1 USGPM	15.4 ℓ/min
	Total coolant flow (6 ccts.)	4.1 USGPM	15.4 ℓ/min
	Turn configuration	10 wide $\times$ 12 high	
	Resistance (hot) per coil	$64.85 \times 10^{-3}\ \Omega$	
Copper:	Total length per magnet	3,500 ft	1,070 m
	Total mass per magnet	3,325 lb	1.510 kg
	Total length to order	3.900 ft	1,200 m
	Total mass to order	3,170 lb	1,680 kg
Power:	Total current	575.0 A	
	Total Voltage	82.5 V	
	Power	47.5 kW	