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Subject Conceptual design for a C-frame dipole for the ISAC1 to ISAC2 transfer line		

1. Introduction

Previous notes [1,2] have presented designs for dipoles for the transfer beamline from the ISAC1 DTLs to the medium-β section of the ISAC2 accelerator complex. Four identical 59.56° dipoles are required. These designs were complicated by the tight spatial constraints in both the ISAC1 HEBT beamline and the ISAC2 complex. In the former it is desired that the Prague magnet and its object slits remain in their present locations; in the latter space is restricted between the low-β and medium-β portions of the accelerators.

During discussions of the results presented in the above reports it was decided that a rectangular C-frame dipole would be most suitable for the beamline. Such a design would allow unrestricted access on the 'open' side of the dipole in both the ISAC1 and ISAC2 areas. Because one dipole will be located in a window 6 feet wide by 4 feet high in a shielding wall in the ISAC2 complex, the C-frame dipoles should be designed to minimize their heights. However, in response to a Request for Engineering Assistance (REA) we have been assured that there would be no structural problems were it necessary to enlarge this window [3].

This report presents a conceptual design for a C-frame dipole that would be suitable for this transfer beamline.

2. Design parameters

For completeness we repeat here the design parameters given in ref [1,2]. The basic design of the ISAC1 to ISAC2 transfer beamline is given in ref [4]. In that report the following specifications are given.

Beam parameters:	Maximum beam height y_{max}	1.5 cm (0.5906 in.)
	Maximum beam width x_{max}	2.0 cm (0.7874 in.)
Dipole parameters:	Bend angle of dipole θ	59.56°
	Radius of curvature ρ_0	0.920 m (36.220 in.)
	Maximum $(B\rho)_0$	1.2 T-m
	Maximum dipole field B_0	1.3 T
	Magnet air gap g	5.0 cm (1.9685 in.)

2.1 Derived parameters

We choose to design the dipole for a maximum field of 13.5 kG (1.35 T) and an air gap of 2.0 inches (5.08 cm). Combining these values and those given above we obtain the design parameters listed below.

Maximum field	=	B_0	=	1.35 T
Full aperture	=	g	=	0.0508 m (2.0 in.)
Maximum *proton* momentum	=	$[B_0(\mathrm{T})\rho_0(\mathrm{m})]/3.3356$	=	0.37235 GeV/c
Maximum *proton* energy			=	71.182 MeV
Effective length along arc of trajectory	=	$\rho_0\theta$	=	0.95636 m (37.652 in.)
Straight-line effective length	=	$2\rho_0\sin(\theta/2)$	=	0.91388 m (35.979 in.)

2.2 Iron length

We take the iron length to be the straight-line effective length minus the full aperture. Thus

$$\text{Iron length} = 0.91388 \text{ m} - 0.0508 \text{ m} = 0.8631 \text{ m} = 33.980 \text{ in.}$$

We take

Iron length = 0.8636 m = 34.000 inches.

2.3 Ampere turns

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

$$\text{NI per pole} \;=\; \frac{1}{2}\left[1.1\,\frac{B_0(\text{T})\,g(\text{m})}{\mu_0}\right] \;=\; \frac{1}{2}\left[1.1\,\frac{(1.35)(0.0508)}{4\pi\times10^{-7}}\right] \;=\; 30,020 \text{ A-t}$$

where we have allowed for a flux leakage of 10%. Anticipating the POISSON results that follow we take

NI per pole = 28,500 A-t.

2.4 Pole width

The deviation of the central trajectory from a line joining the entrance and exit points is found from

$$\Delta \;=\; \rho_0[1-\cos(\theta/2)] \;=\; 0.12150 \text{ m} \;=\; 4.783 \text{ in.}$$

On each of the pole sides we assume a shim of 0.25 inch at 45° plus a 0.625 inch flat plus a 0.625 inch at 45°. From that point the pole tapers 0.50 inch to the pole root. Thus each pole side has a shim 2.0 inches wide. The nominal pole width is then

$$\begin{aligned}\text{Pole width} &= 2(\text{Shim} + \text{Gap}) + x_{max} + \Delta \\ &= 2(2.00 \text{ in.} + 2.00 \text{ in.}) + 0.7874 \text{ in.} + 4.783 \text{ in.} \\ &= 13.570 \text{ inches} \;=\; 0.34470 \text{ m.}\end{aligned}$$

We will require a field uniformity of better than 0.1% over the area traversed by the beam. If we assume that the dipole is installed such that the (longitudinal) geometric center of the magnet lies midway between the entrance and exit points of the central trajectory and its maximum deviation from those points, then this uniformity is required over a band of width $(\Delta + x_{max})/2$ either side of the longitudinal centerline. The required uniformity, again anticipating the POISSON results below, is obtained if we choose

Base width of pole W_{pole} = 15.00 inches = 0.381 m.

3. Coil design

In §3.2 above we determined that the required Ampere=turns per pole were 28,500. From this we have the following table of Amperes versus turns.

I (Amperes)	100	200	300	400	500	600	700	800	900	1000
N (Turns)	285	142	95	71	57	47	41	36	32	28

We choose

I	=	maximum current	=	500	Amperes
N	=	number of turns per coil	=	56	

in a coil configuration 7 turns wide and 8 layers high.

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

$$\text{Conductor area} \;=\; \frac{500 \text{ A}}{3000\text{A/in.}^2} \;=\; 0.17 \text{ in.}^2 \;=\; 110 \text{ mm}^2.$$

This is satisfied within 10% by Anaconda 0.460 and 0.516 inch-square conductors. Their parameters are listed below.

OD (in.)	0.460	0.516
ID (in.)	0.255	0.287
Copper area (in.^{2})	0.1529	0.1940
Cooling area (in.^{2})	0.05107	0.06469
Mass (lb/ft)	0.5910	0.7495
Resistance at 20°C ($\mu\Omega$/ft)	53.25	41.99
k (British units)	0.01760	0.01520

We assume that each conductor is double-wrapped with insulation such that the *total* insulation per conductor has a minimum thickness of 0.022 inch, a nominal thickness of 0.028 inch, and a maximum thickness of 0.034 inch. With the tolerance of the outer dimension of the conductors listed as 0.004 inch, the dimensions of *wrapped* conductors are as follows.

	0.460 square	0.516 square
Minimum	0.478 inch	0.534 inch
Nominal	0.488 inch	0.544 inch
Maximum	0.498 inch	0.554 inch

Then the *width* of the coil is

	0.460 square		0.516 square	
	Maximum	Minimum	Maximum	Minimum
Wrapped conductor (inches)	3.486	3.346	3.878	3.738
Gapping (6×0.010) (inch)	0.060		0.060	
Ground wrap (4×0.007×2) (inch)	0.056	0.056	0.056	0.056
Total (inches)	3.602	3.402	3.994	3.794

The *height* of the coil is

	0.460 square		0.516 square	
	Maximum	Minimum	Maximum	Minimum
Wrapped conductor (inches)	3.984	3.824	4.432	4.272
Gapping (6×0.010) (inch)	0.060		0.060	
Keystoning [5,6] (8×0.013) (inch)	0.104	0.052	0.104	0.052
Ground wrap (4×0.007×2) (inch)	0.056	0.056	0.056	0.056
Total (inches)	4.204	3.932	4.652	4.380

Historically we always have overestimated the coil dimensions; therefore we take

	0.460 square	0.516 square
Maximum coil width	3.500 inches	3.900 inches
Nominal coil width	3.400 inches	3.800 inches
Maximum coil height	4.100 inches	4.500 inches
Nominal coil height	4.000 inches	4.400 inches

We take the conductor dimension D_{nom} to be

$$D_{nom} \;=\; \text{Nominal dimension} + 4(\text{Insulation thickness}) + \text{Turn separation}$$

and further assume a pole-coil gap of $G_{pc} = 0.375$ inches and that the pole corners are rounded with a radius R_{pole} of

$$R_{pole} \;=\; 4\,D_{nom} - G_{pc}$$

Then the nth conductor is a distance

$$D_n \;=\; n\,D_{nom} + \text{Pole-coil separation} + (\text{Pole width})/2 + 4(\text{insulation thickness})$$

from the (longitudinal) center-line of the pole. The (outer) radius of curvature of this nth turn is

$$R_n \;=\; R_{pole} + G_{pc} + n\,D_{nom} + 4(\text{insulation thickness})\ .$$

The length of the straight longitudinal section of the winding is

$$L_{length} \;=\; L_{iron} - 2\,R_{pole}$$

and that of the straight section along the pole-width is

$$L_{width} \;=\; W_{pole} - 2\,R_{pole}.$$

Thus the length of the nth turn is

$$\begin{aligned} l_n \;&=\; 2[L_{length} + L_{width}] + 2\,\pi\,R_n \\ &=\; 2[L_{iron} + W_{pole} + (\pi - 4)R_{pole} + \pi(4(\text{insulation} + G_{pc})] + 2\pi n D_{nom} \end{aligned}$$

and the length of an N-turn layer is

$$L_N \;=\; \sum l_n \;=\; 2\,N\,[L_{iron} + W_{pole} + (\pi - 4)R_{pole} + \pi(4(\text{insulation}) + G_{pc})] + \pi\,N(N+1)\,D_{nom}$$

In our case with $N = 7$ and

Parameter	0.460 square	0.516 square
L_{iron} (inches)	34.000	34.000
W_{pole} (inches)	15.000	15.000
R_{pole} (inches)	1.617	1.841
G_{pc} (inch)	0.375	0.375
D_{nom} (inch)	0.498	0.554
Insulation (inch)	0.007	0.007

we find that the length of a 7-turn layer of 0.460-inch square conductor is 772 inches and that of 0.516-inch square conductor is 780 inches. For either case we take $L_7 = 816$ inches.

Length of 7-turn layer = 68 ft (21 m),

and the length per coil becomes

Length of copper per coil = 544 ft (166 m).

Because 2 coils are required per dipole, then for either conductor we have

Total length per dipole	1088 ft	(332 m)
Allow $\approx 10\%$ for winding losses	122 ft	(33 m)
Total	1210 ft	(365 m)

Then, for the 0.460-inch square conductor (of mass 0.5910 lb/ft) or for the 0.516-inch square conductor (of mass 0.7495 lb/ft) , we should order

	0.460-inch square		0.516-inch square	
A total length of	1220 ft	(372 m)	1220 ft	(372 m)
A total mass of	720 lb	(327 kg)	915 lb	(415 kg)

4. Power requirements

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

$$R_{20^\circ C} = \text{(Resistance per foot)(Coil length)}$$

so that

$$\begin{aligned} R_{20^\circ C} &= (53.25\times10^{-6}\Omega/\text{ft})\times(544\text{ ft}) = 0.0290\ \Omega\ \text{[0.460-inch conductor]}. \\ &= (41.99\times10^{-6}\Omega/\text{ft})\times(544\text{ ft}) = 0.0229\ \Omega\ \text{[0.516-inch conductor]}. \end{aligned}$$

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:

$$\begin{aligned} R_{hot} &= R_{20^\circ C}[1 + (\text{Temperature coefficient}/^\circ\text{C})dT(^\circ\text{C})] \\ &= \begin{cases} 0.0290[1+0.00393(30)] = 0.0324\ \Omega\ \text{per coil [0.460-inch conductor]}. \\ 0.0229[1+0.00393(30)] = 0.0256\ \Omega\ \text{per coil [0.516-inch conductor]}. \end{cases} \end{aligned}$$

Thus at a current of 500 A we require a voltage of 16.2 V per coil of the smaller conductor and of 12.8 V per coil of the larger conductor. Therefore, allowing for lead loss, we choose power supplies that have

	0.460 square	0.516 square
I (A maximum)	500	500
V (V total)	40	30
P (kW total)	20	15

5. Cooling requirements

In these calculations we use the British system of units. The power required per coil is:

$$\begin{aligned} \text{Power per coil} &= I^2 R_{hot} \\ &= \begin{cases} (500)(500)(0.0324) = 8.10\ \text{kW [0.460 conductor]}. \\ (500)(500)(0.0256) = 6.40\ \text{kW [0.516 conductor]}. \end{cases} \end{aligned}$$

The required flow rate is given by:

$$v(\text{ft/sec}) = \frac{2.19}{\Delta T} \times \frac{P(\text{kW})}{\text{Cooling area (in.}^2\text{)}}\ .$$

For $\Delta T = 72^\circ\text{F} = 40^\circ\text{C}$ and choosing $v = 2.50$ ft/sec to define the maximum power dissipation per water circuit, we have

$$P_{max} = \begin{cases} \dfrac{(2.50)(72)(0.05107)}{2.19} = 4.198\ \text{kW/water circuit of 0.460 conductor.} \\ \dfrac{(2.50)(72)(0.06469)}{2.19} = 5.317\ \text{kW/water circuit of 0.516 conductor.} \end{cases}$$

From these we calculate the number of cooling circuits per coil (excluding lead loss) as

		0.460 square	0.516 square
P	Total power per coil	8.10 kW	6.20 kW
Number of circuits	P / P_{max}	1.93	1.17

Thus we take

$$\text{Number of cooling circuits per coil} = \begin{cases} 2 \text{ [0.460-inch conductor]} \\ 1 \text{ or } 2 \text{ [0.516-inch conductor]} \end{cases}$$

We make an allowance for two cooling circuits per coil of the larger conductor in the event that the pressure drop is too large for a single cooling circuit. A flow rate of $v = 2.412$ ft/sec per water circuit of a coil of the smaller conductor and one of 2.915 ft/sec per water circuit of a coil of the larger conductor with one cooling circuit. Should two cooling circuits be required, a flow rate of 1.458 ft/sec is required. The volume of flow required per circuit is found from

$$\begin{aligned} \text{Volume/circuit} &= v\left[\frac{\text{ft}}{\text{sec}}\right] \times A_{H_2O}(\text{in.}^2) \times 60\left[\frac{\text{sec}}{\text{min}}\right] \times 62.4\left[\frac{\text{lb}}{\text{ft}^3}\right] \times \frac{1}{144}\left[\frac{\text{ft}^2}{\text{in.}^2}\right] \times \frac{1}{10}\left[\frac{\text{IG}}{\text{lb}}\right] \times 1.20095\left[\frac{\text{USG}}{\text{IG}}\right] \\ &= 3.12247(v(\text{ft/min}))A_{H_2O}(\text{in.}^2) \text{ USGPM} \\ &= \begin{cases} 3.12247(2.412)(0.05107) = 0.385 \text{ USGPM [0.460 conductor].} \\ \begin{cases} 3.12247(2.915)(0.06469) = 0.589 \text{ USGPM [0.516 conductor, 1 cooling circuit].} \\ 3.12247(1.458)(0.06469) = 0.295 \text{ USGPM [0.516 conductor, 2 cooling circuits].} \end{cases} \end{cases} \end{aligned}$$

Thus the calculated flow requirements for the two types of coils are as follows.

	0.460 conductor		0.516 conductor			
	2 circuits		1 circuit		2 circuits	
	USGPM	ℓ/min	USGPM	ℓ/min	USGPM	ℓ/min
Volume per cooling circuit	0.385	1.457	0.589	2.229	0.295	1.115
Volume per coil	0.770	2.914	0.589	2.229	0.589	2.229
Volume per magnet	1.540	5.829	1.178	4.459	1.178	4.459

6. 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 $k = 0.0176$ for the 0.460 conductor and $k = 0.0152$ for the 0.516 conductor we obtain:

$$dP = \begin{cases} (0.0176)(2.412)^{1.79} = 0.0851 \text{ psi/ft [0.460 conductor],} \\ \begin{cases} (0.0152)(2.915)^{1.79} = 0.1032 \text{ psi/ft [0.516 conductor, 1 cooling circuit],} \\ (0.0152)(1.458)^{1.79} = 0.0299 \text{ psi/ft [0.516 conductor, 2 cooling circuits],} \end{cases} \end{cases}$$

and the total pressure drop across one cooling circuit is

$$\text{Pressure drop per cooling circuit} = \begin{cases} 23.2 \text{ psi [0.460 conductor.]} \\ \begin{cases} 56.1 \text{ psi [0.516 conductor, 1 cooling circuit.]} \\ 8.12 \text{ psi [0.516 conductor, 2 cooling circuits.]} \end{cases} \end{cases}$$

7. Iron dimensions

We begin by taking the width of the coil slot as

$$\begin{aligned} \text{Coil-slot width} &= \text{Maximum coil width} + 2(\text{Pole-coil gap}) \\ &= \begin{cases} 3.50 \text{ inches} + 2(0.375 \text{ inch}) = 4.25 \text{ inches [0.460 conductor].} \\ 3.90 \text{ inches} + 2(0.375 \text{ inch}) = 4.65 \text{ inches [0.516 conductor].} \end{cases} \end{aligned}$$

We assume that the field rises from zero at the inner edge of the coil slot to $0.6B_0$ at the pole flat and is constant at B_0 across the pole flat. In this context the pole flat is taken as the outer edge of the flat portion of the pole shim and the coil slot as the width of the coil slot plus the 0.5 inch and 0.625 inch tapers of the pole shim. This assumption is made both on the yoke side and open side of the magnet regardless of the non-existence of an outer yoke. Setting B_y and t as the yoke flux and thickness, respectively, we then may calculate the flux in each yoke by setting it equal to that through the gap region. Thus

$$B_y t = \frac{2[\text{Coil-slot + pole shim}][0.6B_0]}{2} + [\text{Width of pole flat}]B_0 \ .$$

In our case with

	0.460 square	0.516 square
Coil slot (inches)	4.250	4.650
Shim (inches)	1.125	1.125
Width of pole flat (inches)	13.875	13.875

we find the following values for $B_y t$.

$$B_y t = \begin{cases} \frac{13.5}{2}[(4.250 + 1.125)(0.6) + 2(13.875)] = 209.1 \text{ kG-inches [0.460-inch conductor].} \\ \frac{13.5}{2}[(4.650 + 1.125)(0.6) + 2(13.875)] = 210.7 \text{ kG-inches [0.516-inch conductor].} \end{cases}$$

For either case we choose $t = 15.00$ inches thus making the yoke flux approximately 14 kG.

Yoke thickness	15.00 inches
Yoke field	$\approx$14.0 kG

The iron width of the dipole is

$$\begin{aligned} \text{Iron width} &= \text{Yoke thickness + Coil-slot width + Pole base width} \\ &= \begin{cases} 15.00 + 4.25 + 15.00 = 34.25 \text{ inches [0.460 conductor],} \\ 15.00 + 4.65 + 15.00 = 34.65 \text{ inches [0.516 conductor],} \end{cases} \end{aligned}$$

and total width of the dipole is

$$\begin{aligned} \text{Dipole width} &= \text{Iron width + Pole-coil separation + coil width} \\ &= \begin{cases} 34.25 \text{ in. } + 0.375 \text{ in.} + 3.50 \text{ in. } = 38.125 \text{ inches [0.460 conductor].} \\ 34.65 \text{ in. } + 0.375 \text{ in.} + 3.90 \text{ in. } = 38.925 \text{ inches [0.516 conductor].} \end{cases} \end{aligned}$$

The total length of the dipole is

$$\begin{aligned} \text{Dipole length} &= 2[(\text{Pole-coil separation}) + (\text{Maximum coil width})] + \text{Pole length} \\ &= \begin{cases} 2(0.375 + 3.50) + 34.00 = 41.750 \text{ inches [0.460 conductor].} \\ 2(0.375 + 3.90) + 34.00 = 42.550 \text{ inches [0.516 conductor].} \end{cases} \end{aligned}$$

To keep the vertical height as small as possible, we let the pole flat and the coil be at approximately the same distance from the magnet's centerline. Thus the pole height is

$$\begin{aligned} \text{Pole height} &= \text{Maximum coil height + Insulation pad} \\ &= \begin{cases} 4.100 \text{ in. } + 0.125 \text{ in. } = 4.225 \text{ inches} \Longrightarrow 4.25 \text{ inches [0.460 conductor],} \\ 4.500 \text{ in. } + 0.125 \text{ in. } = 4.625 \text{ inches} \Longrightarrow 4.75 \text{ inches [0.516 conductor],} \end{cases} \end{aligned}$$

and the lengths of the side yokes are

$$\text{Length of side yoke} = 2(\text{Pole height}) + \text{Gap}$$
$$= \begin{cases} 2(4.25 \text{ inches} + 1.00 \text{ inch}) = 10.50 \text{ inches [0.460 conductor].} \\ 2(4.75 \text{ inches} + 1.00 \text{ inch}) = 11.50 \text{ inches [0.516 conductor].} \end{cases}$$

9. Iron mass

From the preceding data we have

	0.460-inch square			0.516-inch square		
	Height (in.)	Width (in.)	Area (in.^{2})	Height (in.)	Width (in.)	Area (in.^{2})
Top yoke	15.00	34.25	513.75	15.00	34.65	519.75
Bottom yoke	15.00	34.25	513.75	15.00	34.65	519.75
Top pole	4.25	15.00	63.75	4.75	15.00	71.25
Bottom pole	4.25	15.00	63.75	4.75	15.00	71.25
Side yoke	10.50	15.00	157.50	11.50	15.00	172.50
Total			1312.50			1354.50

Thus, using an iron density of 0.2833 lb/in.^{3} we find

	0.460 square	0.516 square
Area of yoke (in.^{2})	1,315	1,355
Volume of iron (in.^{3})	44,710	46,070
Mass of iron (lb)	12,670	13,052

We take

Iron mass for 0.460-inch square conductor	12,750 lb	(5,785 kg) .
Iron mass for 0.516-inch square conductor	13,100 lb	(5,945 kg) .

The table on page 10 presents a summary of these calculations. Figure 1 shows the overall geometry of the magnet as well as the detail of the pole shim.

8. POISSON results

As noted previously, the program POISSON [7] was used to test the validity of the above calculations. The program was run only for the case of a coil constructed from the 0.460-inch square conductor, the assumption being that results would be similar for the case of the larger conductor. The outputs from the POISSON runs were analyzed using the programs PLOTDATA [8] and PHYSICA [9].

POISSON was run with a mesh of width 0.200 inch in the horizontal plane and one of 0.125 inch in the vertical plane. Figure 2 is a contour map of the predicted field distribution in the yoke and pole of the magnet. Figure 3 is a similar map of the field distribution in the magnet gap. In this figure field contours in the pole should, of course, be ignored because they are figments of the contouring process.

From figure 2 it is seen that the field in the yoke is more-or-less as calculated in §7—that is, in the order of 14 kG. However, regions of (near) saturation are predicted at the corners of the coil slot and in the shims along the side of the pole.

Similarly, figure 3 shows that the field is predicted to be reasonably uniform at (13,512.5 $\pm$ 2.5) G ($\pm$0.019%) over a region bounded by $x = \pm 4$ inches from the transverse centerline of the pole ($x = 26.75$ inches) and $y = \pm 0.5$ inch from the (vertical) midplane of the dipole.

It should be remembered that the results shown in figures 2 and 3 are for the design field of 13.5 kG, a value approximately 5% larger than the maximum field at which the magnet is expected to be run. Consequently, one may expect the fields in the (unsaturated sections) of the yoke to be reduced proportionately when operating at the expected maximum field. This is *not* to be expected in the saturated regions.

Figure 4 shows the predicted variation of the field in the gap as a function of distance from the midplane. It is seen that over the region 24 inches $\leq x \leq$ 30 inches particles above (and below) the midplane experience the same field as do those on the mid-plane.

9. Discussion

This report has presented a study of an C-frame dipole that could be used in the ISAC1 to ISAC2 transfer beamline. The study considered magnets with coils fabricated from different sizes of conductor. As indicated in the summary (Table 1), there is little to choose between the two.
If the smaller, 0.460-inch square conductor is used, the overall size of the dipole is slightly smaller than that of a dipole constructed with coils made with a 0.516-inch square conductor. The smaller conductor requires two cooling circuits per coil as opposed to one or two circuits per coil made from the larger conductor. Also, coils made from the smaller conductor require a larger power supply than is necessary for coils made from the larger conductor. Consequently, a magnet fabricated with the larger conductor would be slightly less expensive to operate.

The design of the magnet is such that portions of the pole will be at or close to saturation when the dipole is operated at its maximum field. This, however, should not cause operational problems.

POISSON calculations indicate that the field uniformity of the dipole should be reasonable. However, a more detailed three-dimensional analysis should be made—particularly near the entrance and exit of the dipole.

References

1. G. M. Stinson, *Conceptual designs for dipoles in the* ISAC*1 to* ISAC*2 transfer line – H-frame design*, TRIUMF report TRI-DNA-02-2, April, 2002.
2. G. M. Stinson, *Conceptual designs for dipoles in the* ISAC*1 to* ISAC*2 transfer line – Arc-shaped design*, TRIUMF report TRI-DNA-02-3, March, 2002.
3. Reply to REA number I-281, TRIUMF, May, 2002.
4. R. E. Laxdal and M. Pasini, *ISAC-II Optics Specifications*, TRIUMF report TRI-DN-01-xx, March, 2002.
5. G. S. Clark, *Private communication*, who pointed out ref[6)], TRIUMF, July, 2002.
6. B. Zimmerman, *Magnet Coil Fabrication*, Proc. International Symposium on Magnet Technology, Eds. H. Brechna and H. S. Gordon, Stanford Linear Accelerator Center, September, 1965.
7. M. T. Menzel and H. K. Stokes, *User's Guide fro the POISSON/SUPERFISH Group of Codes*, Los Alamos National Laboratory Report LA-UR-87-117, January, 1987.
8. J. L. Chuma, *PLOTDATA Command and Reference Manual*, TRIUMF Report TRI-CD-87-03b, June, 1991.
9. J. L. Chuma, *PHYSICA User's Guide*, TRIUMF Report TRI-CD-98-01, February, 1998.

Summary of the calculated dipole parameters

		0.460-inch conductor	0.516-inch conductor
Yoke:	Iron length (inches)	34.00	34.00
	Iron width (inches)	34.25	34.65
	Iron Thickness (inches)	15.00	15.00
	Coil-slot width (inches)	4.25	4.65
	Side yoke height (inches)	10.50	11.50
	Total height (inches)	40.50	41.50
Pole:	Base width (inches)	15.00	15.00
	Height (inches)	4.25	4.75
	Shim (each side of pole) (inches)	2.00	2.00
Iron:	Total weight (lb)	12,750	13,100
Coil:	Conductor OD (inch)	0.460	0.516
	Turn configuration (wide × high)	7 × 8	7 × 8
	Nominal width (inches)	3.40	3.80
	Nominal height (inches)	4.00	4.40
	Resistance (hot) Ω per coil	0.0324	0.0256
	Number of cooling circuits	2	1 or 2
	Flow per circuit* (USGPM)	0.385	0.589 (0.295)
	Flow per circuit* (ℓ/min)	1.457	2.229 (1.115)
	Pressure drop per circuit* (psi)	23.2	56.1 (8.12)
Copper:	Length per magnet (ft)	1,100	1,100
	Weight per magnet (lb)	650	825
Power:	Maximum current (A)	500.0	500.0
	Maximum voltage (V)	40.0	30.0
	Total power (kW)	20.0	15.0
Magnet:	Gap (inches)	2.00	2.00
	Total height (inches)	40.50	41.50
	Overall length (inches)	41.75	42.55
	Total flow (USGPM)	1.54	1.18
	Total flow (ℓ/min)	5.83	4.46
	Total weight per magnet† (lb)	13,400	13,925

* Value for 1 cooling circuit (Value for 2 cooling circuits).

† Exclusive of power and cooling headers.

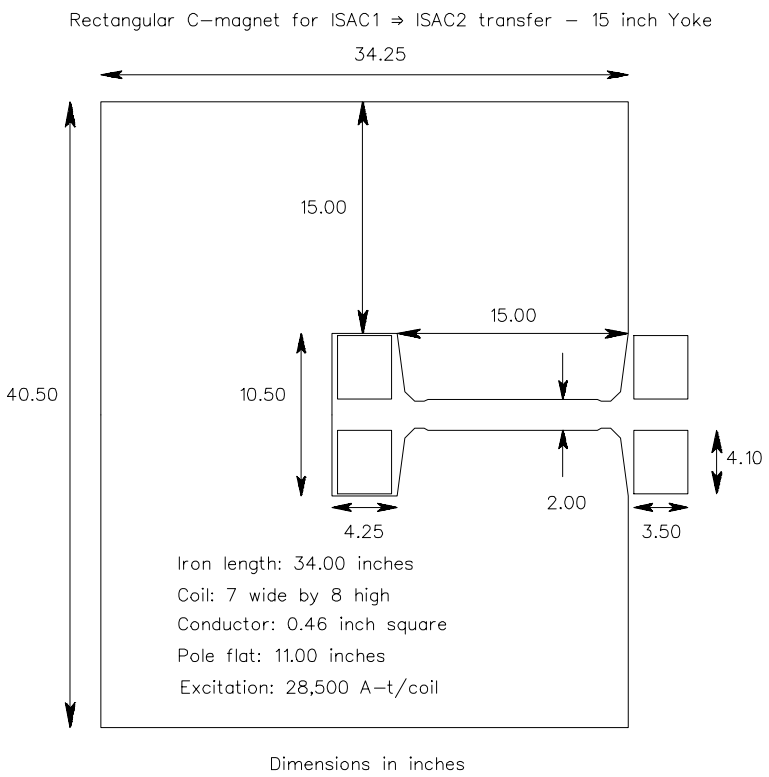

Fig. 1(a). Estimated yoke dimensions for the C-frame dipole. The coil-slot and other dimensions are for the 0.460-inch square conductor.

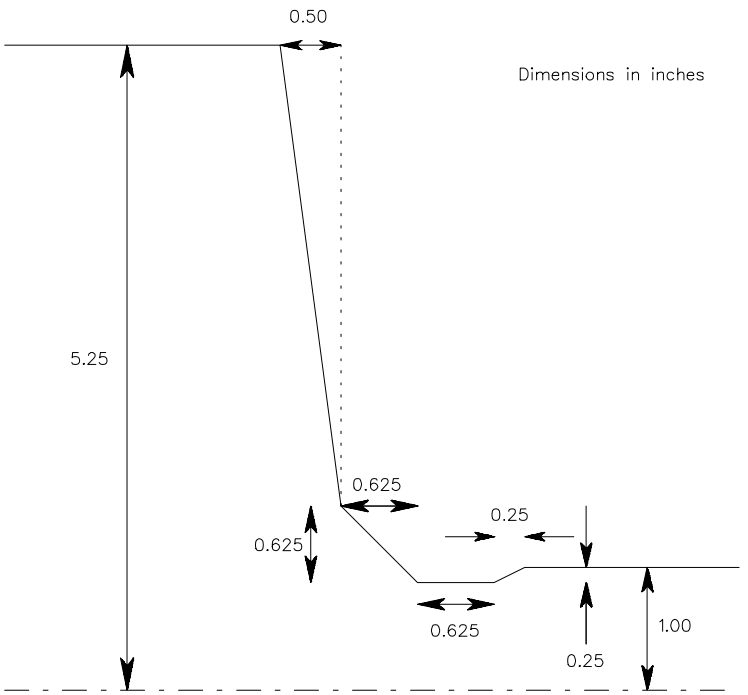

Fig. 1(b). Detail of the shim on the pole edge of the dipole.

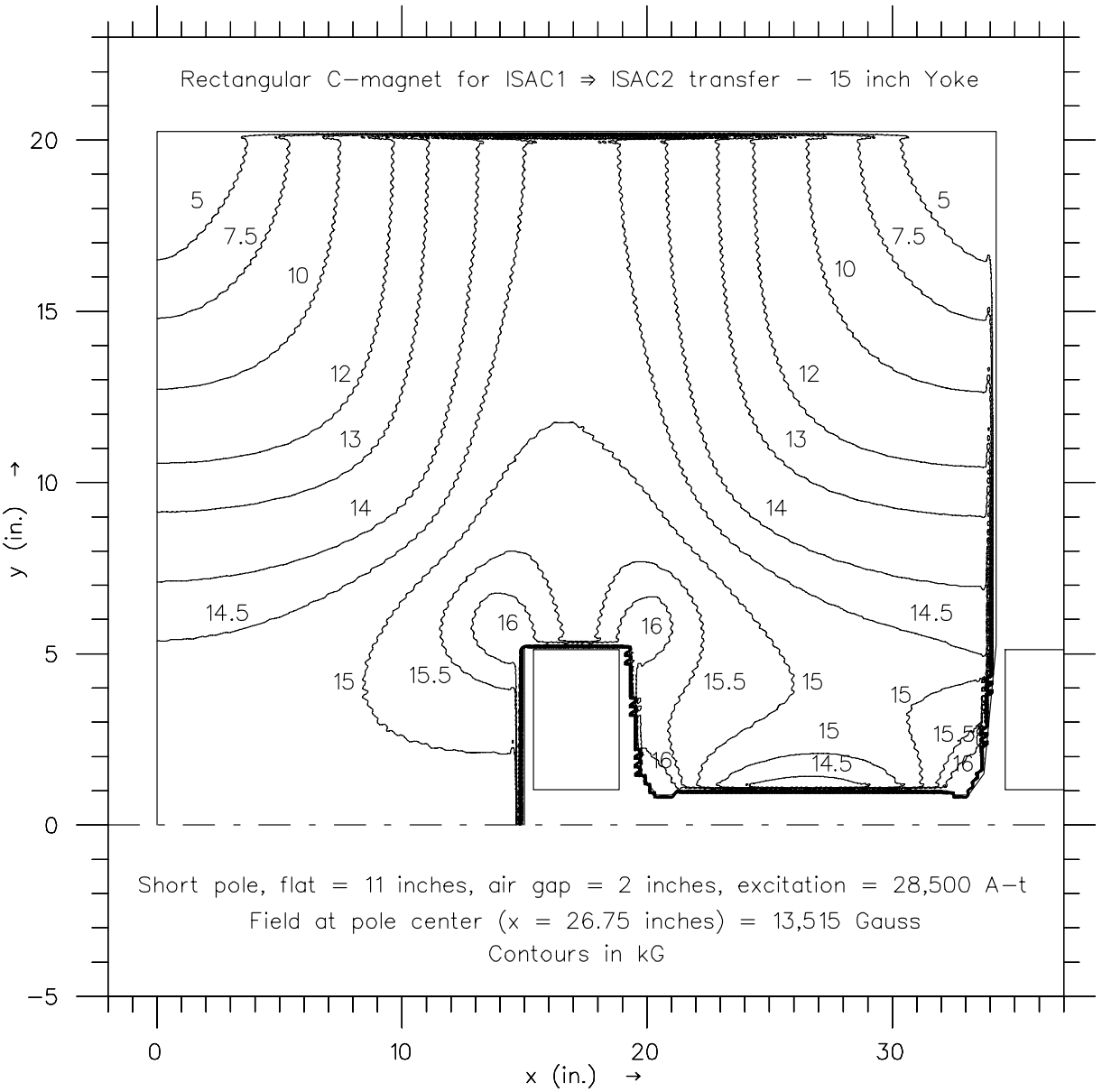

Fig. 2. The POISSON prediction of the field in the yoke of the dipole.

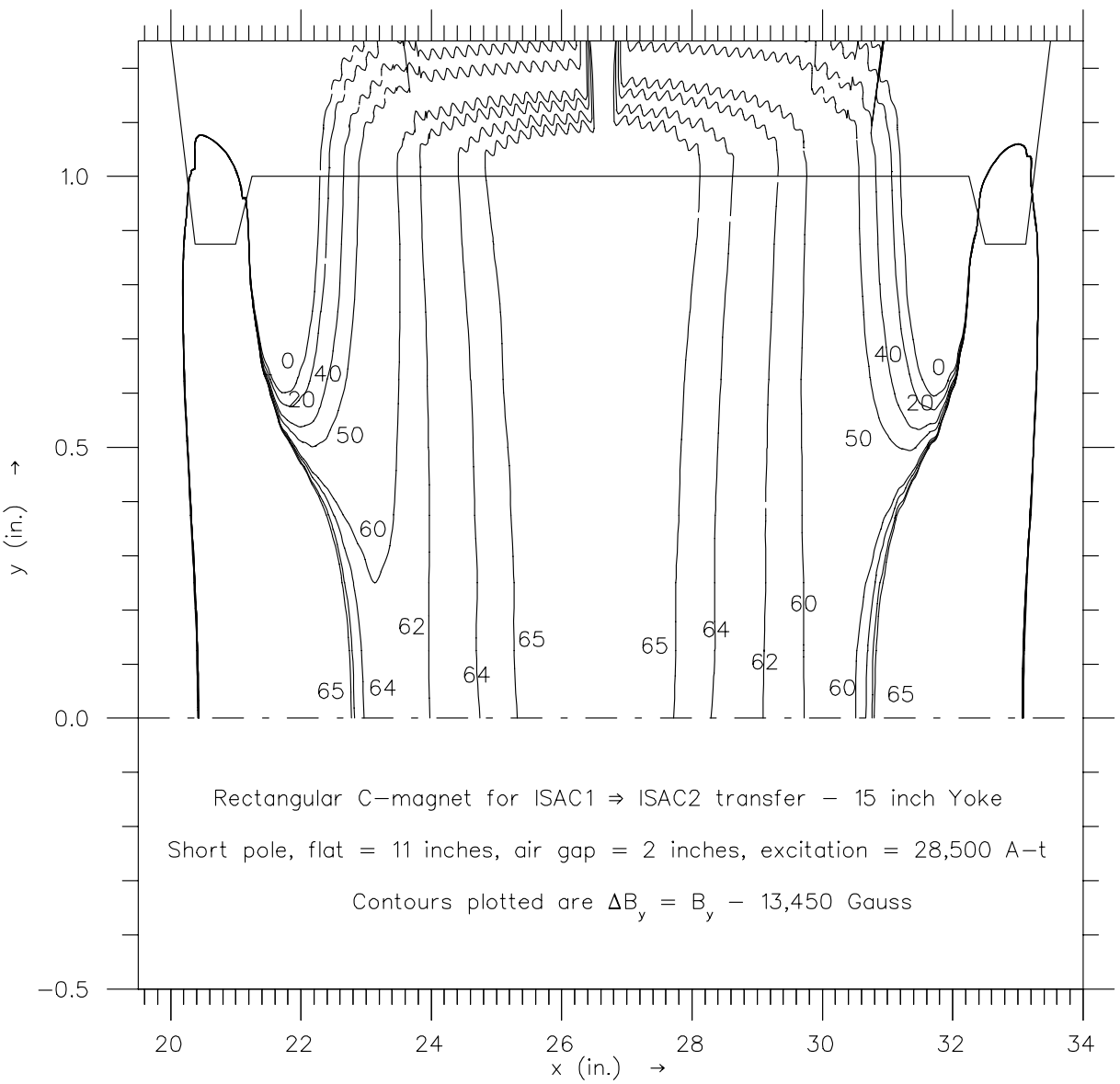

Fig. 3. The POISSON prediction for the field in the gap of the dipole.

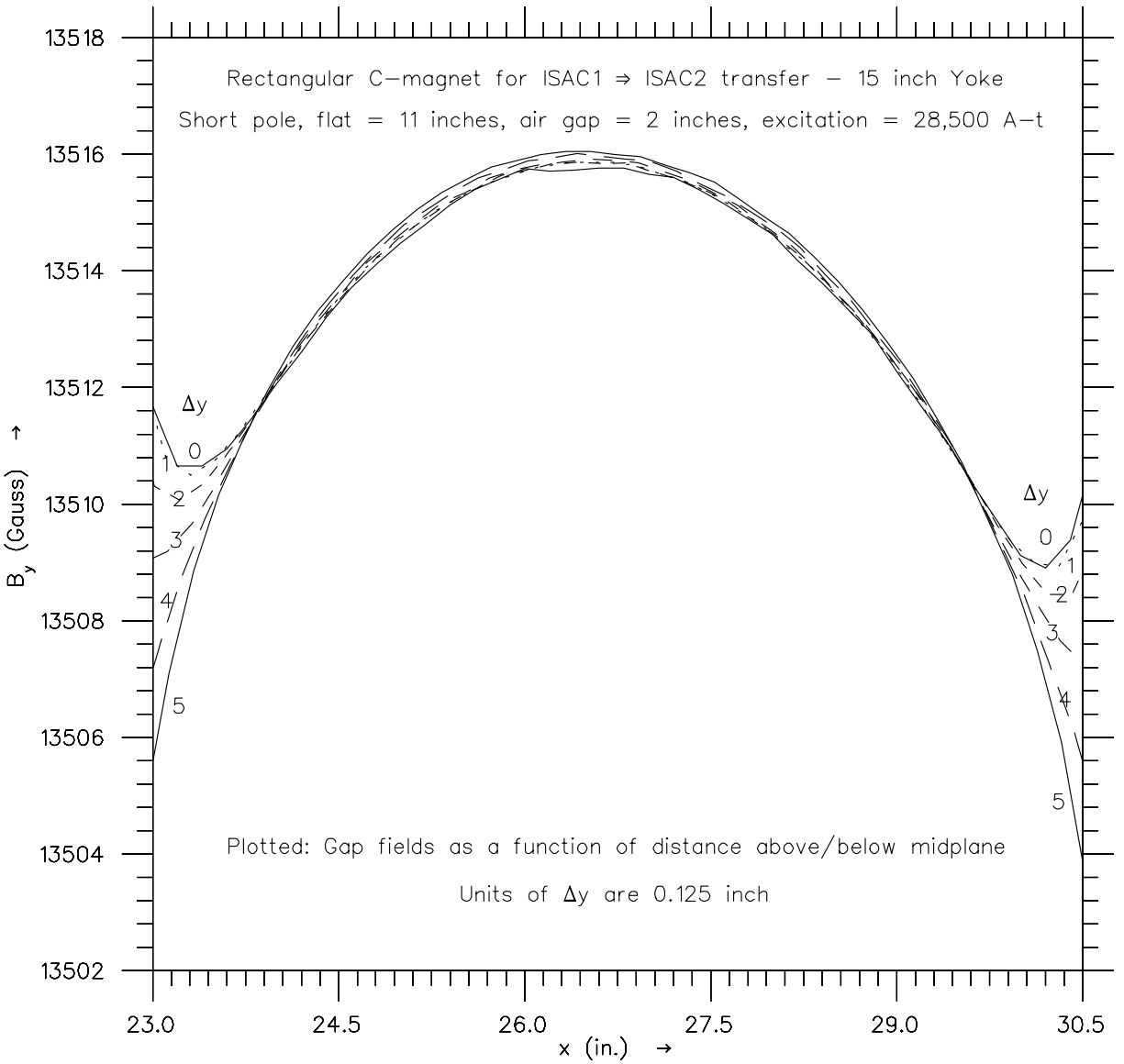

Fig. 4. The POISSON prediction for the variation of the field in the gap of the dipole as a function of distance off the midplane.