MICE with & without flips
(Incuding an appendix with increased space between focus and matching coils)

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9/17/03

Abstract

Currents are given for all coils in the MICE experiment for a number of configurations. These examples include a)SFOFO cells with flips at all three absorber locations; b) with no flip between the two cells, but flips between the cells and detectors, and c) with no flips. Solutions have minimum betas between the baseline value of 43 cm to a minimum of 7 cm

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1 Introduction

This note updates the previous compilation of matched solutions, but with the coil dimensions as given in Edd Black's figure of 7/10/03. It also gives solutions without field flips between the cells, with or without flips between the cells and detectors. All solutions are obtained by tracking small amplitude particles with ICOOL.

2 Lattice cells

First we determine currents for a long lattice of identical cells, that give required minimum betas, and with the momentum acceptance centered about 200 MeV. These are two constraints, and match the two currents (in focus and coupling coils) that can be chosen. We do this with

1) alternate cells having opposite polarities and zero axial fields at the cell ends (where the hydrogen will be located); and
2) with the polarities of all cells the same, and thus finite axial fields at the cell ends.

The dimensions used are those in the MICE experiment (see fig 1a and table 1). Solutions are found for minimum betas at the cell ends, of 43, 25, 15 and 7 mm. For comparison we also look at the performance of a uniform coil located outside the RF (fig 1b).

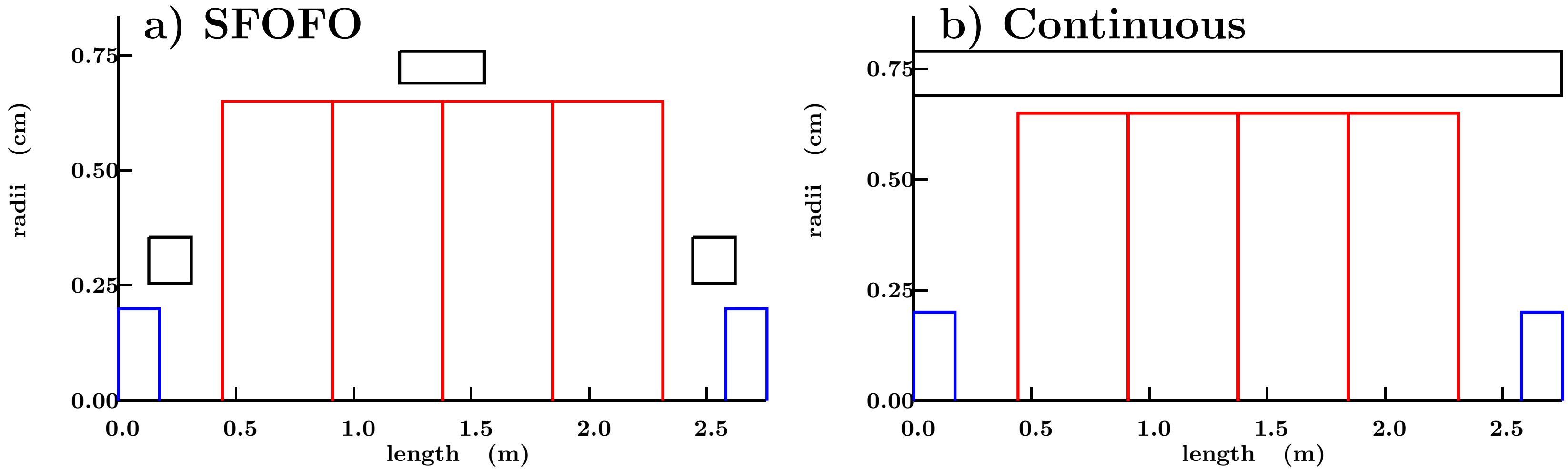

Figure 1

len1 m	gap m	dl m	rad m	dr m	I/A A/mm^2	n I A	n I l A m
0.220	0.260	0.180	0.255	0.100	106.67	1.92	3.68
1.285	0.885	0.360	0.690	0.069	106.28	2.64	12.02
2.530	0.885	0.180	0.255	0.100	106.67	1.92	3.68

Table 1

	beta cm	file	Focus A/mm^2	Coupling A/mm^2
SFOFO	43	ac1e1	106.67	106.28
	25	ac2e1	132.00	96.62
	15	ac3e1	149.00	80.52
	7	ac4e1	175.67	40.26
Non-Flip	43	dd1e1	58.33	96.62
	25	dd2e1	76.67	86.96
	15	dd3e1	95.00	76.49
	7	dd4e1	113.67	45.09

Table 2

Table 2 gives the current densities in the coils for each case. It is seen that in order to reach low betas, the focus coil current densities in the SFOFO case, must be very high. In practice, this will mean that such low betas can only be explored with lower momenta. But the focus coil currents are much less in the Non-Flip cases, so it may be possible to explore even the 7 cm beta case at 200 MeV with Non-Flip. It does not appear that the Non-Flip at 43 cm (base line) case could run at much higher momentum, because the coupling coil currents are not much reduced. But the Non-Flip lattices at 25 and 15 cm beta do use lower current for both coils and might be possible at higher momenta.

Figure 2 shows a) the magnetic fields vs length for all cases, and b) the beta functions at the cell ends vs. the track momentum.

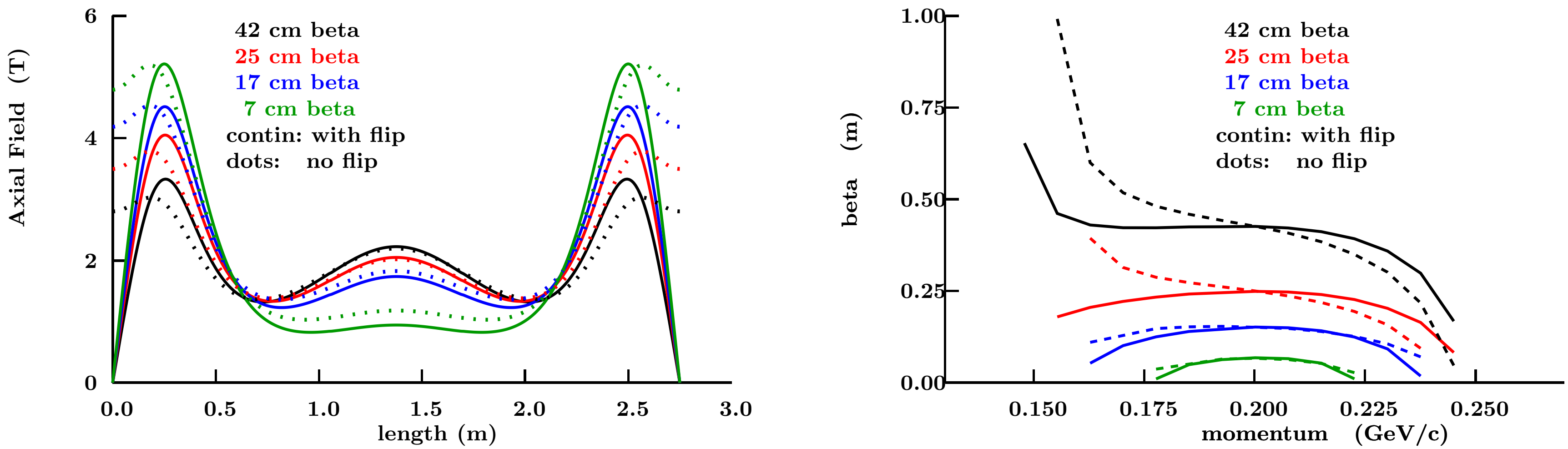

figure 2

Table 3 gives the maximum fields, total amp m of conductor, and approximate momentum acceptance, for each of thee case: Alternating fields, uniform fields, and non flip lattice. For the largest beta (43 cm), the maximum fields of all types is about the same, but for lower betas, the field required for a continuous magnet rapidly rises, while those for the SFOFO and Non-Flip cases rise much slower. The total amp m of conductor is also larger for the continuous case than either of the others, but the Non-Flip examples always have less Amp-m than the SFOFO. Whether this advantage will persist when the Amp-m of the flips is included, remains to be seen.

The momentum acceptance for a continuous magnet is, of course, infinite, but for a beta of 43 cm the other lattices have substantial acceptance (+/- 25%). The acceptance of the non-flip case for this momentum is a little worse (22%) and the beta is less flat over the acceptance. But, and this was a surprise to me, the acceptance of the non-flip is greater than for the SFOFO when tuned for lower betas.

	beta	cm	43	25	15	7
Alternating	B max	T	3.3	4.0	4.5	5.2
		amp m	19.4	20.0	19.4	16.7
	Δp	%	25	24	19	10
Uniform B	B	T	3.0	5.2	8.6	18.4
		amp m	30.7	52.8	88.0	188
	Δp	%	∞	∞	∞	∞
Non-flip	B max	T	3.0	3.75	4.5	5.2
		Amp m	15.0	15.1	15.2	12.9
	Δp	%	22	20	19	13

Table 3

3 Experiment Parameters

Using the cell designs discussed above, we now look at half the MICE experiment. The geometry is shown in figure 3.

For each cell design, we adjust the two matching coils M1 and M2 to give a match from the cell into the detector. The detector end coil (E1) is simultaneously adjusted to keep a flat field in the detector.

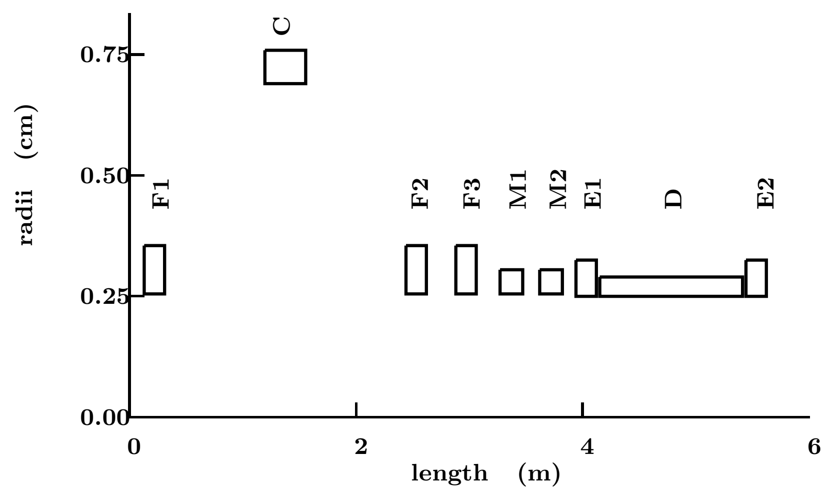

Figure 3

len1 m	gap m	dl m	rad m	dr m	I/A A/mm^2	n I A	n I l A m
0.220	0.260	0.180	0.255	0.100	106.67	1.92	3.68
1.285	0.885	0.360	0.690	0.069	106.28	2.64	12.02
2.530	0.885	0.180	0.255	0.100	106.67	1.92	3.68
2.970	0.260	0.180	0.255	0.100	-106.67	1.92	3.68
3.360	0.210	0.200	0.255	0.050	-69.85	0.70	1.23
3.710	0.150	0.200	0.255	0.050	-97.74	0.98	1.72
4.030	0.120	0.180	0.250	0.075	-66.67	0.90	1.63
4.240	0.030	1.260	0.250	0.040	-80.95	4.08	6.92
5.530	0.030	0.180	0.250	0.075	-85.93	1.16	2.10

Table 4

Table 4 gives the dimensions of all coils in one half of the MICE experiment, together with currents for the Base line SFOFO case. Table 5 gives the differing currents for the SFOFO and Non-Flip examples tuned for differing betas. All currents are given for 200 MeV/c nominal momentum. Figure 4a shows the magnetic fields vs length, and figure 4b shows the on momentum betas as a function of length for the various cases.

The first four lines in table 5 are for the SFOFO cells, with differing betas. In all cases, the highest current densities are in the focus coils, and it will be these that limit the momentum. For the lowest beta (7 cm) the focus coil current density would be 175 A/mm^2 at 200 MeV/c. If the real limit is 132 A/mm^2 then this implies that we could only test this case at a momentum of 150 MeV/c.

The fifth and sixth lines are for the Non-Flip cell solutions, but with flips introduced between the cells and detector, as might be needed to stop dark current electrons entering the detectors. It is seen that the maximum current densities in these examples are in the focus coils at the flips, and are a little higher than in the SFOFO case.

The last four lines give solutions with no flips, either between the cells, or between the cells and the detectors. These solutions are interesting in that the current densities in the focus coils are low, and they may allow testing of low beta solutions at the design momentum of 200 MeV/c. The intermediate beta solutions (25 and 15 cm) might even allow operation at higher momenta. But this will require more study, because although the current densities in the focus coils are lower, yet the fields generated by these coils are higher than in the SFOFO case.

	beta cm	file	F1 A/mm^2	C A/mm^2	F2 A/mm^2	F3 A/mm^2	M1 A/mm^2	M2 A/mm^2	E1 A/mm^2	D A/mm^2	E2 A/mm^2
SFOFO	43	ac1e1	106.67	106.28	106.67	-106.67	-69.85	-97.74	-66.67	-80.95	-85.93
$+-+-$	25	ac2e1	132.00	96.62	132.00	-132.00	-69.23	-81.71	-68.15	-80.95	-85.93
	15	ac3e1	149.00	80.52	149.00	-149.00	-63.65	-59.70	-69.93	-80.95	-85.93
	7	ac4e1	175.67	40.26	175.67	-175.67	-44.84	3.76	-80.00	-80.95	-85.93
Semi-Flip	43	dc1e	58.33	96.62	90.00	-90.00	-88.58	-55.08	-72.59	-80.95	-85.93
$-++-$	25	dc2e	76.67	86.96	113.33	-113.33	-94.12	-49.87	-72.59	-80.95	-85.93
Non-Flip	43	dd1e1	58.33	96.62	58.33	58.33	94.10	90.67	62.22	80.95	85.93
$++++$	25	dd2e1	76.67	86.96	76.67	76.67	99.28	63.11	68.15	80.95	85.93
	15	dd3e1	95.00	76.49	95.00	95.00	82.94	47.73	72.59	80.95	85.93
	7	dd4e1	113.67	45.09	113.67	113.67	60.90	-3.73	77.04	80.95	85.93

Table 5

It may be noted that, for the non-flip solutions, the current densities in the matching coils are generally higher than in the baseline (SFOFO) examples. And they are the highest of any coil in the non-flip 43 and 25 cm beta cases. To assure the maximum flexibility for non-flip solutions, one might consider increasing these matching coil thicknesses (eg from 50 to 75 cm). This would assure that it was not the matching coils that would limit the operating momentum.

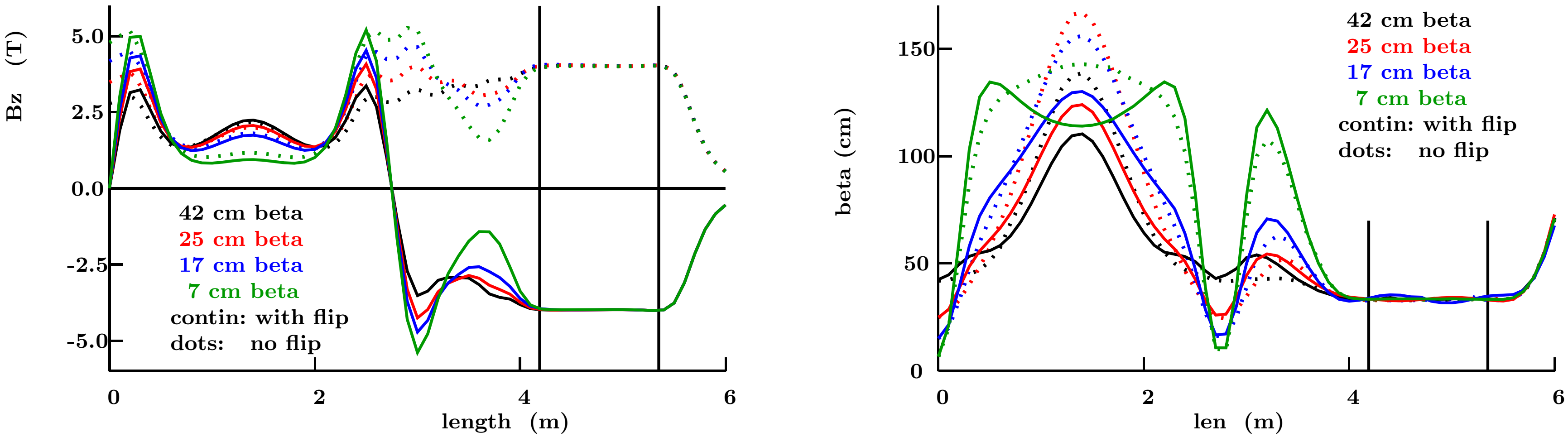

Figure 4

4 Conclusion

Well matched solutions have been found with and without field flips, for minimum betas between 43 and 7 cm. In the case with flips, the lower beta cases will require operation below 200 MeV/c. But for the non-flip cases, lower beta solutions may be testable at 200 MeV/c, and a non-flip case at an intermediate momentum may be the case that can be testable at a higher momentum. To assure the maximum flexibility for non-flip solutions, one might wish to consider increasing the matching coil thicknesses (eg from 50 to 75 cm).

5 Appendix: Solutions with increased space between focus and matching coils

This is the table of dimensions and currents for the 42 cm base line with increased pace between focus and first matching coils (42.2 cm), as sent to me from Edd Black dated 8/18/03. When I ran my matching program with these new dimensions, I got reasonable matching without moving the coils, but the current densities were too high in the first matching coil (up to 142 a/mm^2), and rather small in the second ($\leq$ 60 A/mm^2).

I have, therefor, changed the thickness of the two matching coils: increasing the first from 5 to 7.5 cm, and decreasing the second from 5 to 3 cm. These changes keep the current densities in the more reasonable range of 0 to 100 A/mm^2, and allow for some flexibility.

I am concerned that the current densities are high in the detector end coils. Their length has been reduced from 18 cm to 12 cm without increasing their thickness, so the current densities in these coils are now up to 128 a/mm^2.

len1 m	gap m	dl m	rad m	dr m	I/A A/mm^2	n I A	n I l A m
0.440	0.260	0.180	0.255	0.100	106.67	1.92	3.68
1.505	0.885	0.360	0.690	0.069	106.28	2.64	12.02
2.750	0.885	0.180	0.255	0.100	106.67	1.92	3.68
3.190	0.260	0.180	0.255	0.100	-106.67	1.92	3.68
3.812	0.442	0.202	0.255	0.075	-80.79	1.22	2.25
4.212	0.198	0.202	0.255	0.030	-100.06	0.61	1.03
4.563	0.149	0.120	0.250	0.075	-108.89	0.98	1.77
4.743	0.060	1.260	0.250	0.040	-80.95	4.08	6.92
6.063	0.060	0.120	0.250	0.075	-128.89	1.16	2.10

The following table gives the curret densities for 3 different betas, for both flip and non-flip cases.

	beta cm	file	F1 A/mm^2	C A/mm^2	F2 A/mm^2	F3 A/mm^2	M1 A/mm^2	M2 A/mm^2	E1 A/mm^2	D A/mm^2	E2 A/mm^2
SFOFO	42	al1e2	106.67	106.28	106.67	-106.67	-80.79	-100.06	-108.89	-80.95	-128.89
	25	al2e1*	132.00	96.62	132.00	-132.00	-80.3*	-83.5*	-111.11	-80.95	-128.89
	7	al3e1*	149.00	80.52	149.00	-149.00	-72.6*	-53.5*	-113.78	-80.95	-128.89
No-flip	42	el1e1*	58.33	96.62	64.81	58.33	81.8*	96.8*	108.89	80.95	128.89
	25	el2e1*	76.67	86.96	113.33	-113.33	-92.5*	8.7*	-122.22	-80.95	-128.89
	7	el3e2	95.00	76.49	113.33	-113.33	-98.95	15.52	-122.22	-80.95	-128.89

The *'s indicate where, rather than rerun the optimizer, I have scaled from a fit with the earlier 50 cm thick matching coils. The scaling leaves the totla curret the same in the M2 case, but is 5% higher for M1 to correct for the greater average diameter of the coils.