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Title: Multipolar Magnetic Elements for Weak Fields and Correctors

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INTRODUCTION

Low energy charged particles beam transport need low amplitude electromagnetic fields with high quality.

Classical solutions using magnets with water-cooled coils and soft iron magnetic circuits are rarely well adapted. Particularly, a very low remanent field implies the use of soft magnetic materials with low coercive force. An efficient shielding against external magnetic fields is also necessary.

It is worth noting that the fields tolerances are only required for the integral values.

Through three examples, we can give the main principles of practical realizations of such magnets.

For an electron beam line now in construction called MACSE at the Orme Des Merisiers - Saclay Nuclear Center, for electrons of 2MEV and 15MEV, we have to build 20 identical quadrupoles and 20 identical dipoles.
Each pair of quadripole and dipole forms a single element. Moreover, a magnetic spectrometer for energy measurement is also to be built for this line.

All the parameters are given in the table.

A) To match the required magnetic tolerances, we use coils made from two thick copper plates bonded onto a thin fiber-glass epoxy layer which can be rolled into cylinders. The shape of the coil is such that magnetic field integrals are constant within the useful area. The drawing of the windings is given by a computer code directly usable by a laser beam apparatus adapted to electronic printed circuit film generation. A chemical attack follows, giving a flat double-face circuit which is rolled and keeps its form. We can superpose the cylindrical quadrupole and dipole to make a combined lens.

The magnetic circuit is made of a thin soft magnetic material (μ Metal) which is also rolled into cylinder, so we can insure good quality magnetic fields with low coercive force, no saturation and almost the same length of the magnetic field lines.

We have to re-treat thermically the soft material after its rolling to re-obtain its good initial magnetic properties.

With a unique film of the windings, many circuits can be developped on a same plate which decreases the unitary cost and makes this manufacturing industrially available.

B) The second example is also given for electron beams of 10MEV for a free electron laser project in the Bordeaux Nuclear Center - CESTA. In this case, the focusing of the beam is obtained by a short solenoïd in each cell (150 KEV energy gain). But a double dipolar correction around the solenoïd is needed. the very small space between the solenoïd and the chamber makes the coils precedently described available for a large number of horizontal and vertical dipoles.

The magnetic circuit, in this case, is given by ferrite cores piled around the cylindrical chamber.

In this example also, where the total length is shorter than the diameter, the tolerances are obtained by the drawing of the windings also given by the computer code.

The table (1) gives the main parameters and magnetic measurements results.

In both cases, the current is of the order of 5A and the resistance from one to a few Ohms.

	DIPOLE	QPOLE	DIPOLE
	ORME	ORME	CESTA H etV
W el	15 Mev	15 Mev	10 Mev
ρ/e	$5.2\ 10^{-2}$	$5.2\ 10^{-2}$	$3.5\ 10^{-2}$
α (RAD)	$5\ 10^{-3}$		10^{-2}
∫Bdl (Tm)		$130\ 10^{-4}$	
∫Gdl (T)	$2.6\ 10^{-4}$		$3.5\ 10^{-4}$
Lmagn (m)	$70\ 10^{-3}$	$70\ 10^{-3}$	0.178
L (MAX)	$84\ 10^{-3}$	$84\ 10^{-3}$	0.21
Φ circuit-	$42\ 10^{-3}$	$46\ 10^{-3}$	0.228
spires (m)			
Φ retour-	50.10^{-3}	$50\ 10^{-3}$	0.25
Fer (m)			
N1/2(sur	32	32	34x2=68
πr) (1face)			
I (AMP)	3.7	5	4.5
R (OHM)	0.5x2	0.2x2	3
V (volt)	4	2	13.5
I Alim (A)	10	10	10
V Alim (V)	25	25	25

C) A third example is shown through the design of a spectrometer dedicated to energy measurements of a 2 MEV electron beam.

The table (2) gives the main parameters.

We have chosen a window-frame type magnet, equipped with two coils wounded around lateral legs. The magnetic circuit is made of 2mm thick sheets of anhyster (a soft magnetic material with very low coercive force and a Bmax of 1.6T). We have sliced the sheets from a cylindrical rod of 60 mm diameter.

These sheets are screwed on the internal faces of a rectangular box, 15 mm thick, of an amagnetic inox to prevent the external part of the magnetic field from interacting with the internal one. The outside part of the box is coated with 2 mm thick sheets of soft iron. Finally, all of this is enclosed inside a soft iron box for support, alignment and magnetic shielding from external fields. In this example too, the magnetic fields lines have almost the same length due to the shape; the thickness of the sheets is optimized for the maximum value of the permeability.

With this technic, we can easily match the required tolerances at a rather low cost.

W electrons	2 Mev
B	70 to 400 Gauss
Air Gap	40 mm
Length	200 mm
N per coil	140
Coil width	15 mm
Angle	30 °
Useful width	± 7.5 mm
I	9 A
Copper diameter	1.8 mm
Sheets thickness	2 mm

CONCLUSION

We have described through three examples the methods and processes to be applied for magnetic correctors and lenses in the range of a few gausses to a few hundred gausses, located in a limited space. First, we use thin current circuits designed by a computer code to give integral of magnetic fields within the required tolerances; second, we use high quality magnetic materials in thin sheets in order to neglect the remanent field and to have almost infinite permeability. We have to mention the magnetic shielding realized by successive magnetic enclosures which is very often necessary.

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