QUADRUPOLE AND SEXTUPOLE FOR DUAL BORE RING

A. Mikhailichenko
Cornell University, Wilson Lab., Ithaca, NY 14853, USA

Abstract

Latest results of testing the compact dual bore quadrupole and sextupole represented. Dual bore quadrupole tested in cryostat up to ~150 A feeding current generating ~1 kG/cm in each aperture. Sextupole was tested in Dewar and able to generate ~0.7 kG/cm of integrated field. Transverse size of the magnets cold masses is about 180 mm. Dual bore water cooled room temperature apertures are 54 mm in diameter each and the distance between centers of these apertures is 79 mm.

1 INTRODUCTION

This work was initiated by publication [1], where it was suggested to upgrade Cornell storage ring CESR, with new dual bore vacuum chamber sharing the same room temperature bending magnets and superconducting dual bore focusing magnets.

These superconducting magnets include dual bore quadrupole, dual bore sextupole, and dual bore dipole correctors. Also some dual bore octupoles or skew quadrupoles will be used instead of dipole correctors. All three types of these magnets will share the same cryostat and considered as one unit. First results of tests of quadrupole in Dewar described in [2]. In [3] the latest concept of dual bore collider described. The room temperature dipoles for this new ring described in [4].

In [5] the test of cryostat for dual bore quadrupole lens described. It was found that cooling of HTS leads was not adequate. For normal operation the number of current leads from room temperature to the cold mass is twelve per magnet unit. That is why utilization of High Temperature Superconductor (HTS) leads is crucial here.

The field quality of the quadrupole was tested in Dewar before and showed that the field accuracy required has been achieved.

In this publication we describe the latest results from dual bore quadrupole tested in cryostat. Sextupole lens design and results of its test in Dewar is represented also.

2 QUADRUPOLE

The quadrupoles share the same iron yoke. Axes separation is 79 mm. The field quality required for the quadrupole is about $[B_y(x) - G\cdot x]/G\cdot x \le 5\cdot 10^{-4}$, where $B_y(x)$ is the field across the aperture, G is a gradient. When dual bore lenses shared the same yoke, however, the quadrupole symmetry in the iron and in each magnet becomes broken. Now dipole and sextupole components are the strongest among allowed. To compensate this effect, some appropriate non-symmetrical deformation of the poles required. All these effects in dual bore lens described in [6].

The lens design chosen, where the poles *and* the coils acting *together* for the field generation [7]. A racetrack type superconducting coils used there. They have single layer windings, with thickness of a single wire.

For the requirements of the beam optics the gradients in both neighboring lenses have the same sign and about the same value. So the neighboring currents on the sides of the septum have the same value also. The last yields that vertical component of magnetic induction in the iron septum is absent practically. Yoke septum is 4 mm thick.

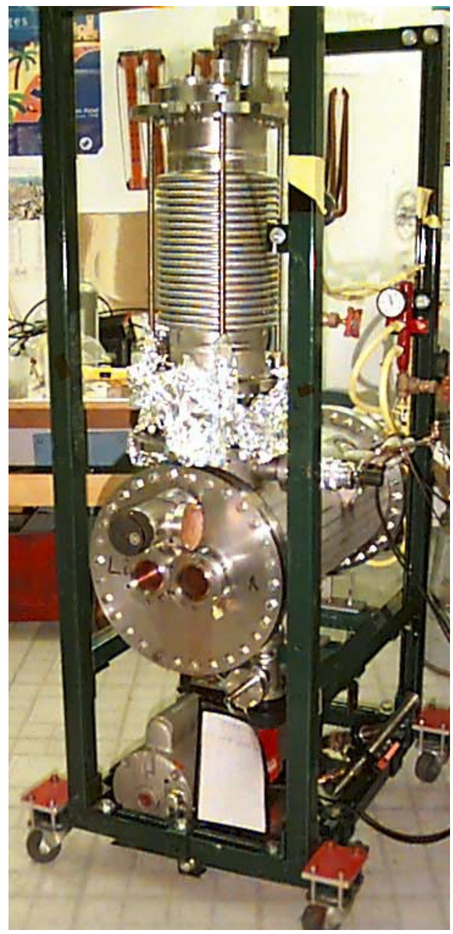

Figure 1: Dual bore quadrupole magnet installed in a cryostat for cryogenic test. In a vertical bellow there are joints allowing the He filling from standard Dewar. Diameter of the main body is ≅ 10 inches.

At the end of the lens some soft iron shields made. They prevent the field interference from neighboring lenses.

Cryostat and first test with it described in [5]. At present times the filling could be done from a standard 100 L Dewar, Fig.1. Vacuum inside the cryostat goes typically to 2.8 10^{-8} Torr as a result of cryocooling.

After adding some Nitrogen cooled local shield for covering HTS leads, the current achieved was 149.5 A, while the specification for the leads is 150 A. Meanwhile

the design current is 100A only. In this test the HTS leads made by American Superconductor were used. These leads are 30.5 cm long. The side to side warm chamber distance (septum) in cryostat is about 25 mm.
Parameters of quadrupole are represented in a Table below.

Parameter	Value
$\int Gds,[kG]$	33.5
$G,[kG/cm]$	0.77
Current, A	100
Turns/pole	43
Room aperture, *cm*	5.4(dia)

So the test proved, that the principles chosen for quadrupole design approach were right.

3 SEXTUPOLE

The field distribution in the aperture of a sextupole

$$\overline{B} = B_x - iB_y = (-i)Sz^2 = 2Sxy - iS\cdot(x^2 - y^2) = \\ = (-i)Sr^2e^{i3\varphi} \quad (1)$$

where $z = x + iy = r\cdot\exp(i\varphi)$ – is a complex variable. The fields generated inside aperture in the same manner as for the quadrupole.
The cold mass of the sextupole is represented in Fig.2. The poles manufactured with the rest of yoke and made as parts of a *cylinder*. At the end they have some cut which improves the harmonics content.
Six racetrack type single layer coils generate the necessary field profile, Fig. 2. For generation the field required, we used here both, pole shape and coil positioning. We would like to attract attention, that for ideal sextupole in whole aperture the walls between poles must be curved. For simplicity of fabrication this was not used here, as the field quality required for sextupole is ten tomes weaker, than for quadrupole.
Wire is a superconducting one with 54 filaments of NbTi of 0.4318 *mm* (0.017in) in diameter. Each wire wrapped by Kapton insulation and impregnated by Bondal. Coil has 23 turns per pole.
The field formation described in detail in [8]. Magnetic lines picture is represented in Fig.3 and the transverse field distribution is represented in Fig.4. All calculations have done with numerical code MERMAID [9].
One can see that pure sextupole symmetry is broken here also, similarly to the quadrupole lens. Moreover, the lines in the septum of the yoke, right side on Fig.3, are more condensed and hence reduce the field strength at the right side additionally. To compensate this effect one can make the pole radiuses at the left and right side of the lens slightly different. The field behavior is represented in Fig.4 for the same pole radiuses, but optimized for less harmonics content. Zero of the field is slightly shifted on 0.042 *mm* to the right side.

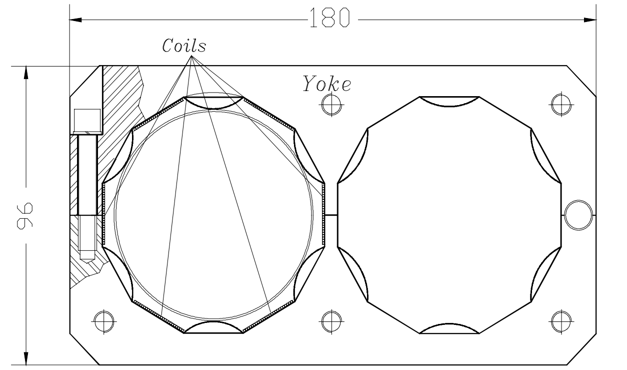

Figure 2: Sextupole cold mass. Dimensions are in *mm*. The inner boundary of the helium container is the inscribed circle shown. It has 2¾ inches in diameter.

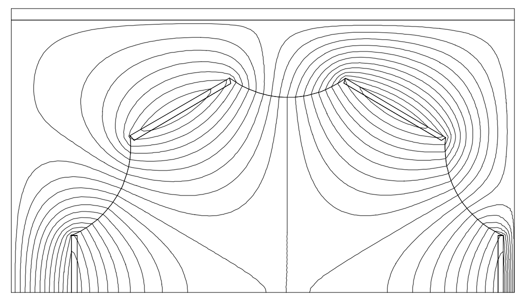

Figure 3: Magnetic lines in sextupole. Upper half of the left aperture in Fig.2 is shown. Neighboring sextupoles have the same value.

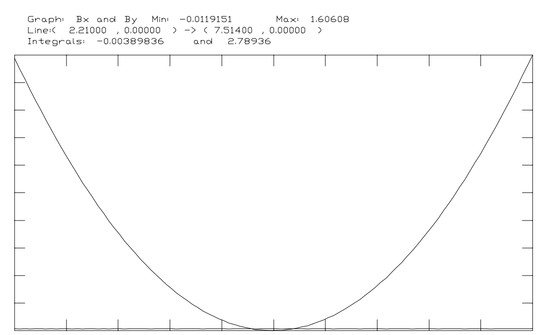

Figure 4: Vertical field behavior as a function of transverse coordinate. Slight asymmetry is visible here

Expansion of the field behavior made around mechanical center of the sextupole gives the formula for the feeding current 2.5 *kA·turns*/pole or 108 *A* of feeding current. This current is about *three times* the working one. With this current the field dependence is

$$B_y(x/cm)[kG] \cong -0.112 - 4.1\cdot10^{-4}\cdot x + 0.229\cdot x^2 - \\ -4.7\cdot10^{-4}\cdot x^3 + 1.9\cdot10^{-4}\cdot x^4 + 2.8\cdot10^{-5}\cdot x^5$$

So the field deviation within aperture remains within $2\cdot10^{-3}$. This is what required. Parameters of SC sextupole were normalized to the CESR sextupole [10], Fig.6. Was found that operation of SC sextupole at 40A equivalent in terms of *integrated* field to 6 A of feeding

CESR's sextupole. The maximal harmonics amplitude was found of 60% lower than the in CESR's sextupole.

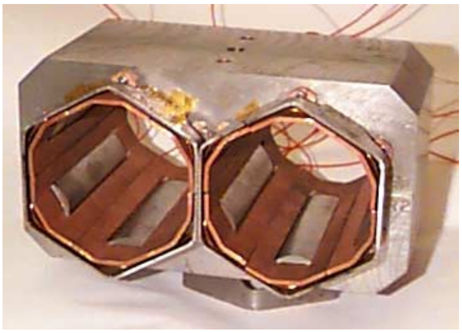

Figure 5: The sextupole cold mass. End covers are visible.

Parameters of the Sextupole are summarized in Table below. Aperture of sextupole is, naturally, the same as the quadrupole one.

Parameter	Value
$\int Sds, [kG/cm]$	0.7
$S, [kG/cm^2]$	0.055
Current, A	35
Turns/pole	23

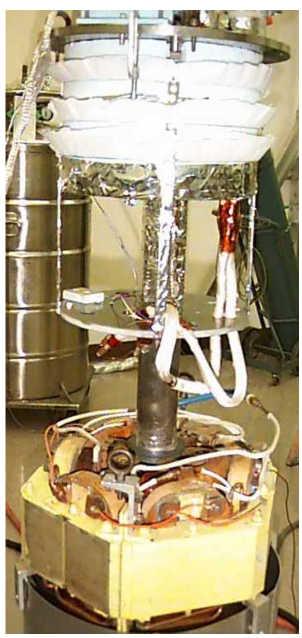

Figure 6: At the left the sextupole sown just removed from Dewar. At the right -the same rotating coil set, located inside vertical coaxial tubing, positioned in standard CESR sextupole for calibration and comparison.

4 CONCLUSION

The nonlinarities in each magnet aperture arisen due to sharing the same yoke can be taken into account by proper choice of problem for modeling. The same ideas of cancellation interference between the magnets sharing the same iron found for quadrupole were applied to sextupole. This could be applied also to any other dual bore multipole elements (such as skew quadrupole, octupole and dipole corrector). Serially installed quads and sextupoles in each module also give the way to manage the field quality of whole unit.

Mostly strong interference occurs at the magnet dual edge. Solution of this problem in application to the dual bore magnet was found in thin profiled covers for the coil's parts running in outer to the yoke space, Fig. 5.

HTS leads were successfully used here. The set of tests done proved the principles of design made.

During this work proceeded it was developed technology for coil fabrication [11], design of dual bore multipoles concept, cryostat design. Dual bore quadrupole was fabricated and tested in Dewar and in cryostat, sextupole was fabricated and tested in Dewar.

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