MULTI-ELEMENT CORRECTOR MAGNET FOR THE STORAGE RING NEWSUBARU

Y. Shoji[#], NewSUBARU/SPring-8, University of Hyogo, Japan

Abstract

Multi-element octupole-base corrector magnets will be installed in the electron storage ring NewSUBARU in place of vertical steering (skew dipole) magnets. The new magnets use coil windings to produce the skew quadrupole, skew sextupole, normal octupole, and skew dipole fields. The skew dipole element is used to achieve vertical steering. In designing the magnet, careful consideration was given to field interference caused by a neighboring magnet, which was in close proximity to the corrector magnet. The magnetic field with field interference was calculated using OPERA-3D..

INTRODUCTION

The magnets described here will replace the existing vertical steering magnets (stV) in the 1.5 GeV electron storage ring NewSUBARU [1]. The magnet specifications were driven by the accelerator requirements, geometrical constraints, and power supply considerations. The goal is to control the vertical beam position, coupling, higher order momentum compaction factor, and resonances. We expect improvement of the beam lifetime and injection efficiency in normal operation as well as improved isochronism during extreme quasi-isochronous operation.

Multi-functional magnets are commonly used in synchrotrons as weak corrector magnets in order to save space. There are many examples of two-functional magnets using main and extra windings or pole-face windings [2]. As a multi-functional magnet, some groups have adopted a 12-pole geometry in order to achieve multiple functions in a single package [3]. In contrast with other groups, we have adopted an 8-pole geometry. We have configured the coils so that each power supply for the magnet controls a single function: vertical (skew) dipole, skew quadrupole, skew sextupole, and normal octupole.

M REQUIREMENTS

Space Requirement

Fig. 1 shows the present lay-out of the magnets. The room for the new magnet is the same as that for the existing vertical steering magnet, a narrow space between the BPM (beam position monitor) and the quadrupole magnet. The yoke of the existing stV is made of bulk iron with a length of 0.06 m. However, a length of 0.08 m is possible by reconfiguring the water cooling pipe for the vacuum beam duct.

The minimum possible bore radius is determined by the cross section of the vacuum chamber. When the pole

is shaped with an equi-potential line of octupole scalar field, a radius of 35 mm is possible. With a flat pole shape, which has a larger region of good field, the radius must be 40 mm or more.
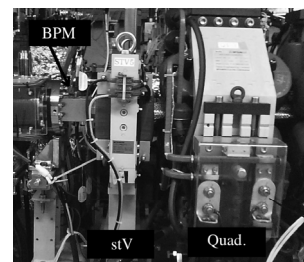

Fig. 1: Current layout of ring elements near the stV.

Requirement for the Dipole Element

The dipole element of the new magnet should be compatible with the existing power supply and control system. The basic parameters of stV are shown in Table I. In order to minimize change, it is desirable, although not necessary, to maintain the same field strength per current.

Because of the interference with the quadrupole magnet nearby, the integrated field strength of stV was reduced by 10%. The strength shown in Table I was the reduced value based on the calculation using OPERA-3D.

Table 1: Parameters of stV

Parameters	Quantities
Magnetic Yoke Length	60 mm
Pole Gap	100 mm
Cross Section of Coil Conductor	2 mm X 3 mm
Coil	425 turns/pole
Total Length of the Conductor	452 m
Cooling Method	air
Maximum Current	6.2 A
Maximum Integrated Field Strength	0.0081 Tm

Requirement on the Multi-pole Elements

The requirements on the various elements are based on experience running NewSUBARU. The skew quadrupole strength is based on the strengths currently needed to decouple the horizontal and vertical tunes. The skew sextupole strengths are based on the current 'normal' sextupole system, allowing resonance correction. The normal octupole strength is enough to correct the higher order momentum compaction factor [4]. The magnet parameters needed in order to meet the beam-based requirements are listed in Table II.

As a simple guideline for the field quality of multi-pole elements in NewSUBARU the deviation from the ideal field should be smaller than 3×10^{-4} Tm at a

_____
[#]shoji@lasti.u-hyogo.ac.jp

horizontal displacement (*x*) of 30 mm. Here the mechanical acceptance, determined by the synchrotron light absorber, is between -27.8 mm and +28.3 mm. At the location of the corrector magnet the horizontal beam size is at its largest in the whole ring.

Table 2: Field elements of corrector magnet

Element	Integrated Strength	Coil Turn/ Pancake	Coil Current	Effective Length
Dipole	0.0081 Tm	129, 92	6.2 A	0.19 m
Quadrupole	0.04 T	42	10 A	0.12 m
Sextupole	2 T/m	42, 31	10 A	0.11 m
Octupole	200 T/m^2	42	10 A	0.10 m

MAGNET

Magnet Design

The basic magnet design [5] is an 8-pole yoke. The dipole and the sextupole fields are produced by coils around the back leg between each pair of poles. The quadrupole and octupole fields are produced by coils on the poles. The yoke length is set to the maximum, 80 mm. The bore radius is 50 mm, much larger than the geometrical limitation, which is required to maintain enough good field region. Some parameters of the magnet are listed in Tables 2 and 3.

The configuration of coils for each element is shown in Fig. 2. There are no coils around the back-legs on the median plane (the right and the left), so that the magnet can be separated here into its upper and lower halves. This allows the magnet to be easily installed into the ring. We use the same conductor as that used in stV, the total length of which was 488 m. The increase of the coil resistance is within tolerance.

Table 3: Parameters of corrector magnet.

Parameters	Quantities
Magnetic Yoke Length	80 mm
Bore Radius	50 mm
Cross Section of Coil Conductor	2 mm X 3 mm
Cooling Method	air

One expected problem of the larger bore radius was that much larger coils had to be used for the dipole field. As a result much larger currents would be required. The current in the coil can be calculated using the scaling law of $I \propto r^{-(N/2)}$. Here *I* is the coil current, *r* is the bore radius, and *N* is the multi-polarity of the field. In our case, the scaling law was correct for the octupole, sextupole and quadrupole. However, the integrated dipole field did not obey the scaling law because the effective length

increased by approximately 10%, requiring the coil current to also be increased by approximately 10%.
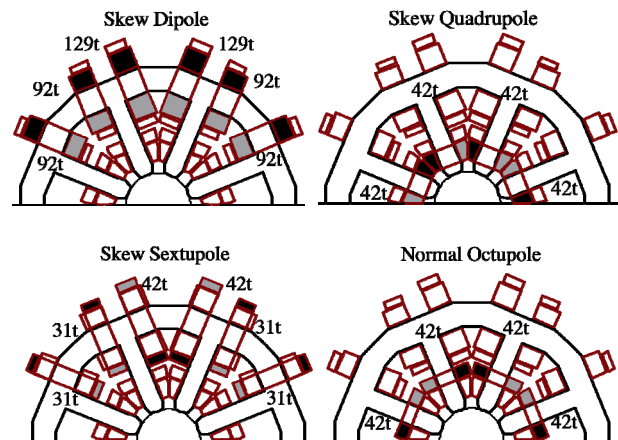

Fig. 2: Cross sections of the upper half of each element of the magnet illustrating the configuration of the coils. The shaded areas indicate the coils which were used in each element.   Black and grey shaded areas indicate the direction of the current.

Magnetic Field Calculation

The magnetic field distribution for each element was calculated using a 3-dimensional simulation code, OPERA-3D.   In addition to the multi-element magnet, we also considered the nearby quadrupole magnetic yoke as shown in Fig. 3. The space between the yoke edges of the two magnets was 0.12 m.
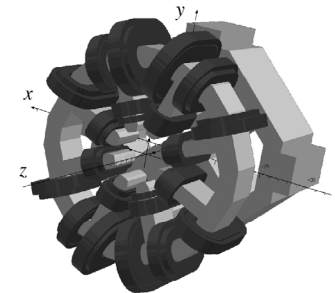

Fig. 3: 3D structure model of the multi-element corrector magnet (front) with the quadrupole lattice magnet nearby (back).

Fig. 4 shows the integrated field distributions of each element, with bore radius of 50 mm and 40 mm. In the case of the 40 mm bore radius, the dipole and sextupole field do not satisfy the guideline previously specified for the field quality. As a result we chose to enlarge the bore radius to 50 mm.

The distribution of the field components along the beam axis is shown in Fig. 5. The effective length of the magnet is larger for lower multi-pole field components. The interference with the quadrupole yoke nearby is considerable only for the dipole element.

This interference affects the sextupole field component of the dipole element. Fig. 8 shows the distribution of the sextupole components along the beam axis. The sextupole field produced by the dipole coils changes its sign along the beam axis and the effect of the quadrupole yoke is clearly seen. At the edge of the quadrupole yoke, the rapid reduction of the dipole field produces a sextupole field component. The number of coil turns for the dipole

element is chosen such that the integrated sextupole field is zero.
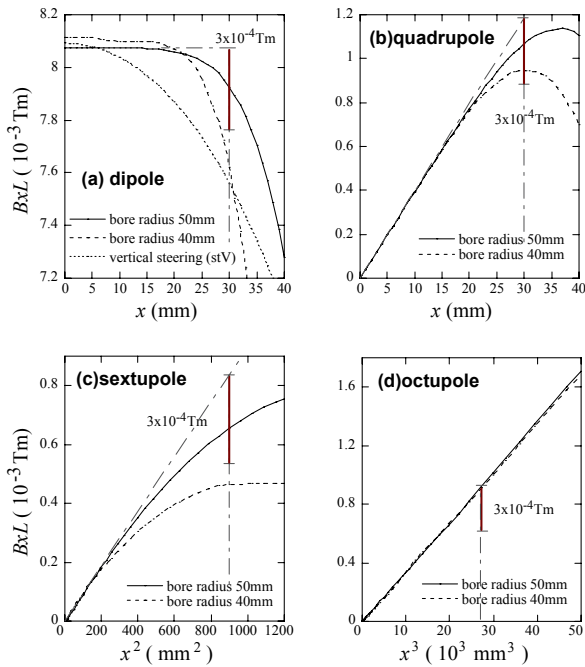

Fig. 4: Deviation of the integrated dipole, quadrupole, sextupole, and octupole field shape from the pure multipole. Only the element of interest is powered to full current. The bar in figures (a)-(d) shows the guideline of the acceptable error.
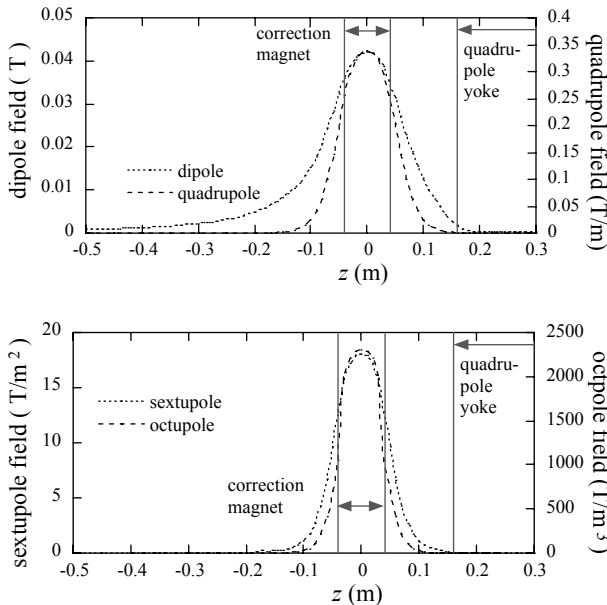

Fig. 5: Distribution of the field strength of the each element along the beam axis (z).

CONSTRUCTION

Six magnets were under construction. The yoke is a laminated core composed of 0.5 mm thick silicon steel plates. The number of coil turns for the dipole winding was changed from the calculation (129t & 92t) to 126t &

92t because of the space requirement. The re-calculated field distribution contained a skew sextupole component, which was much smaller than the error field guide line. Fig. 6 shows the first magnet assembled to check the geometry.

Fig. 6: The first magnet (not completed). The octupole and quadrupole coils were set in one coil package.

SUMMARY

A multi-element corrector magnet was designed using magnetic field calculations. Three-dimensional calculations using OPERA-3D were used to take into account the effect of interference with a nearby magnetic yoke. The bore radius of 50 mm was required in order to obtain a large enough region of suitable magnetic field. Reductions in the fields of the multi-pole components, caused by the nearby quadrupole yoke, were calculated to be negligibly small. Only the sextupole magnetic field components, produced by the dipole coil windings, were considerably changed by the nearby yoke. Taking this effect into account, the four coil-families designed were capable of independently producing the skew dipole, skew quadrupole, skew sextupole, and the normal octupole field components.

REFERENCES

[1] A. Ando, *et al.*, *Jour. of Synch. Rad.*, vol.5 pp.374-375, 1998.

[2] for example, Y. Shoji, *et al.*, *IEEE Trans. on Appl. Superconductivity*, Vol.14, pp.453-456 (2004).

[3] for example, A. Makarov, *et al.*, *IEEE Trans. on Appl. Superconductivity*, Vol.18, pp.334-33 (2008).

[4] Y. Shoji, S. Hisao, and T. Matsubara, Proc. of 9th European Particle Accelerator Conference, pp.2356-2358 , 2004.

[5] Y. Shoji, "Design of a Multi-Element Corrector Magnet for the Storage Ring NewSUBARU" to be published in I*EEE Trans. on Appl. Superconductivity,* 2010.