DESIGN, FABRICATION, MEASUREMENT, INSTALLATION AND ALIGNMENT OF 2 TYPES OF QUADRUPOLE-SEXTUPOLE COMBINED MAGNETS FOR THE UPGRADE OF THE 1.2 GEV BOOSTER SYNCHROTRON AT TOHOKU UNIVERSITY

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Abstract

The upgrade of the 1.2 GeV booster synchrotron is part of the recovery program from the March 11 2011, Great East Japan Earthquake. The replacement of standard quadrupoles by combined quadrupole-sextupole magnets will tame the head-tail instability by changing the chromaticity from the natural, negative, values to positive values, and prevent the unstable m=0 mode to develop.

In January 2012, Sigmaphi was awarded a contract for the design of 2 kinds of combined magnets and the fabrication of 8 magnets of each type, including rotating coil and Hall probe measurements of every unit. The contract also required disassembly of the old quadrupoles and installation of the new combined magnets, including disassembly/reassembly of the vacuum chambers and fitting with new UHV gaskets. Finally, all the booster magnets, namely 8 dipoles, 4 achromat quadrupoles and the 16 new combined function magnets were to be realigned within ±0.2 mm accuracy by mid-January 2013. The presentation outlines the main steps of the different operations and presents the achievements and results.

DESIGN

A general overview of the status of the project is given in [1] and we concentrate here on the magnets.

Table 1 presents the requirements for the new magnets.

Table 1: Magnet Requirements

Requirement	QSF	QSD
Quadrupole	k=2.01044 m^{-2}	k=2.21750 m^{-2}
Sextupole	2.4 times 4-pole m=4.825061 m^{-3}	3.8 times 4-pole m=8.426508 m^{-3}

Additional requirements are listed below

- Same geometry as old magnets including coil shape and electrical/water connections. Only the pole face may be changed.
- Magnetic centre at ±0.5 mm from mechanical centre in both transverse dimensions
- Alignment error may not be larger than ±0.2 mm
- 1 year from contract to end

All these requirements put together make a very demanding job with little freedom.

Many different designs of such combined magnets can be found in the literature. The extra function is added on top of the main multipole either through pole shaping [2][3], or by using extra coils that superimpose a second multipole [4][5]. By requirement, we must not only adopt the first scheme but we must also abide to the very strong constraint of keeping the magnetic circuit within the yoke shape of the existing magnets.

The pole profile [6] of such a combined function magnet is a superposition of the potentials, hence an equation $kxy+\frac{1}{6}m\left(3x^2y-y^3\right)=\frac{1}{2}kR^2+\frac{1}{6}mR^3$

The field components are summarized in table 2.

Table 2: Field Components

Field component	Bx	By
Quadrupole	ky	kx
Sextupole	mxy	$\frac{1}{2}m\left(x^2-y^2\right)$

Thus, the vertical component in the horizontal plane (y=0) is equal to $B_y = kx+\frac{1}{2}mx^2$

Starting from the above theoretical pole profile with a pole radius of 50 mm and maximum coil current of 700 A we can aim at designing a pole profile that satisfies the requirements. However, as shown below, incompatible symmetries generate differential saturations which prevent required fields to be achieved with the prescribed yoke thickness. The possible m/k ratio was redefined as m/k(QSF) ~ 1.0 (2.4) and m/k(QSD) ~ 1.8 (3.8)

The pink and green rectangles locate the 4 and 6-poles and the matching arrows the resulting field, adding on the right and subtracting on the left.

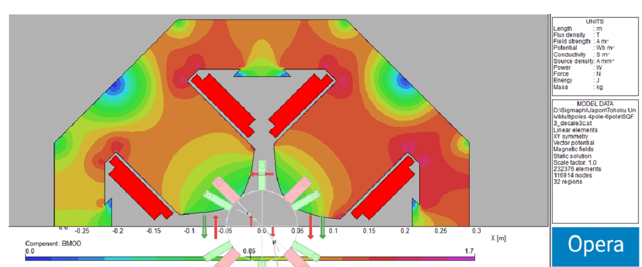

Figure 1: 2d cross-section of a combined magnet showing the strong differential yoke saturation.

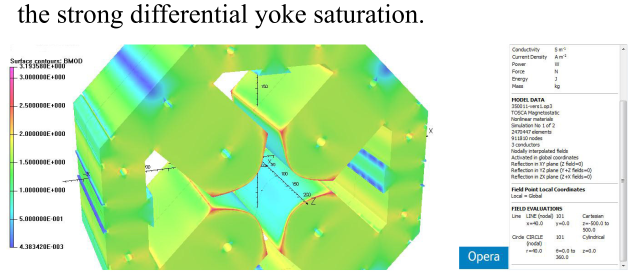

Figure 2: Opera3d model

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MEASUREMENTS

For pure multipoles, iso-modulus lines are concentric circles $\left|B^{(n)}\right| \propto r^{n-1}$ but for combined multipoles, the modulus $\left|B^{(2+3)}\right| = k^2r^2 + \frac{1}{4}m^2r^4 + \frac{1}{2}mx^3$ is not purely radial.

Hall probe measurements are therefore better suited than harmonic coils for some data.

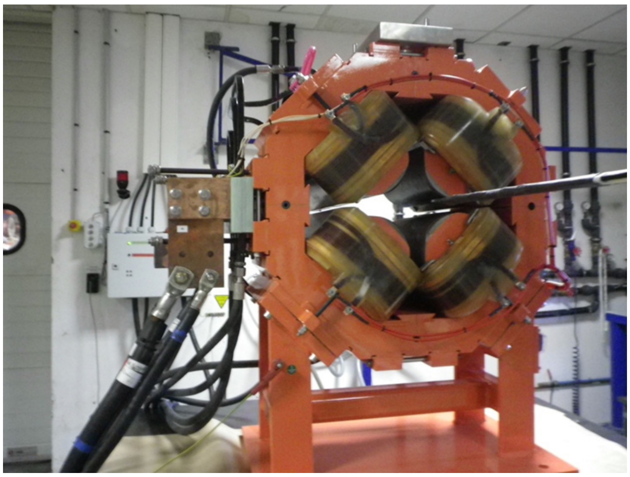

Figure 3: Hall probe median plane measurement.

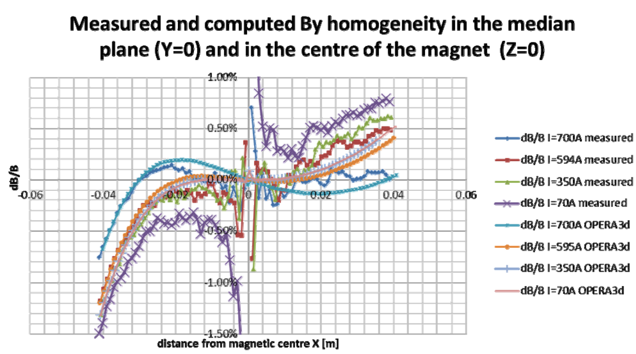

Figure 4: Homogeneity is computed from Hall probe data

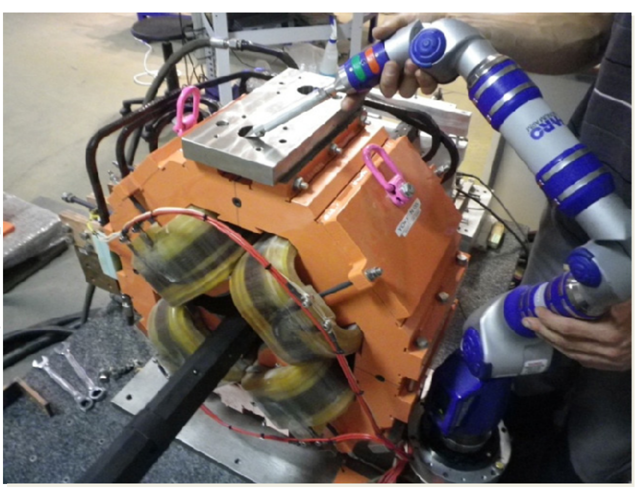

Figure 5: Faro arm fiducialization is performed on the harmonic coil measurement bench.

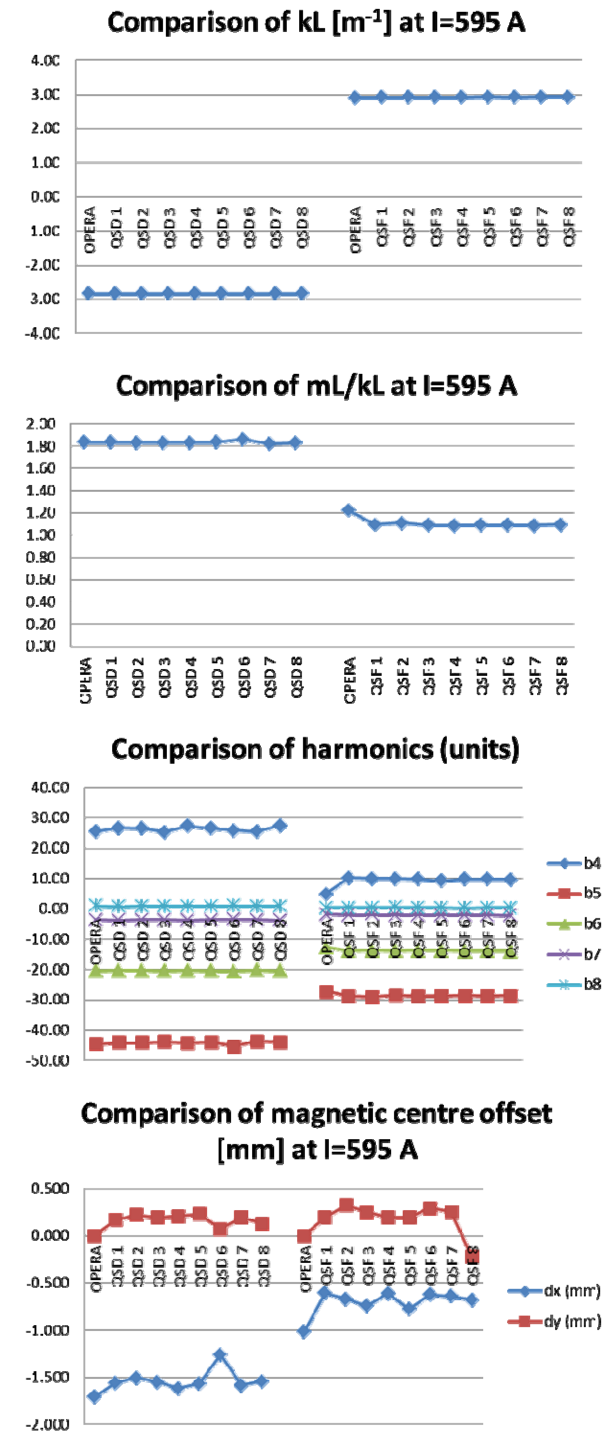

Figure 6: Some of the harmonic coil results showing a good reproducibility between magnets and a good agreement with the Opera3d models.

INSTALLATION AND ALIGNMENT

Replacing magnets in an existing facility is much more complex than installing new magnets in a newly built place since space is usually very crowded as shown in figures 7 below.

Disassembly and storage of the old magnets also required disassembly of the vacuum chambers and replacement of all UHV gaskets after installing the new magnets.

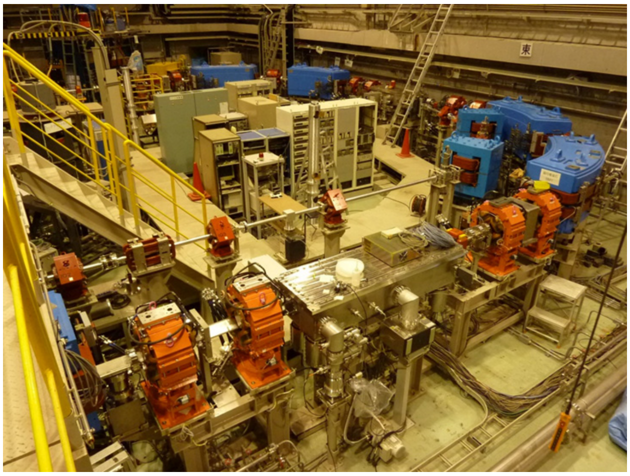

Figure 7: South and East sides with new magnets installed.

Alignment was performed using the following material.

- Tracker: Leica AT401
- Targets: Leica red-Ring Reflector 1.5”
- Monument holders: Hubbs 1.5 TSM M10
- Target holders: Hubbs 1.5 SMN 40mm 25mm outer diameter 46 mm.
- Software: Polyworks IMInspect Probing

Achieved accuracies are shown in figures 8 and 9.

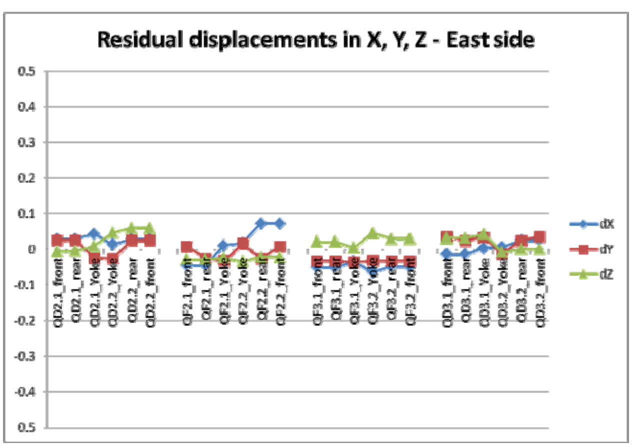

Figure 8: Alignment errors are much smaller than the required ±0.2 mm (East side).

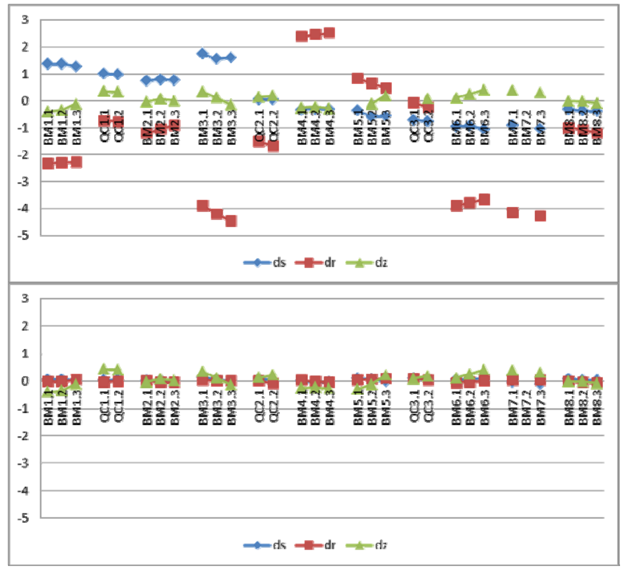

Figure 9: Dipoles and central quads positioning error before and after realignment (mm).

CONCLUSIONS

We have successfully designed, built, measured, installed and aligned 2 types of combined 4+6-poles.

All specifications were met but the integrated sextupole which is impossible to achieve with the prescribed geometry. A new set of possible m/k ratio was redefined.

Besides the 16 new magnets, the contract also included the removal of old quads, change of all UHV gaskets and realignment of all magnets including the 8 big dipoles.

Everything was finished by mid-January 2013, within the 1-year allotted time-schedule.

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