HARMONIC MEASUREMENT AND ADJUSTMENT OF DIAMOND QUADRUPOLES

Christopher Bailey, Neil Marks (Diamond, Oxfordshire), Fred Goldie, Ben Leigh (Tesla Engineering Limited, West Sussex)

Abstract

The 254 quadrupole magnets for Diamond, manufactured by Tesla Engineering Ltd, were measured for harmonic content to a level around 1 part in 10^4. In order to meet the demanding requirements on field quality, procedures were then developed to adjust the relative positions of the magnet quadrants such that the desired harmonic levels were achieved. This process was integrated into the analysis software so that the required changes were specified. The measurements were performed on a seven-coil rotating coil rig, which also enabled the alignment of the magnet in five spatial degrees of freedom to the specified accuracy. In this report we describe the measurement and correction procedures and present a summary of the results that were obtained.

DIAMOND QUADRUPOLES

There are nine different variations of storage ring quadrupoles in the Diamond lattice. These comprise combinations of two different pole widths, three different lengths and four different mechanical supporting arrangements at the horizontal midplane. These variations allow for the passage of the synchrotron radiation beamlines past the magnets. There are four basic combinations of pole width and magnet length giving different nominal magnetic length and good field widths up to r=36 mm. These were treated as separate groups, known as NS, NM, NL and WM, during the measurements.

MEASUREMENT SYSTEM

Mechanical stability and alignment

The Harmonic measuring bench in its original configuration proved to be insufficiently stable for the proposed method of positional measurement. This led to an extensive program reengineering the structure on which the active parts of the bench and magnets are mounted. This eventually settled on using a standard Diamond girder as a mount for all components. Some interface structures were required to lift the coil mounts to the correct height. A hardened version of the mounting surface of a girder had been manufactured for the original implementation, and this was mounted onto the standard girder to reduce the risk of wear to the girder, as all the magnets were mounted on to it at least twice. The key alignment issue was to ensure that the axis of rotation of the harmonic coil was parallel to and directly above the keyway at the specified height. The axis of rotation was surveyed by attaching a target to the outer surface of the coil assembly and taking multiple measurements while the coil was rotated through a full turn. This was repeated close to each coil mount, and the coil axis derived as the centre of the cylinder that passed through these two circles, (see fig 1). The magnets were initially mounted on a standard set of shims for measurement.

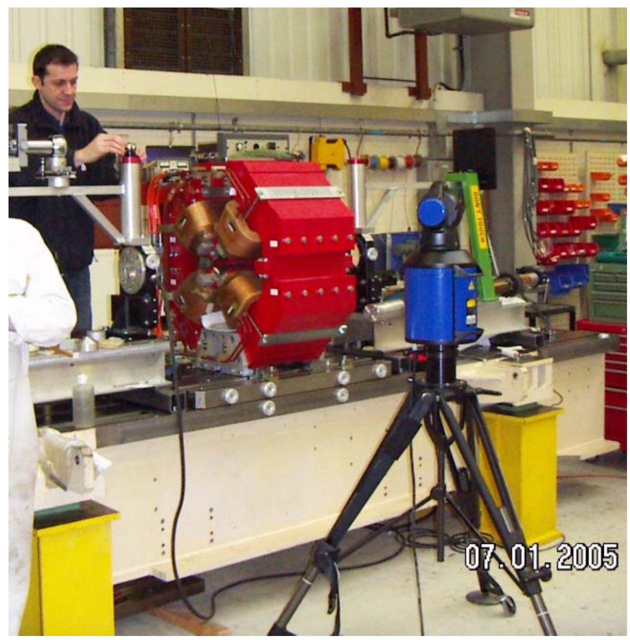

Fig 1 Surveying the rotating coil bench, mounted on a Diamond girder.

Calibration

In order to keep track of any changes to the measuring rig over time a series of repeat measurements of the same magnet was set up. This procedure was also used to re-establish the base orientation of the calculations each time the rotary shaft encoder in the rig had to be refitted.

When repeatedly measured with the compensated coils the largest variation between measurements of any harmonic was 0.3 parts in 10^4. This included measurements with different shaft encoders fitted to the rig. The measured roll angle of the calibration magnet varied in the range of ±0.01° over many weeks as long as the encoder was not moved. Initially this was tracked, but later during the sequence it was just measured to be sure it was still within the expected variation. There was a ±15µm maximum variation in Δy and maximum ±25µm in Δx.

Temperature variations

The measuring rig was set up on the factory floor, which is not a temperature controlled environment. This gave rise to significant concerns that there might be a variation in the calibration of the system with the temperature variation. It was shown that the variation on the centring of the coil in the magnet was only 1.1 μm/°C, which was deemed to be an insignificant effect. The other possibility that the harmonics might be affected by temperature was measured in the variation of harmonics in the calibration series with no convincing correlation seen.

INITIAL HARMONIC VARIATION

The design of the magnet poles meant that the mechanical measurement of the build tolerances was difficult, but the assembled magnets were mechanically measured to be in tolerance. However, when they were measured on the harmonic bench the harmonic variation was significantly larger than expected, given that the build was within mechanical specification.

HARMONIC ADJUSTMENT

Finite element modelling

A detailed half geometry model [1] of the Narrow pole type of magnet was produced, with sufficiently detailed mesh that the spacing between the top and bottom halves of the magnet could be varied by ±50 μm. The field harmonics were extracted from these models and the changes in the octupole strength used to calibrate the anticipated shim and skim sizes required to correct normal octupole. A similar process was started for correcting the sextupole but practical measurements had been made before an adequate mesh was set up to model these small rotations.

Table 1 Modelled harmonic variations, in parts in 10^4, at 25mm, for N type magnet after changes in spacing.

component	-50 μm	nom	50 μm	50μm step
Dipole	0.024	0.021	0.026	0.016
6 -pole	0.000	0.000	0.000	0.003
8 -pole	1.297	0.000	-1.283	-1.290
12-pole	0.227	0.153	0.079	-0.075
16-pole	0.000	0.000	0.000	0.006
20-pole	-0.022	-0.021	-0.020	0.001

Test modifications

On the basis of the calibrations calculated in the modelling an attempt was made to correct the octupole content of one magnet. The effects of this correction agreed reasonably closely with the models. A series of changes to adjust normal sextupole components were then made. Correction of skew sextupole required changing the spacing on the vertical split line in the magnet. Due to the details of the construction of the magnet this was much more difficult to implement. However this gave us the ability to correct normal sextupole, octupole and skew sextupole, which were the main harmonics to be outside the desired tolerances.

Table 2 Measured changes in spacing required to produce changes in the relative harmonic field strengths of 1 part in 10^4, at the reference radius. Sextupole requires only one side changing.

Field Harmonic	Required spacing
Normal Sextupole	60 μm
Skew Sextupole	15 μm
Normal Octupole	38 μm

Practical implementation

In order to enable delivery to proceed in as timely a manner as possible, a system had to be set up to allow decisions concerning whether a magnet needed corrections to be taken a swiftly as possible, and where possible without reference to Diamond, therefore limits for the acceptable harmonics were calculated. These had two levels, one at which the magnet needed correction, and a lower one at which Diamond were to be consulted as to whether the magnet could be accepted.

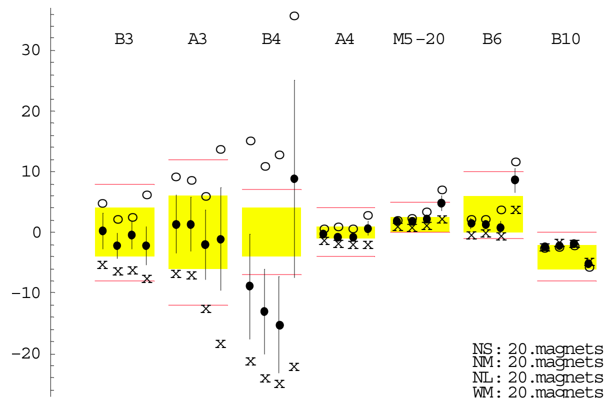

Fig 2 Harmonic Results for 20 worst magnets of each type, as built. See fig 4 for key.

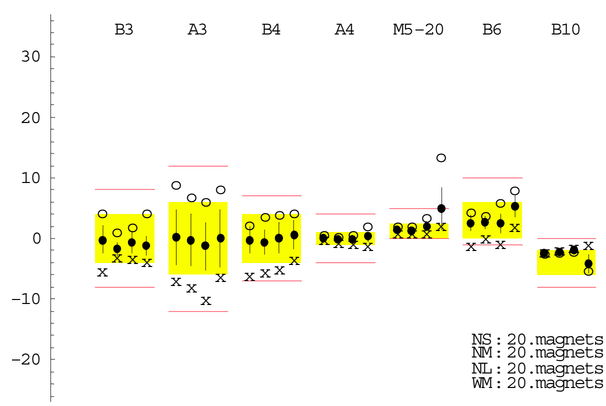

Fig 3 Harmonic results for 20 worst magnets of each type, after correction. See fig 4 for key

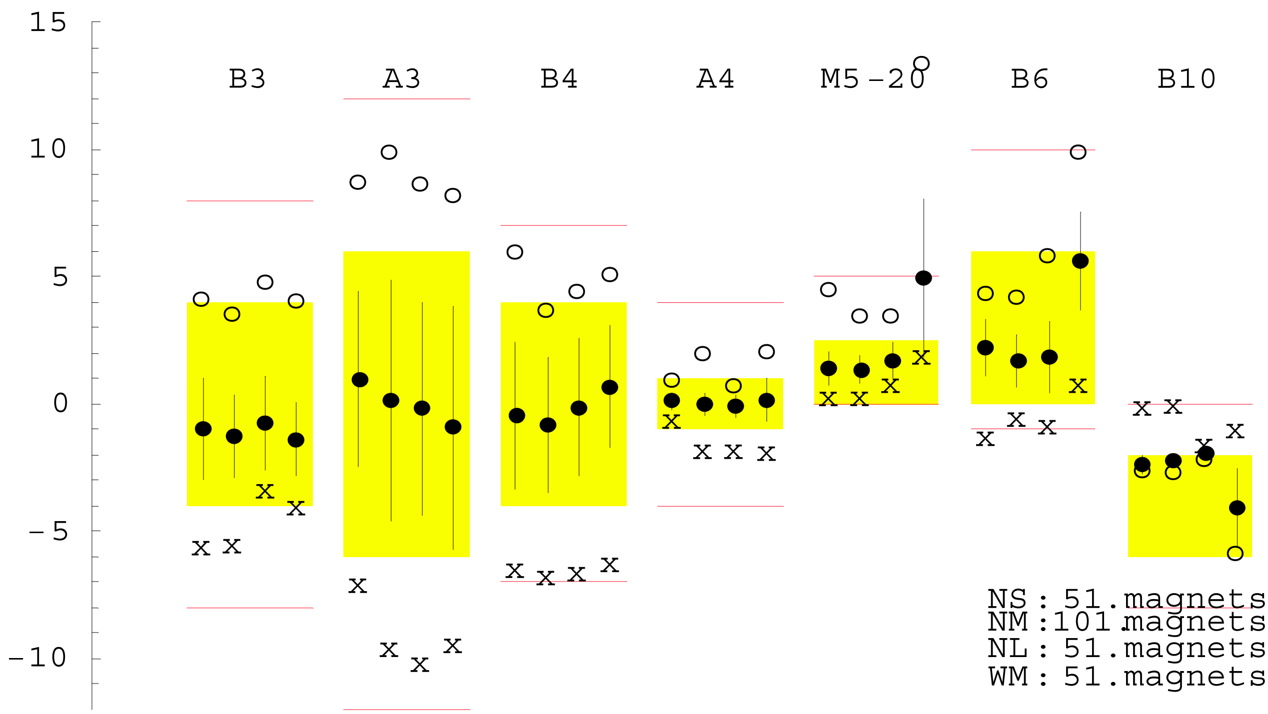

Fig 4 Harmonic results for all magnets, as delivered. The filled circles show the mean value of each parameter, the lines give a ±sigma spread, and the o and x the maximum and minimum value. The filled box is the target ±one sigma range, and the lines the limits. B gives normal and A skew components, 3 sextupole, 4 octupole, M5-20 is sum of magnitude of other components. In each bar 4 types of quadrupoles are plotted. Values calculated at r=25mm for N type magnets and r=36mm for W type magnets.

It was decided that this lower level was the target for the mean plus or minus one sigma variation of each component within the production run for each type of magnets.

Corrections to the normal octupole and sextupole were implemented by changing the thickness of the supports at the split plane. This was done either by machining off the top surface of the supports or by adding mica strips. Practically this was done with a 40µm resolution. The skew sextupole was given a more relaxed limit due to the more difficult correction, following further beam dynamics calculations to evaluate the effects. The analysis software developed for the measurements included indication of which of these conditions had been met and the size of any required corrections. Results shown in figs 2,3,4. The final harmonic range was in specification with the exception sum of harmonics between 5 and 20 in the WM magnets, for which mean + sigma was 8 parts in 10^4.

The shims and skims required to correct the sextupole components are very large, which suggests that the changes applied are not corrections of the errors that produce the effect but balancing changes. The octupole changes match the finite element modelled variations well indicating that they are corrections.

MAGNETIC ALIGNMENT

The seven coil system allows 6 parameter magnet position and orientation data to be extracted from the measurements, though the dz, along the beam axis, data was only used to ensure that the magnet had been positioned accurately on the rig.

The position and orientation data was used to calculate the appropriate vertical shim and horizontal key sizes to achieve optimal positioning of the magnetic axis. Maximum allowable deviations were specified, and keys and shims selected from a standard range to achieve the tolerance. These are of course all coupled, so it is the complete combination that specifies position.

Table 3 Final position and angle deviations

Parameter	Mean value	Standard deviation
dx (µm)	2.4	22.6
dy (µm)	-3.8	17.0
Roll (µRad)	-1.5	77.6
Pitch (µRad)	-18.1	122.5
Yaw (µRad)	2.5	84.2

CONCLUSION

Following correction the harmonic errors for all magnets were within the tolerance, and the alignment in position and angle for all magnets is as specified.

REFERENCES

[1] Vector fields opera 2d