HOT/COLD-SIDE CHARACTERIZATION OF ASYMMETRIC UNDULATOR MAGNETS

F.-J. Börgermann, VACUUMSCHMELZE GmbH & Co KG, Hanau, Germany
S. Marks. LBNL, Berkeley, California, USA

Abstract

The homogeneity of permanent magnets for use in undulators is predominantly described by small variations in remanence (± 1%) and magnetic angles (± 1°). The definition and measurement of the so-called hot/cold-side-effect has proven to be useful as characterization of higher order variations of the local magnetic moment. Values lie typically in a range of ± 2% or less and are symmetric about zero. In a batch of magnets for a new elliptical polarized undulator (EPU) at LBNL, we found an asymmetric distribution for this hot/cold-side-effect. In this paper, we present a theoretical model which can explain these asymmetries on basis of the non-symmetric geometrical cut-outs of the magnet.

INTRODUCTION

Applications using permanent magnets to control charged particle trajectories require a high degree of homogeneity of all Cartesian components of the magnetic moment in order to achieve optimal performance. Vacuumschmelze GmbH & Co KG (VAC) as a material producer has taken significant steps forward on this approach during past years (2004 – 2007) based on a research collaboration with DESY and BESSY in a project funded by the German ministry of education and research (BMBF) [1]. Thus, in the last years we were able to provide magnets with typically less than 1% remanence distribution and less than 1° angular error even for a lot of large scale undulator projects.

For such homogeneous magnets with already small remaining errors in the dipole moment, the higher order effects or near field effects come closer into focus as they contribute to the horizontal and vertical field integrals.

Various strategies of single magnet or module characterization of the near-field behaviour of the magnets have been described and are in use for at least a pre-sorting of magnets in order to reduce the shimming efforts [2, 3].

Besides these detailed, but time-consuming methods, a first indication of such "finger-prints" of residual inhomogeneities is given by the so-called hot/cold-side effect. It is measured by a Hall-probe at a defined distance (typically the half width of the undulator gap) from both pole faces of an individual magnet.

For standard undulator magnets, this value is intended to be as small as possible and typically lies in ranges of ±2 % or less. The distribution normally is symmetrical about zero.

EPU UNDULATOR MAGNETS FOR LBNL

At LBNL, a new undulator for the Advanced Light Source (ALS) was designed as an elliptical polarizing undulator (EPU) consisting of rectangular shaped magnets assembled on individual keepers before fixture to the girder.

Geometry of the Magnets

The magnet design of LBNL'S EPU magnets is based on an already proven mechanical design. The rectangular permanent magnet cross section has a small rectangular cut-out on the inner bottom face (for fixture at a guiding rail on the aluminium keepers) and a slit of several millimetres depth on the diagonal opposite face, but still below the top face. The magnets are fixed to the keeper by simple flat clamps extending into this slit. From the manufacturers view, these slits are not the simplest geometry for fixture of the magnets, but can be produced without risk of damage or potential hairline cracks at least for NdFeB-permanent magnets (Fig. 1).

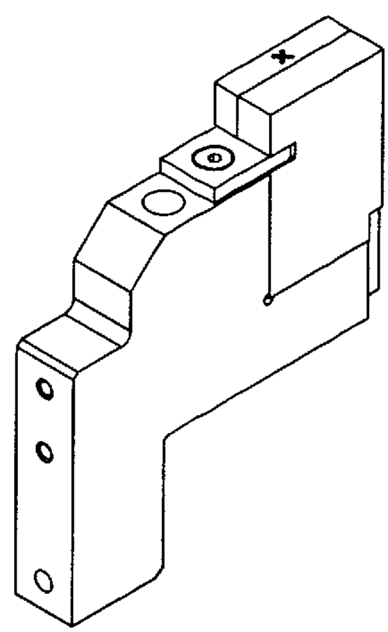

Figure 1: Magnet geometry assembled to the keeper.

Results of Magnetic Measurements

The magnets are specified with a remanence variation of less than ±1 % and angular misalignment of less than ±1 °. In addition, the hot-/cold-side effect measured at a distance of 5 mm from the pole faces was expected to be less than ±2 %.

The distribution of the measured results of the production lot of A-type magnets is given in Fig. 2.

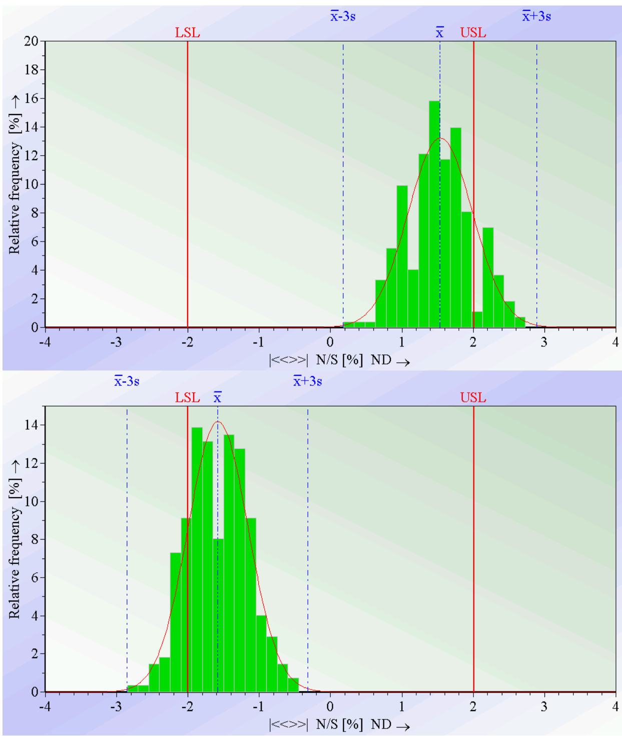

Figure 2: Distribution of hot-cold-side measurements "N/S" for magnets A1 (top) and A2 (bottom).

For A-magnets with preferred direction along the longer dimension (perpendicular to the gap), an unusual result was obtained.

Whereas the distributions of remanence and magnetic misalignment angles are well centred inside the tolerances, the distribution for the hot-/cold-side effect is asymmetric and partially out of the expected tolerance. It is measured as

$$HC[\%] = \frac{|B_N| - |B_S|}{|B_N| + |B_S|} * 200 \qquad (1)$$

This shift is not attributed to the method of production, as the magnets were prepared as single parts from a pressed block and the machining direction is chosen randomly relative to the pressing orientation. Moreover, the sign of the shift changes between the A1 and A2 magnets; for A1 with S-pole on the top face it is positive, for A2 with N-pole on the top face it is negative. Thus, the shift of the distribution depends on the sign of magnetization only. This means, that the bottom face, or face closest to the beam, is the "hotter" face in both cases.

Field Scan Measurements

Hall-probe scans at a measuring distance identical to the hot-/cold-side-measuring distance (in our case: 5 mm) were performed above the top and bottom face of a typical A2-magnet. The results in Fig. 3 and 4 reveal a field profile dropping from a maximum value in all directions. The region with field values close to the maximum is a little bit smaller for the bottom face compared to the measurements above the top face. This may be interpreted as a slight flux concentration in the vicinity of the smaller bottom surface area compared to the larger top surface area. From these measurements, we also found comparable hot-/cold-side values in sign and magnitude as with the single-spot measurements.

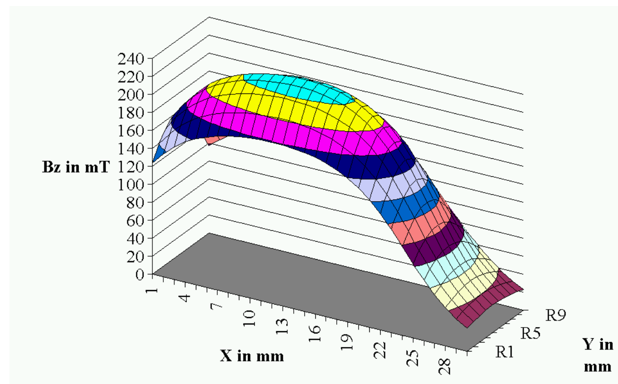

Figure 3: Field scan above the top face of an A2-magnet.

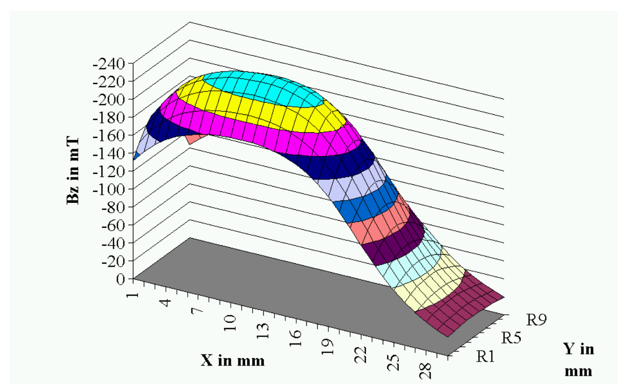

Figure 4: Scan above the bottom face of an A2-magnet.

THEORETICAL MODEL

This behaviour is not known from other, in general more symmetric, EPU- or planar undulator magnet designs and may be explained by the geometrical asymmetries of the actual magnet design. Whereas planar magnets most often are designed with chamfered or rectangular cut-outs for mechanical clamping on 4 corners, most other EPU-magnets have 2 rectangular cut-outs along one diagonal of the large face.

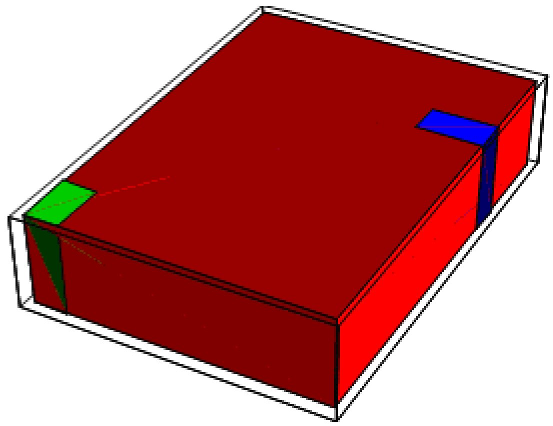

Figure 5: Calculation model for the LBNL magnet. Main magnet as rectangular parallelepiped (red) with cut-outs (green and blue) in opposite magnetization direction.

Locally, this situation is also asymmetric, but globally it does not prefer the top or bottom face.

For the LBNL-design, however, the bottom cut-out and the slit close to the top surface impose a clear geometric asymmetry, which causes asymmetries in the near field as calculated from simple analytical permanent magnet models or with the use of RADIA [4].

One easy approach for such a model is the superposition of the real magnet (red) from an ideal rectangular parallelepiped (circumscribing all partial blocks) with nominal magnetization and two smaller magnets (green, blue) at the position of the corner cut-out and the slit, both with opposite magnetization (see Fig. 5).

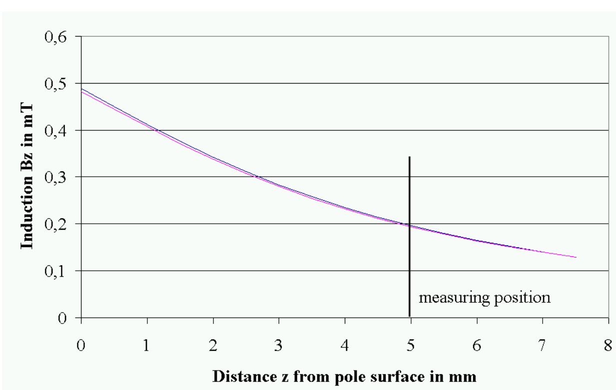

Figure 6: Induction above the pole faces of an A2-magnet.

Calculating the magnetic induction (flux density) along the axis of this “assembly”, (Fig. 6) we find a larger field value at nominal measuring distance from the (smaller) bottom surface and a smaller value at the same distance from the (larger) top surface. The relative values at both measuring position for the real magnet lead to a hot-/cold-side value for the ideal magnet model of NS = -1.2% for the N-pole at the top face or NS = +1.2% for the S-pole on the top face.

These values are in close coincidence with the median values of the measured hot/cold-side-effect results on the production lot (Fig. 2).

This indicates that the majority of the systematic shift of the hot/cold-side values is caused by the asymmetric geometry of the magnet and not due to inhomogenieties of the magnets.

CONCLUSION

For symmetrical magnet designs, the hot-/cold-side characterisation by a simple two-point Hall-probe measurement provides a good indication of residual inhomogeneities in the near field behaviour. The detailed characteristic (fingerprint) may be evaluated by existing sophisticated, but time-consuming wire-scan measurements or comparable methods [2].

In the case of geometrically asymmetric designs, however, special care has to be taken in the interpretation of hot-/cold-side results, as already the theoretical, ideal magnet with asymmetric geometry will lead to a non-zero hot-/cold-side reading.

On the other hand, given a proper interpretation by our analytical model, we may predict the theoretical shift for the ideal magnet and thus redefine the tolerances band symmetrically about the shifted value in order to characterize the real population. With this interpretation, all of the magnets produced for LBNL lie in a narrow but shifted range of less than ± 1%.

With this interpretation in mind, hot-/cold-side effect measurements are a precise and (from a manufacturer’s view) fast characterization method for residual inhomogeneities.

REFERENCES

[1] F.-J. Börgermann, R. Blank, G.W. Reppel, J. Bahrdt, J. Pflüger, “Improved Homogeneity of Permanent Magnets for Undulators and Wigglers”, Proceedings of the EPAC 2008, Genua, Italy, (2008) p2234-2236.

[2] J. Bahrdt, “Magnetic Measurements of APPLE II Type Undulators”, IMMW12, 2001, Grenoble

[3] M. Zambelli et. al., “Characterization of Pure Permanent Magnet Blocks For Undulators in 4th Generation Light Sources”, Proceedings of FEL2009, Liverpool, UK (2009)

[4] P. Elleaume, O. Chubar, J. Chavanne, "Computing 3D Magnetic Field from Insertion Devices", proc. of the PAC97 Conference May 1997, p.3509-3511