IMPROVED HOMOGENEITY OF PERMANENT MAGNETS FOR UNDULATORS AND WIGGLERS +

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Abstract

The homogeneity of permanent magnets for use in undulators and wigglers was significantly improved in close collaboration between industry and scientific institutes throughout the last three years. Magnets with a variation of remanence of less than +/- 1%, angular errors of +/- 1° and hot-/cold-side effect of +/- 1% can be produced now. A variation of the magnetic angle of less than +/- 0.5 ° is possible for some products. The development was assisted by improved characterization equipment for magnetic dipole moments and magnetic inhomogeneities.

MOTIVATION

Beam guiding applications using permanent magnets for wigglers or undulators have very high demands on the homogeneity, angular errors and hot-/cold side effects of the material. Any deviation from ideal properties will cause extra deflections of the electron beam leading to trajectory and/or phase errors and require extra treatment such as shimming or pole tuning. So far, for commercially available permanent magnets these properties as well as the accuracy of the geometrical dimensions were limited. Therefore a big additional effort was needed to reach final specifications: Magnets were characterized, sorted according to their measured errors and finally sophisticated shimming and/or tuning procedures were applied to obtain the optimum performance of the wiggler or undulator. More perfect permanent magnet material would have a big impact and eventually simplify the whole manufacturing process of insertion devices considerably.

There is another aspect: Large projects such as the European XFEL currently under construction in Hamburg [1] require very large quantities of high quality material with very homogeneous properties. These quantities are well beyond standard production batch sizes. For example for the SASE2 system for the XFEL requires about 10 tons of such material. This is well above the present production batch size of ≈ 2 tons.

In order to improve permanent magnet properties a research project was launched and funded by the German ministry of education and research (BMBF). It was a joint project between Vacuumschmelze GmbH & Co KG, Hanau, DESY, Hamburg and BESSY, Berlin.

The most relevant results for applications in wigglers and undulators applications are presented in this paper.

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STEPS TOWARDS MORE HOMOGENEOUS MAGNETS

The aspects of homogeneity of magnets may be divided into mechanical properties (dimensions, volume, rectangularity), global/integral magnetic properties (remanence, magnetic moment, angular deviation) and local magnetic properties (hot-/cold-side effect). These properties were investigated and improved in several work packages. Table 1 gives an overview over the state of the art in 2004, the objectives of the project and the actually achieved values.

Table 1: improvement of characteristics

	Status 2004	**targets**	**Final status 2007 *)**
Variation of absolute Remanence: - from batch to batch	± 3 %	± 0.5 %	n.a. for 10 t batches
- inside a batch	± 2 %	± 0.5 %	± 0.4 %
Angular misalignment of magnetization	± 1.5 °	± 0.2 °	± 0.5 °
Hot-/Cold-side effect	± 5 %	± 0.5 %	± 1 %
Mechanical tolerances	± 50 µm	± 10 µm	± 25 µm

*) achieved in single lots, not simultaneous in all cases

Powder and Sinter Technology

The remanence of permanent magnets is dominantly influenced by its chemical composition, its sinter density and the degree of orientation of the individual powder grains. Given a close control of the chemical composition, the full material density may be controlled by an optimized sinter process. The orientation of grains is strongly influenced by the pressing procedure (see below). Thus, inside a single batch, the remanence may be controlled to a narrow variance. If the amount of magnet material exceeds several tons, for example as requested for the XFEL project, a powder-blending method was developed. It allows to adjust a stable remanence level by combining a set of several powder batches (Fig. 1).

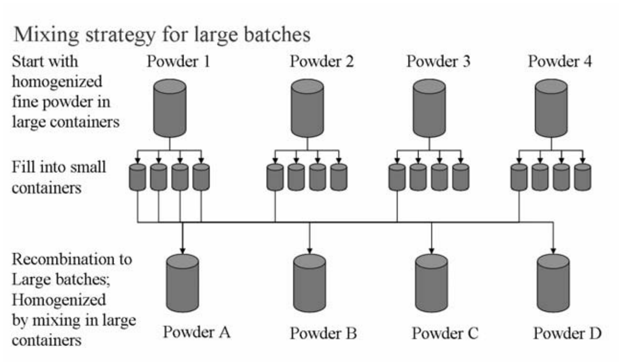

Figure 1: Powder blending method for large lots.

Pressing Technology

Magnets for wigglers and undulators are mainly produced by either the transverse die pressing (TP) or the axial die pressing (AP) method (Fig. 2).

The alignment of the powder particles throughout the pressing process is the determining factor of both the total remanence and its local homogeneity, because these orientations are conserved in the sintering process.

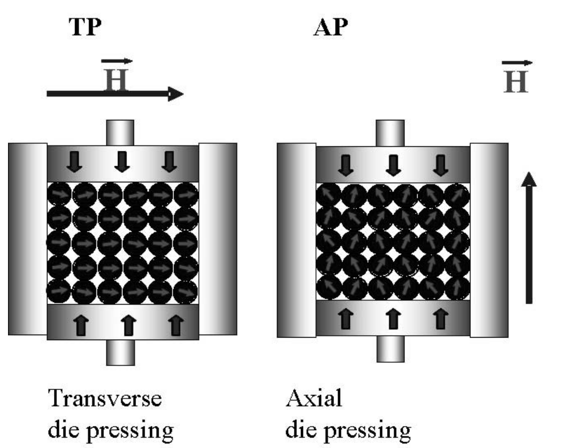

Figure 2: Pressing methods for undulator magnets

For TP magnets an optimized orientation coil and transverse field yoke was built, which significantly improves the local orientation of the powder particles, increases the remanence of the magnets and reduces the variation simultaneously.

Several methods exist for the preparation of the final block from pressed and sintered raw blocks (Fig. 3).

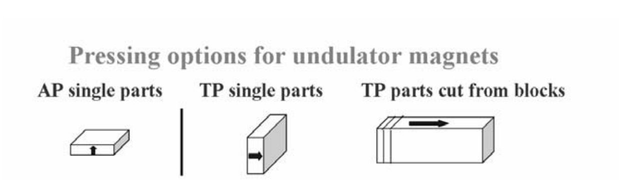

Figure 3: Preparation of final magnets from pressed blocks

The best results are obtained for magnets, whose final shapes are close to the pressed shape. In this case, only one single magnet per pressed block is prepared. This method, however, is economically available only for a small range of aspect ratios between length, width and thickness of the magnets.

Similar results may be achieved by axial die pressing. For one of the XFEL-prototypes magnets with angular deviations of less than 0.5° were produced by this method (Fig. 4). In this case, the control of the hot-/cold-side effect is more complicated. The results show, however, quite narrow distributions. For AP magnets a slightly reduced average value of the remanence has to be taken into account.

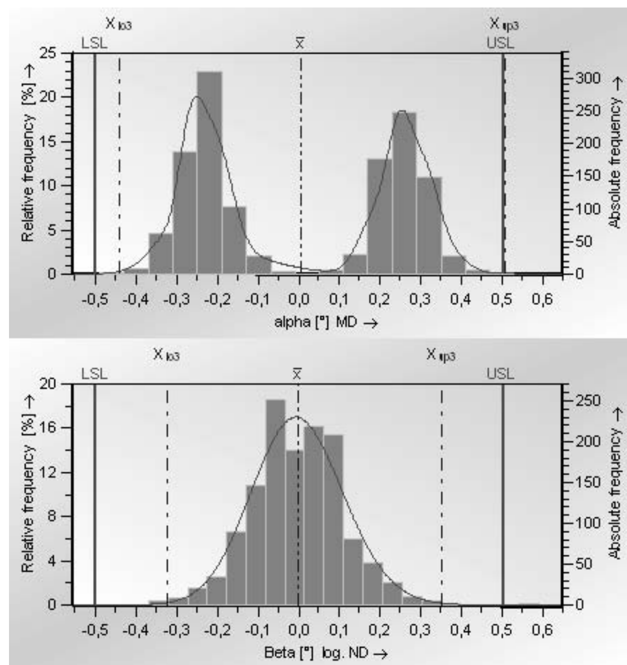

Figure 4: Distribution of angular misalignments for DESY XFEL prototype magnets

A third method is to cut several thin magnets slices out of a long pressed block. This method was improved as well and has the potential to yield a small distribution of angular errors (i.e. less than 1°) with a moderate variation of hot-/cold-side effect. For the results of Fig. 5 several individual magnets were cut as slices from a long pressed block. The hot-/cold-side effect is measured by a Hall-probe at a defined measuring distance and expressed as percentage of the difference between the absolute values on the North- and South pole as percentage of difference of the induction This figure of merit varies strongly with the position of the individual magnet inside the block (x-axis in mm) and with the measuring distance of the Hall-probe.

Thus, the relative importance of the main magnetic characteristics: remanence, angular deviation and hot-/cold-side effect play an important role in the proper choice of the optimum pressing and preparation method.

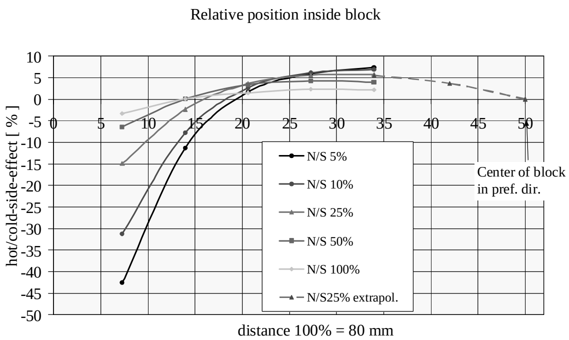

Figure 5: Hot-/Cold-side effect: dependency from measurement distance and position in raw block

Mechanical Finishing

The final mechanical machining of the permanent magnets does not only influence the assembly procedure (angularity, parallelism) but also the overall volume and thus the total magnetic moment variation of the magnets. Additionally, the grinding and slicing process may introduce systematic errors in the alignment of the geometric and magnetic axes. An improved slicing method was developed for a more precise control of this angular alignment.

Due to the granular structure of the sintered material, however, in most cases the final tolerances may only be achieved with a tolerance of ≥ 20 µm. This will set a limit to the volume variation and thus variation of the magnetic moment especially for very small magnets.

Measurement Technology

The improved homogeneity of the magnetic properties and the reduction of variation require improved measurement equipment with higher resolution.

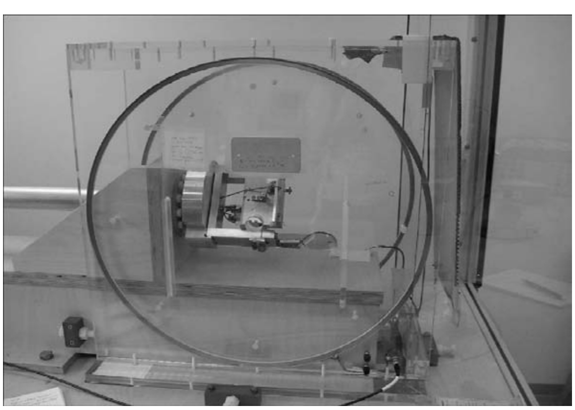

Figure 6: Automated Helmholtz coil [2]

For this purpose, an automated Helmholtz coil system was built [2] (see Fig. 6). This unit allows the determination of the three components Mx, My, Mz of the integral magnetic moment with a typical resolution of better than 0.1%.

Remaining local fluctuations can be detected precisely by moving a single magnet or a magnet pair along a fixed short wire measuring the induced voltage [3]. An improved measurement system (Fig. 7) with a higher signal to noise ratio was built by BESSY and tested in industrial environment. The new wire-scan unit may resolve horizontal and vertical field integrals with a reproducibility of better than $2*10^{-4}$ T*mm.

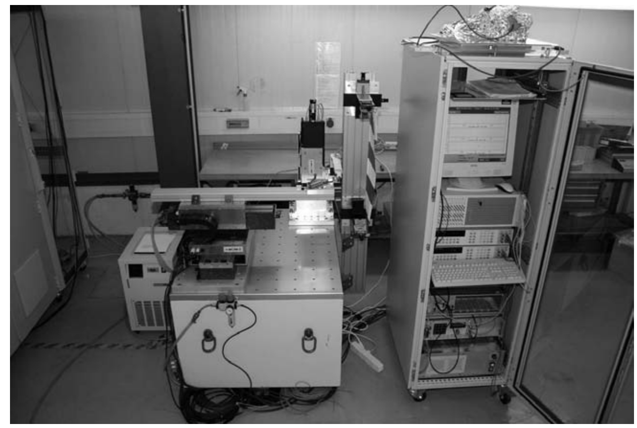

Figure 7: New wire-scan-unit

CONCLUSIONS

In a joint research project the production process for permanent magnets for use in wigglers and undulators has been improved. Magnets with improved properties are now available.

The variation of remanence has been reduced to less than ± 1%. Angular deviations of the magnetic moment from the main axis (angles Alpha and Beta) may be reduced to less than ± 1° or even to less than ± 0.5° in special cases, and thus are close to measurement resolution for the global magnetic properties. The hot-/cold-side effect as measured with a Hall probe is a first indication of remaining inhomogeneities inside a magnet block. It also has been drastically reduced from more than 5% to less than 1%. However it is strongly dependent on the defined measurement distance.

The high accuracy of local field integrals as measured with a new wire-scan system gives detailed information on the spatial distribution of the inhomogeneities.

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