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Magnetisation Inhomogeneities and Sorting

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MAGNETISATION INHOMOGENITIES and SORTING

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Homogenous and 16 sub-block models are used in modelling three permanent magnet sets and the modelling results (one homogeneous and two 16 sub-block modelling) are used in sorting. The field predictions and measurements show that the 16 sub-block model assures successful final tuning of a planar hybrid undulator. Because of the limited space for the shims the homogeneous model may lead in a difficult tuning task, if the sorting is based only on integral values of the magnetisation of such magnets that are manufactured by isostatic compression.

1. INTRODUCTION

This article presents different aspects of magnet sorting when it is based on magnet modelling. It is a summary of experiences gained at VTT Automation when using two different types of magnet models in sorting permanent magnets for two types of hybrid insertion devices (ID) for MAXII in Sweden and DELTA in Germany. The paper briefly explains the used methods and then concentrates on the benefits and experiences we have got using modelling. Visions for future improvements are also put forward. Additionally I will touch on subjects that should be studied to improve sorting.

2. TWO DIFFERENT APPROACHES TO SORT

In principle it is always possible to avoid magnet modelling by measuring the flux density generated by the single magnets on line equivalent to the optical axis of the ID and using the results directly in sorting. For conventional pure-magnet devices this is an appropriate method. If there is ferromagnetic material near the optical axis of the ID, as in the case of hybrid devices, this would need a rather complicated measuring devise. The device should comprise a large enough number of dummy poles and a mechanism for insertion of the magnet into and removal of it from a pole-slot. For pure-magnet devices the modelling may also become preferable if the geometry of the device is such that one magnet can be located in many positions in proportion to the electron beam. This is the case for example if sorting is to be done simultaneously over a range of gaps. If we assume that both methods of sorting produce same results, the choice of method can be based on tradition or personal reasons. This choice may also be influenced by secondary considerations, for example using modelling increases the understanding of the magnetisation inhomogeneties present in permanent magnets. And after all it may also be possible to leave sorting completely out.

3. METHDOS USED AT VTT AUTOMATION

VTT Automation we found it necessary to rely on sorting and modelling of magnets in the construction of hybrid devices where few or a single solid magnet are set in a pole-slot, and magnets manufactured by isostatic pressing are employed. At first magnets were modelled as homogeneously magnetised where the direction and strength of the polarisation was extracted from Helmholtz-coil measurements. The homogeneous model was developed further so that one magnet block was assumed to consist of 16 autonomous homogeneously magnetised sub-blocks. The polarisation vectors of the sub-blocks were fitted to minimise the difference between calculated and measured flux density close to the magnet. The points were taken at 2 mm distance from a magnet surface on six lines on both sides of the block, altogether 186 points for each magnet (fig. 1).

4. DEVELOPMENT OF THE 16-SUB-BLOCK MODEL

The first ID where the sorting was applied was a multipole wiggler (W17.4, 27 full-field poles). In this devise 6 different magnets are in contact with each pole. The homogeneous model was used in modelling and sorting was performed to minimise first integral of the field. The resulting integrals were not as good as expected but neither dramatically bad. The second device was an undulator (U6.6, 77). The used sorting for this devise was about the same as for the wiggler but the measured integrals deviated from predictions far more than in the wiggler case. After a frustrating search for a simple reason (bug in the modelling or sorting code, an effect of a magnetic carriage,...) we came to the conclusion that the reason for the poor predictability of the field was shortcoming of the model we had used to describe the magnets. Because of a tight construction schedule the existing sorting procedure was still used for the next undulator (U5.2, 99), but additionally field in the vicinity of magnet block surfaces was measured as described in fig. 1 for subsequent studies and model development. The measured unfulator field was also in this case far from the prediction.

After the installation of the U5.2 we started to develop a new magnet model for our purposes. It is based on the analytical expressions for the field generated by straight angle magnet blocks published by Maréchal, Chavanne and Elleaume at ESRF in 1990 [1]. When using genetic algorithm in optimisation problems involving fields it is (for some reason) favorable to use a small population, less than 10 individuals. The small population steers the behaviour of the GA into the direction of an other optimisation method called hill climbing [2]. It has been brought forward that the small population goes hand in hand with a relative smoothness of the fitness function - small changes in chromosome make small change in fitness [3]. This means that it is worth at first, before choosing parameters for GA, to test if small random changes make small changes in fitness. An important thing to notice is that the field value at each point is a linear function of the components of the polarisation in each sub block. This makes it possible to use the rather complicated formula of the field at each point only once for each polarisation component and sub-block (the unit polarisation). The optimisation then operates on multipliers of the polarisation. The optimisation of these coefficients can be done with many other methods than the GA. We use GA for historical reasons and we use it also in sorting, phase shimming and shimming of the field integrals in the dynamic aperture.

We tried to keep the number of sub-blocks low and thought that the magnet area that is in direct contact with poles could be a single area. Anyhow it came clear that this central area had to be divided in to smaller sub-blocks to achieve reasonable result in modelling in air. Optimisation tests also showed that Helmhotz-measurements are practically worthless for this modelling. If the optimisation was started from a measured specific value of the total polarisation it did not improve the speed of optimisation compared to a starting it from some artificial, typical value.

5. MODELLING RESULTS

The field of U5.2, calculated from the16 sub-block model, was tremendously different from the precious one. The new numerical field reproduced most of the features that were characteristic in the measured field. This is visualised in figure 2 where there are three graphs of the first integrals on pole positions of the U5.2 derived from measured field values from the homogeneous model and from 16-sub-block model.

From the first integral values of the measurements of the IDs that where sorted with the homogeneous model, we can conclude that fluctuations in polarisation that are important are not only in the amplitude of the polarisation but also in the direction. On the other hand from the field measurements of the blocks we see that local fluctuations exist all over the block. The first integral of the undulator field does not fluctuate around zero, but has large none zero values through many periods. Because the homogeneous model could not predict that feature, we concluded that there often is such a symmetry in the polarisation inhomogeneity – a flower bunch like orientation of the polarisation vectors – that is not seen in Helmholz measurements.

With the homogeneous model the sorting could numerically achieve in a reasonable time a phase-error level below one degree, but when the 16-sub-block model was used the achieved level was above 2 degrees. To get an estimate of the phase-error that would have existed if 16-sub-block model would be used in assembly of U5.2, the difference of the measured and 16-sub-block field values were summed with one of the 16-sub-block sorted fields. This calculation produced a phase-error value of 13 degrees.

The 16-sub-block modelling method was used in sorting of two undulators (U5.87, 87 and U5.5, 93). The modelling of the last magnet batch appeared to be a little bit more difficult than the two earlier ones. That is seen from figure 3 where there are the fitness distributions of the three magnet sets after same number of optimisations. The phase-errors of the measured field values of the 16 sub-block modelled IDs before shimming were 10 degrees and 16 degrees

It is important to notice that sophisticated sorting methods are capable of finding many very good configurations what ever the quality of the magnet batch if there is so many magnets to be used in sorting as it was in these three cases (about 200 magnets). Some information of the quality of the magnet batch is found from the modelling results itself, but the difficulty of the sorting will clarify by looking a distribution of the phase-errors of randomly selected sorts. Distributions of 1000 randomly selected configurations of the three batches we have the data for the 16 sub-block modelling are in figure 4.

6. BENEFITS OF MAGNET MODELLING and FURTHER DEVELOPMENT

Sorting does not remove all the fluctuations in periodicity that result from the local deviations of polarisation. For improvement of the model does not reduce the numerical phase error value of the prediction but on the contrary increases it. In any case, we have to tune the device after assembling the magnets. This means that, most probable any of the logical steps when making undulators can not be avoided by usage of any kind of magnet model, if we use the model only for sorting. But using a better model also for the selection of magnets we may achieve such a sort that virtually no shimming is required.

The figure 4, where the distributions of the phase-errors of 1000 randomly assembled magnets are shown, gives an impression of the relative quality of the three magnet sets at hand. We also can presume that the phase-error of a randomly assembled device would be more than 30 degrees. In our experience, tuning off such a high phase-error requires shims thicker than 1 mm - an acceptable value concerning the magnet circuit. Using 16 sub-block model ensures that there will not be this kind of a problem.

A conclusion from this study is that developing a selection method of magnets for the sort is the next step of this work. Another field of interest where modelling could be used is the development of an isostatic pressing method for making permanent magnets.

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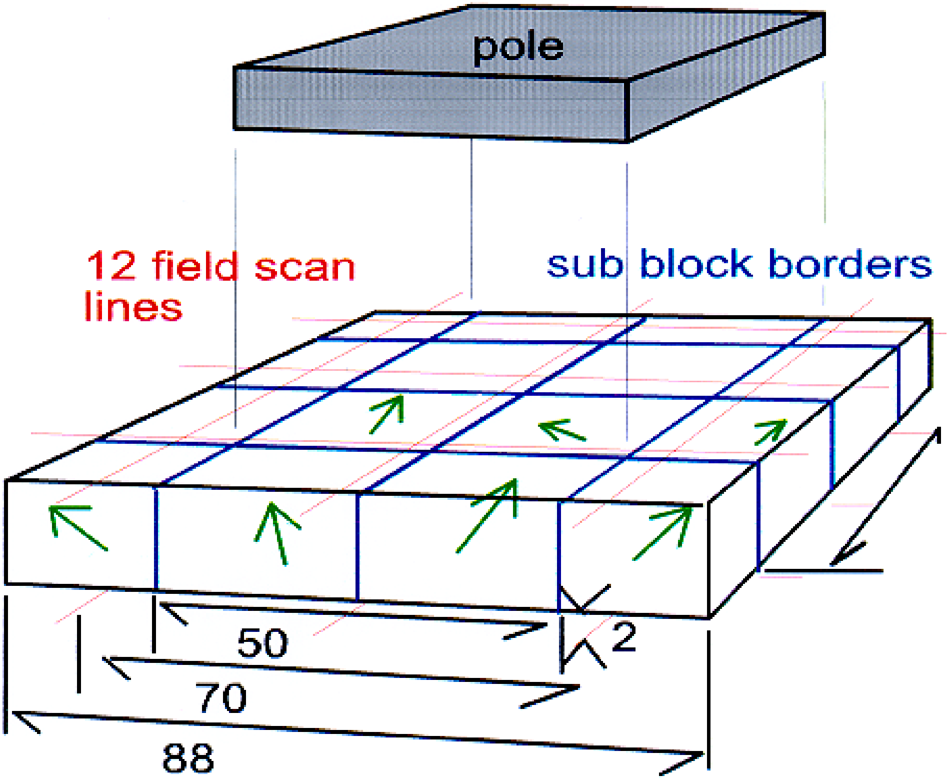

Figure 1. Undulator magnet subdivision and position of the vertical flux density measurements.

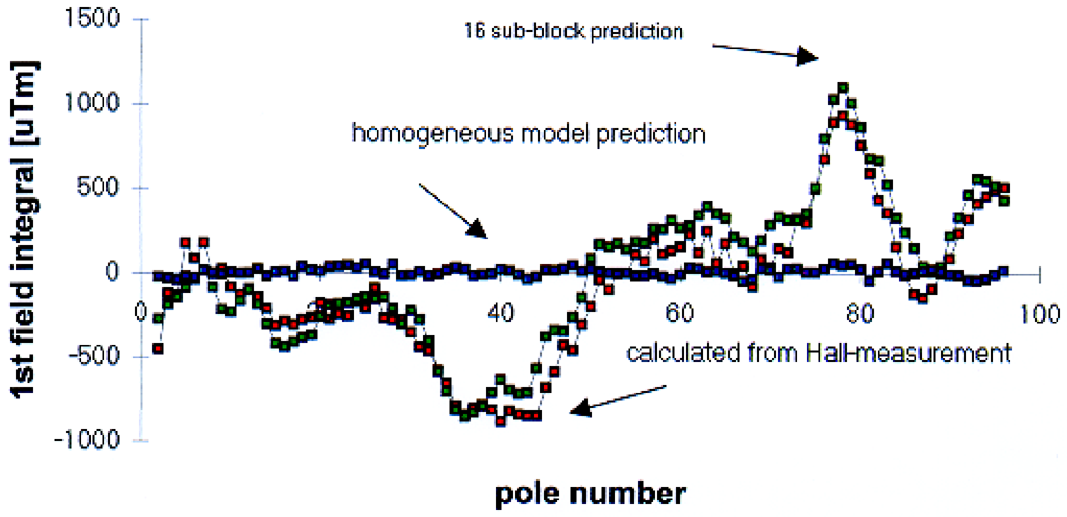

Figure 2. First integrals of the predictions based on the homogeneous and the sub-block model and the measured field.

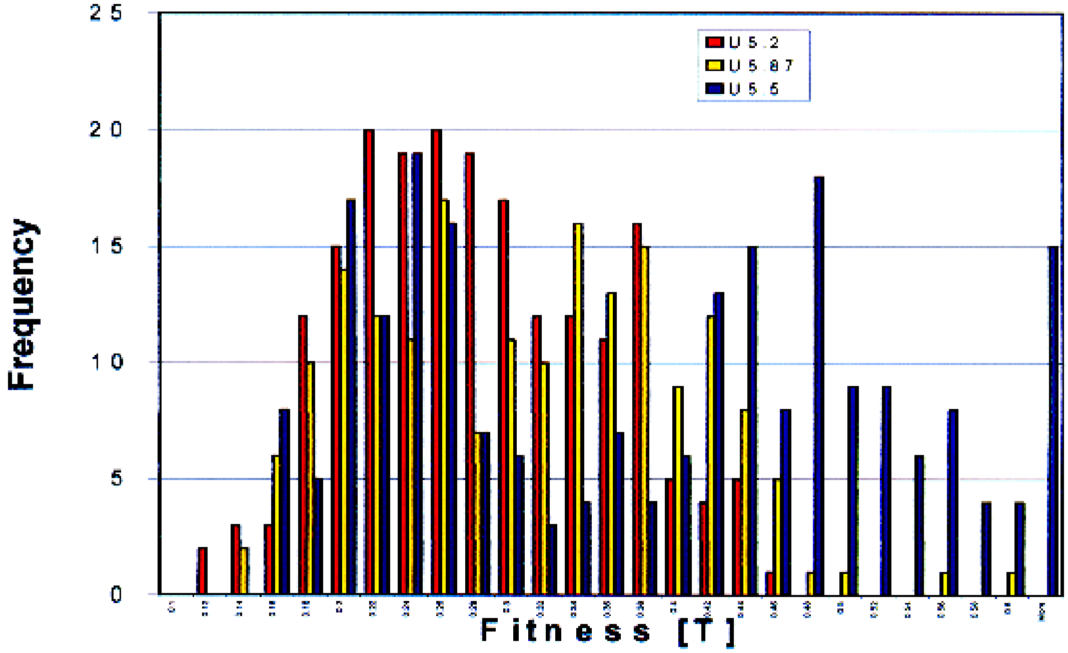

Figure 3. Distributions of the 16 sub-block model fitness of the magnet sets for U5.2, U5.87 and U5.5 after same number of optimisations.

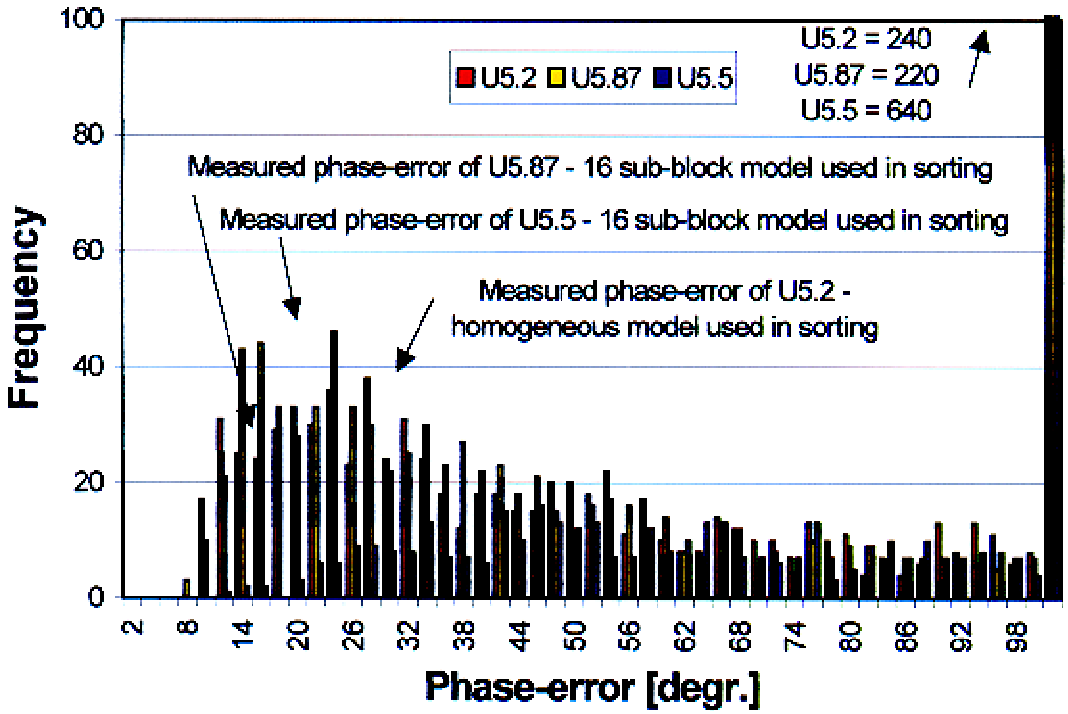

Figure 4. Distributions of the phase-errors of 1000 randomly assembled magnets for U5.2, U5.87 and U5.5