MAGNET BLOCK SORTING FOR VARIABLY POLARISING UNDULATORS

Duncan Scott, ASTeC, Daresbury Laboratory, CCLRC, UK

Abstract

Effective sorting of permanent magnet blocks for undulators can reduce the adverse effects of magnetic in-homogeneities and engineering tolerances on the electron beam. For variably polarising undulators (VPUs) the numbers of different modes of operation make defining the objective function of a particular permutation more difficult than for a planar device. Factors required in defining a good objective function for a new APPLE-II type helical undulator for the SRS are discussed. These factors include calculating the magnetic field integrals, the particle trajectory and rms optical phase error. The effects of different weighting of these functions in the objective function are also discussed. A comparison of different optimisation techniques, including simulated annealing and Monte Carlo methods is also made.

INTRODUCTION

The APPLE-II type VPU was first proposed over ten years ago [1] and since then a number have been built world-wide at laboratories such as the ESRF [2], SSRL [3] and others. There are also a number being constructed at other labs including the SRS [4] and Diamond [5]. Real magnet blocks are not perfectly magnetised. They have errors associated with the direction and magnitude of the magnetic field, as well as in-homogeneities in the magnet blocks. Typically there are engineering tolerances on the dimensions and parallelism of the blocks too. All these factors mean that there is an optimum order in which the blocks should be placed to achieve the "best" undulator. This note will look at ways of quantifying the best order for the magnet blocks in an APPLE-II type undulator.

Optimisation

The process of optimisation for the APPLE-II undulator is simply defined. Each separate order of the magnet blocks defines a point in a configuration space (the space of all possible permutations). At each point in the configuration space there is a merit value defined by the merit function. One of the difficulties in writing a block sorting algorithm for an APPLE-II type undulator is in defining a merit function. Not only are there a huge number of points in the configuration space to consider but there are also several modes of operation of the undulator that have to be accounted for in a merit function. Two separate optimisation techniques will be looked at; one called the Monte-Carlo (MC) method and one based on a simulated annealing (SA) algorithm.

The APPLE-II Undulator Model

The method outlined in this paper has been applied to the new SRS APPLE-II undulator [4]. It will also be applied to the Diamond undulators. The modelling was carried out in Radia [6] using a simplified "square" block shape. Figure 1 shows a schematic of an APPLE-II device and the co-ordinate system used.

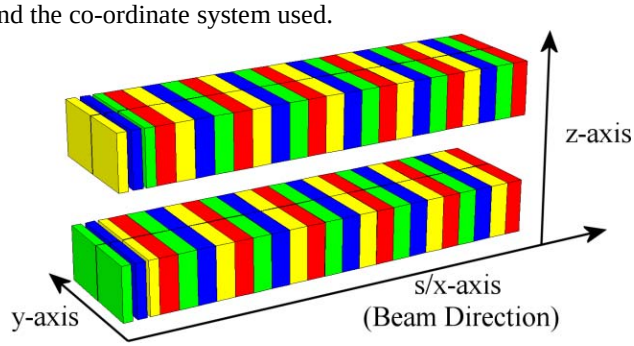

Figure 1: Schematic of APPLE-II and co-ordinates.

BLOCK SWOPPING ALGORITHM

A procedure has been written in Mathematica that imports a set of measured block magnetisations for each component of the magnetic field. These vectors can then be arranged to form an APPLE-type undulator using the Radia code. The magnetic field of this device can then be calculated, on and off axis. From the magnetic field data all contributing factors to the merit function can be calculated. The algorithm can then swop one or more of the blocks in the device (including blocks from a given number of spare blocks) and the merit function is recalculated. The order is then optimised either by a SA or MC algorithm.

MC Algorithm

This is essentially a downhill optimisation process. For a particular block order there is an associated merit value, when blocks are swopped there is a new merit value. If the new merit value was better than the old one then the block swopping is accepted. If the merit value is worse then the block order for the lowest merit value so far achieved is used. The disadvantage of this method is that it will only find a local minimum. However it is simpler to implement than a SA algorithm because there is no need to define a temperature scale.

SA Algorithm

SA algorithms are now widely known and used for magnet sorting. Briefly, the system is said to be at a certain "temperature" and moves to a higher (worse) merit function value are allowed with a probability given by $R < Exp[-\Delta E/T]$, where R is a random number between 0 and 1, T is the temperature of the system and ΔE is the difference between the new and old merit value. Moves to lower merit values are always accepted. Over time (iterations) the temperature is decreased and a solution is "frozen" out. The advantage of this algorithm

is that it can escape from local minima and so more of the configuration space can be explored. Disadvantages are that it can be awkward setting the temperature and rate of temperature decrease. For these simulations the peak temperature was generally set to 2 to 3 times the mean of a range of 1000 random order merit functions values.

DEFINING THE MERIT FUNCTION

The merit function is the weighted sum of a number of components. To understand the components a brief explanation of each is given below. The values are all taken at the minimum gap of the undulator. Which modes each were evaluated for depended upon whether there was any correlation in the results. For example; there was found to be no correlation of the phase errors for horizontal and vertical modes, but the field integrals in those modes were correlated. The terms in square brackets indicate components' abbreviated names.

RMS phase error at poles, σ_ϕ. This is a well known property of the beam trajectory through the device [7] and was calculated for horizontal, vertical and circular polarisation modes [Hσ_ϕ, Vσ_ϕ, Cσ_ϕ].

Final angle of the beam. The final angle was recorded for horizontal polarisation mode only [FA].

'Straightness' range of beam excursion from axis. The range of max. and min. peak displacements from axis for a trajectory calculated from the on axis magnet field was recorded for horizontal polarisation mode [TR].

"Flatness" of the transverse field integrals. The longitudinal field integrals of the transverse components of the magnetic field were calculated at a number of horizontal positions. The "flatness" was defined as the rms distance each value was from a zero gradient ("horizontal") line of best fit (LBF) [FIF].

Intercept of the transverse field integrals. This is simply the intercept of the previous LBF. Figure 2 shows an example field integral calculation. Zero y position is on axis and the blue line is the calculated field integral and the black the LBF [FII].

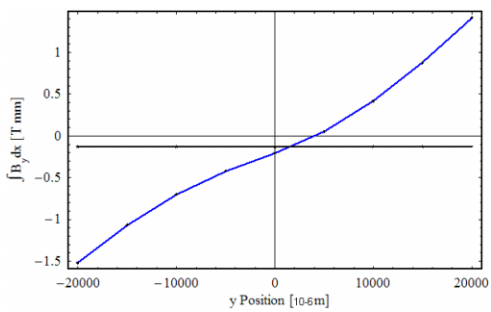

Figure 2: Example field integral data.

Weighting

To give each component an initial equal weighting they were weighted by a mean value calculated from a set of 1000 random block orders. Components were then further weighted depending upon how important they were felt to be or how well they were being optimised.

RESULTS

Tables 1 and 2 give results for 10 000 iterations from different random starts for both algorithms. Typically this took 44 hours of computer time with a 3.2 GHz processor and 2 GB of RAM. The SA algorithm gives a greater % change than the MC one although both arrive at a similar answer.

Table 1: MC results.

Parameter	Start	Finish	% Change
Merit Value	9.1	4.73	48
TR (m)	4.62E-05	3.32E-05	28.08
FA (rad)	3.96E-05	7.29E-06	81.58
By FII (T m)	1.05E-04	4.07E-07	99.61
Bz FII (T m)	2.49E-04	4.75E-05	80.89
By FIF	3.75E-04	3.50E-05	90.67
Bz FIF	1.95E-04	9.74E-06	94.99
Hσ_ϕ (°)	3.28	0.75	77.09
Vσ_ϕ (°)	3.2	0.81	74.56
Cσ_ϕ (°)	4	1.9	52.35

Table 2: SA results.

Parameter	Start	Finish	% Change
Merit Value	14.78	4.19	71.66
TR (m)	1.05E-04	3.29E-05	68.76
FA (rad)	6.62E-05	3.01E-06	95.45
By FII (T m)	4.25E-04	1.35E-06	99.68
Bz FII (T m)	3.72E-04	6.99E-06	98.12
By FIF	5.64E-05	1.26E-05	77.62
Bz FIF	2.32E-04	2.82E-05	87.81
Hσ_ϕ (°)	3.03	1.72	43.28
Vσ_ϕ (°)	2.69	1.59	40.98
Cσ_ϕ (°)	4.76	1.79	62.5

Figures 3 & 4 show the improvement in trajectory for vertical and horizontal modes. Figure 5 gives an example of the improvement in the field integral. The initial value is blue and the optimised value red. All data is for the SA simulation.

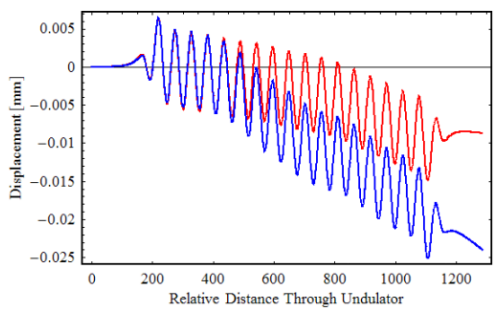

Figure 3: Vertical mode trajectory improvement

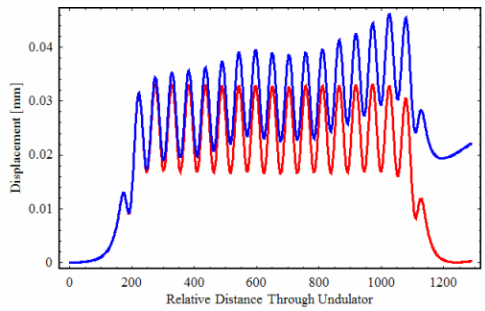

Figure 4: Horizontal mode trajectory improvement

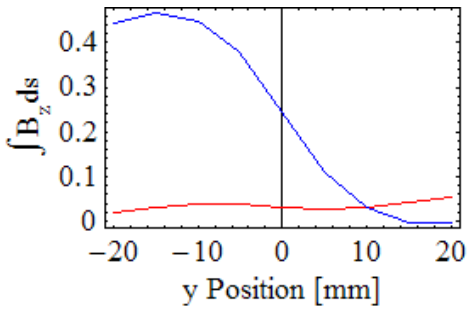

Figure 5: B_z integral improvement

As can be seen, although the vertical mode trajectory has improved it has not optimised as well as the horizontal mode trajectory. For this reason another component was added to the merit function to include the vertical mode trajectory range.

Improved Merit Function Results

With the added component the SA algorithm was run again for 3 000 iterations. The final block order from the previous simulation was used as the starting point. Figures 6 & 7 show the trajectories and integrals.

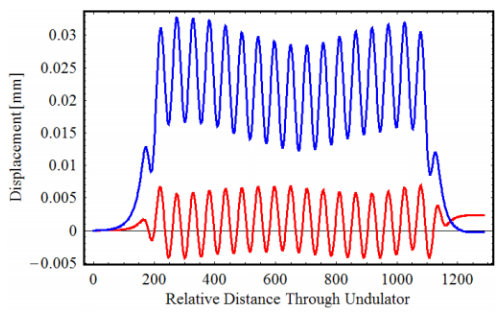

Figure 6: Horizontal (red) and vertical (blue) trajectory.

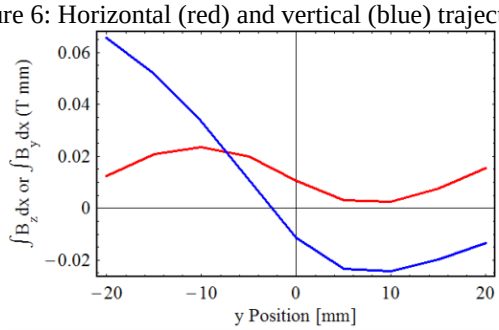

Figure 7: Transverse field integrals Bz (red) By (blue).

Comparison with Measured Field

Figure 8 shows the initial measured magnetic field data compared to the Radia model. Bz is shown for horizontal mode and the gap was 50mm. The datasets are within 2% of each other, which corresponds to the accuracy of Radia [8].

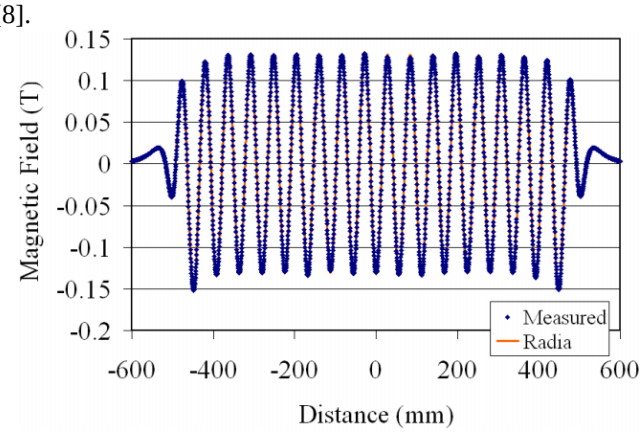

Figure 8: Measured and calculated magnetic field.

CONCLUSIONS & FURTHER WORK

The results show that quite a significant improvement can be made to the electron beam trajectory through the device by changing the block order. By weighting certain factors in the merit function – for example the range of electron beam displacements off axis – they can be selectively improved upon instead of other factors. A minor modification had to be made to the merit function to include the vertical mode trajectory range. In the future a further modification should be made to allow for the true trajectory straightness. Presently only the maximum and minimum values of the electron orbit are considered. This means that a "dip" in the trajectory (as can be seen in Figure 6) can develop with little impact on the merit function. This situation could be improved by taking the co-ordinates of the turning points of the electron trajectory and fitting them to a horizontal straight line. The same could be done in the vertical mode of the device. This will be implemented for the Diamond APPLE-II VPU.

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