HYBRID UNDULATOR TERMINATIONS

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Undulator Magnets (UM) have wide applications ranging from Free Electron Laser to synchrotron radiation sources.

UMs can be realized using Permanent Magnet materials (PM) instead of coils to generate a sinusoidal on axis magnetic field.

Two main different configurations are usually considered namely pure and hybrid configurations. Pure UM uses PM blocks only, arranged in the so called Halbach configuration as it is shown in Fig. 1, where it is also indicated the behaviour of the magnetic

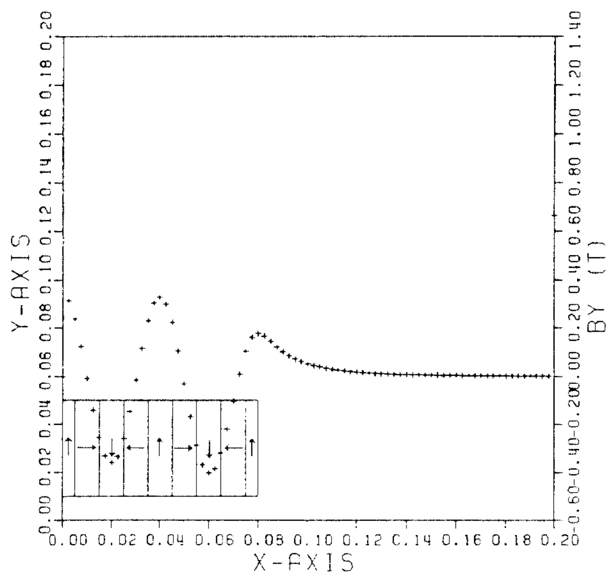

Fig.1 - Behaviour of the vertical magnetic field component at the end of a pure PM undulator. The arrows show the direction of polarization of the PM blocks.

field at the last UM periods. In hybrid UM, PM blocks as well as coils induce magnetic flux in iron poles. In this second case it is necessary to shunt the magnetic flux induced by the iron at the ends of the UM. Therefore the first and the last half periods are anomalous with respect the others. Fig 2a shows one of the possible schemes for the terminations of a hybrid UM. Fig. 2b refers to an unconventional scheme, suggested by K. Halbach, in which rotating cylindrical blocks instead of coils are used in the last half period in order to correct the magnetic field behaviour at the UM end.

A further problem related to both pure and hybrid UM is that of minimizing the first and second longitudinal integrals of the magnetic field, given by the following expressions

$$I_1(s) = \int_{-s}^{s} B_y(s')\,ds'$$

$$I_2(s) = \int_{-s}^{s} ds' \int_{-s'}^{s'} B_y(s'')\,ds''$$

The minimization of sextupolar and in general of multipolar integrated contributions, should be considered but the solution to this problems is out of the scope of this communication, in which infinite polar expansions in the transverse direction are assumed.

In an ideal pure configuration the integrals I_1 and I_2 are automatically zero while in actual cases the remanent field differences among the PM blocks can produce non zero contributions.

The convenience of pure or hybrid choice must be analyzed for any specific applications but in any cases it is strictly related to the range of

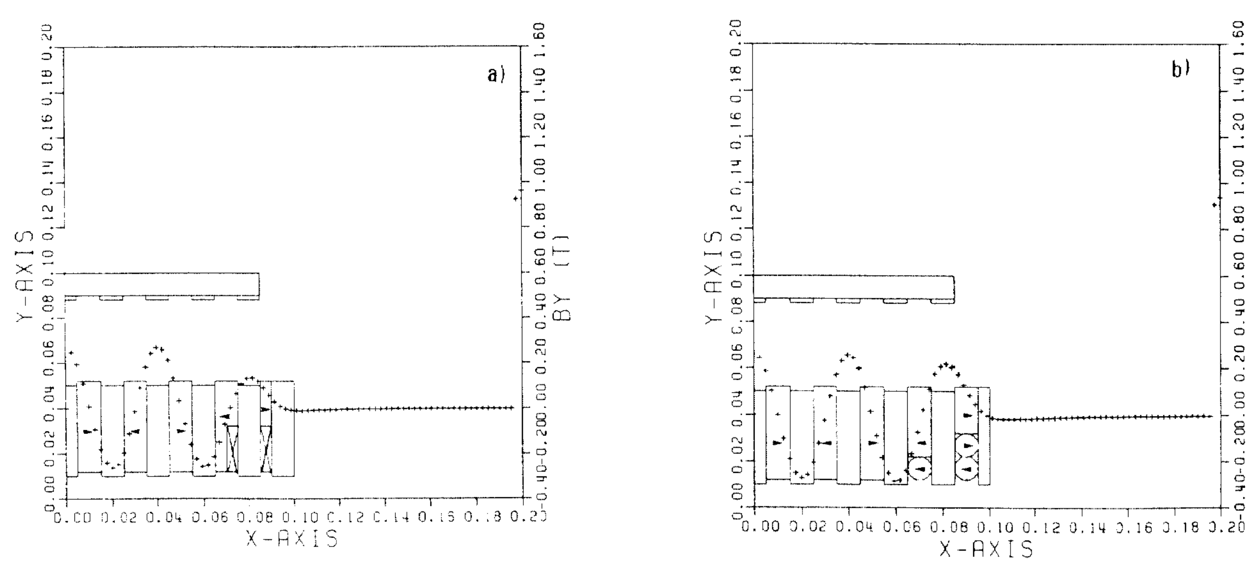

Fig.2 - a) End periods of a Hybrid PM undulator; b) Termination of a Hybrid PM undulator using rotating blocks as suggested by Halbach.

variations of the ratio between the UM period and the working gaps.

The advantages of using a hybrid configuration is that it needs less magnetic material with respect to the pure to reach the same peak on axis magnetic field. Problems due to the differences among PM blocks are less critical because of the presence of iron. Finally the hybrid configuration allows a local tuning of the field by means of iron studs [1]. At the ends of the UM tuning studs alone or in combination with coils can be utilized to correct the field behaviour and minimize the integrals $I_{1,2}$ [2].

A further problem considered in this communication arises when two hybrid undulator sections are connected to operate together without changing the last half poles. The field pertubation induced by the connection is negligible in pure PM undulators (see Fig. 3), while is large in the hybrid case as shown in Fig. 4. The problem of compensating this perturbation is easily solved using the scheme suggested by Halbach i.e. flipping the last rotating block as shown in Fig. 5. Further corrections are possible using the other rotating blocks.

In more conventional schemes, as in Fig 2a, it is possible to reduce the field perturbations acting on the current in the coils and using a hybrid arrangemet of PM blocks that gives an additional magnetic field in order to achieve the continuity condition (see Fig. 6). Tuning studs can also be used togheter with the current in the coils to give further corrections. During single section operations the hybrid arrangement of PM blocks can be moved vertically, like tuning studs, in order to get zero field contributions on the UM axis (see Fig. 7).

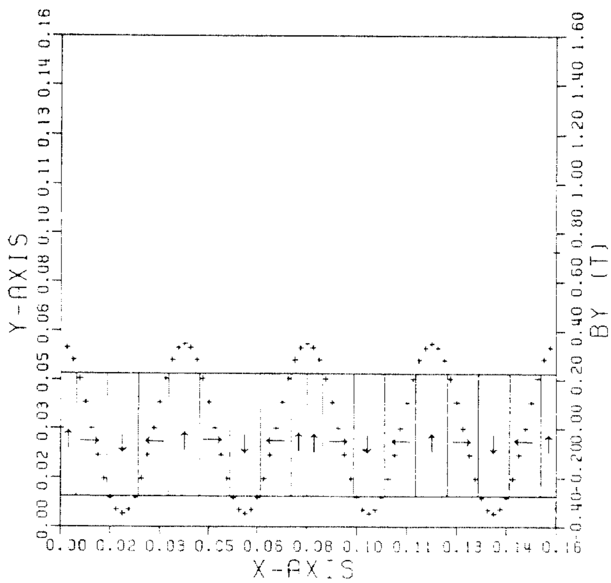

Fig.3 - Magnetic field behaviour for two connected pure PM sections.

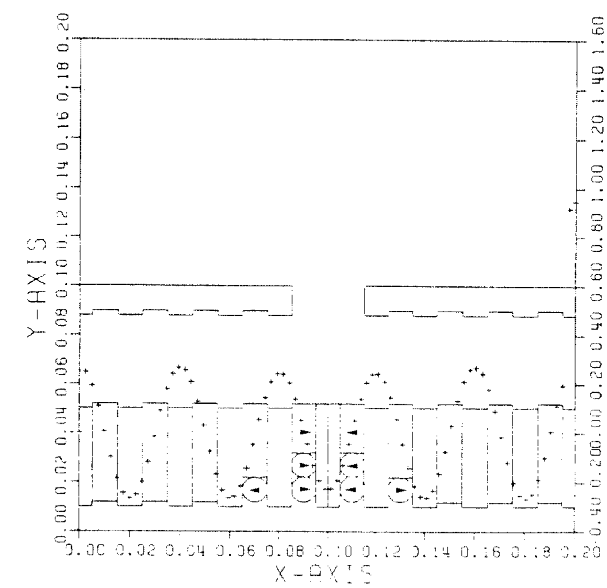

Fig.5 - Magnetic field behaviour for two PM hybrid section with rotating blocks.

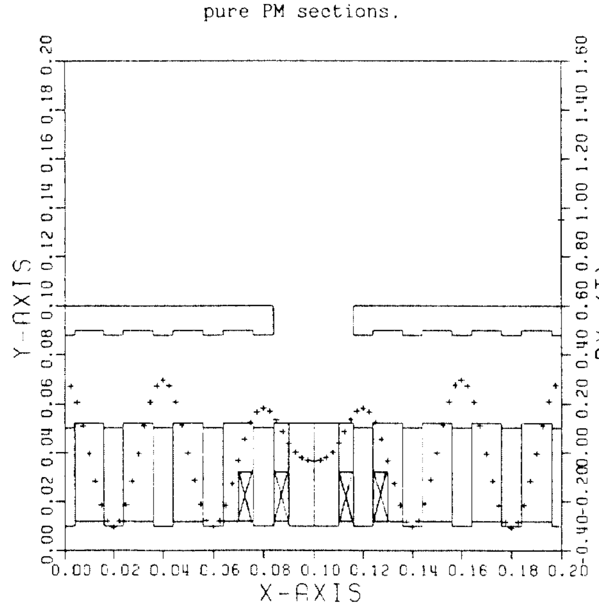

Fig.4 - Magnetic field perturbation due to the connection of two PM hybrid undulator sections.

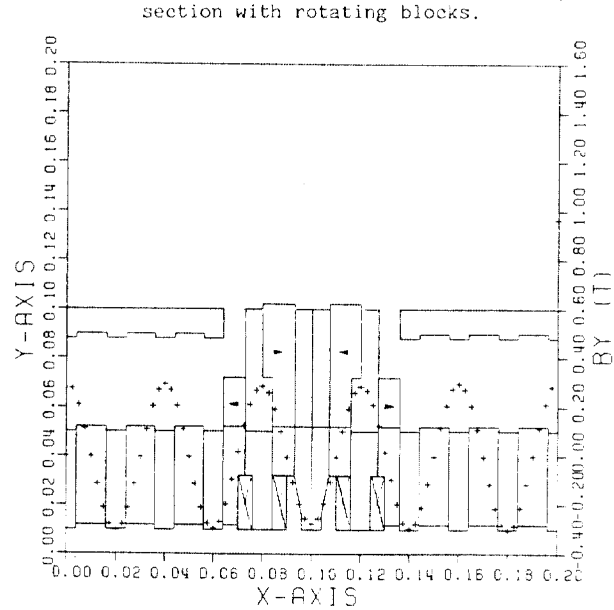

Fig. 6 - Reduction of the magnetic field perturbation for two hybrid sections in one of the possible scheme analized

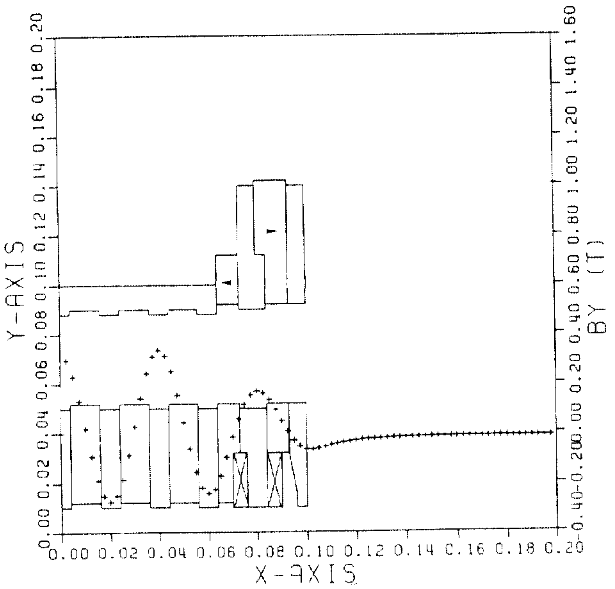

Fig.7 - Magnetic field behaviour for a single section end (same scheme of Fig. 6).

References

[1] K. Halbach, "Permanent Magnet Undulators", Journal de Physique, Vol 44(C1), pp. 211-216, Feb. 1983.

[2] F. Rosatelli, L. Barbagelata, A. Matrone, G. Ottonello, P.Prati, D.Tommasini, F.Ciocci, A.Renieri, E.Sabia, "Development of a Hybrid Permanent Magnet Undulator Prototype for Free Electron Lasers", Proceeding of 9th Int. FEL Conf.,.August 1989, Naples (USA), to be published in Nucl. Instr. Meth.