FIELD DISTRIBUTION IN PLANAR ELECTROMAGNETIC WIGGLER

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Abstract

Biot and Savart formula is used for magnetic field calculations on the axis of planar electromagnetic undulator formed by a strip line with wiggling inner electrode. The latter is designed in such a manner that mid plane of the system sees strip up and down on the undulator period intersecting this planar wire every half of the device period. The holes in vertical parts of the strip may be used to provide transparence for particles and radiation. The other possible way is the use an arrangement consisting of two identical strips with spacing between them. The latter configuration is used for exact calculation of magnetic field distribution on undulator axis. Design under consideration is attractive for both normal conducting as well as superconducting complementation including high temperature superconductors.

1 INTRODUCTION

These is a large variety of undulator type suggested [1], but almost commonly very limited number of them is used in practice. Undulator with permanent magnets seems to be the most attractive for the numerous applications for many reason. Electromagnetic undulators with iron poles are also used, although there are limitations in undulator period shortening because of current density limitation in copper winding. Superconducting winding is the way to overcome such a limitation, but this results in new shortcoming of using low temperature cryogenics. Perhaps, new high Tc superconductor technology may suggest new approach, since current densities achieved allow to reduce the area occupied by winding considerably thus allowing to make a design with short period. Ferromagnetic free approach with guiding magnetic field forming by winding shape in practice results in helical undulator. This scheme allows to form helical magnetic field with any desired period down to millimetres range (microwigglers). Since current up to $10^5 A$ is required to excite magnetic field up to several kilogauss on undulator axis, continuous operation is possible when superconducting option is used. In normal conducting design only pulse operation is possible with duty factor of the order of $10^{-4} - 10^{-5}$. As our experience has shown [2], helical undulator scheme has some inconveniences when used in free electron laser. Since magnetic field is formed by undulator winding, it is not simple to meet necessary requirement while undulator manufacturing and field correction procedure is quit necessary. Although we had find effective induction field correction method, it is reliable in pulse option only. The search for planar undulator scheme that might be more convenient in use results in considerations described bellow.

2 PLANAR UNDULATOR SCHEME AND MAGNETIC FIELD DISTRIBUTION

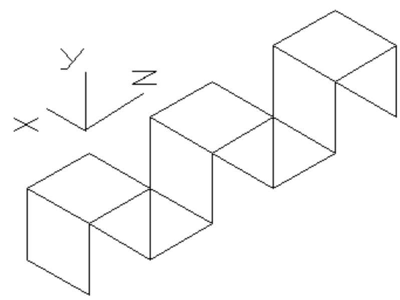

Figure 1: Layout of planar electromagnetic undulator scheme

Let us imagine corrugated metal strip with the current flowing in positive direction of z-axis, as it shown on Fig.1. It is assumed that this strip is infinite in x-as well as in z-direction, while its size in vertical direction may be limited. Under this assumption magnetic field lines are parallel to x-axis and field value is equal to half of surface current line density at any point excluding strip surface itself, while signs are opposite for the points located at opposite strip sides. This fact follows from the symmetry conditions as well as from Ampere's low: $\oint H_l dl = I$,where *I* is the total current passing through the closed loop. In our configuration we chose the loop as rectangle with sides parallel to x- and z-axis and traversing vertical surface of the infinite strip, the length of the rectangle side in z-direction being equal to half of period. Integration over longitudinal sides gives zero, and the rest of integral is equal to *2HL*, where *L* is transverse rectangle size, since *H* simply change sign over half of period. From these evident consideration immediately follows above statement. We'll derive appropriate expression more formally bellow.

Now imagine a charged particle moving in z-direction and traversing arrangement described in the horizontal plane of symmetry. Traversing vertical planes of the strip, such a particle sees consequently uniform magnetic field of varying polarity on its way, thus oscillating in vertical direction and emitting electromagnetic radiation as well. To make the arrangement transparent for the particle and radiation, we should to make apertures in vertical planes. These apertures will distort guiding magnetic field, and we have to estimate such a distortion. In principle, it might be done with perturbation method, but we will chose a little bit different way. We shall consider the planar undulator formed by two identical corrugated strip with some spacing between them in x-direction, and calculate the magnetic field of such configuration on the symmetry axis. The latter represents itself the intersection of vertical and horizontal planes of symmetry. To have less parameters in our calculation, we'll assume any part of two strip system to be infinite in one direction opposite to neighbouring strip. The field distribution may be found by subtracting magnetic field of the strip finite width from the one of infinite corrugated surface. Using Biot and Savart low for static magnetic field:

$$d\vec{H} = \frac{1}{4\pi}\frac{I[d\vec{l},\vec{r}]}{r^3}, \qquad (1)$$

where $d\vec{l}$, $\vec{r}$ are element of length, carrying a current *I*, and co-ordinate vector from the element of length to an observation point, respectively, one can represent strip magnetic field :

$$H_x = \frac{J}{4\pi}(H_{\parallel} + H_{\perp}), \qquad (2)$$

consisting from contribution of horizontal and vertical parts of the strip:

$$H_{\parallel} = -\sum_k \int_{-b}^{b} \int_{k\Lambda/2}^{(k+1)\Lambda/2} \frac{r_{y,k}\,dxdz}{\left[x^2 + y^2 + (z - z_0)^2\right]^{3/2}} \qquad (3)$$

$$H_{\perp} = -\sum_k \int_{-b}^{b}\int_{-h}^{h} \frac{r_{z,k}\,dxdy}{\left[x^2 + y^2 + (z - z_0)^2\right]^{3/2}}. \qquad (4)$$

Here (0,0,Z_0) is observation point, r_y, r_z are the projections of co-ordinate vector from integration point to observation point; $2b, 2h, \Lambda$ are the strip width, full height and period, respectively, and *J* is line current density (A/m). Performing the integration and simplifying the expressions obtained we arrive finally at the next formula for magnetic field of the strip, where dimensions mentioned above are used in normalised form, the system period being used for such normalisation:

$$H_x(\xi)\frac{\pi}{J} = \arctan\left(\frac{\xi F}{\eta}\right) + \arctan\left(\frac{\eta F}{\xi}\right) +$$

$$\sum_{k=1}^{\infty}(-1)^{k+1}\left[\begin{array}{l}\arctan\frac{k/2-\xi}{\eta}F_k^- + \arctan\frac{\eta}{k/2-\xi}F_k^- - \\ \left(\arctan\frac{k/2+\xi}{\eta}F_k^+ + \arctan\frac{\eta}{k/2+\xi}F_k^+\right)\end{array}\right] \qquad (5)$$

The following designations are used:

$$F = \frac{\beta}{\sqrt{\eta^2 + \beta^2 + \xi^2}},\ F_k^{\pm} = \frac{\beta}{\sqrt{\eta^2 + \beta^2 + (k/2 \pm \xi)}}, \qquad (6)$$

where ξ, β, η are normalised z-co-ordinate, strip half width and half height respectively. The field distribution for real planar undulator configuration, consisting of two wide strip with the gap of width 2β (normalised) between them is represented on Fig. 2 for particular case $\beta = 0.1$ and $\eta = 0.5$.

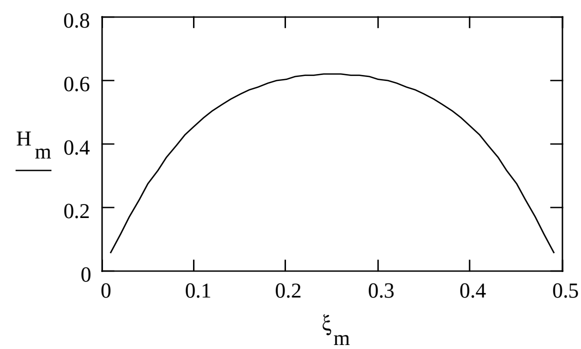

Fig.2: Magnetic field distribution in planar electromagnetic undulator. β=0.1, η=0.5

It is seen that instead of step dependence with sharp field edge, distributions becomes more smooth. Field distribution is normalised by field induced by infinite corrugated plane. The dependence of maximum magnetic field on strips spacing is given on Fig. 3

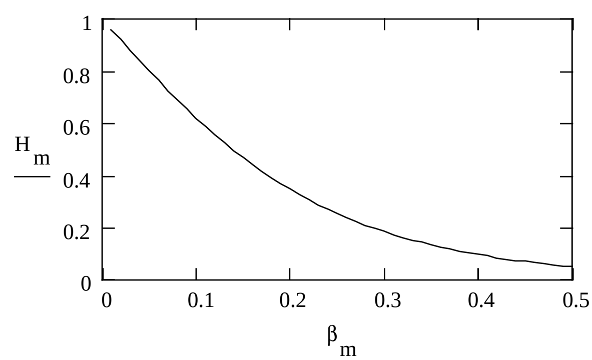

Fig.3: Dependence of magnetic field amplitude on spacing between strips in planar electromagnetic undulator

It is seen from the picture, that field amplitude does drop down drastically for reasonable spacing.

3 CONCLUSION

We have considered briefly some features of planar design of electromagnetic undulator. The questions of real design (including excitation scheme) although of great importance, are out of the topic.

REFERENCES

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