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Physics Procedia 84 (2016) 67 – 73

Physics Procedia

International Conference "Synchrotron and Free electron laser Radiation: generation and application", SFR-2016, 4-8 July 2016, Novosibirsk, Russia

Magnetic measurements of superconducting insertion devices by stretched wire with direct current

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Abstract

The main characteristics of multipole insertion devices (ID) are the first and second field integrals along an orbit trajectory in an accelerator. Such integrals of permanent magnets or traditional electromagnets insertion devices can be obtained by means of longitudinal scanning by Hall probes. Measurements of the magnetic field by Hall probes in superconducting IDs have obvious difficulties because of limited space, temperature deviation along the path, etc. Measurements of the integrals by Hall probes, especially when the integrals has to be equal to zero, it is very difficult to make with a necessary accuracy. At Budker INP along with Hall probes the system of magnetic measurements on the basis of the tense wire with a direct current is used. The method is based on similarity of interaction of a direct current in a stretched wire and an electron beam in an accelerator with magnetic field. The stretched wire with current is a good model to describe behavior of an electron beam when passing through a magnet. Especially the method is useful at measurement of superconducting IDs where it isn't enough space for other probes. The method provides a dynamic control of the field integrals in different modes of a magnet operation (field ramp up or down), allows to measure the integrals quickly and rather precisely.

Peer-review under responsibility of the organizing committee of SFR-2016.

Keywords: superconducting magnets; wiggler; undulator; magnetic measurements

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Peer-review under responsibility of the organizing committee of SFR-2016.
doi:10.1016/j.phpro.2016.11.012

1. Introduction

Multipole superconducting insertion devices (wigglers and undulators, see Ivanyushenkov et al. (2011)) represent sequence of the sign-alternating superconducting magnets with a cross magnetic field located along a beam trajectory of electrons moving in a vacuum chamber of an accelerator. The main objective of the magnet with such magnetic field configuration is generation of the synchrotron radiation (SR, see Bogomyagkov et al. (2016)) or free-electron laser (FEL) radiation (Kulipanov et al. (2015)), and the magnet has to represent the insertion device which magnetic field doesn't disturb an orbit in the accelerator. For performance of such condition integrals of the field (1) and (2) have to be equal to zero:

$$I_1^{x,z} = \int_0^L B_{z,x}(y)dy \tag{1}$$

$$I_2^{x,z} = \int_0^L dy \int_0^y B_{z,x}(y')dy' \tag{2}$$

where $I^{x,z}{}_1$, $I^{x,z}{}_2$ − first and second field integrals of $B_{z,x}$ field components; y − longitudinal coordinate; x − cross horizontal coordinate, z − vertical coordinate, L − magnet length.

In a planar magnetic multipole systems the main working field is the vertical field component B_z. Integrals (1), (2) of the field depend on the magnet design, precision of manufacture of the magnet elements and the currents in the windings. Compensation of the integrals of the vertical field B_z is created by special superconducting magnets powered by individual power supplies and it is a priority the fulfillment of the technical requirements for the quality of the field. Horizontal transverse field, as a rule, much smaller than the vertical field and it is created an uncontrolled manner due to external sources or design features of the magnetic system. Compensation of horizontal field integrals is made with use external steering magnets.

In the case of nonzero of the field integrals, an orbit in an accelerator at magnet exit acquires the angle and the displacement in the coordinate (3):

$$x' = \frac{I_1^x}{B\rho}$$

$$x = \frac{I_2^x}{B\rho} \tag{3}$$

$B\rho$ − beam rigidity.

Before installing of an insertion device on an accelerator must be achieved minimal field integrals with using correction magnets in the stationary state of the magnetic field, and during variation of the field. For this work, a rapid and accurate system of measurements of the field integrals is required. Stretched wire method with DC current is the most suitable for the work.

2. Motivation of the stretched wire method with DC current

The stretched wire method with DC current to measure the integrals of the transverse magnetic field based on the similarity of the equations of motion of charged particles and the stretched wire with DC current in a magnetic field (Bekhtenev et al. (1998)):

$$\frac{d^2x}{dy^2} = \frac{B_z(y)}{B\rho} \tag{4}$$