THREE-DIMENSIONAL FIELD CALCULATION AND FIELD MAPPING FOR A WEDGED-POLE HYBRID UNDULATOR

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Abstract

Three-dimensional field calculation and two-dimensional field mapping were performed for a wedged-pole hybrid undulator. Field distributions in median plane of the undulator were obtained from the calculation and mapping. Calculated and experimental distributions of multipole components along the undulator axis were derived up to dodecapole component from the field distributions by a least-square fitting method. The calculated distributions of the multipoles quantitatively shows very good reproduction of the experimental distributions.

1. Introduction

A free electron laser based on a superconducting linac has been constructed to lase in far infrared region at Japan Atomic Energy Research Institute. A wedged-pole hybrid undulator[1] will be used for the first experiment of the JAERI FEL. In order to fit the undulator to the JAERI FEL system, the undulator was characterized by three-dimensional field calculation and two-dimensional field mapping.

In order to characterize the undulator, a distribution of the multipoles[2] was derived from field distributions in a median plane of the undulator. A strip of the three-dimensional field distribution was obtained by using a conventional finite element method(FEM) calculation code ANSYS. An experimental distribution was obtained by field mapping with a commercially-available and three-dimensionally measuring equipment.

2. Three-Dimensional Field Calculation

The finite element method calculation of ANSYS, which has been commercially-available in Japan, was applied to evaluate the experimental distribution. A 32-bit personal computer system utilizing an Intel 80486 CPU was used for the calculation, because a through-put of the computer system was expected to be higher than that of a main frame computer system. However, a scale of the calculation was limited by mass storage capacity of the system.

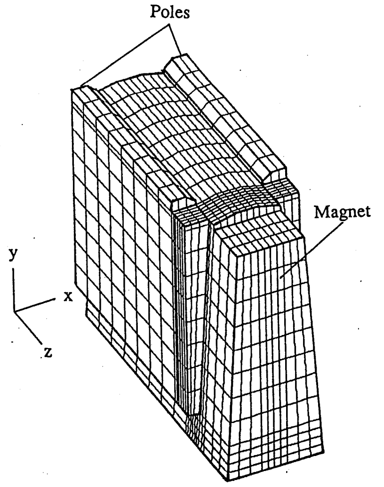

Fig.1 Three-dimentional view of the mesh reproducing a half-periodic and quarter part of the undulator.

A shape of a half-periodic and quarter part of the undulator was reproduced by a mesh form which was shown in Fig.1 in the calculation. Poles and permanent magnets of the undulator were made into wedged-shape which were designed to uniform, and to increase magnetic flux inside the poles. Major specifications of the undulator are summarized in table 1. Edge shapes of the poles and magnets were slightly simplified, and misalignments and asymmetries of the undulator were not taken into account here. Calculated field distribution in the median plane of the undulator is shown in Fig.2, where Z is relative position along the undulator axis, X transversal position in the median plane, and B_y vertical component of the field.

Table 1
Specifications of the wedged-pole hybrid undulator.

Magnet material,	Nd-Fe-B
Undulator period, λu (cm)	3.3
Pole gap range (cm)	1.35-30
Maximum peak field on-axis, Bmax (k Gauss)	5.9
Deflection parameter range, K	≤1.8
Transverse rolloff at ±1cm (%)	≤0.09
Peak field error, ΔB/B (%)	0.4
Total steering error (Gauss-cm)	-11
Number of periods	61.5

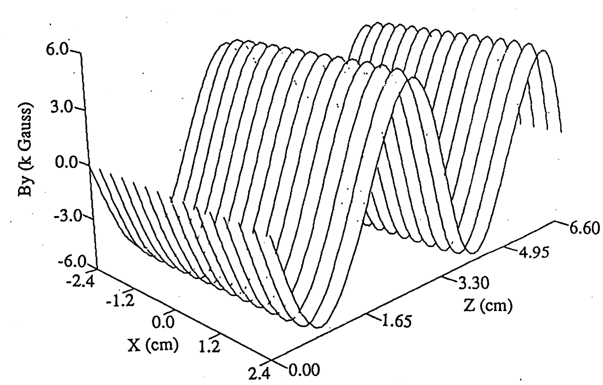

Fig.2 Calculated map in the median plane of the undulator filed.

There should be some end effects in actual undulators because of their finite size. The effects become serious whenever the field distribution around the ends is under consideration. However, the calculation was not performed for the effects because of limitation of the mass storage capacity in the computer system at the moment. Roughly speaking, number of the undulator period was large enough to ignore the effects, so it could be assumed the effects were not problem here. Periodic character of the multipoles is only discussed here.

3. Two-Dimensional Field Mapping

The poles and magnets of the undulator were precisely manufactured and assembled to minimize irregularities of the field caused by asymmetrical magnetization of the magnets and geometrical misalignments of the poles and magnets.

The vertical component of the field in the median plane was mapped by the measuring equipment. A schematic diagram of the equipment is shown in Fig.3. A Hall probe could be positioned in vertical and horizontal directions by actuators in the the resolution of one micrometer. The probe and positioning actuators were mounted on a base that could be smoothly slide on a granite table along the undulator axis. The granite table was aligned to the undulator precisely. A longitudinal position was measured by a positioner which counted trigger signals from an optical linear encoder for each evolution of ten micrometers. Another trigger signal from the positioner was sent to a 16 bits A/D converter for each interval of two hundred micrometers. Whenever the A/D converter received the trigger signal, the converter was energized to convert an analog signal of a field strength from a gauss meter to a digital one. The digital was acquired in a personal computer for off-line analysis.

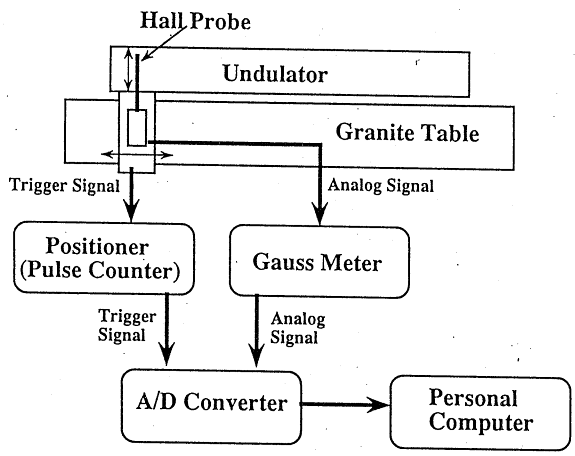

Fig.3 Schematic diagram of the measuring equipment.

The mapping was performed only four periods around center of the undulator. As a typical example of the field map shown in Fig.4, the median plane and origin of the mapping coordinate was determined from the field strength at the tenth pole from the end.

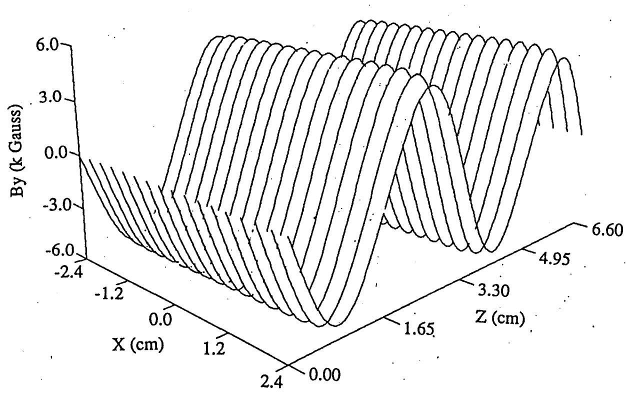

Fig.4 Measured map in the median plane of the undulator filed.

4. Multipole Field Components

Data of the two dimensional field map obtained from the measurement and the calculation were divided into a number of strips of the transversal field distribution. The multipole filed components from dipole to dodecapole were derived from each strip by least square fitting to a following fifth order polynomial:

$$B_y(x) = \sum_{n=0}^{5} B_n x^n \quad , \qquad (1)$$

where B_n was coefficient of 2(n+1)-pole component, x transversal position, $B_y(x)$ the vertical component of the magnetic field as a function of the transversal position. A distribution of the multipoles along the undulator axis was obtained through a data reduction method mentioned above. Reduced data from the measured and calculated are shown in Fig.5 and Fig.6 respectively. The higher multipoles mixed in with the fundamental dipole were distributed in very similar fashion with the dipole. The multipoles of which n is odd were vanished completely in Fig.6, because we assumed that the calculation was not taken into account of misalignments and asymmetries of the undulator.

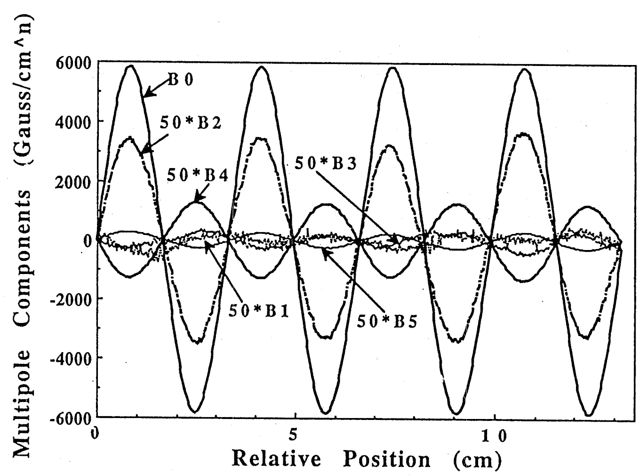

Fig.5 Longitudinal distribution of the multipoles obtained from the measured map. The higher multipoles were multiplied by fifty, to compare with others easily.

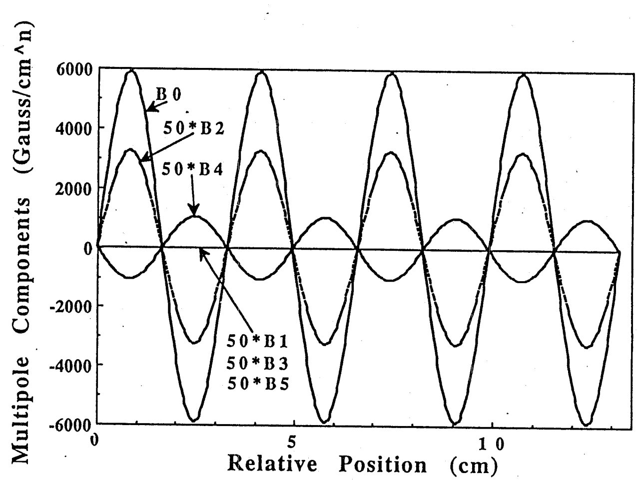

Fig.6 Longitudinal distribution of the multipoles obtained from the calculated map. The higher multipoles were multiplied by fifty, to compare with others easily.

6. Conclusion

The characterization of the wedged-pole hybrid undulator was successfully performed by three-dimensional field calculation and two-dimensional field mapping. Calculated and experimental distributions of multipole components along the undulator axis were derived up to dodecapole component from the field distributions by a least-square fitting method. The calculated distributions of the multipoles quantitatively shows very good reproduction of the experimental distributions.

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