ADJUSTMENT OF ADIABATIC TRANSITION MAGNETIC FIELD OF SOLENOID-INDUCED HELICAL WIGGLER

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Abstract

A solenoid-induced helical wiggler is suitable for a compact free electron maser operated by low energy electron beam. It consists of two staggered-iron arrays installed perpendicularly to each other in a solenoid magnet. It is tried, in this work, that the adiabatic transition field is also produced by staggered-nickel plates with different thickness in five periods. It is most important how to decide each thickness of the nickel plate. After it is decided by repeated combination of the simulation and practical measurement of the magnetic field distribution, exact thickness is selected by the precise measurement of the field distribution referring to an equivalent electric circuit of the wiggler.

INTRODUCTION

We have constructed a solenoid-induced helical wiggler for a compact free electron maser operated in a usual small laboratory which does not have electric source capacity available enough [1,2]. It consists of two staggered-iron arrays inserted perpendicularly to each other in a solenoid electromagnet. In order to lead/extract an electron beam into/from the wiggler, adiabatic transition (AT) field is necessary at the both sides of the wiggler. In this work the AT field was produced by staggered-nickel plates with different thickness in five periods. The thickness of each nickel plate was decided by the field analysis using the MAGTZ computational code based on a magnetic moment method. However, exact thickness was found by the precise measurement of the field distribution with the greatest circumspection to obtain a homogeneous increment of the AT field. The change of AT field distribution was studied by referring to an equivalent electric circuit of the wiggler.

STRUCTURE OF THE WIGGLER

The detailed structure of the solenoid induced helical wiggler is shown in the previous papers [1,2]. The dimensions of the solenoid magnet are as follows; length of 1270 mm, inner diameter of 50 mm and outer diameter of 170 mm. Wound number of a copper coil is 3371 turns. When a coil current is 100 A, the axial field is about 0.3 T. The staggered iron arrays constructed by iron blocks with a shape of gable are installed inside the solenoid magnet. Two sets of the arrays are aligned perpendicularly on x-z and y-z planes, respectively. One of them is shifted by a quarter period to the other. The helical field is induced between every pair of the staggered iron blocks.

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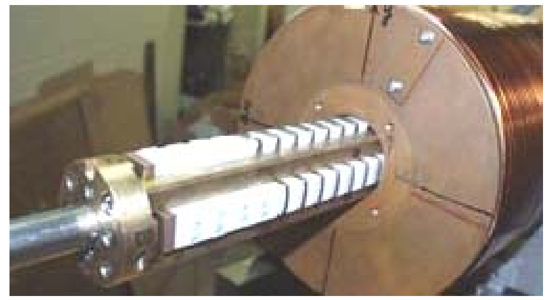

Figure 1: Adiabatic transition part of the solenoid-induced helical wiggler.

Adiabatic transition (AT) magnetic field is created by setting staggered nickel plates with different thickness in the five periods at the both sides of the iron blocks arrays. Fig. 1 shows the AT part pulled out from the solenoid magnet.

ANLYSIS OF MAGNETCI FIELD

At first time, the field distribution was studied for a wiggler without any AT part in order to compare the result analyzed by MAGTZ computational code with that measured using a Hall element with an active region of 1.8 mm in diameter. Figs. 2 and 3 show the field of the

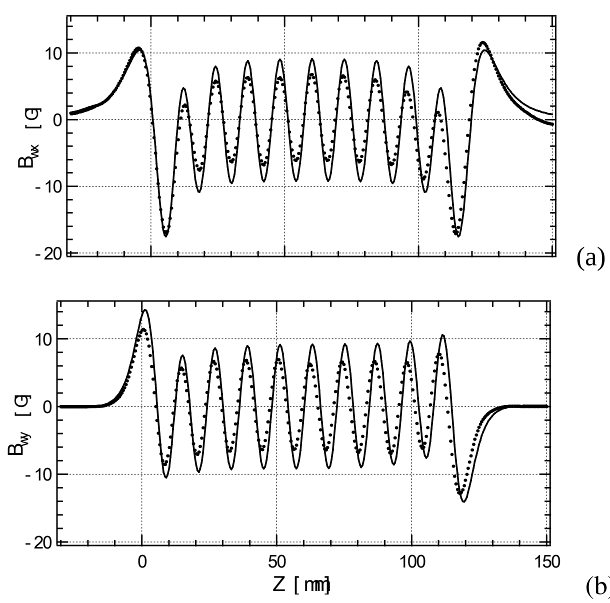

Figure 2: Simulated (solid line) and measured (dotted line) field distribution of the wiggler with a period of 12 mm.

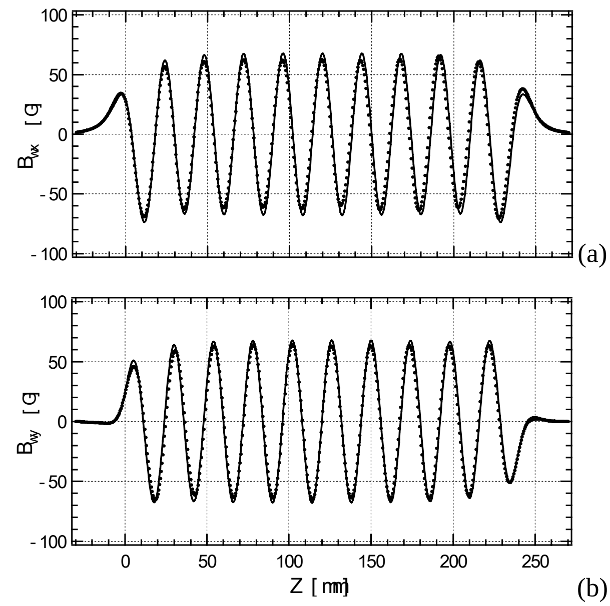

Figure 3: Simulated (solid line) and measured (dotted line) field distribution of the wiggler with a period of 24 mm.

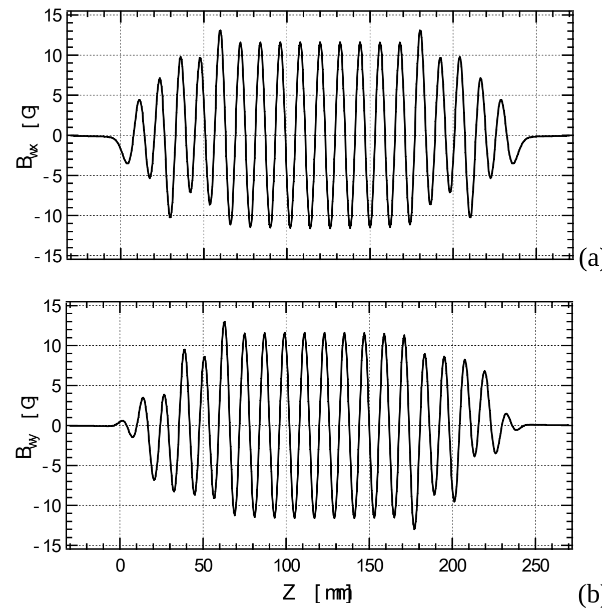

Figure 4: Simulated field distribution of the wiggler with adiabatic transition parts made of nickel plates of which each thickness is decided according to $h_0 \sin^2\left(0.1\pi z/\lambda_w\right)$.

wiggler with a period of 12 mm and 24 mm, respectively. Solid and dotted lines represent the calculated and measured field distributions, respectively. It is seen that calculated field is in agreement with the measured field for the latter wiggler. For the former wiggler with shorter period, on the other hand, calculated field is higher than measured values. However the field varies similarly to each other. It is, usually, more difficult to align precisely each constitutional component of a wiggler with shorter period. This fact seems to bring the measured field weaker than that calculated for a perfectly aligned wiggler.

In this work, we have investigated the wiggler with a period of 12 mm rather than 24 mm, because we want to perform a free electron maser (FEM) operated at shorter wavelength. To complete a whole wiggler, AT field is necessary at the both ends of the uniform field created by the iron blocks arrays. When iron plates are used at AT part, it was confirmed by both calculation and measurement that gradual increment of the field was not accomplished because of the high permeability of iron. That is why a nickel plate was selected as a material with low permeability.

At first time, each thickness of the nickel plate was selected according to the formula $h_0 \sin^2\left(0.1\pi z/\lambda_w\right)$ where h_0 is the height of the iron block, λ_w the period of the wiggler and z the distance from the entrance/exit of the wiggler including the AT parts. Fig. 4 shows a calculated field distribution for a 10 periods wiggler added with AT parts consisting of nickel plates. Each AT part has 5 periods. Although the AT field increases gradually, abnormal change is seen near the iron block. After the measurement of the field distribution, the thickness of a specified plate was changed. These procedures were repeated several times and then the ultimate decision of each thickness of nickel plate was decided by the measurement of the field distribution changing the thickness of each plate step by step.

There are two kinds of induced field of which one is a gap field between faced iron blocks/nickel plates and the other is a leak field between the adjacent iron blocks/nickel plates as shown in Fig. 5 which includes the equivalent electric circuit for them consisting of two trains for Bwx and Bwy. The battery corresponds to nickel plate or iron block. It is considered that the electromotive force becomes higher when the thickness of the nickel plate is thicker. The currents of Ig and Il (I'l) correspond to the magnetic flux of the gap and leak field, respectively. It is considered that I'l is much smaller than Il because of the longer distance between the adjacent ferromagnetic substances. For example, when IgB4 must be increased, the thickness of only a nickel plate of A5 is changed from 5.6 to 5.7 mm. It is seen that IgB4 becomes higher a little as shown in Figs. 6(a) and (b). However the use of much thicker plate (5.8 mm) reduces the IgB4 as shown in Fig. 6(c). These phenomena suggest that sum of Ig and Il is kept to be almost constant for the thickness of A5 thinner than about 5.7 mm but IgB4 decreases for thicker thickness of A5 due to abrupt increase of IlD4. This means that maximum Ig exists for each nickel plate if all thicknesses of the other nickel plates are not varied. In order to increase maximum value of IgB4, the thickness of nickel plate B4 will be increased to 2.0 mm. Figs. 6(d) to (f) show the variation of IgB4 depending on the thickness of A4. IgB4 represents maximum at a certain thickness of A5 in the same way as mentioned above. However the maximum of IgB4 becomes higher. These procedures for two sets of the array were repeated to get uniform increment of Bwx and Bwy along the wiggler axis at AT part. Fig. 7 shows the present field distribution and further adjustment especially for the AT part at the exit of the wiggler will be added.

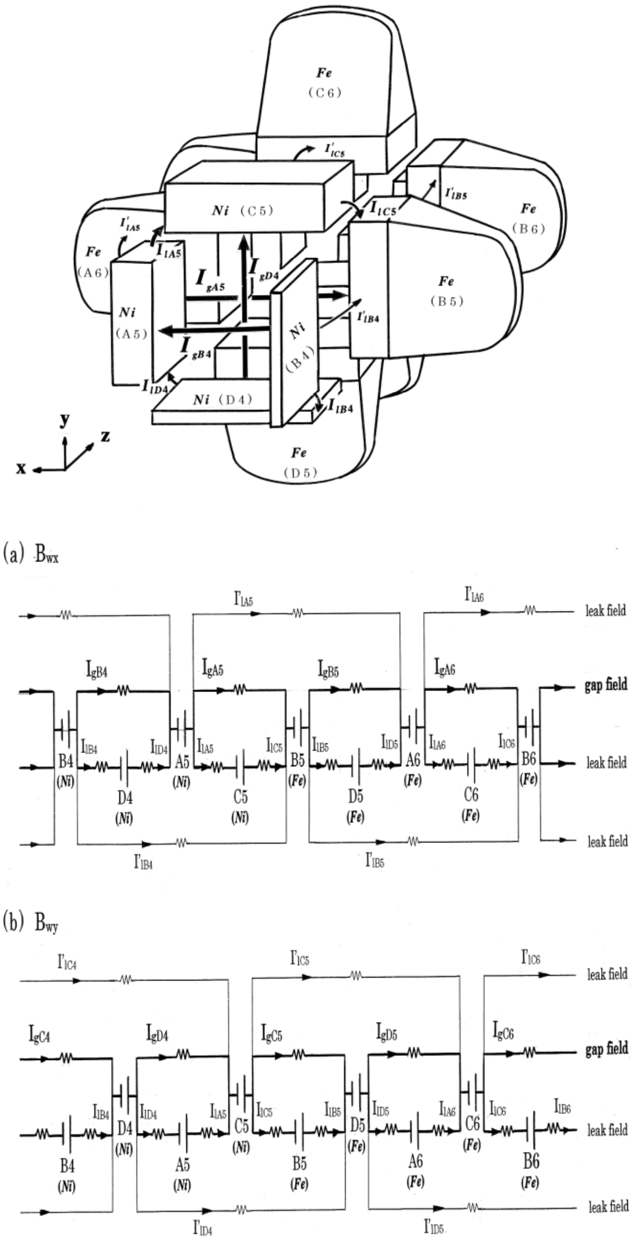

Figure 5: Schematic structure of the partial arrays of iron brocks/nickel plates, and the equivalent electric circuit for them.

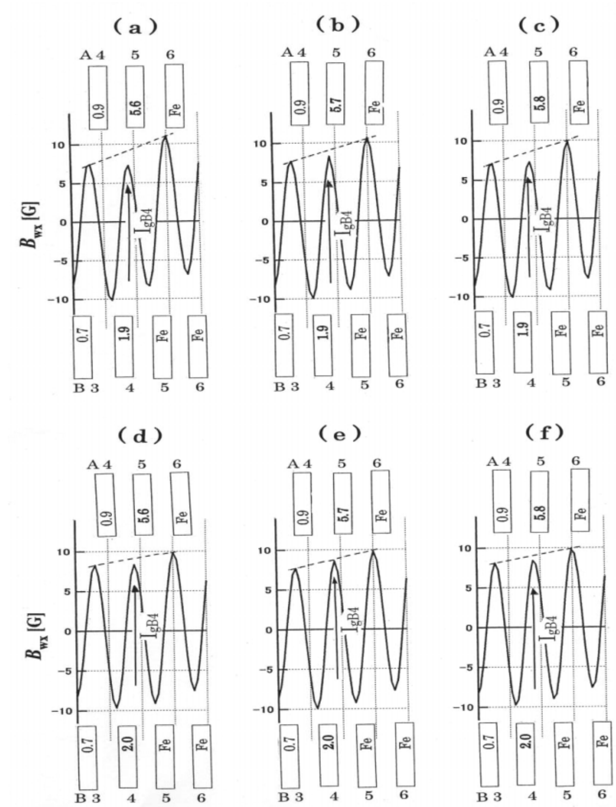

Figure 6: Partial adjustment of B_{wx} by changing the thickness of a nickel plate.

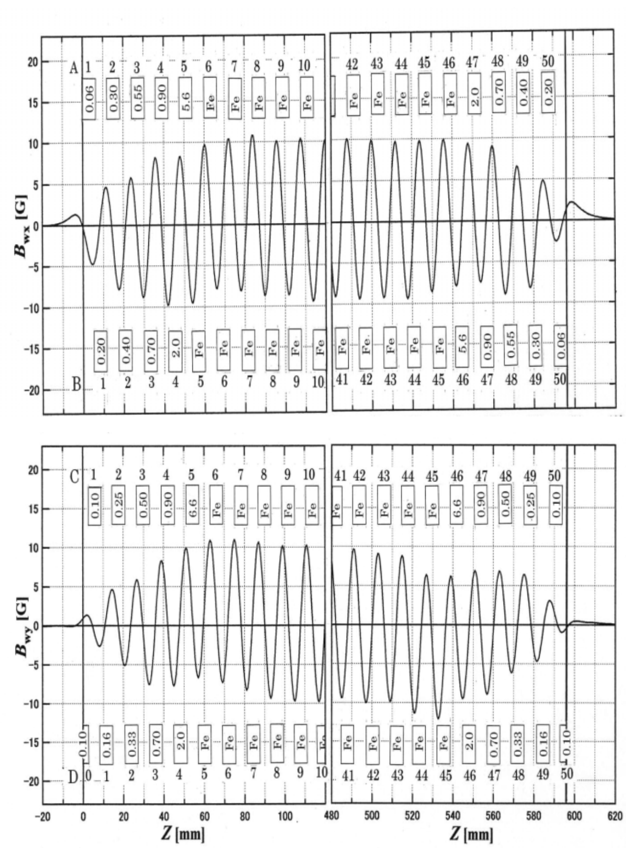

Figure 7: Measured field distribution of the wiggler.

Whenever a nickel plate is changed to another nickel plate with different thickness decided by the method mentioned above, two sets of the array are pulled out, as shown in Fig. 1, from the bobbin tube on which the solenoid coil is wound. We found that the surface of iron block was rubbed against the inner surface of the bobbin, and then the shavings were left there. Although the amount of the remnants is so small that the observation is impossible, they had effect to the field distribution. It will be, however, recommended that every construction of AT part by change of nickel plates is carried out without any cleaning of the inside surface of the bobbin. If it is cleaned to take away the remnants, it is very difficult to get repeatable field distribution.

CONCLUSIONS

Adiabatic transition magnetic field was created by staggered-nickel plates with different thickness in a solenoid-induced helical wiggler. The decision of each thickness of the nickel plate was made by simulation and measurement of the magnetic field distribution referring to the equivalent electric circuit. However ultimate selection of each nickel plate with a proper thickness required the precise measurement of the field distribution with the greatest circumspection, because the simulation could not reflect imperfect alignment of nickel plates and a small amount of the remnants left by the friction between the iron blocks and the bobbin.

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