DESIGN OF A 12T SUPERCONDUCTING WIGGLER FOR ANGIOGRAPHY

T. Keishi and Y. Hosoda
Sumitomo Electric Industries
1-1-3, Shimaya, Konohana-ku, Osaka, 554 Japan

T. Tomimasu and S. Sugiyama
Electrotechnical Laboratory
1-1-4, Umezono, Tsukuba, Ibaraki, 305 Japan

Abstract

Preliminary design of a superconducting wiggler magnet for angiography is described. The magnet is a five pole wiggler and its middle iron pole produces a high magnetic field of 12T on the beam axis. The field is produced by five pairs of superconducting coils and iron cores. NB_3Sn and NbTi superconductors are used for the winding of the coils.

Introduction

The number of patients with heart disease including coronary heart disease is increasing in the industrial countries. Digital subtraction angiography (DSA) with synchrotron radiation has become a powerful and non-invasive method for coronary angiography to investigate heart disease. A system with storage ring and insertion devices to generate sufficient intensity of 34keV photons is necessary for DSA. A compact conventional type 1.5GeV storage ring of about 13m diameter with two 5 pole 12T superconducting wiggler magnets is proposed [1] as a 34keV photon source for DSA. The wiggler magnet needed to produce 12T magnetic field on the beam axis is designed.

Parameters of a superconducting wiggler magnet

The wiggler magnet consists of five pairs of superconducting coils with iron poles as shown in Fig. 1. Five parallel racetrack coils are arranged perpendicular to the electron beam axis. The coils are surrounded by iron yoke to pass magnetic flux and to support the coils. The use of the iron poles and yoke makes it possible to produce 12T field which is higher than the corresponding value when no iron is used. They are useful to increase the magnetic field on the beam axis. The iron yoke also works for a screening of stray field.

The main coil, two auxiliary coils I, and two auxiliary coils II produce nominal field strength of 12.3T, -10.5T, and 4.6T, respectively. The interval of the coils is 230mm and cross section of the main coil, auxiliary coils I, and auxiliary coils II are 80mm x 160mm, 80mm x 160mm, 80mm x 80mm, respectively. The width of the poles is 30mm and their magnetic gap length is 30mm. The parameters of 12T wiggler magnet are shown in Table 1.

Table 1
Parameters of 12T wiggler magnet

Maximum field on the beam axis		12.3T		
Field distribution on beam axis	main coil	12.3T		
	auxiliary coils I	-10.5T		
	auxiliary coils II	4.6T		
Critical wavelength (E=1.5GeV)		0.67Å		
Critical photon energy (E=1.5GeV)		18.4keV		
K parameter (K_{max})		528		
Period length		460mm		
Full gap length	Magnetic pole	30mm		
	Vacuum chamber	15mm		
Horizontal aperture (vacuum chamber)		100mm		
Wiggler length	Magnet	1190mm		
	Overall length	2100mm		
Iron core		no carbon steel		
Coil	Coil name	main	aux. I	aux. II
	Superconductor	Nb_3Sn	Nb_3Sn	NbTi
	Maximum field(T)	10.8	9.3	4.2
	Overall current density (A/mm^2)	127.3	109.5	60.0
	Current(A)	269	232	95

Magnetic field calculation

Magnetic field of the wiggler magnet was calculated with the POISSON program code [2]. Its flux distribution is shown in Fig. 2. Overall current density of the coils can be seen from Table 1. The calculated results of the maximum field of the coils are also shown in the Table 1. Maximum field of the coils is 10.8T and that of the wiggler magnet is 13.5T at the iron pole face of the main coil. Fig. 3 shows vertical magnetic field (By) along the beam axis. The abscissa is a distance (s) measured from the center of the wiggler. The curve of the vertical magnetic field (By) has five peaks at the center of five coils. As shown in Table 1, the peak field values at the main coil, auxiliary coil I,

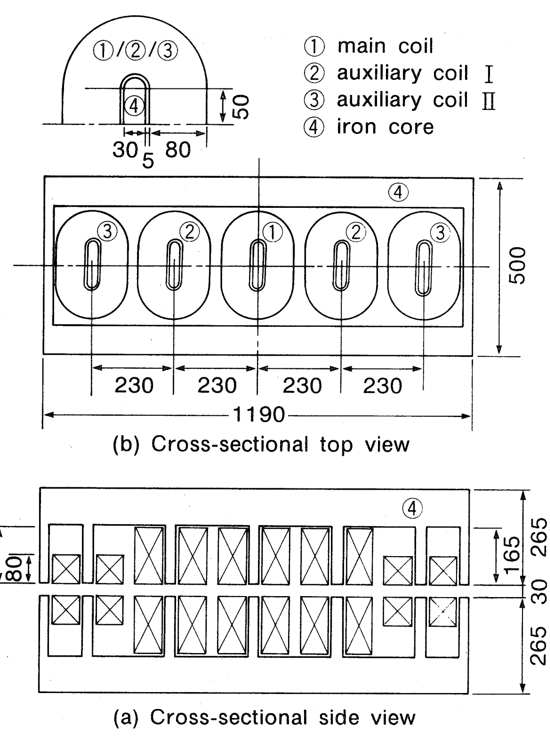

Fig. 1 Cross section of five pole wiggler magnet (mm)

and auxiliary coil II are 12.3T, -10.5T, 4.6T, respectively. The wiggler field has been set to 12.3T to generate synchrotron radiation with the critical wavelength of 0.67Å.

The field strength along the beam axis has been adjusted to make the integrated value of Eq.(1) nearly equal to zero and not to affect the electron orbit outside the wiggler. The integration along the curve By(s) of Fig. 3 is given as follows:

$$\int_{-L/2}^{L/2} By\, ds = -1.45\times10^{-5} \text{ (T m)} \qquad (1)$$

where L: effective magnetic length of the wiggler
s: distance along the beam axis
By: vertical magnetic field

The integrated value of Eq.(1) is considered to be small enough.

The trajectory of an electron under the magnetic field was calculated. The horizontal displacement (x) is shown in Fig. 3. The maximum horizontal displacement is 1.73cm at the auxiliary coil I. The horizontal displacement is -0.48cm at the middle of main coil (s=0). The horizontal displacement(x) and tilt angle (x') become zero at the exit of the wiggler because the integration of Eq.(1) nearly equals zero. The radius of curvature at the middle of main coil (where the field strength is 12.3T) can be obtained from Eq.(2):

$$\rho = 3.36E/By=0.41 \text{ (m)} \qquad (2)$$

where ρ : radius of curvature (m)
E : electron energy (GeV), E=1.5
By: vertical magnetic field (T)

The vertical magnetic field and horizontal displacement was calculated for the case that no iron is used and magnetic field is produced only by coil winding. These results are shown in Fig. 4. The peak field values at the main coil, auxiliary coil I, and auxiliary coil II are 9.2T, -7.6T, 3.4T, respectively when the coils are excited by the same overall current density as Table 1. The magnetic field when iron core is used is 3.1T greater than that when no iron is used. The use of iron core for the wiggler is considered to be very useful.

The maximum horizontal displacement is 1.16cm at the auxiliary coil I. The horizontal displacement is -0.73cm at the middle of main coil (s=0).

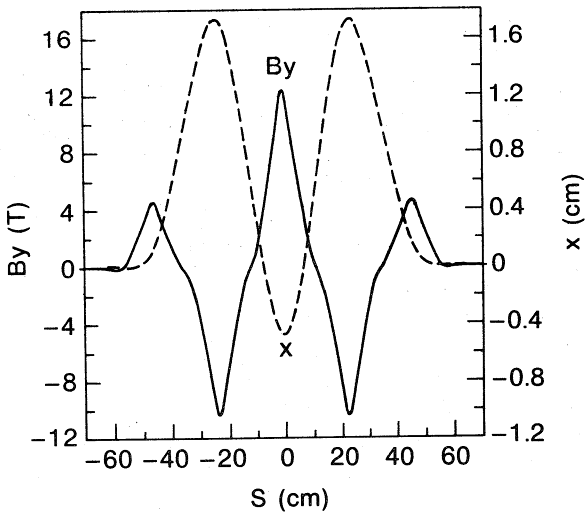

Fig. 3 Vertical magnetic field and beam trajectory (wiggler with iron core)

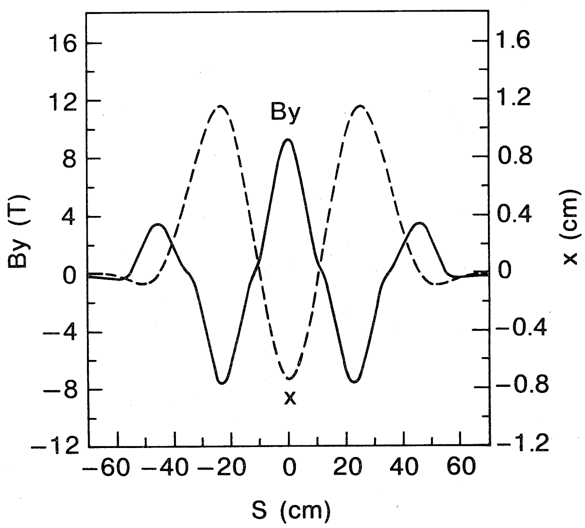

Fig. 4 Vertical magnetic field and beam trajectory (wiggler without iron core)

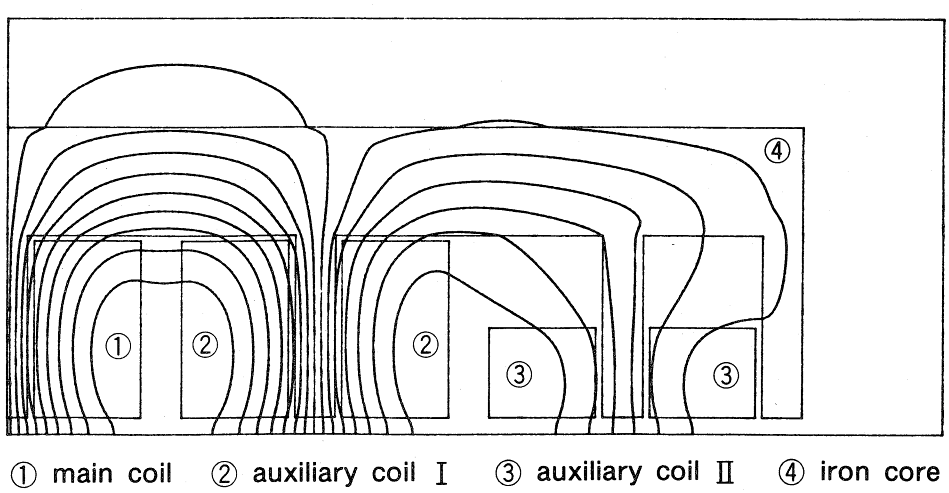

Fig. 2 Flux distribution in the wiggler magnet

Superconducting coils

The maximum magnetic field (Bmax) and overall current density (Joverall) of the main coil are 10.8T and 127.3A/mm^2, respectively. The Bmax and Joverall of the auxiliary coil I are 9.3T and 109.5A/mm^2, respectively. Nb_3Sn superconductor has been chosen for the main coil and auxiliary coil I because critical current density of NbTi superconductors is not sufficient. The Bmax and Joverall of the auxiliary coil II are 4.2T and 60.0A/mm^2, respectively. NbTi superconductor has been chosen for the auxiliary coil II. Preliminary design of the superconductor for the coils is shown in Table 2. The load lines of the coils are shown in Fig. 5. The circle points on the design value curve show the operating point of main coil, auxiliary coils I, and auxiliary coils II. Overall critical current density of the NbTi and Nb_3Sn superconductor are also shown in Fig. 5. Operation current density of the main coil, auxiliary coils I, and auxiliary coils II are 26%, 16% and 15% of the critical current density (Jc overall) of their superconductors, respectively. If the packing

Table 2
Superconductor for the coils

Coil	Superconductor	Cu/superconductor ratio	Conductor size
main	Nb_3Sn	1.25	1.25mm dia.
auxiliary I	Nb_3Sn	1.25	1.25mm dia.
auxiliary II	NbTi	3.5	1.6mmx0.86mm

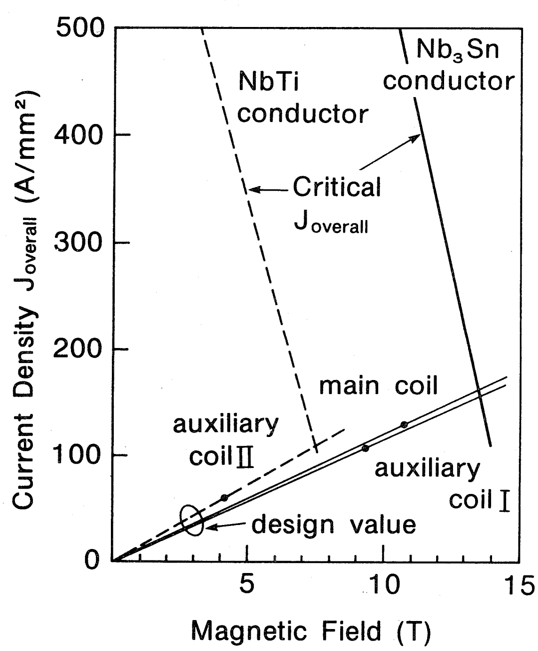

Fig. 5 Load line of the coils and critical current density of superconductors

factor (λ) of the superconductor in the coils in 50%, operation current density of the main coil, auxiliary coils I, and auxiliary coils II are 52%, 32%, and 30% of the λ Jc overall of their superconductors, respectively.

Cryostat Design

The horizontal stainless steel cryostat is designed for the five pole wiggler. The cross section is shown in Fig. 6. A helium vessel is supported by suspension rods in a external vessel. 20K and 80K thermal radiation shields are inserted between the helium vessel and the external vessel. The shields are cooled down by helium refrigerators. The cryostat is thermally insulated with multilayer insulation and vacuum in the external vessel.

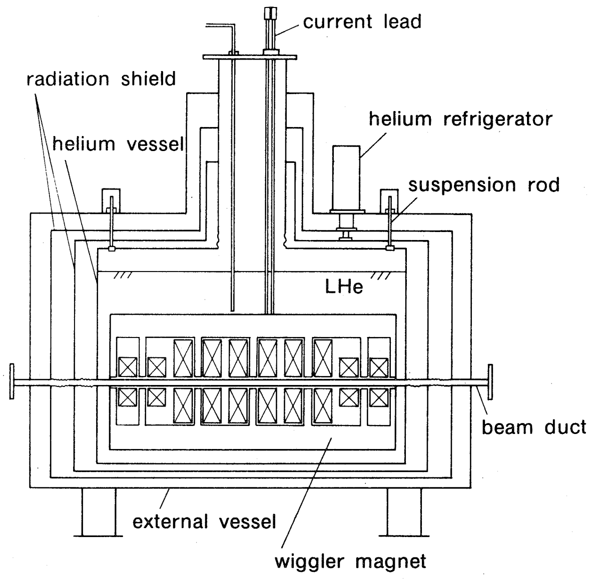

Fig. 6 Cryostat for the wiggler

Conclusion

A five pole 12T superconducting wiggler magnet has been designed. The maximum field of the coil winding of the wiggler magnet was calculated and the superconducting coil has been designed. Nb_3Sn and NbTi superconductors are used for the coil and iron cores are used to increase the peak magnetic field on the beam axis.

References

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2. J.L.Warren, G.P.Boicourt, M.T.Menzel, G.W.Rodenz and M.C.Vasquez, IEEE Trans. Nucl. Sci., NS-32, 2870 (1985)