R&D STATUS OF THE MAGNET SYSTEM FOR THE ATF DAMPING RING

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Abstract

The ATF (Accelerator Test Facility), which has been designed to test the experimental feasibility of accelerator sub-systems for JLC (Japan Linear Collider) [1], is being constructed at KEK to confirm the specification of the JLC total accelerator system. The ATF damping ring (DR) [2] requires very strict conditions for the magnet system to realize very low vertical normalized emittance less than 3×10^{-8} rm and fast damping time. The R&D status of these magnets is described.

Introduction

To obtain knowledge necessary for constructing a TeV energy linear collider, the ATF is being constructed at KEK. Generally the linear collider needs beams with very low emittance. The ATF-DR is a R&D damping ring which produces a beam with very low vertical normalized emittance less than 3×10^{-8} rm and the beam produced by this DR will be supplied to accelerating structures being developed for the JLC and many kinds of tests are being planned. To achieve such a low emittance and the fast damping time, the ATF-DR adopted a combined FOBO lattice and damping wigglers. Specifications of the magnet system have been almost fixed and some R&D magnets, which are a damping wiggler, a combined function bending, quadrupoles and a sextupole, have been manufactured and their magnetic fields were roughly measured. They are waiting for precise field measurements.

Damping Wiggler Magnet

The low emittance and fast damping time of the ATF-DR require high field and short pitch wigglers. These conditions conflict each other, because high field needs more space for magnetic flux sources and this fact makes wiggler pitch longer. Examining wiggler effects on emittance, the η' term is dominant in usual case and free spaces between adjacent wiggler poles have almost little effect on emittance in the lowest order approximation. This fact eases the requirement on the wiggler pitch. Our choice of the pitch is 0.4 m.

We have studied two types of damping wigglers. One is a hybrid magnet option using permanent magnet materials as flux sources and the other is a usual electric magnet with compact coils fed with intense currents. Field calculations by 2-dimensional codes PANDIRA and POISSON gave B_{peak} ,B_{eff} > 2T for the both types, where B_{eff} is defined as $\sqrt{<<B^2>>}$ and $<<B^2>>$ being an integral of the field over the whole wiggler length divided by the pole length, i.e. $\int B^2 ds / L_{pole}$. We chose the electric option taking account of its easy adjustable ability. Furthermore we reduced the values of B_{peak} and B_{eff} to 1.7~1.8T (the calculated value by POISSON) in consideration of power consumption.

One R&D wiggler magnet was constructed and the fields were measured as function of current. The whole structure and the cross section along beam line are shown in Fig.1 and Fig.2 respectively and the measured results are shown in Fig.3 with calculations by POISSON and OPERA-3d (TOSCA). The measured B_{peak} is about 15% smaller than the value calculated by POISSON. It's because 2-dimensional calculation is no longer correct to such a magnet with short poles as our wiggler. On the other hand, the 3-dimensional code OPERA-3d could reproduce the field measurement results very well. The calculation by OPERA-3d has shown that B_{peak} can be increased to ~1.6T by making the poles wider. Hence the poles are modified to be wider for final design.

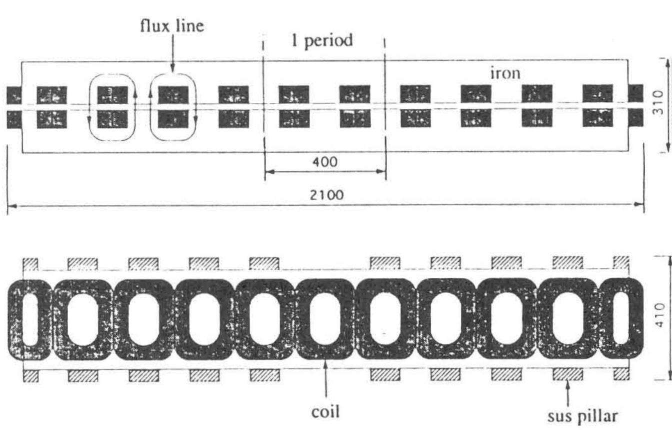

Fig.1 Conceptual figure of the damping wiggler

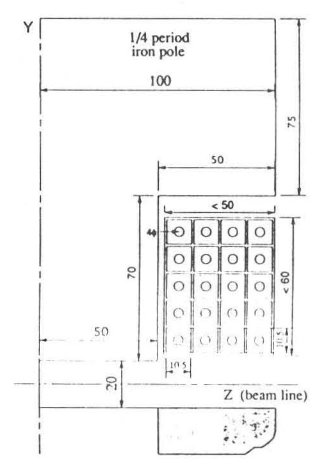

Fig. 2 Cross section of the damping wiggler along beam axis

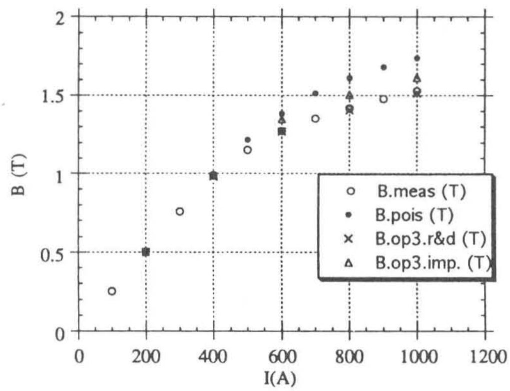

Fig. 3 Measurement results of the R&D damping wiggler with calculations by POISSON and OPERA-3d.

The final parameters of the damping wigglers are listed in Table 1. Eight damping wigglers with wider poles have been already manufactured and are waiting for field measurement. Precise field measurements are also in preparation.

TABLE 1 Damping Wiggler Parameters

total length	2.1 m	one period	0.4 m
full gap	20 mm	current/pole	20 kA
B_{peak}	~ 1.6 T	B_{eff}	~ 1.6 T

Combined Function Bending Magnet

Introducing combined function bending magnets which have defocus quadrupole field, we can reduce the transverse emittance by tuning damping partition number. The parameters of the combined bending magnet are shown in Table 2.

TABLE 2 Combined Bending Parameters

effective length	1.0 m	central gap	32 mm
dipole field B_0	0.9 T	field gradient B'	- 6.1222 T/m
bending radius ρ	5.73 m	(for a 1.54 GeV/c beam)	

This combined bending must be sector type because of the large sagittar about 22mm, otherwise a beam feels varying field as much as 15% of B_0 for a 1 m bending. The logarithmic pole profile was obtained for the sector type combined bending by solving Poisson equation on cylindrical coordinate. The field distribution, its dependence on coil positions, shimming and the field changes due to some manufacturing errors were studied by using POISSON. These studies showed that the accuracy of the poles must be better than 20μm to obtain the required field quality and what kinds of errors are more dangerous.

One R&D combined bending magnet was produced and its cross section is shown in Fig.4. Rough field measurements have been done by using Hall probe. The measurement results showed us some interesting features. The B and B' excitations measured at the center (see Fig. 5) show little saturation. The field mappings were done at 500A and 1000A and show that the gap accuracy is satisfactory. A little saturation is observed at the both ends in the mapping data along the beam direction at 1000A. A little front-back asymmetry localized at the both ends is also observed at the both currents. This asymmetry is thought to be due to position difference of the coil configuration. The multipole fields are obtained from the mapping data. The higher multipoles are mainly localized at the both ends and their integrated values are listed in Table 3.

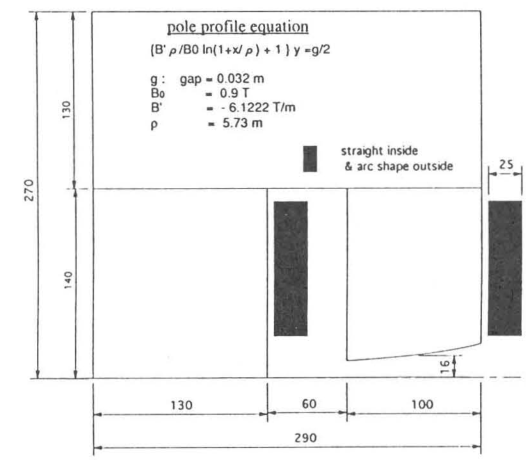

Fig. 4 Cross section of the R&D combined bending magnet

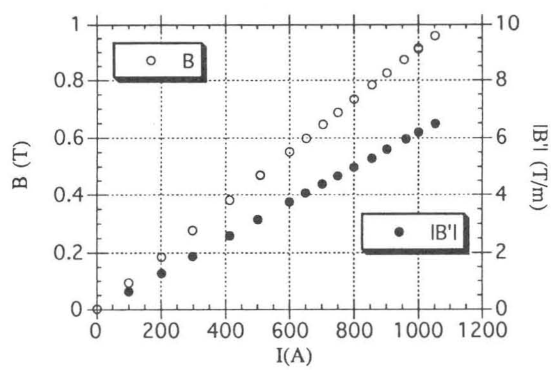

Fig. 5 R&D combined bending magnet B-I, B'-I characteristic curves

TABLE 3 Integrated Multipoles (normalized)

$(bl_{eff})_n$: $bl_{eff}[r] = Bl_{eff}[r] / Bl_{eff}[r_c] = \Sigma (bl_{eff})_n (r/r_0)^{n-1}$
here $r_c = \rho$, $r_0 = 10$ mm.

n	$(bl_{eff})_n$
1	1.
2	- 0.06614
3	$- 5.77 \times 10^{-4}$
4	2.12×10^{-4}
5	3.29×10^{-5}
6	$- 4.81 \times 10^{-5}$

The final design of the combined bending magnets will be completed by taking account of the field measurement results and further calculation by the computer codes. The precise measurement system using coils is also being planned now.

Quadrupole Magnet

The total number of quadrupoles required for the ATF-DR is about 100. Examining the optics results on the quadrupoles, we reduced the number of the quadrupole types to produce. These are shown in Table 4.

Table 4 Quadrupole Parameters

r_{bore} (m)	B'(T/m)	length (m)
0.016	55	0.18, 0.06, (0.10)
0.022	26	0.18, 0.06, (0.10)
0.016 (skew)	10	0.06

* The 0.10 m long quadrupoles will possibly be replaced by 0.18 m or 0.06 m quadrupoles by modifying the optics.

The uniformity of the quadrupole fields in 12mmϕ is required to be better than 0.1%. It needs manufacturing accuracy better than 30μm to achieve the required field quality. Two R&D quadrupoles were constructed with accuracy of 20μm. Those parameters are listed in Table 5.

Table 5 R&D Quadrupole Parameters

	type1	type2
pole length (m)	0.06	0.06
r_{bore} (m)	0.016	0.016
B'_{design} (T/m)	52	55
current/pole (Aturns)	5576 (328A×17)	6000

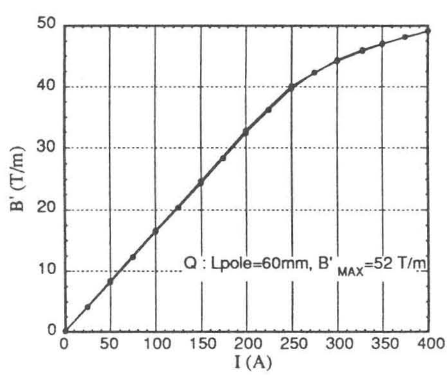

Fig. 6 R&D type-1 quadrupole B'-I characteristic curve

Rough field measurements were done by Hall probe and the results (see Fig.6) show that the field strength is about 10% less than the design value calculated by POISSON. But the integrated field gradient satisfies the required strength due to the effective length longer than the pole length. The discrepancy between the measured data and POISSON calculation is due to the short pole length and this fact implies that 2 dimensional calculation is not valid anymore. The field measurement results were well reproduced by OPERA-3d.

Sextupole Magnet

The ATF-DR needs about 70 sextupoles and their parameters are listed in Table 6.

Table 6 Sextupole Parameters

pole length (m)	0.06
r_{bore} (m)	0.016
B"(T/m^2)	6000
current/pole (Aturns)	3900 (325A×12)

The required manufacturing accuracy is as same as the quadrupoles. One R&D sextupole was constructed with accuracy of 20μm.

Rough field measurements were done as same way as the quadrupoles and we got the similar results (see Fig.7). Although the measured field strength is about 10% less than the design value by POISSON, the integrated sextupole field satisfies the required strength. The measurement results were also well reproduced by OPERA-3d.

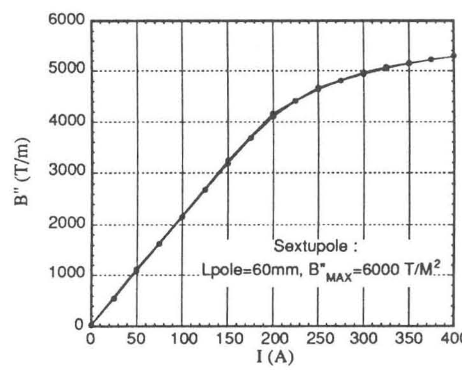

Fig. 7 R&D sextupole B"-I characteristic curve

Summary

Some R&D magnets for the ATF-DR were manufactured and the rough field measurements of them were performed by Hall prove. The final designs of the ATF-DR magnet system have been almost fixed by taking account of the measurement results of the R&D magnets and calculations by POISSON and OPERA-3d. Some magnets in actual use have been already manufactured and the others are under way. The precise field measurements are also in preparation now.

References

[1] JLC Group, "JLC-1" ,KEK Report 92-16, December 1992.
[2] J.Urakawa et al., "The Damping Ring of Accelerator Test Facility for Linear Collider" ,KEK Preprint 92-54, July 1992.