Design of the 1.8 Tesla Wiggler for the DAΦNE Main Rings

C. Sanelli and H. Hsieh
INFN Laboratori Nazionali di Frascati
C.P. 13 - 00044 Frascati (Roma) - Italy

Abstract

This paper describes the electromagnetic and mechanical design of the eight wiggler magnets for DAΦNE Main Rings. The wigglers have a large 1.8 Tesla flat top magnetic field, 64 cm period and 4 cm gap. The magnetic 3-D calculations, the electromagnetic design and the adopted mechanical solutions, with particular attention to the vacuum chamber problems are described. A full scale prototype (5 full poles and two half pole) will be constructed in order to verify the accuracy of magnetic calculations, the end pole design and the multipole content.

1. INTRODUCTION

A 510 MeV electron positron colliding beam facility, known as DAΦNE, is currently under design and construction at INFN's Frascati National Laboratory, Frascati, Italy. The project consists of two storage rings, Accumulator, electron/positron linac and transfer lines. There are four wigglers needed in each storage ring for radiation damping purpose. The magnet is iron core electromagnetic type, the median plane field is 1.8 Tesla at a magnetic gap of 40 mm. It has a period length of 640 mm, a total number of three periods are needed to satisfy the storage ring lattice requirements. We have carried out very careful magnetic calculation, both in two and three dimensional, to assure that both the dipole field uniformity and the higher harmonic content of this magnet are within the limits set by the machine physics group. In view of the critical nature of this wiggler to the performance of the storage rings, we deem necessary to have a full size prototype to verify, by careful magnetic measurements, the validity of our magnetic computations. In addition, the shaping of the end poles and field clamps will also be determined iteratively by the magnetic measurements.

2. ELECTROMAGNETIC DESIGN

2.1. *Magnetic computations*

The initial profile of the center pole was investigated by utilizing POISSON. The combination of high on-axis field (1.8 Tesla) and long field flat top (16cm) results in very high induction in the steel. therefore a three dimensional study was deemed necessary to obtain more accurate field characteristic of this magnet. The half "full" pole, the end pole and the ending field clamp were simulated by means of Magnus (magnetostatic 3-D code). It was not possible to investigate the entire magnet structure due to the limitation of the mesh point number that even in this simplified case was increased to about 32000. The condition that $\int B_z * ds = 0$ (where B_z is the vertical component of the field and s is the longitudinal coordinate) was achieved by few iteration of varying the mechanical length of the end pole. It was decided that the end poles of the prototype will be made 10 mm longer than that of computational result, the final length will be iteratively determined by the magnetic measurements. The following results are referred to this configuration. The transverse dimension of the magnet was optimized to reduce the harmonic content of the magnetic field. Fig. 2.1.1 shows the geometry of the wiggler iron core analyzed by Magnus.

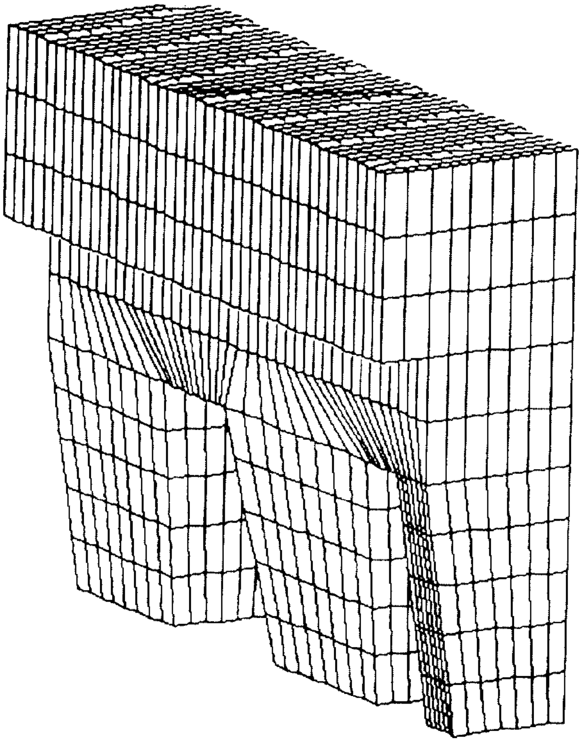

Fig. 2.1.1 - The wiggler iron core simulated in 3-D

The field profile along the longitudinal axis of the magnet, is shown in Fig. 2.1.2.

The maximum positive field is 1.81 Tesla and the negative peak field is -1.65 Tesla. A slight positive overshoot is predicted by the code due to the field clamp, approximately 215 Gauss.

With the above geometry, the $\int B_z * ds$ is strongly negative (-9553.4 Gauss) mainly due to the end pole length increase. The same integral at 10 mm parallel offset is about -1 Gauss lower. These data give an idea of the transverse field flat top, whose profile, at the wiggler midplane, is shown in Fig. 2.1.3.

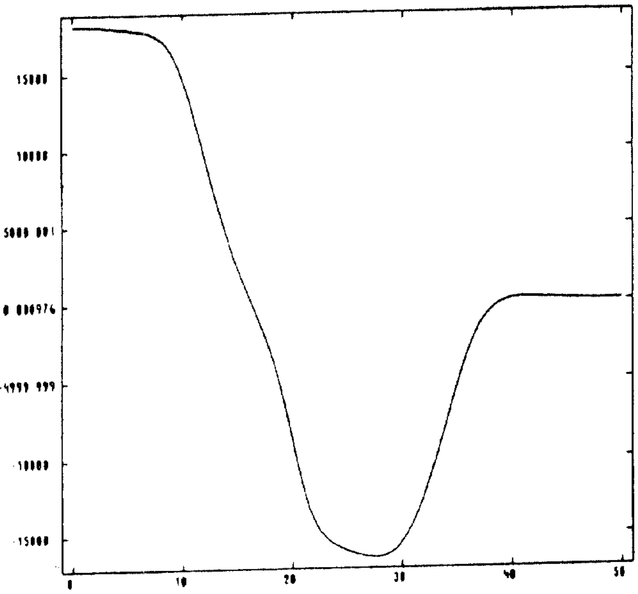

Fig. 2.1.2 - Longitudinal magnetic field profile

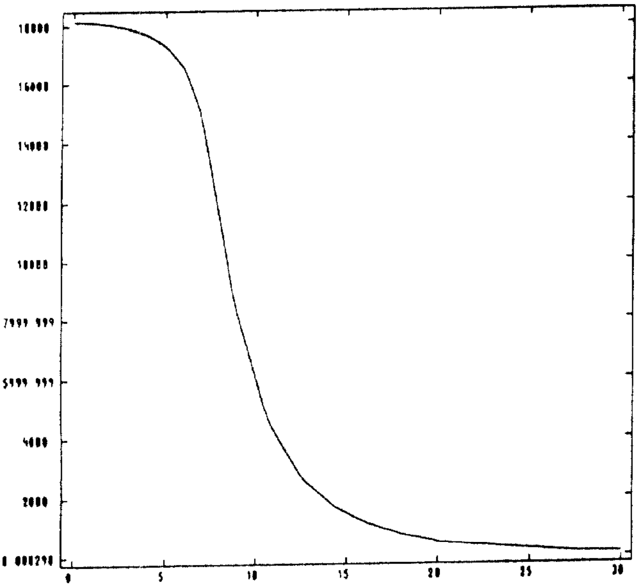

Fig. 2.1.3 - Transversal magnetic field profile

2.2. *Electrical and hydraulic design*

Following up the magnetic computations, the mechanical dimensions of the wiggler poles have been fixed. The special vacuum chamber for this wiggler imposes strong constraints to the coil dimensions. The coil cross section is rectangular with slight tilt to conform to the shape of the magnet pole. The equivalent electric center of the coil was conscientiously placed as close as possible to the magnet median plane, this results in reducing , pole to pole, magnetic flux with the benefit of increasing the lateral reluctance and then the flat top field at the gap. Table 1 lists the magnet parameters

Table 1. Wiggler magnet parameters

Nominal beam energy (Mev)	510
Magnetic field at the gap center (Tesla)	1.8
Wiggler period (mm)	640
Number of periods	3
Amper - turns per pole (A)	54000
Turns per pole	80
Cu cond. cross section (mm * mm)	7 * 7
Cooling hole diameter (mm)	4.0
Nominal Current (A)	675
Maximum Current (A)	750
Current density (A/mm^2)	18.5
Max. Current density (A/mm^2)	20.6
Nominal Voltage (V)	376
Max. Voltage (V)	418
Nominal Power (kW)	254
Max. Power (kW)	313
Water circuits per coil in parallel	5
Total cooling water flow rate (l/min)	160
Water velocity (m/sec)	3
Pressure drop (Atm)	4.5
Water temperature increase (°C)	30

3. MECHANICAL DESIGN

3.1 *Magnet structure*

Figure 3.1.1 shows the complete mechanical design of the wiggler system. The magnet yoke is made of low carbon steel equivalent to AISI 1006 or lower carbon content. The pole pieces are bolted to the return leg with appropriate locating dowels so that they can be detached and modifications can be made during the cause of magnetic measurement. The return leg is made with mechanical stiffness as criteria, it is anticipated that the deflection along the longitudinal direction will be less than 30 micrometers.

Wiggler vacuum chamber is made of aluminum alloy and it is an integral part of the storage ring arc chamber, no mechanical flanging is contemplated. The width of the chamber is in the order of 50 cm wide, the synchrotron radiation will only strike the down stream copper photon absorbers where thermal and gas desorption problems can be effectively dealt with. Due to the width of this chamber, the transverse ribbings are mandatory from both stress and strain points of view. These ribbings prevent the total utilization of the available space between the poles by the coil package. This constraint results in high power consumption to some extent. The axis of the wiggler is 12.5 mm offset from that of vacuum chamber due to the beam orbit offset through the wiggler. The coils are partially nested inside the chamber cavity, the cooling water supply and return will utilize the void space between coils and chamber wall due to the axis offset.

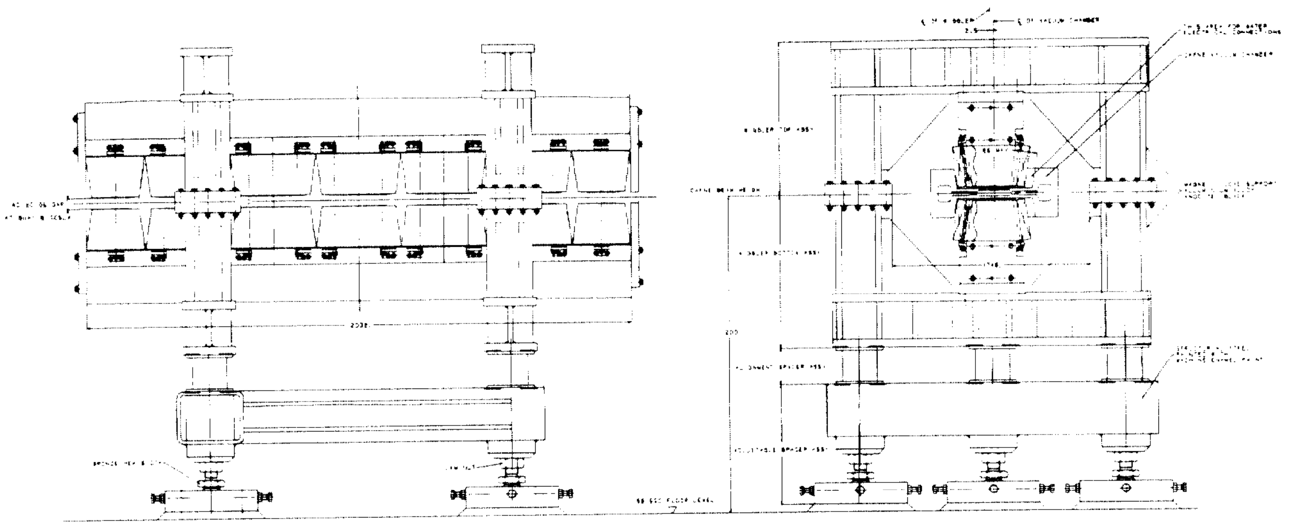

Fig. 3.1.1 - Wiggler system

3.2 Wiggler support structure

The magnetic pressure between the poles is in the order of 40 metric tons. The support structure near the wiggler will be made of non-ferromagnetic material to avoid the possible electromagnetic coupling with the stray field resulting in perturbation to the field quality. The geometry of the vacuum chamber dictates that the wiggler assembly has to be parted along the magnet median plane during the installation process, top half of the assembly to be lifted by building crane, the bottom half assembly to be lowered by removing the alignment spacers. It is further required that re-installation of the wiggler and ring chamber shall need no re-alignment to recover the original placement accuracy, therefore, the locating dowels have to be implemented at all interface planes. The adjustable frame assembly will provide the necessary adjustments during the initial alignment process.

3.3 Wiggler Prototype

There are four wigglers required for each storage ring, total of eight for the total project. The first wiggler delivered by the industry will be utilized as a prototype. Extensive magnetic measurements will be carried out prior to the release of serial production.