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The 1.8 Tesla Wiggler for the Main Rings of DAΦNE, the Frascati Φ-Factory

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Abstract

DAΦNE is a Φ-Factory, presently under construction at INFN, Laboratori Nazionali di Frascati. To improve radiation damping and control beam emittance, eight 1.8 Tesla room temperature wiggler magnets will be installed in two main rings. A full size prototype, built by Danfysik (Denmark), has been designed and completely characterized at LNF. This paper describes the mechanical design of the magnet and the magnetic measurements.

Comparison between the measured field and the 3-D FEM code calculations is also presented.

1. INTRODUCTION

DAΦNE, an electron-positron collider [1] working at the Φ resonance energy (510 MeV per beam), is being realized in the INFN Frascati National Laboratory. Commissioning is foreseen in fall 1996.

In order to achieve a luminosity improvement by two orders of magnitude with respect to existing facilities at the same energy, a double ring scheme has been chosen, with up to 120 bunches crossing in two low-β interaction points, where detectors with longitudinal field are installed.

Beam-beam interaction set limits to the maximum achievable luminosity, which are particularly severe at low energy. Experience with existing e^+e^- storage rings [2] and theoretical considerations [3] show that radiation damping is a strong parameter in determining the achievable luminosity. For this reason 4 wigglers have been inserted in each ring, in the center of the achromats, which increase the radiated energy from 4.3 to 9.3 KeV per turn. In addition, by slightly changing the betatron functions in the wigglers, it is possible to tune the beam emittance over a wide range in order to reach the optimum luminosity at any beam current.

Two conditions in the wiggler field must be satisfied to avoid closed orbit distortion: the vertical field integral along the beam trajectory must vanish and the field distribution must be symmetric with respect to the wiggler center. Moreover, it is necessary that the integrated sextupole term, caused by the finite pole width, does not affect the nonlinear motion of the stored particles.

A wiggler prototype built by Danfysik (Denmark) has been delivered in January 1994, and a complete set of electric and hydraulic tests, mechanical and magnetic measurements has been performed, in order to release authorization for series production.

2. MECHANICAL DESIGN

Figure 1 shows a view of the assembled wiggler prototype [4].

The magnet yoke is made of low carbon steel. The final half-pole plates are bolted to the return leg with suitable locating dowels, to allow easy detaching and modification, if required, during magnetic measurements. The width of the wiggler vacuum chamber is ≈50 cm, and due to this large size transverse aluminum ribbings are mandatory both for stress and strain.

In the final configuration these ribbings have a rounded "C" shape, which is different from the original design. The Table 1 recalls the most important parameters of the wiggler design.

Table 1 - Wiggler magnet prototype 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)	56160
Turns per pole	80
Cu cond. cross section (mm * mm)	7 * 7
Cooling hole diameter (mm)	4.0
Nominal Current (A)	702
Maximum Current (A)	750
Current density (A/mm^2)	18.7
Max. Current density (A/mm^2)	20.6
Nominal Voltage (V)	377
Max. Voltage (V)	403
Nominal Power (kW)	265
Max. Power (kW)	302
Water circuits per coil in parallel	5
Total cooling water flow rate (l/min)	146
Water velocity (m/sec)	2.65
Pressure drop (Atm)	4.5
Water temperature increase (°C)	30

2.1 Tests and Mechanical measurements

A set of electrical and hydraulic measurements [5] has been performed on the prototype. The measured values are very close to the design ones. The major discrepancy is the nominal current (702 A instead of 675 A). The gap between the poles, without magnetic field, varies between 40.12 mm and 40.17 mm.

The attractive force produced by the magnetic field reduces the gap by 0.35 mm (with a standard deviation of 0.05 mm), as predicted by 3-D simulation, and corresponds to about 34 tons. The vertical parts of the four "C" side ribbings, directly supported by four jacks, do not move (negligible compression): the yoke movements are due to the combination of bending and rotation of the "C" ribbings.

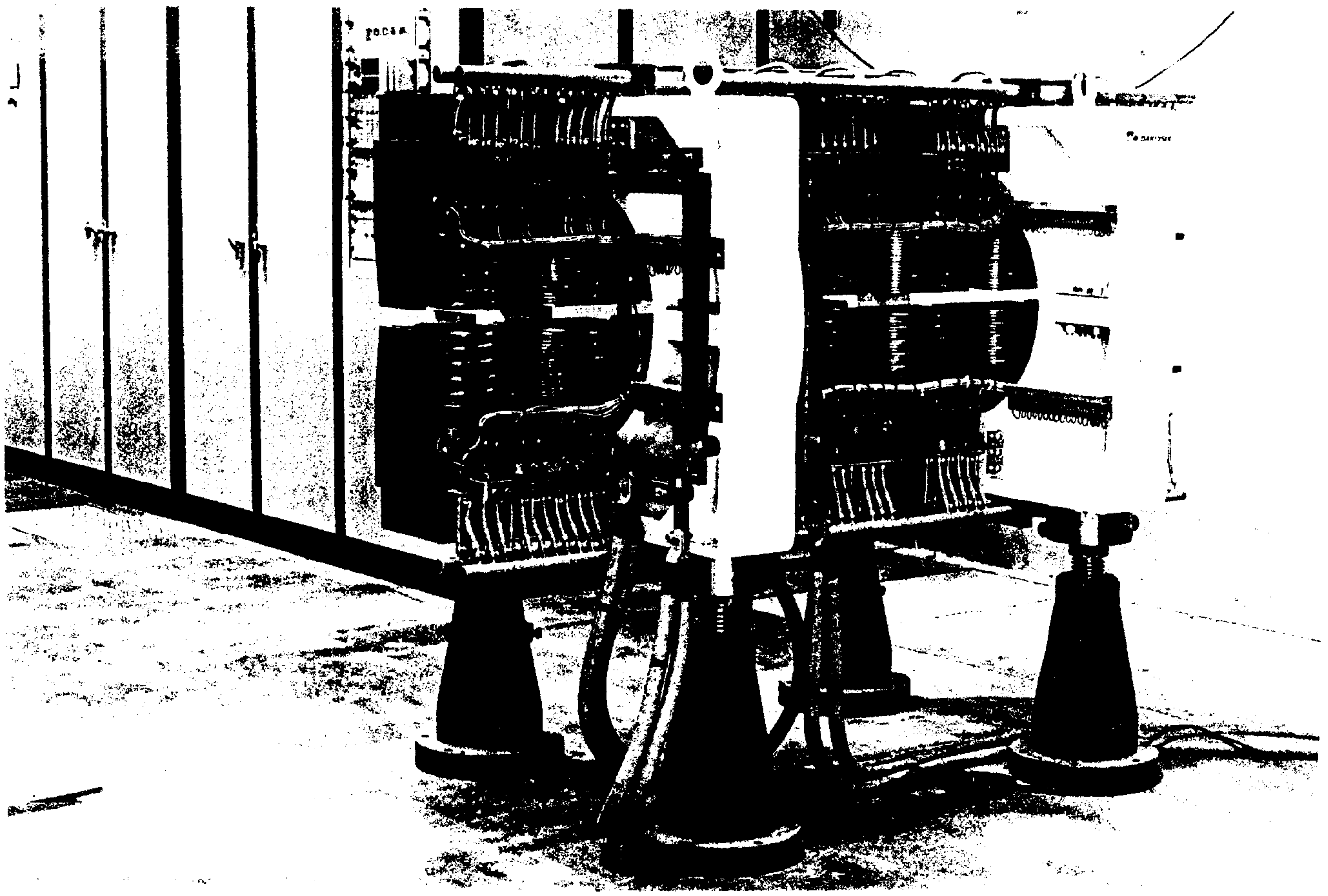

Figure 1. Wiggler prototype.

3. MAGNETIC MEASUREMENTS

A first set of measurements [5] with a 3 m long flip-coil has been performed, in order to rapidly find the current in the end poles required to make the field integral vanish on the wiggler axis as a function of the current in the main poles. Compensation on the particle trajectory is much more cumbersome, since one has to perform point to point measurements on the wiggler horizontal symmetry plane and integrate the equation of motion of the electrons in the measured field. An exact solution can be found only after a certain number of iterations. Due to the limited width of the poles (14 cm) and the large amplitude of the oscillating trajectory inside it (≈2.5 cm), the wiggler will be displaced towards the outside of the ring by half this amplitude. In this case the field integrals on the trajectory and on the wiggler axis have the same value within the required closed orbit tolerance.

Figure 2 shows the current in the end poles and the maximum field in the main poles measured with a Hall probe as a function of the current in the main poles. probe can be displaced horizontally and vertically in 5 mm steps by means of precision pins on the carriage.

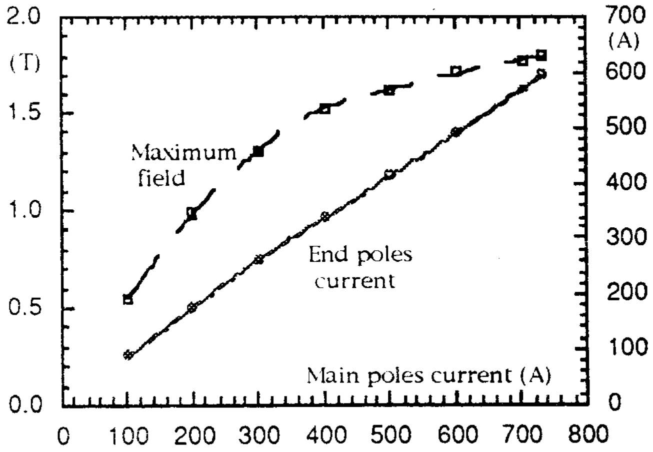

Figure 2. End poles compensation curve.

The behaviour of the field as a function of longitudinal, horizontal and vertical position inside the wiggler has been investigated by means of a Hall probe (Bruker B-H15 Teslameter) calibrated against a NMR (Metrolab PT2025) device. The probe is mounted on a pneumatically suspended carriage in a reference guiding box.

The longitudinal position of the probe is monitored by an encoder with 0.1 mm resolution, and the Figure 3 shows the vertical field distribution on the wiggler axis. The compensation curve of Figure 2 has been checked at the maximum field and at a few intermediate points by integrating the point-to-point measurements, and found in agreement within ≈10 A in the end pole current. Repeatability of the integrated field in a longitudinal scan has been found to be within ±1 Gm.The dependence of the integrated field on the horizontal coordinate gives an estimate of the sextupole term in the wiggler field expansion.

Figure 4 shows the result of the measurement, where the second order best fit yields a sextupole integrated term of -2.2 T/m, about ten times smaller than the contribution of a chromaticity correcting sextupole.

Numerical simulations have shown that the perturbation introduced by the wiggler is not harmful to the nonlinear behaviour of the particles in the rings. The symmetry of the field with respect to the wiggler center has been found to be within 50 G at the maximum excitation. Again, numerical simulations have shown that the effect on the closed orbit is negligible.

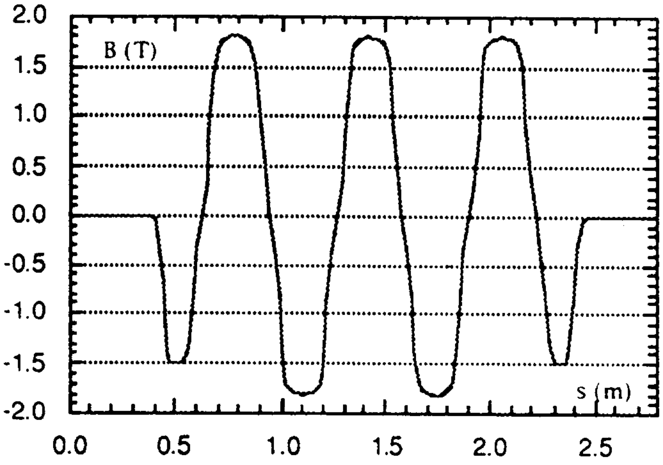

Figure 3. Vertical field along the wiggler axis

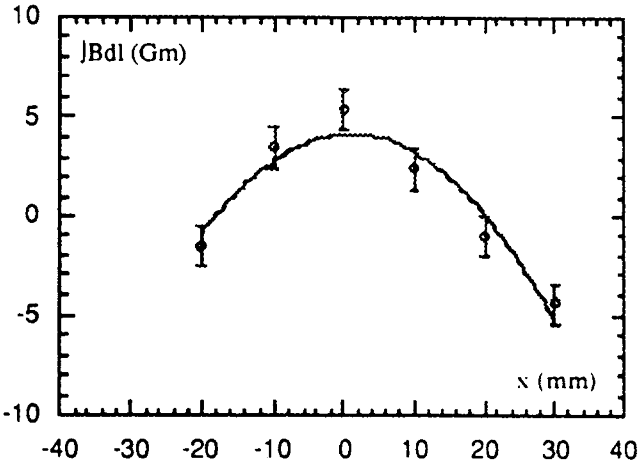

Figure 4. Integrated sextupole term in the wiggler field.

4. COMPARISON WITH MAGNETIC F.E.M. DESIGN

We have compared the measured field with the prediction of the 3-D finite element code MAGNUS [6] in a section of the wiggler starting from the midpoint of the last full pole, going through the end pole and the field clamp, and ending up in the fringing field region.

Figure 5 shows the calculated field (line) and superimposed experimental points (dots): the agreement is quite satisfactory.

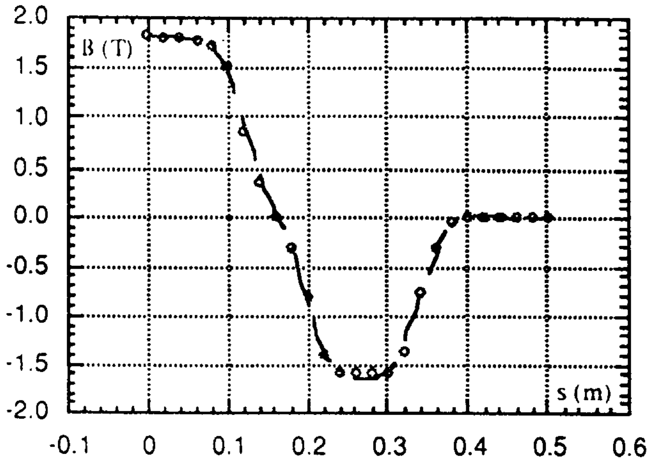

Figure 5. Comparison between measured and calculated field

5. CONCLUSIONS

A complete set of mechanical, electrical, hydraulic and magnetic tests has been performed of the prototype wiggler magnet delivered by Danfysik to LNF in January 1994. These tests have suggested a number of modifications to be developed on the final version of the magnet and the power supplies. Using both a rotating coil system and a Hall probe driven by an accurate positioning system, the field integral on the wiggler axis has been carefully compensated at several operating points. Although some asymmetries in the field and a non-negligible sextupole term have been evidenced by the measurements, we feel confident that the magnetic quality of the wiggler meets the requirements of the DAΦNE Main Rings.

3. REFERENCES

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