A New Hybrid Tunable Quadrupole Proposal for the DAΦNE Main Ring Low Beta Insertions

C. Sanelli, A. Cattoni
INFN-Laboratori Nazionali di Frascati
C.P. 13, 00044 Frascati (Roma) Italy
L. Barbagelata, F. Crenna, M. Grattarola, G.C. Gualco and F. Rosatelli
ANSALDO RICERCHE, Divisione Nuove Tecnologie
Corso Perrone 25, 16161 Genova, Italy

Abstract

A hybrid, tunable, p.m. quadrupole prototype, 5.3 T/m, 45 mm bore radius, 280 mm in length, for Daϕne has been designed and built in a collaboration between Ansaldo Ricerche - Genova and the Frascati National Laboratory Magnet Group. Magnetic calculation, constructive design and the first acceptance test results are briefly reported in this paper.

1. INTRODUCTION

In the Daϕne Φ Factory, electrons and positrons circulate in two separate storage rings, whose top view is about elliptical, intersecting in the horizontal plane, giving rise to two interaction points (I.P.), each one placed at the centre of a long straight section. On both side of each I.P. a triplet of quadrupoles is needed, to focalize the beams and to obtain a minimum value of the β_y function, which is a design parameter of paramount importance to achieve a high luminosity (1, 2, 3). Likely every I.P. will be surrounded by a large detector incorporating the most of the straight section, vacuum chamber and the triplets of the low-beta insertion included. In addition the first detector will be equipped with a big solenoid, may be superconducting, about 6 m in diameter and 5 m in length, whose magnetic field should not be seen by the machine beams. Shielding solenoids, coaxial with the beams are needed (4), limiting even more the allowance for the low-beta insertion quads.

2. BOUNDARY CONDITIONS FOR THE LOW BETA INSERTION QUADRUPOLES

The detector requests, aimed to maximize the solid angle, impose to confine the machine components, shielding solenoids included, in a conical zone with the vertex centred in the I.P. and a half aperture angle of 8.5 degrees. Taking into account the machine optics lay-out, this comes out in the following constraints for the overall radial extension of the quads:

- First quadrupole, the closest to the I.P., outer radius $\leq$0.067m
- Third quadrupole, the farthest from the I.P., outer radius $\leq$0.156 m.

Having available in our storage a stock of about 500 prismatic Recoma Magnets, 9x9 mm^2 in cross section, 70 mm in length, we came to the decision of trying a hybrid permanent magnet quadrupole, equipped with two tuning studs per pole, wedge shaped, just to learn what were the possibilities of solving our problems.

3. MAGNETIC CALCULATIONS

The hybrid quadrupole geometry has been analyzed with PANDIRA (2D-code) at LNF and with PE2D and TOSCA at Ansaldo (2D and 3D codes respectively). Pandira and PE2D gave nearly the same results but the 3D analysis gave quite different results. The basic geometry has been carefully studied and modified to obtain the maximum gradient. At the beginning we set the radial length of the iron wedge the same of that of the p.m blocks. The calculations showed that there is (like on the p.m. undulators (5)) a gradient increase of the order of 3 % when the p.m. block is overhanging the wedge. Consequently we decided to shorten the wedge length, decreasing at the same time the fringing field outside the quadrupole. Even the position of the permanent magnets was optimized to get a higher gradient, moving the p.m. block toward the quadrupole centre. Note that when this distance is too much reduced, the flux going out from the p.m. block closes on itself and it does not penetrate into the iron, so that one loses the 'iron dominated' condition.

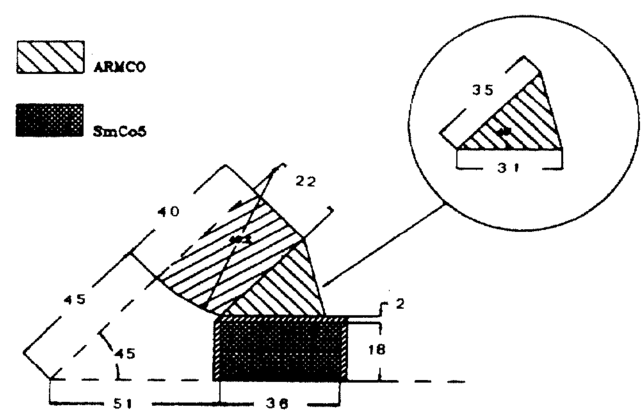

Fig. 3.1 - Basic geometry, 1/8th of the quadrupole

Taking into account all these considerations the Pandira run predicted a gradient of 5.74 [T/m]. The pole profile was approximated with an arc of circle. The calculations made at Ansaldo by means of PE2D showed nearly the same results, 5.84 [T/m] with circular pole profile and 5.67 [T/m] with hyperbolic pole profile. The last profile had the advantage to reduce the gradient variation from 8 to 3 * 10^{-3} at 12 mm far from the quadrupole centre.

Fig. 3.1 shows the basic geometry. Fig. 3.2 shows the gradient variation as calculated by Pandira with the wedges closed and opened respectively.

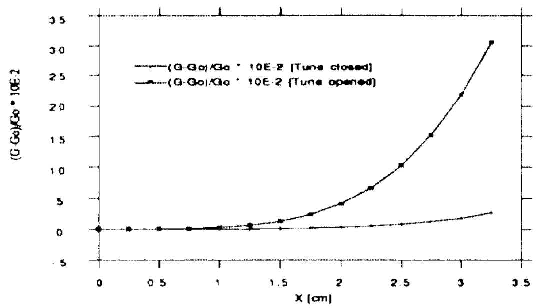

Figure 3.2 - Gradient uniformity from Pandira

The Tosca calculations, made at Ansaldo, gave results strongly different from the 2D codes. The predicted value at the centre of the quadrupole was 4.87 [T/m].

4. PERMANENT MAGNET MEASUREMENTS AND SORTING

The characterization of the permanent magnets for the quadrupole has been carried out in three steps :

1) Preliminary characterization by a Hall effect gauss-meter
2) Dimensional measurements
3) Measurements of the angular deviation and of the relative strength of magnetization.

A total of 568 permanent magnets have been measured. The average measured magnetic field has been: $B_{average}$ = 0.281 Tesla with standard deviation 0.008 Tesla. Only 426 magnets were chosen and dimensionally measured. The magnets whose transverse dimensions differed from the nominal value (9 mm) by more than 0.05 mm have been discarded. 397 magnets have been accepted.

These magnets have then been magnetically characterized. The equipment set up at Ansaldo Ricerche, allows to measure the relative strength of magnetization (with respect to a reference magnet) and the angular deviation of magnetization from the nominal direction. The nominal direction is defined as the vertical axis perpendicular to the reference magnet face. The magnet to be measured ($|M|$) and the reference magnet ($|M_r|$), both with parallel and anti-parallel magnetic moments, are kept in rotation inside the bore of a coil at a frequency of 1200 turns/minute. An harmonic analysis (FFT) of the induced voltage allows to obtain the amplitude and the phase of the fundamental and then the ε and θ values (where ε is defined as $(|M| - |M_r|)/ |M_r|$ and θ is the angular deviation of the magnetization with respect to the reference one). The experimental errors are : $\pm 10^{-4}$ for ε and $\pm$ 1 mrad for θ.

After the preliminary magnetic characterization, 13 magnets, whose $|M|$ and θ were as close as possible around the distribution centre, have been chosen and 12 of them have been measured with respect to an arbitrary magnet, then, among these, the magnet number 186 was picked out for final reference. 396 magnets have been measured with respect to that magnet and the following results were obtained:

- standard deviation of ε = 0.014
- standard deviation of θ = 0.010 rad.

The hybrid quadrupole needs four flux generators, four layers of 16 magnets each, for a total of 256 permanent magnets. Sorting has been carried out forming 8 groups of magnets, 32 magnets for each group. The magnets of the same group are as similar as possible among them, both in regard to ε and to θ. Each 32 magnet group has at its time been divided in 8 groups, 4 magnets each, as similar as possible. The 4 magnets have been mounted one behind the other to obtain the best longitudinal homogeneity.

One time the four flux generators have been assembled, they have been magnetically tested using a Hall effect Gaussmeter. The Hall Probe was put at 29 mm from the permanent magnets surface and it was moved longitudinally along four lines parallel to the quadrupole axis, two above and two below the flux generator surfaces, and the magnetic field was recorded. In addition a map along a transverse axis, at the same distance from the magnets surface, in correspondence of the flux generator mid-plane, has been carried out. The maximum deviation among the four flux generators is about 4%.

5. MECHANICAL DESIGN AND CONSTRUCTION

5.1 Mechanical design

The quadrupole prototype is essentially composed by four iron poles, four magnet assemblies, above defined as flux generators, and eight tuning studs (wedges), all supported by an outer cylindrical structure. Each pole is fixed to the structure. Calibrated spacers of different thickness can be placed on the pole back in order to be able to change the bore radius. Each magnet assembly is made up by magnet blocks not glued but mechanically clamped by an external aluminum structure. The four magnet assemblies are mounted in calibrated slots in the outer cylindrical structure. The movable tuning wedges slide on the lateral sides of the magnet assembly boxes. The gap between the tuning wedges and the poles can be set from 0 to 4.5 mm. The outer cylindrical structure was designed to allow the splitting of the quadrupole in two parts for mounting operations around the vacuum chamber.

5.2 Materials and machining

The following materials have been used for the different quadrupole parts :

- Magnet assemblies: SmCo5 magnet blocks with nominal residual field Br=8.5 kGauss and coercive force Hc=8300 Oe.
- Poles and tuning wedges: ARMCO pure iron (99.7 %)
- Outer cylindrical structure: ERGAL aluminum alloy.
- Screws and bolts: AISI 304 stainless steel and brass.
- Pins: AISI 304 stainless steel.

The two parts of the cylindrical structure were obtained from a massive extruded bar. After a pre-machining they were heat treated for stabilization and then finished on the contact surfaces, pinned and bolted each other. The whole assembly was then finished machining to obtain the final structure. The pole profile was realized by means of a numerical control machine.

The calculations were performed in 2D geometry by means of the PE2D code (Vector Field).An hyperbolic profile was chosen. The optimization was performed to minimize the relative gradient variation ΔG = (G-Go)/Go at 20 mm from the quadrupole centre (G=local gradient; Go = gradient in the centre). The optimization started with the theoretical pole profile: $y(x) = Ro^2 / 2x$; where Ro=45 mm is the bore radius and only those profiles compatible with the geometrical and the assembling constraints were taken into consideration. The ΔG value was decreased from $8.13*10^{-3}$ to $2.92*10^{-3}$ with the profile:

$$y(x) = \frac{h*x+a-h^2}{x-h}$$

where : $a = 700\ mm^2$, $h=5.362$ mm $(20 \leq x \leq 50\ mm)$

6. MAGNETIC MEASUREMENTS

A first set of magnetic measurements has been performed by means of a Hall effect Gauss-meter at Ansaldo Ricerche.Field maps on the horizontal and vertical axes laying on the medium transverse plane and on the planes in front and on the back of the quadrupole, for different wedge positions, have been carried out. In addition, field integral maps along lines parallel to the longitudinal axis at ±16, ±18, ±20, ±22 and ±24 mm from the quadrupole centre on the horizontal and vertical axes have been recorded. Finally, the fringing field outside the magnet has been measured and the relative curves plotted. For obvious reasons only a few curves are reported here. The average measured gradient with the wedges closed is 5.268 T/m. The gradient with the wedges completely opened is 4.574 T/m. This allows a tune range of 13.2%. The maximum measured gradient value is -8.2 % lower than the Pandira calculation and +8.1 % greater than the Tosca evaluation.

Fig. 6.1 shows how the gradient decreases opening the wedges.

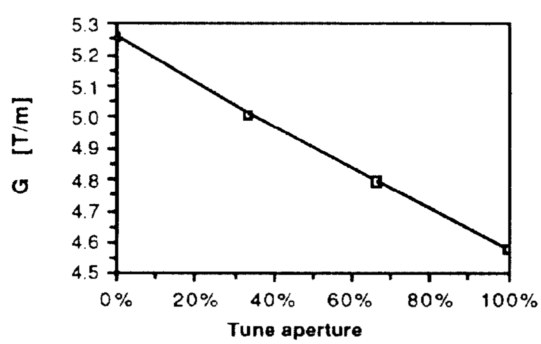

Fig. 6.1 - Absolute gradient variation vs tune aperture

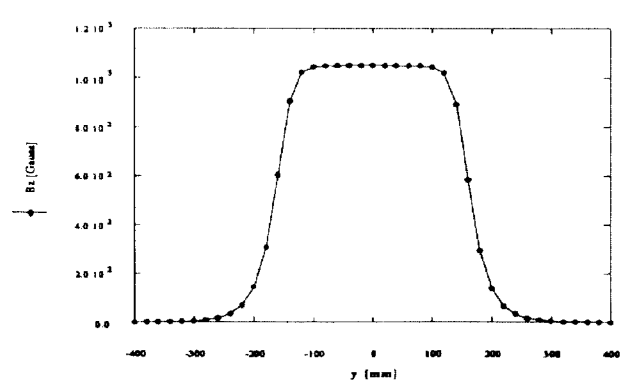

Fig. 6.2 - Longitudinal field profile

The magnetic length of the quadrupole has been calculated using the field integral maps. The average value, on a total of 20 curves, is 338.74 mm ±0.4 mm. Fig. 6.2 shows the field variation along an axis parallel to the quadrupole axis but horizontally shifted 20 mm from the quadrupole centre.In fig. 6.3 the gradient variation in terms of ΔG/Go, where Go is the gradient at the quadrupole centre (Go=5.268 T/m) , is reported.

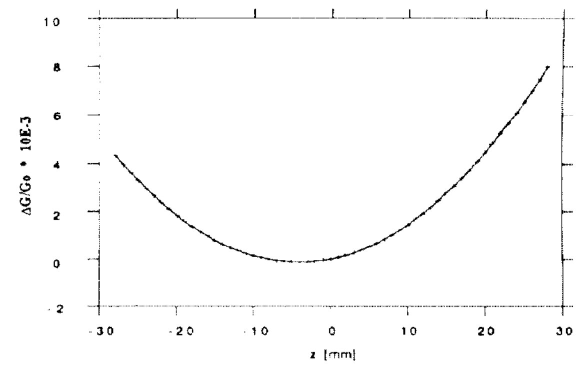

Fig. 6.3 - Gradient uniformity at the quad midplane

7. CONCLUSIONS

The magnetic measurement program is not yet completed and a deeper investigation is still needed. The major items that must be analyzed are:

- determine the displacement of the magnetic axis with respect to the mechanical one;
- made the harmonic content analysis by means of rotating coil;
- balance the quad, using the tune wedges, at a fixed gradient value;
- modify the pole profile to increase the gradient homogeneity and consequently decrease the multi-pole terms;
- superimpose a solenoidal field and measure the total effect;
- study the better way to shield the external fringing field.

We hope to complete the work before the end of this year, using the automatic multi-pole magnet measurement system, model 692, based on rotating coil technology, that has been ordered to Danfysik and whose delivery term is October 1992.

This type of hybrid, tunable quadrupole is Patent pending.

8. REFERENCES

[1] The DAΦNE Project Team: "DAΦNE Design Criteria and Project Overview", Proc. of the Workshop on Physics and Detectors for DAΦNE, Frascati, April 9-12, 1991.

[2] The DAΦNE Project Team: "DAΦNE: The Frascati Φ-Factory " Proc. of P.A.C.1991, S. Francisco, May 6-9, 1991.

[3] M.E. Biagini et Al.: DAΦNE Lattice Update, Technical Note L-4, INFN LNF,Accelerator Division, Dec.2, 1991.

[4] "Proposal for a Φ–Factory" LNF-90/031(R) 30/Apr./1990

[5] K.Halbach et Al. "CSEM-Steel Hybrid Wiggler/Undulator Magnetic Field Studies- IEEE Trans. Nuclear Science NS-32-5 (1985).