Design, Manufacture and Testing of DAΦNE Transfer Lines Magnets at Ansaldo GIE
Part I - Linac Beam Diagnostic Branch

A. Bixio, L.Ghirlanda, F.Terzi
ANSALDO GIE
Via N. Lorenzi 8, I-16152 Genova, Italy

Abstract

In April 1993 Ansaldo GIE, Magnet Dept., was awarded by INFN-LNF with a contract for the turn-key construction of the Transfer Lines for the e^+e^- Φ-factory DAΦNE in Frascati, Rome. The contract includes resistive Dipoles, Quadrupoles and Correctors of 14 different types, more than two hundreds of vacuum chambers and diagnostics, the whole support system, installation and preliminary alignment of the lines for a total length of about 155 m.
Conceptual and detailed design have been developed in 1993 on LNF baseline design, and now Ansaldo has manufactured the first batch of magnets, which are currently under magnetic test. Design highlights and testing results are presented.

1. INTRODUCTION

The Italian 'Istituto Nazionale di Fisica Nucleare - Laboratori Nazionali di Frascati' awarded Ansaldo GIE in April 1993 with the turn-key construction of the Transfer Lines for the e^+e^- Φ-factory DAΦNE [1]. The energy of the particles is 510 MeV (up to 800 MeV for Spectrometer and Beam Test Facility lines).
Starting from a detailed technical specification [2] supplied by DAΦNE staff, Ansaldo has developed the conceptual study of this part of the project, completed and approved in late 1993.

A dedicated staff was devoted to fulfil the following tasks, to be completed in very short time:

- detailed design and fabrication of magnets and supports;
- detailed design and fabrication of vacuum chambers;
- detailed design and fabrication of diagnostics;
- magnetic measurement benches: design and installation;
- alignment study, installation and alignment on site.

Up to now Ansaldo has produced and tested the first batch of magnets requested by LNF, the Linac Beam Diagnostic Branch magnets, and the associated vacuum chambers, diagnostics etc., which are representative of the whole production, as illustrated in the following paragraphs.

2. MAGNETS DESIGN

There are 101 magnets needed for the Beam transport from Linac to Accumulator, and back to the Main Storage Rings; but the Transfer Lines have been designed to fit in existing buildings; due to this fact and to the special design of the optics suitable for $e^- + e^+$, there are 14 different types of magnets to be individually designed. In Table 1 the outstanding features of the magnets and the conventional appellation are reported.

dipole name	magnet gap (mm)	defl. angle (deg.)	magn. length (mm)	magn. field (T)	nom. current (A)	power (kW)
DHPTT01/02	25	45	1113	1.20	553**	30**
DHSTT01	25	45	1113	1.20	553	30
DHPTS01	25	6.52	683	0.44*	184**	2.2**
DHRTE02/03	20	31.06	757	1.22	156	2.9
DHRTE01/TT01	30	30.2	757	1.18	233	6.5
DHRTP01	30	18.26	451	1.20	238	4.4
DHRTP02	30	13.88	451	0.91	173	2.3
DHSTB01/02	42	45	1353	1.55*	585	21
DHSTS01	30	60	1803	1.55*	232	7.2
DHYTT01	31	36	1000	1.07	98	3.9
DVR	54	11	350	0.93	91	4.9
CHV (corr.)	154	0.1	250	0.015	8	0.05

* @ 800 MeV   ** DC operation

quadrupole name	magnet bore (mm)	magn. length (mm)	magn. grad. (T/m)	nom. current (A)	power (kW)
QUAD A	70	300	7	82	1.0
QUAD B	60	200	10	86.5	0.86

Table 1. Outstanding magnets features

Briefly, the magnets may be generally grouped as follows:

- one "C" dipole magnet, for pulsed operation, straight, laminated yoke (DHPTS);
- three "C" dipole magnets; two for pulsed operation, bent with sector like ends, laminated yoke with the same cross section of the previous one (DHPTT); one of them (DHSTT) will be used for continuous duty, with higher stacking factor requirement, so it is made with lamination without standard insulating coat;
- three "H" dipole magnets, bent with sector like ends, solid yoke (DHSTS, DHSTB);
- sixteen "H" dipole magnets, straight, solid yoke (DHRTE, DHRTP, DVR);
- one "Y" magnet, parallel ends, solid yoke (DHYTT);
- forty-six quadrupole magnets, solid yoke (type A and B);
- thirty-one corrector magnets, solid yoke (CHV).

2.1 Electromagnetic design

All the magnets (except "Y" magnet, where the PACDE Lab. - Electrical Dept. of the University of Genoa was involved in the e.m. design), have been entirely designed by our staff in Ansaldo GIE, based on the baseline design of LNF. The 3-D code used for e.m. calculation is OPERA-3d ver. 2.3 by Vector Fields Ldt., and a final check has been made for each solution with 2-D code POISSON, Los Alamos, ver. 1987, showing substantial agreement between them and with 2-D calculations previously done by LNF. The first results on magnetic measurements obtained on the first batch of magnets, displayed in prototype paragraphs, confirm the calculations.

2.2 Construction design development and materials

In early 1994 the mechanical and electro-hydraulical design and the fabrication drawings of the Linac Branch magnets were submitted to LNF for approval, and the first batches of raw materials were delivered to our workshops.
In spite of the large variation in shape, function and dimensions among the magnets, many efforts were made to standardize materials and ancillary equipment for serial production. In agreement with LNF we selected the main components from firms thoroughout Europe, and the quality standard respected well or even surpassed the design requirements.
Main raw materials for yokes, poles and coils are:

- fully annealed OFHC hollow copper conductor, four different sizes from 17.5 to 104 mm^2;
- epoxy resin from CIBA, Ansaldo formulation based on Araldit F;
- non-oriented silicon steel sheets for pulsed magnets core, thickness 0.35 mm, type UNI-EU106 Fe V 270-35 HA;
- 210 to 365 mm thick steel plates for solid dipoles, specially rolled from ingots, quality better than grade AISI 1004;
- steel plates for quadrupoles and correctors yoke, 25 to 50 mm thick, quality equivalent to grade AISI 1006.

3. LINAC BEAM DIAGNOSTIC BRANCH MAGNETS CONSTRUCTION AND TEST

The first part of the line requested by LNF to be installed was the Linac Branch Line, to be used for Linac run tests at commissioning. So, the first magnets to be manufactured was the two dipoles (DHSTS01 and DHPTS01), four Quadrupoles B and a corrector CHV of this line: together with various beam tubes and diagnostics; the components in this part of line, as mentioned, is well representative of the entire transfer lines.

The mentioned magnets have been manufactured during April and May 1994, tested by our Quality Assurance, and they are currently under magnetic measurements. In the following paragraphs we would like to display some of the relevant construction items and to anticipate the first measurement results, compared with 3-D design.

3.1 Pulsed dipole DHPTS01

This is a laminated magnet, for pulsed operation up to e^- energy of 800 MeV: peak voltage is foreseen to be 670 V.
The pole is straight, being the beam sagitta well within requested good field values.

Laminations, "C" shaped and 0.35 mm thick, are coated with double side organic resin to obtain 50 $\Omega \bullet cm^2$ interlaminar resistance. The obtained steel stacking factor is 96.5%, and the total weight is about 380 kg.
End floating shim placements have been foreseen.

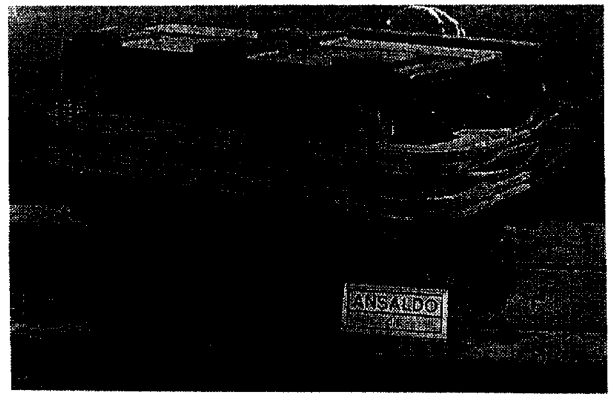

Figure 1. Dipole DHPTS01

The coil conductor dimensions are 6x6 ϕ3.5 mm; it is fiberglass insulated and wound in double pancakes (two per pole); like the entire production (excluded Correctors), the pancakes are vacuum impregnated in epoxy resin with Ansaldo special process. There are four cooling water circuits, with a temperature rise of 15°C at nominal current. Table 2 shows the main electromagnetic parameters, as recorded after the preliminary tests, and their comparison with electromagnetic calculations.
The magnetic length has been measured without shims.

	nominal field B0 (T)	magn. length Lm (mm)	field uniformity (required ±2 10^{-3})
design	0.441	683	±0.3 10^{-3}
measured	0.444	684	±0.7 10^{-3}

Table 2. DHPTS01 main electromagnetic parameters at Inom=184.3 A (preliminary results)

3.2 Spectrometer dipole DHSTS01

This is a large magnet, milled from thick plates, designed to operate at e^- energy of 800 MeV. The pole is curved sector like ends. It is the heaviest of the T/L, weighting about 5900 kg. End floating shim placements have been foreseen.

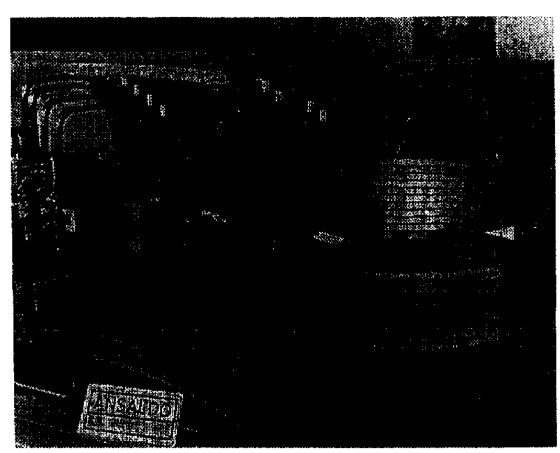

Figure 2. Dipole DHSTS01

The coil conductor dimensions are 12x12 ϕ7 mm; one coil per pole, racetrack shape, same insulation method, as the previous one. There are four cooling water circuits, with a temperature rise of 15°C at nominal current. Up to now, in the preliminary tests, the nominal field at magnet center has been measured showing good agreement with design (1.54 T measured vs. 1.55 T calculated at nominal current)

3.3 Quadrupole type B

This magnet is assembled with machined plates, to be used thoroughout the Lines at 510 and up to 800 MeV energy. The pole tip shape is a simple 5- step polygon, being the required field uniformity less or equal 1%; with the 3-D optimized shape, the harmonic content fits the good field values. The quadrupole weight is about 95 kg.

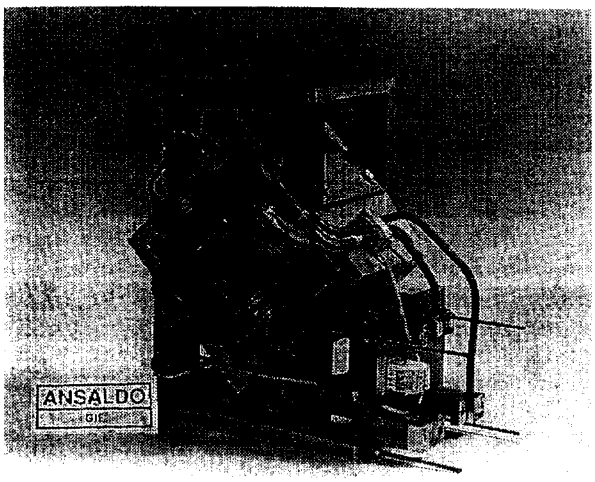

Figure 3. Quadrupole type B

The coil conductor dimensions are 5x5 ϕ3 mm; one coil per pole, racetrack shape, same insulation method as the previous one. There are two cooling water circuits, with a temperature rise of 14°C at nominal current. Table 3 shows the main electromagnetic parameters, as recorded after the tests and their comparison with electromagnetic calculations: it is the mean value on 5 produced and measured quadrupoles, and the spread of the values is represented by the Standard Deviation parameter.

		design	measured	spread, Std. Dev.
integr. field (rotating coil)	T*m	0.2498	0.2486	4.1 E-04
center field (hall plate)	T	0.0503	0.0490	6.7 E-05
nom. gradient G2	T/m	9.993	9.942	0.016
magn. length Lm	m	0.201	0.197	6.6 E-04
6th harmonic, center	%	0.59	0.58	5.0 E-04
10th harmonic, center	%	0.45	0.43	1.0 E-04
6th harmonic, integr.	%	1.17	0.99	4.0 E-04
10th harmonic, integr.	%	0.46	0.37	8.0 E-05

Table 3. QUAD_B main electromagnetic parameters at Inom = 86.5 A - Radius= 25 mm

3.4 Corrector CHV

This is a very simple magnet, assembled with four plates 12 mm thick on which are wound four coils; it is designed for horizontal and vertical dipole correction.
The coil conductor is enamelled 5 mm^2 copper wire; it is wound on the yoke and impregnated in epoxy resin. Table 4 shows the main electromagnetic parameters, as recorded after the preliminary tests, and their comparison with electromagnetic calculations. The magnetic length has been measured without shims.

	nominal field B0 (T)	magn. length Lm (mm)
design	0.015	250
measured	0.015	230

Table 4. CHV main electromagnetic parameters at Inom = 8 A

4. CONCLUSIONS

Now, the first and most crucial step has been done. The results of the first magnets produced, although the magnetic measurements have not been completed, has given satisfactory confirms to the correctness of design, and give us chance to start the manufacture of the whole production.

In the same time we are beginning the manufacturing activities on DAΦNE Storage Ring Magnets.

5. ACKNOWLEDGEMENTS

We are pleased to acknowledge the Ansaldo GIE DAΦNE Team: S. Angius, G.C. Bruzzone, G. De Barbieri, S. Moz, G. Murru, R. Ricco, A. Veardo; the Sincrotrone Trieste (Quadrupoles prototypes Magnetic Measurements and alignment study) and Ansaldo Ricerche (Dipole Magnetic Measurements and thin wall vacuum chambers) staffs and all the people in the workshops for their collaboration to this project.

A special thank to H. Hsieh of the DAΦNE Project, for his wise and meaningful suggestions, to C. Sanelli and all other people in Frascati who contributed to this paper.

6. REFERENCES

[1] The DAΦNE Project Team, presented by G. Vignola, "DAΦNE, The Frascati Φ-Factory", IEEE Proc. of 1993 Particle Accelerator Conference, Washington, USA, vol.3, p.1993.

[2] C. Biscari, V. Chimenti, H. Hsieh, C. Sanelli, F. Sannibale, M. Serio, G. Vignola, "Specifications for Electon/Positron Transfer Lines - DAΦNE Project", LNF Specification No. TL-00.21-SP01-4-A.