MAGNETS AND POWER SUPPLIES FOR ARES

A. Cattoni, G. Raffone, C. Sanelli,

INFN -LNF, P.O. Box 13, 00044 Frascati (Roma) Italy

Abstract

Following the optical parameters of the superconducting Linear Accelerator Ares, the magnetic structure of the machine has been developed. Dipoles, quadrupoles and their power supplies have been designed. They cover an energy range from 24 MeV to 600 MeV. The magnets have been studied by means of 2D and 3D codes, POISSON and MAGNUS. This paper reports the status of the magnetic structure project.

Introduction

The ARES[1] accelerating complex consists of a 510 MeV once-recirculated SC Linac and of two-rings colliding beam Φ-factory.

The Linac serves as: an injector for the storage rings; a FEL driver; a test facility. It presents a number of features that are very attractive for the HEP, Nuclear Physics and Material Science (Synchrotron Radiation), namely:

- continuous beams with very high intensity and energy resolution;
- production of FEL radiation in the short wavelength region;
- possibility of testing the high charge, low emittance, high peak current, high repetition rate operation regime required by linear colliders.

The Φ-factory first stage design luminosity, at 510 MeV, is 10^{32} cm^{-2} s^{-1}. The storage rings are separated vertically and meet at a single interaction region; the opposite straight sections are dedicated to RF and injection. The rings are optimized at the Φ production energy but can reach a top energy of 0.6 GeV.

The magnetic structure

The matching sections between the s. c. Linac cryomodules, as well as the recirculation lattice, need warm magnets (Quadrupoles and Dipoles) whose optical arrangemement is described elsewhere in this Conference. Here only the most significant design features and basic parameters of the Linac magnetic components are described. The Φ-Factory magnets will be reported in a paper to follow.

Linac Quadrupoles

The quadrupoles in between the SC cavities are fully symmetric quadrupoles with an aperture radius of 55 mm. The pole profile is, at this design stage, assumed to be circular. The required quadrupolar constants and field gradients are given below for two energies.

Emax [GeV]	Length [m]	K^2 [m^{-2}]	Gradient [T/m]
0.1	0.2	2.9	1.0
0.3	0.2	1.6	1.6

The quadrupoles have been optimized for the maximum gradient of 1.6 T/m by means of the 3-D code Magnus[2]. The gradient has been determined by analyzing the field content over a cylindrical region of radius R_N around the quadrupole axis. The gradient function along the radius can be expressed in cylindrical coordinates as:

$$G(x) = \sum_{n=1,\infty} (n \cdot r^{n-1})/(R_N)^n \cdot b_n$$

where n is the harmonic number of the field component, b_n the corresponding expansion coefficient and r the radial cylindrical coordinate. The coefficients b_n found by Magnus with R_N =50 mm are the following:

n	1	5	9	13	17	21
b_n	760	-10.5	2.6	8.3	-10.1	-8.2

Better accuracy will be obtained by proper shaping of the pole tips in the course of more detailed work still in progress.

Fig 1 shows the gradient along the radius in the median plane of the quadrupole. Magnus predicts a gradient variation of -0.1% for x>17 mm and of -1% for x>32 mm.

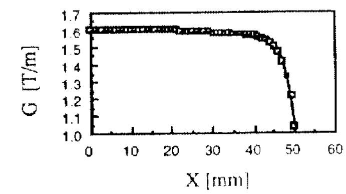

Fig. 1 - Quadrupole gradient as function of radial distance from axis.

The magnetic length of the half quadrupole defined as:

$$L_{mag} = \int [G(s)/G_0] \cdot ds$$

has been calculated by integrating over a line parallel to the quadrupole axis, passing through a point 5 mm far from the quadrupole centre.

Fig. 2 shows the normalized value of G(s) with respect to the value on the central plane.The value for (L_{mag}/2) obtained by integrating the curve of Fig. 2 (half length) is 103.6 mm, this means that the mechanical length of the quadrupole must be about 7 mm less than the designed one (150 mm) to obtain the desired magnetic length of 200 mm. The same cross-section has been adopted for the two kinds of quadrupole. Corrector windings are provided for dipolar correction of the orbit. The quadrupole fringe field will be shielded to protect the SC cavities.The mechanical lay-out of the quadrupole is shown in Fig. 3. Table I lists the basic parameters.

Table I - Quadrupole basic parameters.

Gradient	[T/m]	1.6
Inscribed radius	[mm]	55
Pole field	[T]	0.09
Pole shape		circular
A-turns per pole		2000
Current	[A]	40.8
Current density	[A/mm2]	3.14
Turns per pole		49
Copper conductor		4.5*4.5Ø3
Magnetic length	[m]	0.2
Magnet resistance	[mΩ]	200
Power	[W]	341
Voltage	[V]	8.2
Iron weight	[Kg]	73
Copper weight	[Kg]	15.5

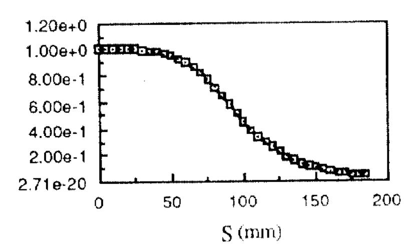

Fig. 2 - Normalized value of G(s) with respect to the value on the central plane.

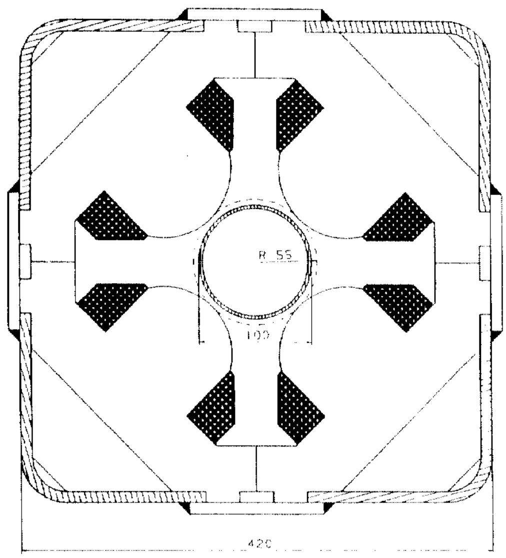

Fig. 3 - Mechanical lay-out of the Linac Quadrupole.

The main characteristics of power supplies needed to individually power each quadrupole are listed in table II.

Table II - Quadrupole power supply characteristics.

Voltage	[V]	12.5
Current	[A]	50.0
Stability		$\leq 1*10^{-4}$
Ripple (rms)		$\leq 1*10^{-4}$
Resolution		$\leq 1*10^{-4}$

The reserve voltage necessary to account for voltage drops on connections is included.

Recirculation arc dipole magnets

With a nominal field of 1.13 T (@ 0.34 GeV) and a maximum field of 1.3 T, the dipoles can be regarded as conventional magnets.

The magnetic circuit has been designed so as not to exceed 1.8 T anywhere in the iron when the gap field is 1.3 T.

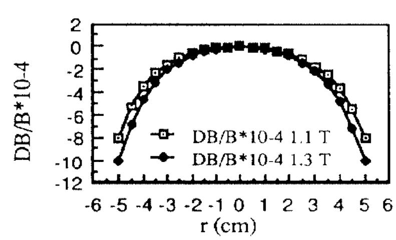

Fig. 4 - Field profile of the recirculaton arc dipole.

The field profile has been studied by means of POISSON[3]. At the moment the final shimming has not been taken into account.

The field quality is already satisfactory at both the nominal and the maximum energy, as can be seen from Fig. 4 and from the following Table III.

Table III - Dipole field quality.

	@x=20mm	@x=30mm
$(DB/B)*10^{-4}$@1.13 T	-0.57	-1.50
$(DB/B)*10^{-4}$@1.3 T	0.80	-2.06

The laminated magnet yoke is curved to follow the beam radius of curvature and has parallel end faces. A possible technical assembly is shown in Fig. 5.

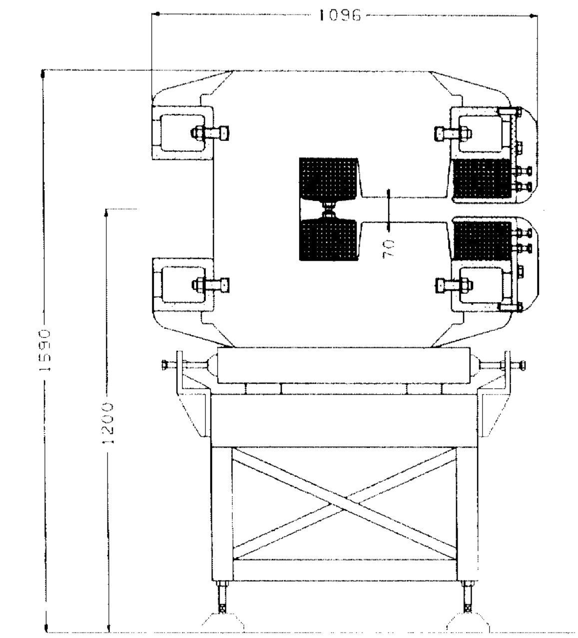

Fig. 5 - Mechanical lay-out of the recirculation arc dipole.

The design current density is very close to the one that minimizes the sum of capital and running costs[4]. It is 3.4 A/mm^2 at the nominal field and reaches 3.85 A/mm^2 at 1.3 T. With the chosen steel dimensions, at maximum field value, the iron absorbs about 8.5 % of the applied Ampere-turns.

The dipole main parameters are listed in Table IV.

Table IV - Recirculation arc dipole parameter list.

Energy	[GeV]	0.34
Bending radius	[m]	1.0
Magnetic length	[m]	0.785
Nominal field	[T]	1.133
Pole/gap ratio		3.8
Return leg/pole ratio		0.92
Gap	[mm]	70
Pole width	[mm]	266/244
Amp-turns per coil		34,000
Current	[A]	354
Current density	[A/mm^2]	3.4
Turns per pole		96
Conductor: Copper		12*12Ø7
Coil resis.(@60°C)	[Ω]	0.051
Coil inductance	[H]	0.115
Power per dipole	[kW]	12.8
Voltage per dipole	[V]	36
Iron weight	[Kg]	2586
Copper weight	[Kg]	506
Total weight	[Kg]	3092

No attention has been at the moment paid to the longitudinal effective field profile. Work with the three dimensional code Magnus is in progress to determine the mechanical length that will give the required magnetic length. As far as the power supplies for the dipoles are concerned, each recirculation arc (180°) contains four 45° dipoles that can be series connected. The resulting circuit has the following electrical characteristics :

- Circuit resistance (@ 60° C): 0.408 Ω
- Static circuit inductance: 0.92 H

and the output voltage and current required from a classical twelve-phase bridge converter, with a 10% allowance for voltage drops on connecting cables, are :

- d.c. Voltage : 160 V
- d.c. Current : 360 A.

The main transformer power is ≈ 62 kVA, with a secondary voltage of 115 V and a line current of 170 A.

The ripple at full current is about $6*10^{-5}$. Additional filtering is however foreseen to guarantee a current ripple of less than $1*10^{-4}$ down to current levels of ≈ 10% of the maximum value. The power supply resolution is better than $1*10^{-4}$. A long term stability of the same order or better can easily be reached by means of a high stability ($1*10^{-6}$) commercial transducer.

Recirculation arc quadrupole

The recirculation arc lattice contains 34 quadrupoles. The magnetic length, 0.3 m, is the same for all quadrupoles. The values of k^2 range from a minimum of 1.08 m^{-2} (G= 1.22 T/m) to a maximum of 13.32 m^{-2} (G = 15.1 T/m). The quadrupole has been optimized for the average value of k^2, i.e. 6.68 m^{-2} ; the currents are then scaled so as to reach the other gradient values with the same cross section of the lenses. A single type of quadrupole is thus foreseen at this first-order optimization stage.

The electromagnetic design has been made using the bidimensional code Poisson; two possible solutions, both with hyperbolic pole profiles have been studied. The first fits around a rectangular vacuum chamber with a cross-section of 11 (horizontal) * 7 (vertical) cm^2, the second fits around an elliptical vacuum chamber inscribed in the above rectangle. In both cases the pole profile is hyperbolic. Because of the four-fold symmetry of the magnet only one-half pole, has been studied.

The magnetic field can be expressed in complex form as:

$$(B_x - i\, B_y) = i*\sum n *(A_n + i\, B_n)/R * (z/R)^{(n-1)}$$

where B_x and B_y are the horizontal and vertical components of the field respectively, n is the harmonic number, A_n and B_n are the coefficients of the expansion, R is a normalization radius and z is the complex variable. The normalization radius is 60 mm for the rectangular vacuum chamber case and 40 mm for the other case.The field along the x axis can be obtained by simply replacing z by x and the gradient by taking the first derivative. In our approximation B_n is identically zero for all n's and A_n takes on the values shown in Table V for the optimized quadrupole at the average gradient. The gradient uniformity for the two quadrupole apertures is shown in Fig. 6.

Table V - Quadrupole gradient uniformity.

n	Rectangular V.Ch n(An)/R	Elliptical V.Ch n(An)/R
2	3955.3	2661.2
6	-136.09	-78.40
10	-88.39	-3.188
14	-19.956	-20.765
18	31.174	8.020

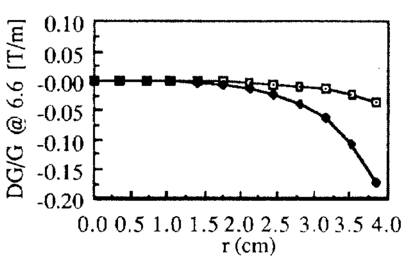

Fig. 6 - Arc quadrupole gradient uniformity for: -□- rectangular vacuum chamber; -◆- elliptical vacuum chamber.

The predicted gradient variation is: -0.1 % @ r=16.3 mm and @ r=11.2 mm respectively and -1% @ r=27.3 mm and r=20.4 mm respectively. The maximum value of the field in the iron is always lower than 1.8 T . Correction windings producing about 10 % of the total Ampere-turns are included in the main coils. They can be used to generate dipolar fields in both planes. Table VI lists the main parameters of the two kind of the quadrupoles.

Fig. 7 shows the mechanical lay-out of one of the two optimized quadrupoles.

Table VI - Main parameters of the two quadrupoles.

		Recta. v.c.	Ellip. v.c.
Gradient (nominal)	[T/m]	6.6	6.6
Inscribed radius	[mm]	62	44
Pole field	[T]	0.435	0.29
Pole shape		Hyper.	Hyper.
A-turns per pole		10,250	5160
Current	[A]	157.5	151.8
Max Current	[A]	454	368
Nom.Curr.Density	[A/mm^2]	3.55	3.42
Max.Curr.Density	[A/mm^2]	10.23	8.29
Min.Curr.Density	[A/mm^2]	0.66	0.63
Turns per pole		65	34
Copper cond.		8*8Ø5	8*8Ø5
Magnetic length	[m]	0.3	0.3
Magnet resistance	[mΩ]	132	60
Nominal voltage	[V]	20.8	9.0
Max.Voltage	[V]	60	22
Nominal power	[W]	3300	1366
Maximum power	[W]	27,240	8,170
Iron weight	[Kg]	193	94
Copper weight	[Kg]	116	53

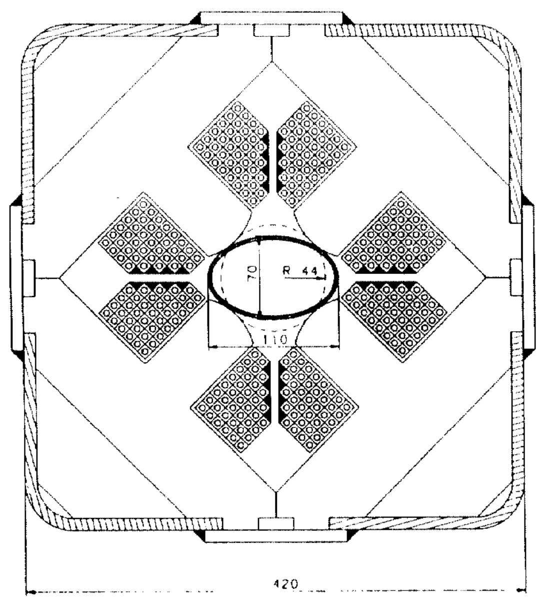

Fig. 7 - Mechanical lay-out of one of the two optimized quadrupoles.

Aknowledgments

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