The Frascati Φ-Factory Injection System

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Abstract

The injection system, for the Frascati Φ–factory DAΦNE [1], is designed to store $\approx 10^{13}$ positrons and electrons in the two main rings in an overall injection time at startup of ≈10 minutes. The system will consist of a high current electron Linac (E≈250 MeV), a low current high energy electron-positron section (E>510 MeV) and a compact damping ring in order, to avoid injection saturation, to increase longitudinal acceptance and to decouple the design of the main rings from injection requirements. The two Linac sections will provide ≈0.3 nC of positrons within ±1% energy spread in 10 ns pulses for injection at 50 Hz into a single 76 MHz bucket of the damping ring. Extraction of the high quality damped bunch from the accumulator will take place at 1 Hz, filling one main ring bucket at a time. The Linac design foresees 3 m long $2\pi/3$ TW constant gradient accelerating sections with SLED systems in order to increase the energy gain. The magnetic structure of the damping ring is designed to be accommodated in a 12x12 m^2 hall, and it is made of four quasi-achromatic bending sections and four long straights to accommodate injection and extraction pulsed elements and the RF system.

I. INTRODUCTION

DAΦNE, the Frascati Φ-factory project, is a high luminosity ($>10^{32}$ $cm^{-2}s^{-1}$) storage ring running at a centre of mass energy of 1020 MeV. To achieve such a high luminosity, a large number of electron and positron bunches (120) circulate in two separate rings, colliding at a small angle in the horizontal plane. The total number of particles in each ring exceeds 10^{13}, thus setting challenging requirements on the design of the positron injection system. Since the operating time structure of the bunch configuration will be chosen upon the results of machine commissioning, single bunch injection has been recommended, so that the use of a small full energy storage ring which serves as an accumulator between a positron/electron Linac and the main ring seems to be the only possible solution to store the whole charge in the required injection time of ≈10 minutes. To mantain a high average luminosity, topping-up will be performed when the stored current drops below a given level, so that full injection will be necessary only at machine start-up.

Particles accelerated from the Linac will be injected at 50 Hz into the accumulator, extracted at 1 Hz and injected into the main rings, filling one bucket at a time. In order to reach the design positron current, 360 pulses will be transferred from the accumulator to the main ring. In the case of electrons, due to the larger current from the Linac, injection rate is foreseen to be much faster.

Table 1 shows the efficiencies assumed to estimate the required current from the Linac injection section.

Table 1
Injection, transport and extraction efficiencies

Transport from Linac gun to converter	0.4
Electron-positron conversion @ 250 MeV	0.008
Transport from converter to accumulator	0.9
Injection into accumulator	0.5
Extraction from the accumulator	0.9
Transport and injection into main ring	0.8

With these assumptions the positron charge per pulse delivered by the Linac is 0.3 nC, while the electron charge from the gun is 95 nC.

II. THE LINAC

The schematic layout of the DAΦNE Linac is shown in Fig.1. The main Linac components are: thermionic gun, prebuncher and buncher at the Linac frequency f = 3GHz, high current TW electron Linac with output energy ≥ 250 MeV, electron-positron converter, positron capture section, low current e^-e^+ TW Linac with energy ≥ 510 MeV, magnetic focusing elements.

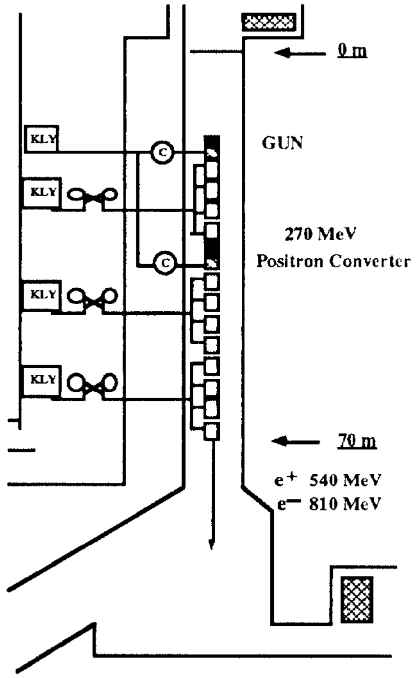

Figure 1. Layout of the Linac.

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The gun, dimensioned for the maximum positron peak current, will be used for both operating modes. The main gun parameters are listed in Table 2.

Table 2
Main gun parameters

Type	Pierce, triode
Cathode radius	R_k = 40 mm
Cathode diameter	D_k = (25÷30)mm
Anode potential	Ua = 100 kV
Current	Ig = 10 A
Emittance(invariant)/π	$\varepsilon_n = 1\text{x}10^{-4}$ m·rad
Macrobunch length	t_b = 10 ns
Repetition rate	f_r = 50 Hz

The bunching system will consist of a TM010 single cell cavity prebuncher and a 10÷20 MeV buncher with few graded β cells. The buncher length will be about 1÷1.5 m. The purpose of the system is to bunch the 'continuous' electron current emitted by the gun in a train of micropulses which corresponds to less than 15 degrees of the period of the Linac radiofrequency, and to accelerate the electrons to relativistic velocities before injecting them into the constant phase velocity (v=c) accelerating structure of the Linac.

According to the analysis presented in [2] we propose the use of $2\pi/3$ travelling wave (TW) constant gradient (CG) accelerating structures together with a SLED type pulse compression system. The advantages of such a structure in comparison with others, i.e. $\pi/2$ TW or $2\pi/3$ TW constant impedance (CI), are described in [3]. In our case their best features are: lower sensitivity to frequency deviations, lower beam loading derivative and lower sensitivity to beam breakup in comparison with CI structures. It is also important that such structures have been successfully tested in large size accelerators like SLAC, DESY and LEP.

We have optimized the optimum section length, the field gradient and the minimum klystron number for the following parameters: quality factor Q = 15,000; beam pulse duration t_b=10ns; klystron output power P=45 MW; RF pulse duration t_k=4.5 μs; storage cavity (for pulse compression) quality factor $Q_c=10^5$; effective electron energy at the converter Ec > 250 MeV; output positron current i^+>30ma (at 510 MeV in ±1%).

The Linac will be installed into the 70 m long existing tunnel of the ADONE Linac. Assuming a Linac filling factor of 0.7, the total length of the accelerating sections should be around 50 m corresponding to a field gradient of about 20 MV/m. Our analysis shows that the optimum section length is 3 m. Some possible configurations for the DAΦNE Linac, based on the 3 m long sections are given in Table 3.

All the configurations presented in Table 3 fulfil the above mentioned requirements. Additional informations, like reliability and costs are then necessary to support the final choice. From this point of view the solutions with lower gradient (i.e. 21 MV/m) are preferable since:

- most of the existing large electron Linacs operate below 20 MV/m.
- the existing tunnel in the LNF area allows the installation of about 50 m of active Linac which means a possible total energy of 1000 MeV with an accelerating gradient of 20 MV/m.
- as shown in Table 3 we estimate that a 20 MV/m Linac is cheaper than a 30 MV/m one.

Table 3
Possible DAΦNE Linac Configurations

Nº sections	14+2*	12+2*	10+2*
E(MV/m)	21	21	30
i^+ (ma)	50	36	50
W_c (MeV)	390	270	380
W_t (MeV)	930	810	940
Nº klystr. **	4(4)	3(4)+1(2)	5(2)+1(2)
cost. (relat.)	1.05	1.	1.13

* 20 MeV Bunchers
** The number of sections per klystron in brackets.

The main components of the positron source are: the converter, the magnetic focusing and the high gradient capture accelerating section. The converter will be made of high Z materials such as Ta or Au, resistant to thermal and mechanical stresses. The average power of an electron beam passing through the converter will be about 1.2 kW, the power dissipated in the converter being about 16% (ie. ~ 200 W) of the total beam power. Considering the good performances of the ADONE converter [4,5], which can dissipate about 10 kW, we intend to adopt a similar solution for DAΦNE. Since the electron energy on the converter will be more than twice that of ADONE Linac, also the thickness of the target should be larger (e.g. ≈ 2 radiation lengths).

The electrons will be focused by a quadrupole triplet to form a spot with a diameter smaller than 1 mm, the positrons will be confined by a very intense tapered magnetic field of the order of 5÷6 Tesla generated by a flux concentrator [6]. Further optimization of the capture efficiency can be obtained by adding after the flux concentrator a short very high gradient accelerating capture section with the proper phase [7].

III. THE ACCUMULATOR

The use of an accumulator between the Linac and the main rings has the following major advantages:

- it avoids injection saturation due to the large number of injection pulses (≈$1.6\text{x}10^4$) by subdividing them into 45 pulses into the accumulator times 360 pulses into the main rings;
- it provides a larger longitudinal acceptance, since the RF frequency of the accumulator can be much lower than the main ring one;
- it decouples the design of the main rings from injection requirements, since the emittance and energy spread of the damped beam from the accumulator are much smaller than those of the beam coming directly from a Linac.

The length of the accumulator has been chosen as 1/3 of the main ring circumference, to easily synchronize injection of any desired bucket of DAΦNE. For the same reason, the RF frequency of the accumulator cavity is exactly 5 times lower than the main ring one.

Fig. 2 shows the layout of the positron/electron accumulator with the schematic of the transport channels from the Linac and to the main rings. Positrons will be injected into the accumulator from the left channel and extracted from the right one, while electrons will follow the opposite path. A symmetric set of four kickers will provide the necessary orbit distortion for injection and extraction of both electrons and positrons.

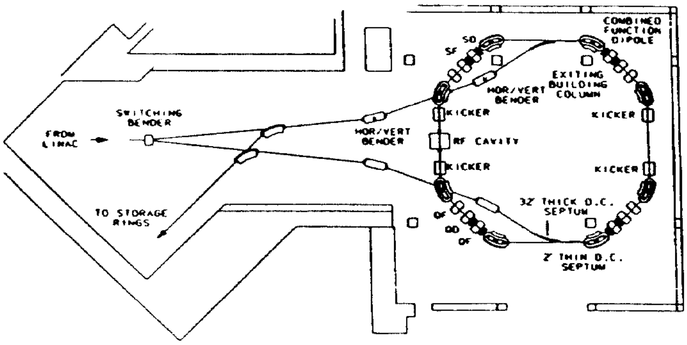

Figure 2. The Accumulator Layout.

The accumulator lattice, derived from the storage ring ACO in Orsay [8], has a fourfold symmetric periodicity, and has been chosen to optimize injection performance. The optical functions of one fourth of the ring are shown in Fig. 3.

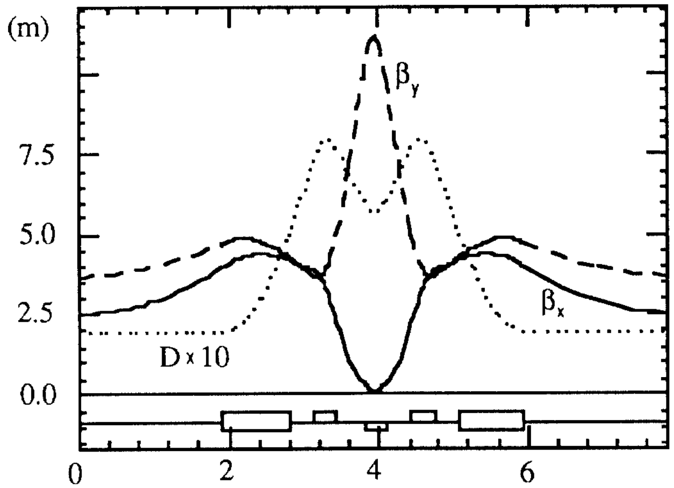

Figure 3. Optical Functions of one fourth of the Ring.

Four low-dispersion 3.6 m long straight sections provide enough space for the kickers, the injection septa and the RF cavity. Each bending section includes two 45° magnets with field index n=0.5 to ensure the best damping partition, a quadrupole triplet to tune the horizontal phase difference between the kickers and the septa and a couple of sextupoles to correct the chromaticity in both the horizontal and the vertical plane.

The gradient bending magnets will be H-shaped with a bending radius of 1.1 m, corresponding to a centre field of 1.55 T, with a minimum gap of 5 cm. The quadrupoles are designed to a magnetic length of 34 cm, with a maximum gradient of 8.3 T/m and a bore radius of 5 cm. The sextupoles have a magnetic length of 10 cm, with a maximum gradient of 80 T/m^2. Four kickers are used simultaneously for injection of electrons and positrons from the Linac. This arrangement has been chosen to exactly cancel the perturbation of the already stored beam at each injection pulse. Only two of them provide the necessary kick to extract the beam from the accumulator. The required kicker pulse length is ≈100 nsec and the maximum strength is 67 G·m for injection and 110 G·m for extraction. Table 4 gives a parameter list for the accumulator.

Table 4
Parameters of the accumulator

Energy (GeV)	0.51
Circumference (m)	31.52
Straight section length (m)	3.67
Horizontal betatron wavenumber	2.89
Vertical betatron wavenumber	1.13
Dispersion at Straight Section Centre (SSC) (m)	0.13
Horizontal β at SSC (m)	2.51
Vertical β at SSC (m)	3.87
Maximum dispersion (m)	0.81
Maximum horizontal β (m)	4.24
Maximum vertical β (m)	10.40
Horizontal betatron damping time (msec)	19.71
Vertical betatron damping time (msec)	19.71
Synchrotron damping time (msec)	9.86
Momentum compaction	0.059
Emittance (mm·mrad)	0.27
r.m.s. energy spread (%)	0.042
Horizontal r.m.s. beam size at SSC (mm,no coupling)	0.82
Vertical r.m.s. beam size at SSC (mm,full coupling)	0.72
Horizontal chromaticity (sextupoles off)	-4.13
Vertical chromaticity (sextupoles off)	-4.10
RF frequency (MHz)	76.09
RF voltage (MV)	0.1
Harmonic number	8
RF energy acceptance (%)	±1.55
r.m.s. bunch length (cm, radiation only)	2.86

IV. REFERENCES

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