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The DAΦNE Injection System

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ABSTRACT

DAΦNE is a double ring Φ-factory, presently being assembled in the INFN (National Institute for Nuclear Physics) Frascati National laboratory (LNF). Its injector [1] consists in an electron (800 MeV) and positron (550 MeV) Linac, a damping/storage ring, called Accumulator, and ≈180m long Transfer Lines between the three rings. The reasons for the choice of this configuration, the main parameters of the injector accelerators and the status of the injector are described.

INTRODUCTION

DAΦNE is a Φ-factory, namely a high luminosity electron-positron storage ring collider operating at the energy of the Φ resonance (1020 MeV in the center of mass). Its main physics goal is the measurement of the ratio ε'/ε in CP violating K decays [2], with an accuracy one order of magnitude better than presently achieved at fixed target accelerators. The statistics required to reach this precision is of the order of 10^{10} K_S K_L pairs per year, which can be produced at the peak of the Φ resonance with an average luminosity of 5×10^{32} $cm^{-2}s^{-1}$ and an overall efficiency of 30%. This luminosity is between one and two orders of magnitude larger than that obtained at existing facilities in the same energy range [3].

Like in the case of the τ-charm Factory proposal discussed in these Proceedings, DAΦNE is a multibunch, high current two rings collider. A first stage is foreseen for the initial operation with 30 bunches and a total stored current of ≈1.2A in each beam. The expected luminosity in this configuration is $\approx 10^{32}$ $cm^{-2}s^{-1}$, which will enable the experimental detectors to test their equipment and take the first physical measurements. After this phase, the number of stored bunches will be increased to its maximum value of 120, equal to the harmonic number of the RF system. Both the total current and the luminosity are expected to increase by the same factor as the number of bunches.

It is clear that such a large stored current ($\approx 10^{13}$ particles in each beam), together with the necessity of frequent refilling of the rings to get rid of the short beam lifetime due to the strong Touschek effect at low energy, requires an extremely powerful and reliable injection system. For this reason, a combined system consisting of a Linac and a small storage ring, acting both as a fast damper and as an intermediate storage device, has been chosen.

REQUIREMENTS TO THE INJECTION SYSTEM

The expected single beam lifetime in DAΦNE ranges between 1 and 3 hours [4], depending on the lattice configuration and beam-beam parameters. For a given maximum luminosity and beam lifetime, there is an optimum time interval between successive ring refillings, which depends on the time required to inject the beams. For DAΦNE it comes out that the average luminosity can be ≈75% of the maximum one if the beams are refilled each hour with a total injection time of ≈5 minutes [5].

It is clear that, in order to achieve this goal, it is convenient to inject on top of the already stored beam, without dumping the residual beam in the rings before injection. This requires the whole injection system to run at the operating energy of the collider Main Rings (510 MeV per beam). This mode of operation is called "topping up" and is expected to refill ≈30% of the maximum stored current at the beginning of the experimental runs.

It is very useful to have the possibility of injecting any possible bunch pattern in the collider: the main reasons are the different stored bunch number at the various development stages of the facility, the accurate study of the beam-beam effects during commissioning, the investigation of the parasitic crossings near the interaction points, the use of a gap in the beam pattern to counteract ion trapping. We require therefore that a single bunch at a time be delivered from the injector. This makes also the task of injecting all bunches with the same number of particles easier.

Last, but not least, the Accelerator Division of LNF has been asked to host the whole DAΦNE facility, in order to save on both cost and time, inside the buildings dedicated to the operation of ADONE, the 3.0 GeV c.m. e^+/e^- storage ring running at LNF from 1969 to 1993. This explains the peculiar layout of the facility and the long Transfer Lines shown in Figure 1.

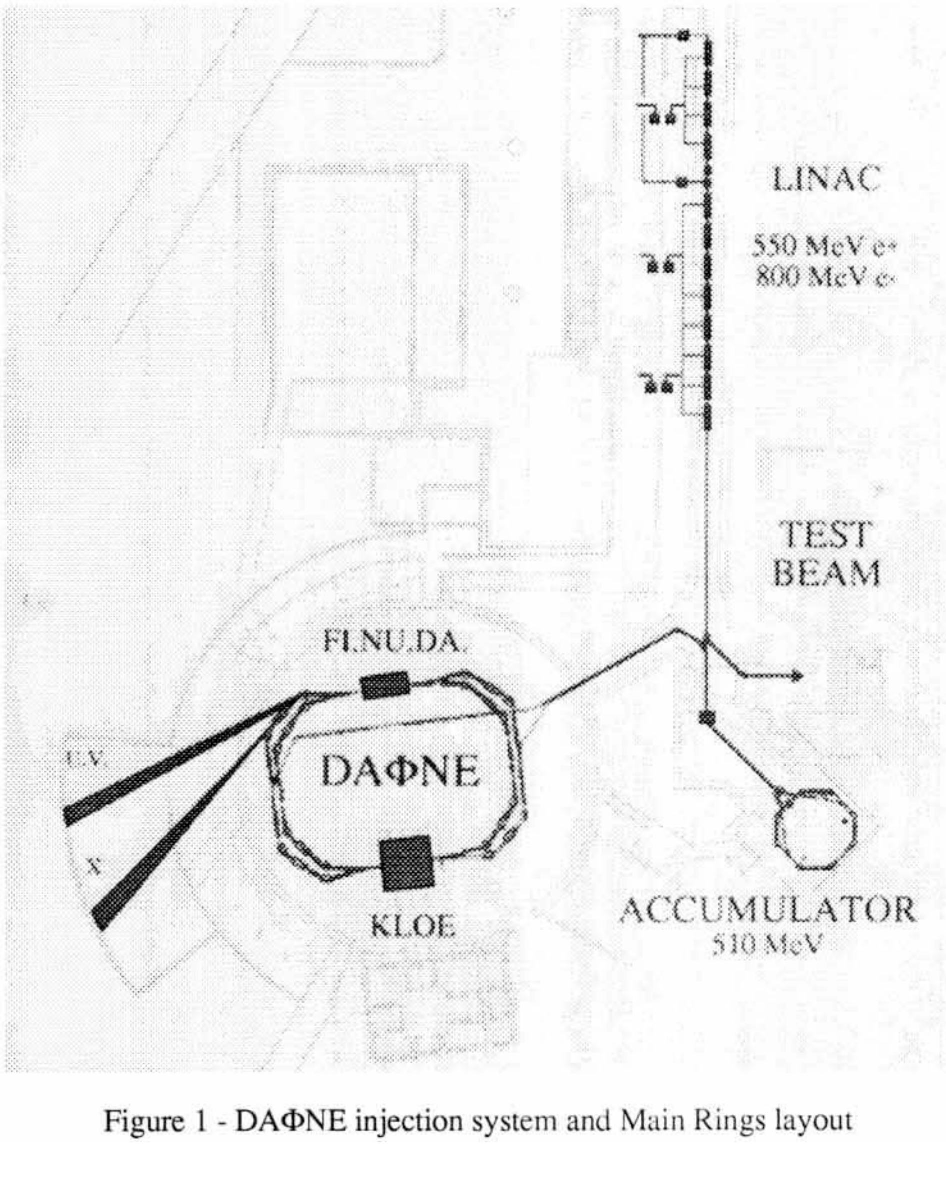

Figure 1 - DAΦNE injection system and Main Rings layout

THE INJECTION SYSTEM DESIGN

We have chosen to build an intermediate storage ring, called Accumulator, between the Linac and the DAΦNE Main Rings for the following reasons:

- **To avoid saturation:** with the positron current available from the Linac $\approx 1.5 \times 10^4$ pulses are needed to fill the positron ring with the required current. If the beam is injected directly from a Linac, it is therefore necessary to lose less than ≈0.01% of the beam already stored in the Main Ring at each injection pulse to keep a positive injection rate. This is a rather severe requirement. With an intermediate Accumulator, it is possible to store an entire DAΦNE bunch into the Accumulator with ≈100 Linac pulses, damp it down to its natural emittance and energy spread, extract and inject it into the Main Ring. This drops the above mentioned tolerance to ≈1%.

- **To increase the longitudinal acceptance:** the typical length of the pulse from a Linac operating with the energy doubling system is in the order of 10 ns, while the bucket length in the DAΦNE Main Rings is only 2.7 ns, to cope with the large number of stored bunches required to meet the luminosity requirements. An intermediate ring can be equipped with a lower frequency RF cavity: the DAΦNE Accumulator bucket is 13.6 ns long, and the improvement in longitudinal acceptance is ≈ a factor 5.

- **To improve the quality of the beams injected into the Main Rings:** the emittance and energy spread of a positron beam damped and extracted from the Accumulator are much smaller than those of a beam extracted from a Linac at the same energy. It is therefore possible to design the Main Rings with a smaller acceptance, with substantial saving on overall cost and more comfortable tolerance on the field quality of the magnets and dynamic aperture. The optical characteristics of the beam extracted from the Accumulator are compared in Table 1 to those of the beam at the end of the Linac.

The injection procedure, both starting from scratch and in the topping up mode, will be the following:

- Insert the converter target, set the Transfer Line and the Linac to the positron mode and inject positrons, at 50 Hz pulse rate, in a single bunch in the Accumulator until the desired number of particles in a single Main Ring bunch is reached.
- Wait 5 damping times to damp the stored beam in the Accumulator.
- Extract the damped bunch from the Accumulator and inject it into the positron Main Ring.
- Repeat the three points above for all positron bunches to be stored in the Main Ring.
- Extract the positron converter, set the Linac and Transfer Line to the electron mode and repeat the four points above with electrons.

Injection rates and number of particles involved in each step are discussed in the last Section.

TABLE 1. Comparison between Accumulator and Linac beam quality.

	Accumulator	Linac
positron emittance (mm.mrad)	0.25	5
electron emittance (mm.mrad)	0.25	1
positron energy spread (%)	0.041	1
electron energy spread (%)	0.041	0.5
bunch length (cm)	4	≈60

LINAC

The Linac of the DAΦNE injection system has been built by TITAN BETA (USA) and delivered to LNF at the end of 1994. It has been assembled in the halls of the old ADONE [6] injector and it is now fully operational in the electron mode, at the design beam performance. Commissioning with positrons is under way. The main parameters of the Linac are given in Table 2.

Positron production is realized by means of a tungsten target, where the 250 MeV high current electron beam produces electron/positron pairs. The particles extracted from the target are focused by a very strong tapered pulsed magnetic field (≈6T) generated by a flux concentrator [7] followed by a high gradient accelerating capture section. The overall efficiency of positron production and acceleration is expected to reach 0.9%.

TABLE 2. DAΦNE Linac parameters.

General	
RF frequency (MHz)	2856
Klystron power (MW)	45
Number of klystrons	4
Number of SLED energy doubling systems	4
Number of accelerating sections	16
Repetition rate (Hz)	50
Beam pulse width (ns)	10
High Current Electron Linac	
Number of accelerating sections	6
Input current from gun (A)	≤10
Input energy from gun (KV)	120
Output current (A)	> 4
Output energy (MeV)	250
Output emittance (mm.mrad)	≤ 1
Energy spread (%)	± 5
Beam spot radius (mm)	1
Positron Linac Mode	
Number of accelerating sections	6
Input energy from positron converter (MeV)	8
Output current (mA)	36
Output energy (MeV)	550
Output emittance (mm.mrad)	≤ 5
Energy spread (%)	± 1
High Energy Electron Mode	
Output current (mA)	150
Output energy (MeV)	800
Output emittance (mm.mrad)	≤ 1
Energy spread (%)	± 0.5

TRANSFER LINES

The Transfer Lines [8] from the Linac to the Accumulator and from the Accumulator to the Main Rings are built by ANSALDO (Italy). All the elements within the injector halls (see Figure 1) have been installed and tested. The last part, inside the Main Rings hall, will be assembled together with the rings, in fall 1996. Its total length is ≈180 m, mainly because of the necessity to place the Accumulator in an existing hall, used before for fixed target experiments with the beam from the old ADONE Linac.

The design of this transport system is rather unusual, mainly because of the small space available in the tunnels connecting the Linac Hall to the Accumulator and Main Rings ones. In particular, a common part of the channel is shared by the beam injected from the Linac to the Accumulator and by the beam extracted from the Accumulator and injected into the Main Rings (see Figure 1). Since the beam is extracted from the Accumulator at a frequency of the order of one pulse per second, it is not possible to change the settings of the d.c. magnets between the injection and extraction modes. The lattice of the common part has been therefore designed with the same quadrupole strengths in the two modes, with proper matching performed in those branches of the line where the beam injected into the Accumulator is separated from the beam extracted from it. The two dipoles in the common part work instead in a pulsed mode, in order to cope with the opposite directions of the injected and extracted beams.

Due to the lack of space inside the Accumulator Hall, the channels from the Linac pass below the storage ring vacuum chamber and are then brought to the storage ring level on its internal side by means of vertically deflecting magnets. Other vertical magnets are also used in the channels connecting the Accumulator to the Main Rings to compensate for the different levels of the two machines.

The DAΦNE Transfer Lines are equipped with strip-line monitors, current monitors, secondary emission flags which can be moved into and extracted from the beam line to check beam position and shape, dipole correctors to steer the beam position and slits to measure and/or tailor the beam profile and energy spread.

ACCUMULATOR

The Accumulator [1] is completely assembled and commissioning is expected to start in May 1996. Its optical, RF, magnetic and mechanical design has been completely realized by LNF staff. The construction of the magnets have been performed by TESLA Engineering (UK), while the vacuum vessel, diagnostics, supports and general project management were supported by OXFORD Instruments (UK). The RF has been built by CERCA (France).

The shape of the Accumulator was mainly dictated by the small size of the Hall where it was installed. Its length (32.56m) is exactly on third of the Main Ring circumference to make synchronization of the two machines easier. Its RF system runs on the 8th harmonic of the revolution period, and is exactly 1/5 of the Main Ring one. In this way the three generators (one for the Accumulator and two for the Main Rings) can be driven by the same synthetizer, keeping the beams always at the same phase with respect to each other.

The Accumulator lattice has been designed with the following tasks:

- short damping time to allow 50 Hz injection
- large acceptance and vanishing dispersion in the injection straight sections to reach high injection efficiency
- fixed length (1/3 of the Main Rings one) to make synchronization possible

- symmetric structure to allow injection and extraction of electrons and positrons, in the two opposite directions, with the same d.c. and pulsed fields in the machine.

A schematic layout of the ring is shown in Figure 2: the lattice is symmetric with respect to the two axes in Figure 2 passing through the centers of the four long straight sections without quadrupoles and sextupoles. These two axes define four quadrants, each one containing two half straight sections and one bending arc: each arc is composed of two 45° H-type low gradient bending magnets, three quadrupoles and two sextupoles for chromaticity correction.

All magnets symmetric with respect to the two axes are connected in series to the same power supply: there are therefore three quadrupole and two sextupole families. In this way it is possible to select the two betatron tunes and set vanishing dispersion at the injection and extraction straight sections (those without quadrupoles and sextupoles on the right and left sides in Figure 2). The arcs, however, are almost achromatic, and the dispersion in the RF and kickers straight sections at the top and bottom of Figure 2 is very low (13 cm). The rather high horizontal tune (3.12) keeps the maximum dispersion in the ring below 0.9 m.

Four pulsed kickers deliver the maximum flexibility to the 50 Hz injection into the Accumulator: two "short" ones are placed aside the RF cavity in the straight section on the bottom of Figure 2, and two "long" ones in the opposite straight at the top of the same Figure. At each injection pulse from the Linac, the stored beam is shifted by all four kickers fired together, during a single turn in the machine, near and parallel to the injection septum on the internal side of the ring. Extraction is performed, in principle, by the two "long" kickers only, but the others can also be used to improve, if necessary, the extraction efficiency.

Table 3 is a list of the optical properties of the Accumulator and Figure 3 shows the optical functions for one of its quadrants.

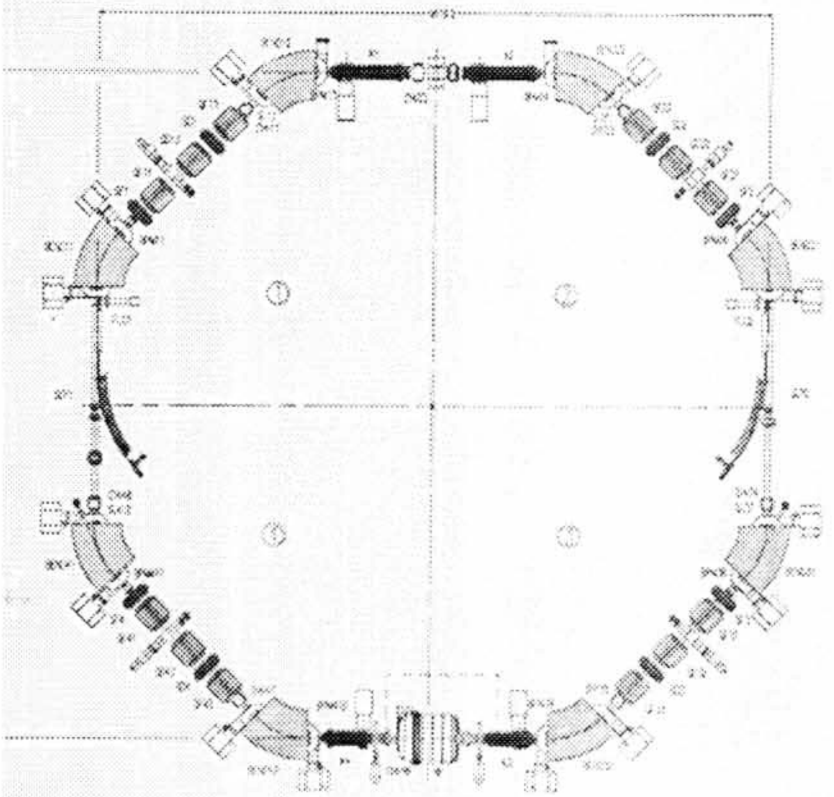

Figure 2 - DAΦNE Accumulator layout

TABLE 3. DAΦNE Accumulator lattice parameters

Energy (GeV)	0.51
Circumference (m)	32.56
Straight sections length (m)	3.50
Horizontal betatron wavenumber	3.12
Vertical betatron wavenumber	1.14
Horizontal betatron damping time (ms)	21.42
Vertical betatron damping time (ms)	21.42
Synchrotron damping time (ms)	10.71
Momentum compaction	0.034
Natural emittance (mm.mrad)	0.253
R.m.s. energy spread (%, radiation only)	0.041
Horizontal chromaticity (sextupoles off)	-4.4
Vertical chromaticity (sextupoles off)	-4.2
R.F. frequency (MHz)	73.65
R.F. voltage (KV)	200
Harmonic number	8
Energy loss per turn (KeV)	5.17
Synchrotron frequency (KHz)	37.76
R.F. energy acceptance (%)	±2.98
R.m.s. bunch length (cm, Z/n = 2Ω)	4
Beam lifetime (minutes, P=10 nTorr, Z=8, Z/n=0)	≈35

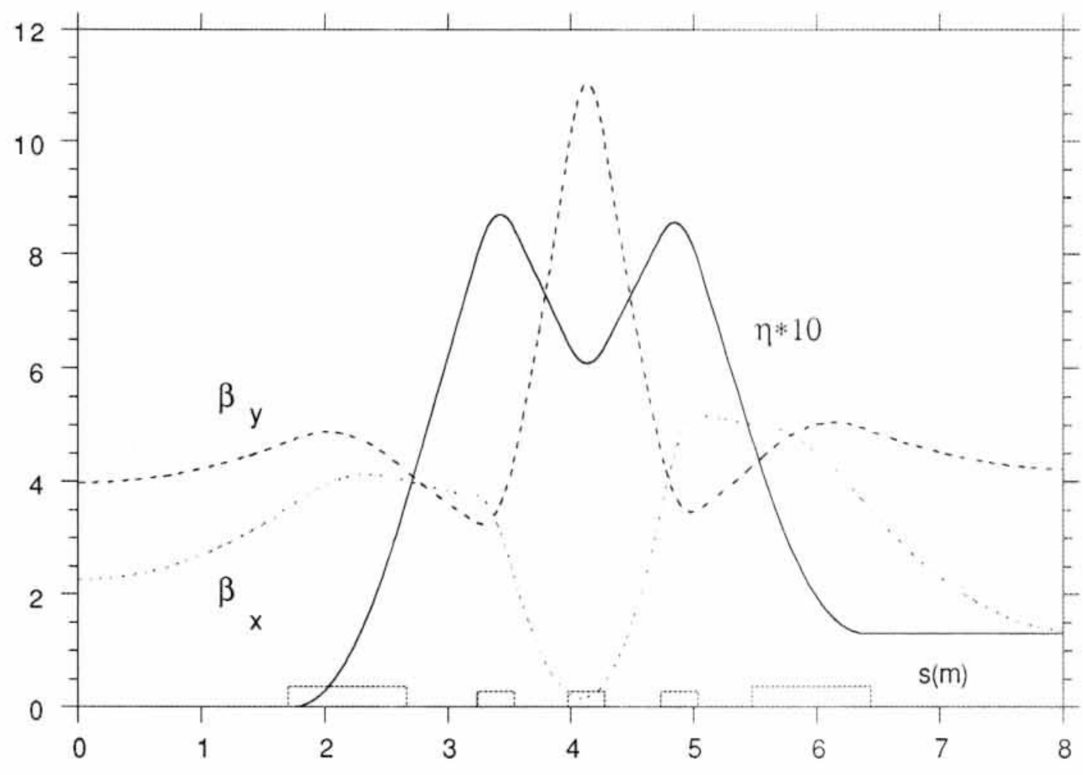

Figure 3 - Optical functions of one Accumulator quadrant

CONCLUSIONS

The above described injection system is now almost completely assembled at LNF and its first part, injection from the Linac into the Accumulator and extraction from the Accumulator is ready for commissioning. The injection budget at each step of the injection procedure into the DAΦNE Main Rings is given in the following Table 4 for 100% efficiency. It can be seen from this Table that full current filling of both Main Rings from scratch can be realized in 10 minutes even with 40% overall efficiency. Refilling the rings in the topping-up mode with 30% of the maximum current can be achieved in 5 minutes if the overall efficiency is better than 60%.

TABLE 4. DAΦNE injection system parameters

	From scratch	Topping up
Maximum rate of Transfer Line pulsed magnets (Hz)	2	
Dead time per pulse (s)	0.2	
Pulse positron current from Linac (mA)	36	
Pulse electron current from Linac (mA)	150	
Pulse length from Linac (ns)	10	
Injection rate into Accumulator (Hz)	50	
Number of positron per Linac pulse	2.2×10^9	
Number of electrons per Linac pulse	9.2×10^9	
Positrons to be stored in each Main Ring bunch	8.9×10^{10}	3.0×10^9
Number of Linac pulses into the Accumulator	40	14
Time per bunch (s, including dead time and repetition rate)	1.0	0.5
Number of bunches to be injected into the Main Ring	120	
Total positron injection time (min)	2	1
Time to switch from positron to electron mode (min)	1	
Electrons to be stored in each Main Ring bunch	8.9×10^{10}	3.0×10^{10}
Number of Linac pulses into the Accumulator	10	3
Time per bunch (s, including dead time and repetition rate)	0.5	0.5
Number of bunches to be injected into the Main Ring	120	
Total electron injection time (min)	1	1
Total injection time (100% efficiency)	4	3

REFERENCES

[1] R. Boni, S. Kulinski, M. Preger, B. Spataro, M. Vescovi, G. Vignola "The Frascati Φ-Factory Injection System", 1991 Particle Accelerator Conference, San Francisco, p.961

[2] Proceedings of the Workshop on Physics and Detector for DAΦNE, the Frascati Φ-Factory, INFN, Laboratori Nazionali di Frascati, April 9-12, 1991

[3] L.M. Barkov et al. "Status of the Novosibirsk Φ-Factory Project", Particle Accelerator Conference, San Francisco, 1991, p.183

[4] M. Biagini, C. Biscari, S. Guiducci "DAΦNE Main Rings Lattice Update", DAΦNE Technical Note L-22 (18/3/1996)

[5] S. Guiducci "Beam Lifetime in DAΦNE", DAΦNE Technical Note L-12 (24/2/1993)

[6] F. Amman et al. "Remarks on two beam behaviour of the 1.5 GeV electron-positron storage ring ADONE", 8th International Conference on High Energy Accelerators, CERN (1991), p.132

[7] D. Sherden 'Tapered solenoid for SPC Positron Source", SLC Design Book, MEMO CN-22, 1980

[8] C. Biscari "Transfer Lines update", DAΦNE Technical Note I-14 (24/4/1996)