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PERFORMANCE AND OPERATION OF THE DAΦNE ACCUMULATOR

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Abstract

DAΦNE [1] is an electron/positron collider, in operation at INFN Frascati since the beginning of 1998. Its injection system [2] consists of a 0.55 GeV positron (0.8 GeV electron) Linac, an intermediate damping ring, called "Accumulator", and ≈ 180 m long Transfer Lines connecting the Linac to the Accumulator and the Accumulator to the collider Main Rings. The Accumulator is a 0.55 GeV storage ring, operating in the single bunch mode, where electrons and positrons accelerated by the Linac are alternatively captured and stacked with high efficiency, due to its large acceptance and short damping time. The high quality damped beam is then extracted and transferred to the collider. The whole injection system has been designed to fill the Main Rings in few minutes. The operating experience with the Accumulator has demonstrated the feasibility of this goal.

1 INTRODUCTION

Among several projects of electron-positron "factories", namely high luminosity colliders running at the peak of high cross section resonances, DAΦNE [1] is presently under commissioning at INFN Frascati. The appellation "factory" for a collider comes from the peculiar characteristic of being capable of producing an extremely high rate of a given type of particles. In the case of DAΦNE, the particles are K mesons from the decay of the Φ resonance (≈ 5.10^3 nb at 1.02 GeV c.m.).

The design luminosity of DAΦNE is 5.10^{32} $cm^{-2}s^{-1}$. This value exceeds by almost two orders of magnitude the maximum luminosity achieved at the same energy (0.51 GeV per beam) at the VEPP-2M collider of Novosibirsk [4]. This strong improvement is obtained by realizing the collider as a double ring structure with two low-β interaction regions where the counterrotating beams cross at a small angle in the horizontal plane. With this arrangement it is possible to store in each ring a large number of bunches (up to 120), each crossing the other beam only in the two interaction regions. With respect to a single ring collider, where, unless the beams are separated at the high-β crossing points by means of electrostatic separation schemes, the maximum number of bunches is half the number of low-β interaction regions (typically 1 or 2 in such low energy range), the luminosity can therefore be improved proportionally to the number of stored bunches. The limitation on this number comes from the minimum bunch spacing, determined by the crossing geometry and the minimum separation required between bunches of the opposite beams at parasitic crossings near the interaction points.

It is clear that this double ring scheme with many bunches requires a very large average stored current in each ring. In the case of DAΦNE the design value for the maximum current is ≈ 5 A.

The beam lifetime at low energy is dominated by the Touschek effect: it is estimated to be ≈ 2 hours in the design configuration of the beam. Flexible operation of the collider requires injection of any bunch pattern, at least in the commissioning stage, so that it should be possible to store each bunch individually in the rings. A very powerful injection system, running in the single bunch mode at the operation energy of the collider is therefore required to fill the Main Rings from scratch at full current in few minutes. With such a system, the rings can also be refilled without dumping the stored beam, keeping the average luminosity of the collider very close to the maximum one.

2 DESIGN PHILOSOPHY

The RF bucket width in the DAΦNE Main Rings is 2.7 ns. With the maximum positron current available from the Linac [2] (≈7 0 mA positrons and 300 mA electrons), ≈ 10^4 injection pulses would be necessary to fill the positron ring. With such a large number of pulses, strict requirements on the injection aperture are mandatory to avoid saturation. With an intermediate booster between the Linac and the collider this large number can be split into two factors, the number of injection pulses into the booster (≈ 80 for the same longitudinal acceptance and full efficiency) to reach the full current of a single Main Ring bunch times the number of bunches (120).

There are two additional important advantages of this choice:

- the RF system in the booster can run at a lower frequency, thus improving the longitudinal acceptance (in our design the frequency is 5 times lower, thus reducing the number of injection pulses into the booster from ≈ 80 to ≈ 15 at full efficiency).
- it is possible to damp the beam in the booster before extraction: in this way the beam quality (emittance and energy spread) is typically one order of magnitude better

than the corresponding one of a beam accelerated by a Linac at the same energy, thus substantially reducing the aperture requirements in the collider.

The booster, called "Accumulator", has been designed under the following constraints:

- reference orbit length exactly 1/3 of the DAΦNE Main Ring one to allow easy synchronization;
- symmetric structure to allow injection/extraction of both electron and positron beams without changing the magnetic fields;
- low emittance and energy spread, short damping time;
- low dispersion in the injection/extraction sections.

These requirements are fulfilled by designing the lattice as a symmetric structure of four quasi-achromatic sections, each one with two small radius (1.1 m) dipoles with a field index of 0.5 and three quadrupoles [3], separated by long straight sections to accommodate the injection/extraction septa, the kicker magnets and the RF cavity. The chromaticity is corrected by means of 8 sextupoles, 2 in each achromat. The Accumulator layout is shown in Figure 1.

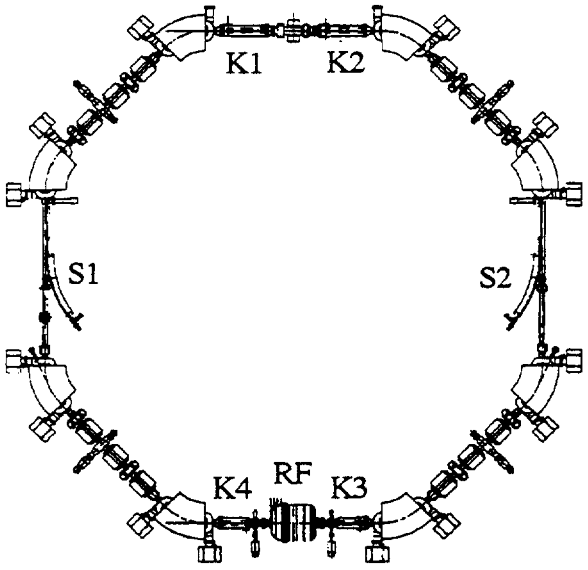

Figure 1: Accumulator layout

Positrons are injected at 50 Hz through septum S1 by a symmetric closed bump generated by the four kickers. When the full single bunch current (≈ 130 mA) is reached, the beam remains stored for 5 damping times to reach its equilibrium emittance and energy spread. The beam is then extracted through septum S2 by means of a single pulse in kickers K1 and K2. The whole cycle requires typically one second. The electrons follow the opposite path, being injected through S2 and extracted through S1. In such a way the ring is operated in a steady configuration.

The horizontal betatron tune of the ring has been adjusted to obtain the correct phase advance between kickers and injection septa for both beams and to have a small average dispersion in the straight sections and bending magnets. Both tunes are slightly above the integer to avoid resistive wall instability. Figure 2 shows the optical functions of 1/4 of the ring. The structure of half ring is obtained by mirror symmetry and the full lattice by repeating the sequence. Table 1 lists the main parameters of the Accumulator.

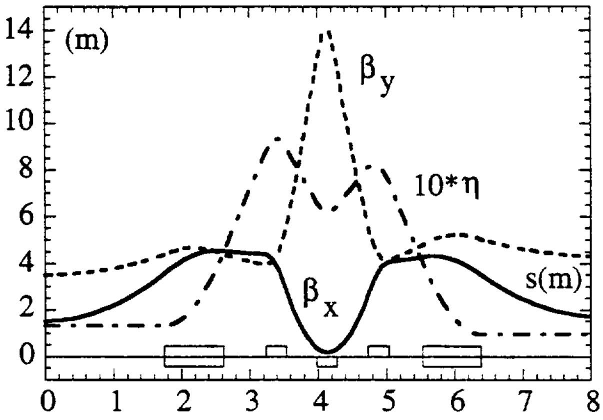

Figure 2: Optical functions of 1/4 of the ring

Table 1: Accumulator parameters

Energy (GeV)	0.51
Circumference (m)	32.56
Maximum single bunch current (mA)	132
Horizontal betatron wavenumber	3.12
Vertical betatron wavenumber	1.14
Horizontal betatron damping time (ms)	21.4
Vertical betatron damping time (ms)	21.4
Synchrotron damping time (ms)	10.7
Momentum compaction	0.04
Emittance (mm.mrad)	0.25
Energy spread (%, rms, radiation only)	0.04
RF frequency (MHz)	73.65
RF voltage (KV)	200
Radiated energy per turn (keV)	5.2
Energy acceptance (%)	>±1.5
Bunch length (cm, rms, radiation only)	1.8

3 OPERATING EXPERIENCE

The Accumulator construction was completed in December 1995. After completing the installation of the Transfer Line from the Linac inside the Accumulator Hall and the electric and cooling systems, commissioning of the ring was easily and rapidly performed. The first electron beam was stored in June 1996. The first positron beam was stored and extracted in November 97, and design performance with both beams achieved at the beginning of 1998. In the commissioning phase the Linac runs at half the nominal repetition rate , and ≈ 50 mA positrons are routinely stacked at 25 Hz in less than one second in a single bunch. The design current corresponding to the required charge per bunch in the Main Rings (132 mA) can be easily reached. The maximum single bunch current stored under stable conditions exceeds 150 mA. The lifetime of the stored beam is largely sufficient for injection into the Main Rings, being more than half an hour at the maximum operating current.

The operation of the Accumulator for the collider commissioning is reliable and downtime negligible.

Figure 3 shows the output of a DC beam current transformer during a typical injection/extraction cycle with electrons for the commissioning of the Main Rings. In this configuration 5 electron pulses are stored in the Accumulator; then the beam is damped and extracted. The repetition rate of this sequence is 1 Hz.

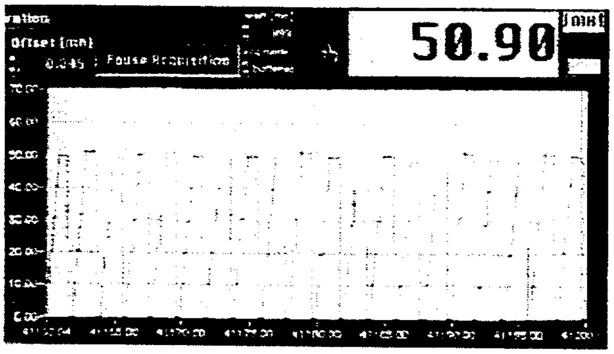

Figure 3: A typical injection/extraction cycle as seen on the DCCT monitor

The overall injection time into DAΦNE depends critically on the injection efficiency of the positrons, since the electron current from the Linac is so large that the injection rate of the electrons is limited by the maximum repetition rate of the pulsed elements in the Transfer Line. The overall transport and capture efficiency from the Linac to the Accumulator for positrons is ≈ 40%. The loss takes place mainly in the Transfer Line due to the fact that we do not use any energy selecting slit at the Linac output. The capture efficiency itself, defined as the stored beam current divided by the beam current at the first revolution inside the Accumulator is 95%. The overall efficiency for electrons is 60%. There is still some margin for improvement in the injection efficiency, since the achieved rates are largely sufficient for the commissioning of DAΦNE, and no machine time was dedicated to the optimization of the injector performance.

The extraction efficiency is defined in a similar way and, due to the small emittance and energy spread of the damped beam, it is close to 100%.

The shift of the synchronous phase and the bunch length have been measured as a function of the current stored in a single bucket of the Accumulator [5]. Due to the high RF frequency of the Main Ring cavities (368.26 MHz) required to store a large number of bunches, injection efficiency into the Main Rings could be affected by bunch lengthening at high current. This is not the case, as it can be seen from Figure 4, showing the result of the measurement: the maximum FWHM bunch length is ≈ 17 cm, to be compared with the Main Ring bucket length of 81 cm. By fitting the measured bunch length values with a standard model [6], the low frequency longitudinal coupling impedance $|Z/n|_0$ comes out to be 3.55 Ω, in good agreement with the predictions of the numerical simulations which take into account the shape of the vacuum chamber discontinuities.

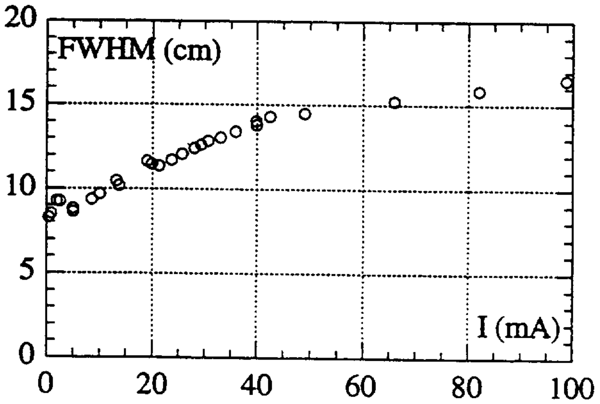

Figure 4: Bunch length versus average current between 60 and 90 KV in the R.F. cavity.

The transverse coupling impedance has also been measured [7]: its value of 70 KΩ/m agrees with the predictions of the simulations. A conservative estimate for the threshold of the transverse mode coupling instability comes out to be 160 mA, larger than the single bunch current in the Accumulator required to fill the maximum design current in each bunch of the DAΦNE Main Rings.

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