NEW INJECTION SYSTEM FOR ADONE

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Abstract

A single-turn injection system has been installed on ADONE to increase the injection efficiency. The machine has now four independent fast kickers, two for electrons and two for positrons, spaced by approximately 2π in horizontal betatron phase.

Kicker firing is synchronized with the Linac pulse and with the RF accelerating voltage in order to select injection into any of the 18 buckets of the storage ring. The design and realization of the kicker magnets, H.V. pulsers and control circuits are presented.

Introduction

In order to increase the injection efficiency for short single bunches, we changed the single kicker, which produced a slow (10μs) orbit deformation for multiturn injection, with a new fast kicker system.

The original injector of the Frascati 350 MeV electron-positron Linac was designed to deliver low-current (0.5 A), long (4 μs) pulses for multiturn injection into the storage ring Adone and for nuclear physics experiments. Injection into the ring completely filled the longitudinal phase space, consisting of 3 buckets provided by a 4-cavity, 8.57 MHz radiofrequency system. In 1982 a new 51.4 MHz R.F. cavity, resonating on the 18th harmonic of the revolution frequency became operational, with the aim of providing short bunches for free electron laser and time-resolved synchrotron radiation experiments.

The multiturn injection system was still sufficient to inject rapidly single electron bunches into the ring, but when a new electron-positron experiment (FENICE) was proposed to measure the neutron-antineutron cross section, it became evident that a completely new injection system was necessary to store positrons into the ring within a reasonable time.

A new injector for the Linac was therefore installed at the beginning of 1988, capable of delivering high current (>15 A) short (10 ns) electron pulses, with the option of increasing the pulse length up to a full revolution time of the ring (350 ns), to allow electron multibunch operation.

Design Criteria

The new system consists of two kickers for each beam spaced by nearly 2π in betatron phase (see Fig.1). To fit in the available straight sections, the kickers for electrons and positrons are inserted in the same straight section. The particles from the Linac enter the storage ring through a magnetic septum at a distance of 7.5 cm in the horizontal plane from the central orbit and parallel to it; after $\pi/2$ of betatron oscillation these particles traverse the kicker and are deflected on the central orbit. The already stored particles perform a complete betatron oscillation, excited in the first kicker $3\pi/2$ upstream the septum and cancelled in the second one. The system is symmetric for the two beams, with two kickers and one septum for each one.

In order to optimize the parameters of the system, a tracking program has been written to study the effect of the kicker pulse on the stored beams of e^+ and e^-. Particle coordinates at the exit of the injection septum are taken as initial conditions and the residual oscillation amplitude in the ring after each successive kicker pulse is computed. Complete betatron phase mixing and reduction of the betatron amplitude by the damping factor between two injection pulses is assumed.

It has been shown that it is possible to inject at a frequency higher than the inverse of the damping time (1Hz) with an efficiency of the order of one.

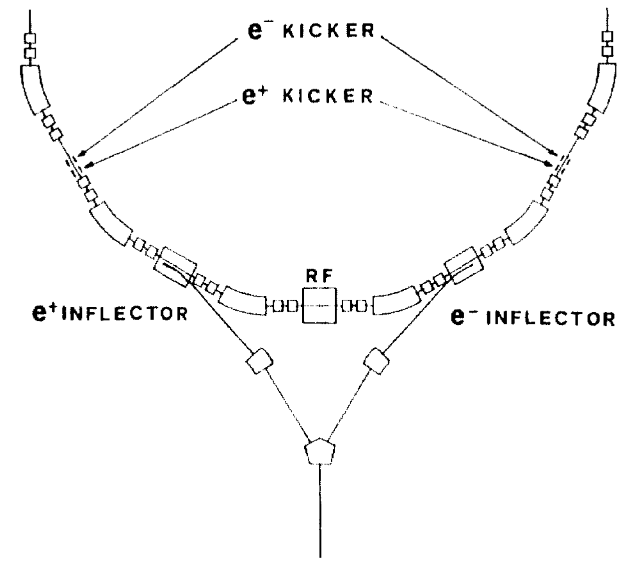

Fig. 1 - New electrons and positrons injection scheme with two pairs of kickers.

Due to the large aperture of the Adone storage ring, the minimum orbit deformation required is nearly half the distance between the septum and the central orbit and corresponds to an angular perturbation of ~4mrad.

To simplify the realization of the kicker power supply, the possibility of using a pulse length greater than the distance Δt between two consecutive bunches (Δt ~120 ns for single bunch - two beams operation) has been considered. In fact a pulse length as long as $4\Delta t$ gives a very small perturbation to the accumulated e^+ beam during e^- injection, even at an injection frequency of the order of 3÷5 Hz. In the case of single beam operation, any number of bunches, up to 18, can be injected with a pulse length up to twice the revolution period (T_0 = 350ns).

With the new injection system, a few modifications to the injection timing system were required. In particular, it has been necessary to synchronize the injector gun trigger with the kicker firing and with the storage ring accelerating RF: the primary injection trigger is first synchronized with a bunch identifier trigger signal at the ring revolution frequency, then it is split and, after the application of suitable delays, is used to trigger the Linac injector gun and one or the other pair of kicker pulsers. By varying the phase of the bunch identifier trigger, it is possible to select the injection into any of the 18 RF buckets.

Each kicker is 0.5 m long. They are located in straight sections #3 and #11, along with a pair of 1 m long electrostatic plates used for the vertical separation of the beams at injection.

Electromagnetic design

The physical aperture at the kicker locations must not be smaller than that already existing in other parts of the storage ring.

The smallest physical half-aperture in the horizontal plane is ~ 75 mm at the injection septa and in the vertical plane ~ 15 mm at the Wiggler magnet.

Effective use of deflecting plates or strip-lines is limited by the constraint of relatively large horizontal separation.

Furthermore, we discarded the hypothesis of using a ferrite kicker because of the additional complication of building a large ceramic section with internal metallization. On the other hand, a ferrite kicker inside the vacuum envelope was deemed dangerous for instabilities and bunch lengthening.

The final choice has been to realize the kicker with two coils inside the vacuum chamber. The vacuum chamber inner diameter around the kicker coils must be the largest possible in order to minimize the reduction of the effective field due to the image currents which establish in the surrounding wall (see fig. 2a). The maximum inner diameter compatible with available flanges was 270 mm.

The kicker coils are connected in parallel to halve the self-inductance presented to the power pulser and hence the maximum voltage. The transition from atmosphere to the accelerator vacuum is accomplished by means of two ceramic feed-throughs diametrally placed. The two coils are paralleled inside the vacuum chamber. The required integrated field is ~ 53 Gs*m at an injection energy of 400 MeV.

In order to evaluate the field-current transfer function, the magnetic field distribution and the value of the self-inductance coefficient, a program has been written, which calculates the current distribution on the surface of the kicker coils, taking into account the image currents and the mutual effect of the coil conductors on each other. From the current distribution (see fig. 2b) one can then calculate the magnetic field as a function of the position, the field-current transfer function, the characteristic impedance of the kicker coils and the inductance of the parallel circuit. The final design is the result of an optimization aiming at reducing the current and at the same time keeping the inductance low to reduce the high-voltage supply.

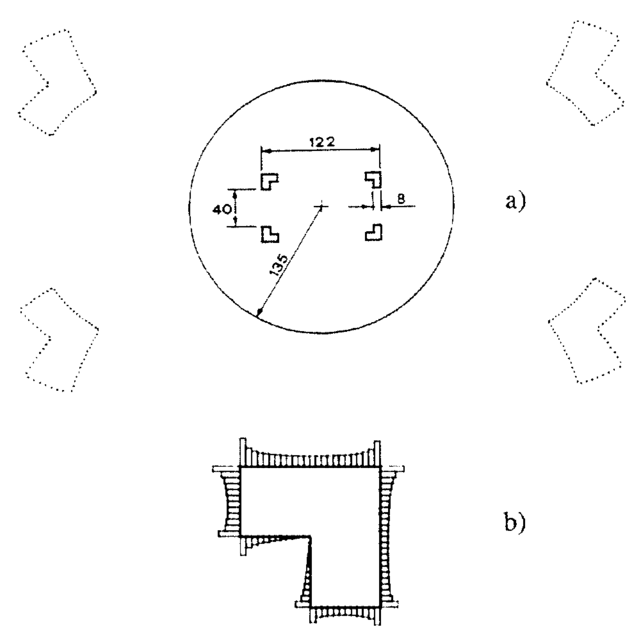

Fig. 2 - a) Cross-section of the kicker coils (all quotes in mm). The boundary conditions are equivalent to a configuration in which, to each elementary conductor distant b from the centre, there corresponds an "image" conductor at a distance a^2/b from the centre (with a the radius of the chamber), carrying an opposite current. The field at the centre is effectively reduced by a factor $(1 - b^2/a^2)$. To minimize the shielding effect of the vacuum chamber it is thus necessary to increase its radius.
b) "Bar-graph" representation of the surface current density in one of the kicker conductors.

A further constraint is given by the required field uniformity. The criterion was followed to make the sextupole coefficient vanish to ensure the best field uniformity in the vicinity of the kicker centre. For extended conductors one has to take into account the weighted average of the current distribution and the optimum value of the coils positions which depends also on the conductor shape. In practice one arrives at the optimum geometry by a trial and error procedure.

The multipolar coefficients are calculated from the Fourier coefficients of the magnetic field "sampled" in 24 equidistant points lying in a circumference of 20 mm radius.

The predicted ratio between the magnetic field and its value at the kicker centre, along with the corresponding measured values are plotted in Fig. 3 as a function of the horizontal distance x from the centre, at various vertical positions y.

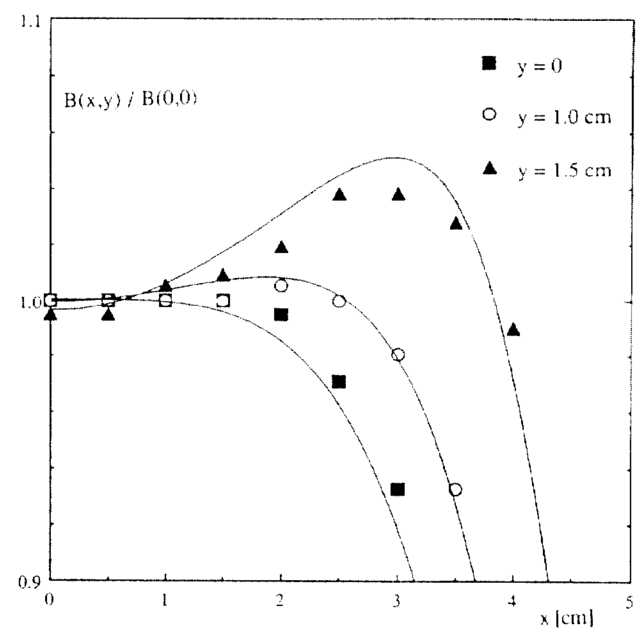

Fig. 3 - Calculated and measured (dots) ratio of the magnetic field to the centre value versus the distance x from the axis.

The results of the simulation of the final geometry are shown in Table I. It is worth noting that the calculated value of the self-inductance coefficient L_k is referred to the kicker coils only and does not take into account the parasitic inductance of the vacuum feed-throughs and of the general wiring of the pulser. A conservative hypothesis was to allow for additional 0.3 to 0.4 μH to the parasitic inductance L_s .

Table I

	Calculated	Measured
Kicker inductance L_k [μH]	0.28	0.27
Parasitic inductance L_s [μH]	0.3 ÷ 0.4	0.43
Characteristic impedance [Ω]	79.0	79.3
Field/current [Gs/KA]	44.5	39.4
Magnetic length [m]	n.a.	0.53
Max current @ 53 Gs*m [KA]	2.25	2.54
Max voltage @ 53 Gs*m [KV]	11.4 ÷ 13.4	16.4
5 % uniform field (@ y = 0) [mm]	$\|x\| < 26.9$	$\|x\| < 28$

Power pulser

The pulser scheme is shown in Fig. 4. Each kicker is powered by a thyratron switch pulser resonantly discharging a capacitor into the kicker inductance. The resulting waveform is almost half-sinusoidal with a maximum current of 3 KA (see Fig 5).

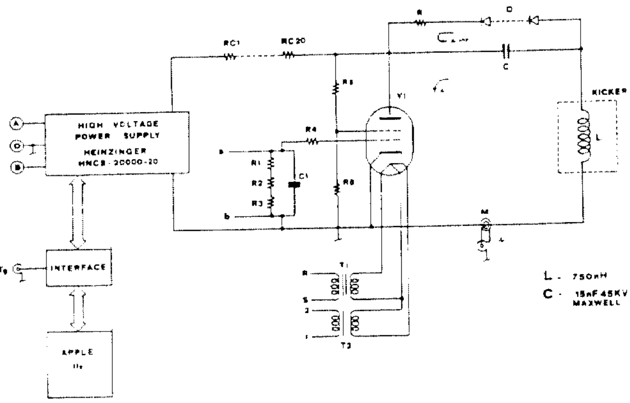

Fig. 4 - Kicker power pulser circuit.

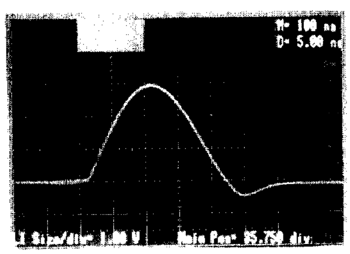

Fig. 5 - Current pulse shape.

A series of fast solid-state diodes and resistances are connected in parallel to the capacitor to prevent high inverse voltage at the thyratron when this is switched off. Due to the critical rate of rise of the anode current, the thyratron reservoir supply is accurately regulated to avoid inverse current pulse discharge.

It is necessary from time to time to trim the trigger delay according to temperature-induced effects in the thyratron pulsers.

The pulser is located very close to each kicker section in order to reduce the wiring impedance. The current pulses are monitored and the power supplies are computer controlled from the control room.

Magnetic measurements

The magnetic field in the kickers was measured before installation in the storage ring. A measurement copper coil 70 cm long and .5 cm large has been used to measure the integrated magnetic field values and its uniformity in the transverse plane. The coil is aligned on the mechanical axis of the vacuum chamber and the induced voltage measured at an oscilloscope after time integration by means of a passive circuit.

A short coil (5 cm) with the same transverse size, placed in the centre of the kicker coil is used to measure the local magnetic field. Then the kicker effective magnetic length is calculated from the voltage ratio of the long and short coils.

The field varies across the kicker coils as a function of the distance from the axis. A magnetic field map was performed by moving the measurement coil in the transverse plane. Fig. 3 shows the magnetic field and its central value ratio versus the transverse coordinate. The integrated magnetic field is flat (better than 5%) within ±28 mm in the horizontal plane and ±15 mm in the vertical one.

Conclusions

The new injection system has been in operation for almost one year with an excellent reliability.

An accumulation rate of 3 mA/min for positrons at 2 Hz has been achieved with an injection efficiency of 70%.

Acknowledgements

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