A FULL ENERGY INJECTOR FOR ELETTRA

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Abstract

A major upgrade to the ELETTRA synchrotron light source is a full energy injector. Such a system significantly increases machine stability and reliability and above all allows rapid refills that top-up the stored beam. Frequent injections are necessary to account for Touschek losses and when operating with low gap insertion devices. Topping-up with insertions in operation and photon shutters open is the final goal. Presently a refill is performed by injection of a 1.0 GeV electron beam from a linac followed by ramping in the storage ring. The final operating energy is 2.0 GeV (~80% of User time in 1999) or 2.4 GeV. This paper describes the proposed full energy injector, machine parameters and constraints. The new system is composed of a 100 MeV linac pre-injector and a 2.5 GeV booster synchrotron with a repetition rate up to 3 Hz.

1 INTRODUCTION

The existing injector of Elettra, is a linear accelerator that can provide a maximum energy of 1.2 GeV electrons but its normal operating energy has been reduced to 1.0 GeV to enhance its reliability. The storage ring is routinely operated at 2.0 GeV and in recent years a significant fraction (22%) of User beam time is at 2.4 GeV. To reach final operating conditions the beam is ramped in energy in the storage ring. Significant effort has been placed in automating as far as possible the refill procedures. A refill is performed once per day and typically lasts 30 to 40 minutes. Energy ramping entails a loss of machine efficiency, introduces stress on machine components and exacerbates machine instability and beam lifetime limitations. The proposed full energy injector would eliminate these problems and make full use of the characteristics of the facility and ongoing upgrades [1]. The chosen configuration is composed of a 100 MeV linac pre-injector feeding a 3 Hz pulsed booster synchrotron matching the maximum energy of the storage ring, namely 2.5 GeV. The injector will be optimised for top-up operation. The repetition frequency of the booster is chosen to minimise construction costs by simplifying the vacuum chamber design and making it possible to adopt a switched power supply that allows greater flexibility and the implementation of top-up operation. The lattice configuration minimises as far as possible construction and running costs and allows relaxed geometries for critical components such as pulsed injection/extraction elements. It is particularly important to minimise interruption of the normal operation of the light source. In view of this a new 100 MeV pre-injector will be constructed rather than relocating the existing one. The pre-injector linac will be constructed to provide a charge output at 100 MeV of 2 nC in 100 ns. This value is similar to the present pre-injector performance. Assuming conservative overall transfer efficiencies a storage ring refill of 400 mA can be performed in 5 minutes with a maximum booster current of 2 mA. This low current value obviates vacuum chamber cooling and no beam instabilities are foreseen.

The pre-injector and booster synchrotron will be placed in the open inner side of the present storage ring building. This maximises the use of available land and allows simple transfer of the beam to the storage ring. The ground in this area has already been levelled and requires little additional work. The limestone bedrock is the base for foundations for the injector, guaranteeing - as for the storage ring - maximum stability. Some preliminary modifications to the storage ring building will be necessary, however, no major interruption of the normal operation of ELETTRA is necessary during construction of the building, until connection to the storage ring is made. The booster and linac tunnels will be cast in reinforced concrete, with a wall thickness satisfying shielding requirements.

Further details of the pre-injector linac [2], booster lattice [3] and RF system [4] can be found in the proceedings of this conference.

2 PRE-INJECTOR LINAC

The linac pre-injector [2] composed of a sub-harmonic 500 MHz pre-buncher, a 3 GHz buncher and a 6m accelerating structure will be built in-house. The design minimises costs while at the same time ensuring high reliability and good safety margins on the achievable beam energy and on the deliverable RF power.

3 BOOSTER SYNCHROTRON

3.1 Lattice

In designing the booster synchrotron several lattice configurations were examined. The following points were taken into consideration for the final choice: the costs of the infra-structure and the space available for building, the need to have long drift spaces for easy extraction and injection, a large dynamic aperture and low power consumption. FODO configurations examined include structures with 20, 21 and 24 cells and hybrids, structures (four, three and two-fold) with missing magnets for the generation of near zero dispersion straight sections and two-fold structures with dispersion suppressors. In the end, a two-fold missing magnet lattice, 118.8 m in circumference, with a compact structure and an effective straight section length of ~6 m for extraction has been chosen [3]. The long straight sections ease operation of the injection/extraction elements and have near zero dispersion. Studies of the dynamic aperture in the presence of uncompensated chromaticity from eddy currents show comfortable apertures for a 0.7 mm thick stainless steel chamber at 3 Hz repetition frequency and

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indicate operation without the use of sextupole magnets. This option is being further evaluated.

3.2 RF System

The booster RF system [4] frequency is identical to the storage ring: 499.654 MHz. The RF voltage will be programmable during the ramp with an overvoltage factor of 2.15 guaranteeing a quantum lifetime of one second at 2.5 GeV. Two ELETTRA type cavities will be used to provide the required peak RF voltage (1281 kV). The required 35 kW of RF power can be provided by either a single 75 kW RF plant feeding both cavities or by two 35 kW plants each feeding a single cavity. The choice is presently being evaluated. For either option the layout of the system can be modular, which will not only reduce maintenance time, but will also allow the system to be easily upgraded.

3.3 Injection and Extraction

The linac beam is transported to the booster injection septum by a 22 m long transfer line composed of 12 quadrupoles, three 35° bending magnets and 16 corrector magnets. Single turn on-axis injection into the booster is performed by a septum magnet and a fast kicker magnet. The design of the injection septum and its power supply closely follows that of the main ring injection septa. The 40 cm long passive septum will be a C shaped laminated iron core magnet operating in-vacuum that will deflect the incoming beam by 16°. The septum is driven by a 43 μs long current pulse. The in vacuum fast injection kicker will deflect the beam by 2.78 mrad onto the booster axis. The flat topped current pulse for the kicker is provided by a delay line discharge circuit. The pulse fall time is of the order of 100 ns. Because of the specified time response the yoke will be made of ferrite blocks.

Extraction from the booster will be performed by a combination of a three magnet closed orbit bump close to the two extraction septa and a fast kicker magnet. Transfer to the storage ring will be done by a 46 m long transfer line composed of 15 quadrupoles, 4 bending magnets and 16 correctors. The laminated in-air bumper magnets will be driven by a 50 ms half sine wave pulse. Each bumper will have a dedicated DC power supply based on switching technology. The fast extraction Kicker provides the 1.7 mrad kick to deflect the electron beam into the gap of the first extraction septum. The magnet will be identical to the fast injection kicker, but will be driven to higher ratings. The same delay line circuit used for the injection kicker will also be used. Because the parameters of the extraction septa are similar to those of the storage ring injection the same magnet layout and design consisting of a pair of Fe-Si laminated core magnets operating in vacuum will be chosen, except for the length that has to be longer because of the higher operating energy. Again, the same LC discharge type of circuit used to drive the booster injection and storage ring injection septa will be used.

3.4 Beam Diagnostics

A total number of 20 button-type BPM’s is foreseen for the Booster. The BPM system electronics will rely on the digital detector board developed in collaboration by Elettra and the SLS [5]. A four channel front end unit directly interfaced to the digital detector board eliminates multiplexing of the BPM signals and allows up to 80 readings during a ramp. The tune measurement system synchronised with the injection and extraction processes will measure the horizontal and vertical machine tunes at least 10 times during the ramp. The foreseen system uses a digital spectrum analyser that samples the signal in time at a very high rate and identifies the resonance by computing the spectrum. To provide significant on line information of booster performance during the ramp the circulating current will be measured with a time resolution of approximately one turn by a "turn-by-turn" measurement of the accelerated charge. This will be done by a combination of commercially available devices (ICT’s and BCM’s) that can be triggered at rates up to 10 MHz.

3.5 Controls

The control systems will be integrated with the existing storage ring one. Open standards and commercial off-the-shelf components will be adopted as far as possible for all basic components. A distributed architecture based on a computer network will be adopted. Four types of computers, Equipment Controllers, Embedded Controllers, Servers and Control Room Workstations are foreseen. The low-level computers (Equipment Controllers) will be modular systems based on standard industrial buses. The ELETTRA control system uses the VME-bus that is still widely used although other standards offer better performance, e.g., cPCI could become an alternative to VME if PC based CPU boards were to be used. In the field of operating systems (OS), OS-9 is likely to be abandoned and other real-time OS’s will be evaluated for the low-level computers.

A Local Area Network based on Switching Fast Ethernet is being installed and will also upgrade the existing control system network. The new injector network will be based on the same technology and provide 100 Mbit/s low-end links and 1 Gbit/s backbones. TCP-IP will be the standard protocol for network communications.

Object oriented techniques will be used to design the general architecture of the control system software and to design and implement applications and services. The Unified Modelling Language/Rational Unified Process is solid, effective and widely accepted. A distributed object model architecture (CORBA) will be adopted.

An interlock system based on PLC’s will fault protect equipment and people and prevent damage by mishandling to either. A SCADA system will be employed to implement a control room console. Furthermore an interface to the control system through the network will be provided as well as a low-level connection to access control.

3.6 Vacuum System

The vacuum system for the booster is a rather simple arrangement and a base pressure of tens of nTorr is sufficient. To minimise, however, the effects of induced eddy currents during the ramp a 0.7 mm thick stainless steel vacuum chamber will be adopted for the bending magnet region. Elsewhere the thickness can be larger. The injection/extraction region will also have special chambers with dimensions up to 43 mm wide by 26 mm high to account for the incoming and outgoing beam trajectories. Elsewhere an elliptical or round tube will be used in the bending magnets. A series of preliminary calculations have been performed to optimise and better understand the stresses and properties of various chamber geometries built of AISI 316 L stainless steel. Choosing a safety factor of three with respect to the plastic deformation threshold, gives the maximum stress value of 65 N/mm^2 for any given chamber geometry. Two dimensional finite element methods have been used to examine various geometries and three dimensional models have been studied, with and without, external stiffening. Deflection and buckling studies have also been made of a 2 m long chamber. Results indicate that the standard chambers outside the injection/extraction regions can be safely built having elliptical cross-sections with a maximum width and height of 36 and 26 mm respectively without the need of external re-enforcement. The chamber used in the injection/extraction region will require external ribs. The vacuum system will be essentially UHV but without bakeout needs. At present a 45 l/s sputter ion pump is foreseen in every short straight section (i.e., every ~3.6 m) placed under a standard pump-out Tee. Multivac power supplies will power the pumps in groups of two and the current drawn by a pump will be used to monitor the pressure in a section.

3.7 Booster Magnets

The lattice is composed of 28 bending magnets, 36 quadrupoles (two families), potentially 24 sextupoles (also two families) and 24 corrector magnets (twelve for each plane). The magnets have been designed to minimise their inductance to reduce the requirements on the power supplies and have a low peak voltage. A preliminary design of the dipoles and quadrupoles has been performed using the program TOSCA. The booster dipole magnet is of the split H type with the core curved to follow the electron beam trajectory. All dipole magnets will be connected in series. The top and bottom magnet cross sections are symmetrical and designed to allow the installation of the stainless steel vacuum chamber by lifting the upper half of the magnet. The laminated steel length of the core will be 1.86 m. The 1T field at 2.5 GeV is generated by a current of 1575A. A preliminary study of the pole profile and of the end bevels has been carried out.

The two quadrupole families use identical magnets and each family is connected in series. Here too a preliminary design minimises the inductance of the power supply load. A fully symmetric quadrupole design with an aperture radius of 28 mm has been developed using TOSCA. The study has been performed with a pole width equal to the bore diameter (56 mm) and with a non tapered hyperbolic pole profile. The nominal gradient of 14.9 T/m has been obtained with 292 A. This first study (with a square end design) gives a gradient field variation of 0.17 (0.02) % due to the 12-pole (20-pole) aberration at a radius of 20 mm.

3.8 Power Supplies

The standard 3 Hz waveform is sinusoidal with a DC offset. Arbitrary waveforms are possible provided that the current slew rate is sufficiently low not to exceed the voltage limits of the power supplies. A switched mode power supply will be adopted allowing variable operating frequencies, programmable ramping and the possibility to operate the booster as a storage ring up to a certain energy. The 28 dipole magnets constitute a load of 90 mH and 300 mΩ with a time constant of ~405 ms. With the standard ramp the current slew rate is 12.8 kA/s and a two-quadrant power supply is needed with peak positive and negative output voltages of 1122 V and -850 V. The two quadrupole families will also have two independent switched mode power supplies. The differences between the two power supplies are small and the same type of two–quadrant power supply can be used for both families.

3.9 Storage Ring Upgrades

The injection system into the storage ring has to be upgraded to 2.5 GeV. Positions, dimensions and deflection angles of all magnets will remain the same but changes will be made to all installed power pulsers. In addition modifications will be made to the septa windings and the stainless steel box containing the laminations in order to eliminate a drift of the peak current with magnet temperature, observed at ELETTRA and traced to the winding not being able to expand freely.

4 OUTLOOK

Formal approval and funding is expected by the end of the year. The duration of the project is foreseen to last three years without any major interruption to User operation.

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