STUDY OF A PULSED SEXTUPOLE MAGNET INJECTION SYSTEM FOR LNLS

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Abstract

An injection system consisting of a pulsed sextupole magnet (PSM) is being considered for Sirius, the project of a new 3rd generation 3 GeV synchrotron source in development in Brazil [1]. This novel injection scheme will be implemented and tested in the existing UVX ring. This will also serve as an opportunity to get acquainted with the new technology and become ready for Sirius. On this paper we report on the ongoing PSM study at LNLS. In particular, details of injection dynamics calculations, magnet and pulsed power supply designs are described, as well as machine preparations for experimental tests in the UVX storage ring.

INTRODUCTION

Recently the idea of a pulsed sextupole magnet (PSM) for the injection system in storage rings has been proposed and its experimental explorations have just started [2-4]. Although there are new technological challenges to be overcome, there are advantages in using PSMs instead of conventional dipole kickers in the injection system. In particular, with a PSM the orbit perturbation of the stored beam can be considerably smaller. This is a very desirable improvement for rings with top-up injection, as are, or are planned to be, all third-generation synchrotrons.

In the future, the PSM injection system will also be considered for the Sirius project. A possibility, for example, is to have the pulsed sextupole installed in one of the 12 5-m short straight sections of the ring, thus avoiding taking up one of the fewer longer sections, as would probably be necessary with a conventional injection.

INJECTION AT THE LNLS UVX RING

In the 1.37 GeV UVX ring, electron beam is injected from a booster that ramps the energy of 30 mA circulating beam from 120 MeV to 0.5 GeV in 2 seconds. As the cycling period of the injector system is about 6 seconds, filling the main ring with a nominal current of 250 mA takes typically from 6 to 10 minutes.

The current injection scheme is realized with three strong pulsed kickers AKC02, AKC03 and AKC04 located respectively in straight sections labelled TR02, TR03 and TR04 (see Fig. 1). The optics of the transport line is matched to the optics of the ring at injection point. At the entrance point the incoming beam is 37 mm horizontally off the unperturbed closed orbit and has an angle of approximately -1.2 mrad.

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Measurements based on beam scrappers indicate a beam acceptance of 30 mm.mrad. This value at the injection point corresponds to a positional acceptance of approximately 20 mm.

The orbit bump of 19 mm generated by the dipole kickers is enough for nearly 100% of the 280 nm.rad injected beam to fall within the ring nominal acceptance in phase space.

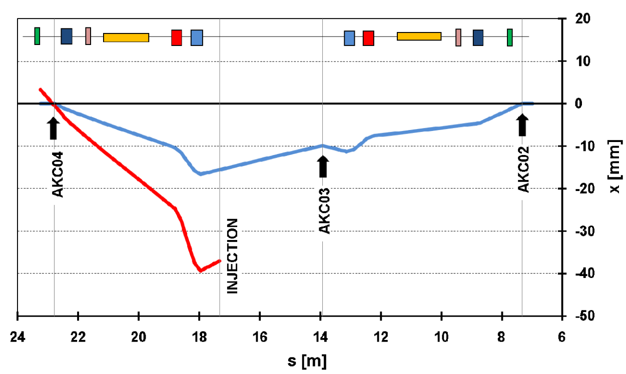

Figure 1: Current LNLS injection scheme with three dipole kickers in straights TR02, TR03 and TR4. The trajectory in blue represents the bumped stored beam and in red the injected beam.

Table 1: Main Injection Parameters

Injection mode	Matched
Injected beam emittance	0.28 mm.mrad
Ring acceptance	30 mm.mrad
β_x @ injection point	16 m
α_x @ injection point	-0.1

New PSM Injection Scheme

For the new PSM injection system the main parameters in Table 1 were kept fixed. Neither the booster-ring transport line nor the ring optics was changed for the current study of the new injection scheme.

The UVX ring has a DBA lattice with a 6-fold symmetry. It has six long straight sections, two of which are used for injection and for RF cavities. Three of the four straight sections with 3m-long free space available for insertion devices (IDs) are already used up.

The present injection study was performed assuming a PSM located in the last empty straight, the one labelled TR07. Relatively small horizontal phase advances (β_x ~ 16m) at the long straights implies small sensitivity of injection efficiency to the precise location of the PSM within TR07. The center of the section was chosen for the installation of the PSM (see Fig. 2). This point is at a distance of 29.3m downstream from the injection point and its relative phase advance is 626º.

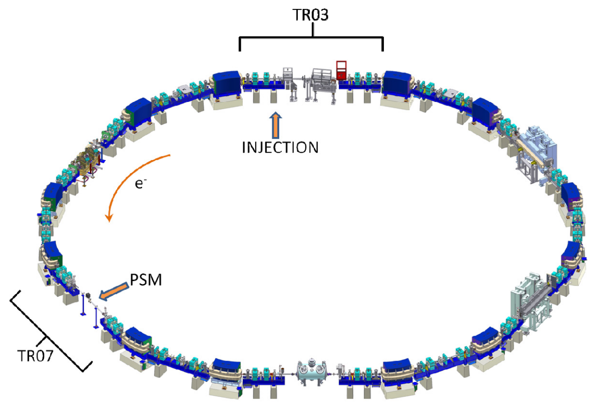

Figure 2: UVX ring.

Simulation

In order to study the efficiency of the injection with the PSM a Matlab® tool was developed that allows easy tweaking of the injection parameters and quick efficiency. For this reason they were not taken into account in the model for this study. Also, instead of elaborating on a precise modelling of non-linear tracking dynamics, a conservative approach was used for the calculation of injection efficiency: particles coordinates were checked for survival against the measured ring acceptance of 30 mm.mrad at every turn in the simulation.

At start, an electron distribution consistent with parameters of the incoming beam is randomly generated in phase space at injection point in TR03. Electrons in the distribution colliding with the 5-mm thick septum walls are flagged as lost. The particles are then tracked for many turns around the ring. At every element position in the model the particles coordinates are checked for collisions with the chamber walls, which are conservatively modelled as cylindrical pipes with a 28 mm radius. Particles are also checked at each turn against the ring acceptance ellipse and flagged accordingly.

Figure 3 shows the tools' interface with the best set of parameters found. The calculated injection efficiency achieved is 83%, with a sextupole strength of 10.8 m^{-2}. The beam distribution centroid arrives in the PSM location for the first time at x = 12.3 mm, receiving a kick of 1.6 mrad. The interface shows a phase space plot with the original injected beam distribution as black points, septum walls physical limits as dashed black lines and

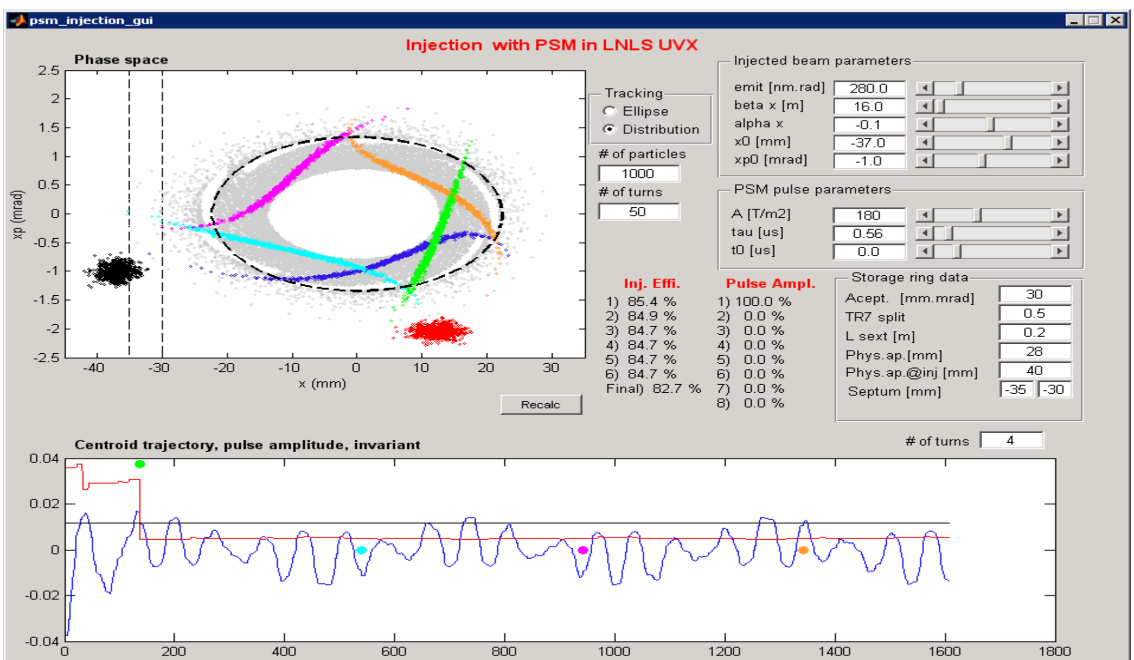

Figure 3: Matlab® GUI of the PSM injection tool.

visualization of results. This tool relies on AT [5] for beam dynamics calculation and tracking. It was designed so that it can be easily adapted for any storage ring and thus can, in the future, be used for studies of the injection system in the Sirius project.

The simulation model of the ring contains non-linear dynamics from chromatic sextupoles in the lattice. During injection IDs have theirs gaps opened or their fields turned off and hence they do not influence the injection ring acceptance at the PSM location as a dashed ellipse. The colored clouds represent the beam distribution at the PSM location at various instants: in red is the beam at the PSM for the first time, just before the 1st kick. In green is the beam right after the first kick. In cyan, magenta, orange and blue are the beam distributions right after the PSM in the 2nd,3rd,4th and 5th turns, when the kick pulse - with full width of 0.56 µs in this configuration - has already subsided completely, since the revolution period in the ring is 0.31 μs. Due to the non-linear field profile of the PSM, the beam distribution is strongly dispersed in angle after the first kick (green points). Points in gray represent the beam at the fifth and subsequent turns. The phase space filamentation caused by non-linear dynamics of the chromatic sextupoles is easily seen in the picture.

The plot in the bottom of the window conveys both the orbit of the beam distribution centroid along the first few turns (blue line) and the linear invariant of the motion (in red) compared to the ring acceptance (in black), plotted element-by-element in the tracking. Colored dots indicate the PSM location where the beam is kicked as it revolves around the ring. Vertical positions of the dots represent their relative kick amplitudes at the moments the beam passes at the PSM.

SEXTUPOLE MAGNET

In order to generate the required kick calculated in the simulation of the injection process, a 3-air-coil magnet with 20 cm in length was designed to produce a sextupole gradient $\partial^2 B/\partial x^2$ of approximately 200 T/m^2 [6]. The magnetic gap was chosen so that an existing ceramic chamber, which is a spare part for the dipole kickers, could be used (Fig. 4). Initial calculations for coil positions were done analytically and field profiles were simulated in static 2D with FEMM® and in transient 2D and 3D with MAGNET®. The required peak current and calculated magnet inductance are listed in Table 2 along with other main parameters of the pulsed power supply.

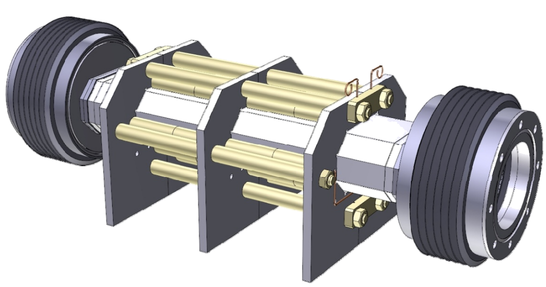

Figure 4: Pulsed sextupole magnet and ceramic chamber.

Table 2: Pulsed Power Supply Specifications

Peak current	3.2 kA
Pulse width	0.56 μs
Load inductance	1.1 μH
Time jitter	3 ns
Repetition rate	(1/6) Hz

PULSED POWER SUPPLY

The topology chosen for the pulsed source of the sextupole is the same as the one in use for the septa at the UVX machine. Basically it is a LC circuit that produces current peaks in a half-sine pulse. Connected to the circuit, there is an accurate source from 0 to 30 kV that charges constantly two capacitors in parallel with the necessary voltage to achieve the specified current peak of 3.2 kA. A recovery circuit was added in order to avoid an opposite (negative) voltage at the end of the half-sine wave current pulse.

The pulse is generated when the LC circuit is closed through the thyratron tube, which is monitored by a microcontroller circuit. Figure 5 shows a measured pulse from the power supply.

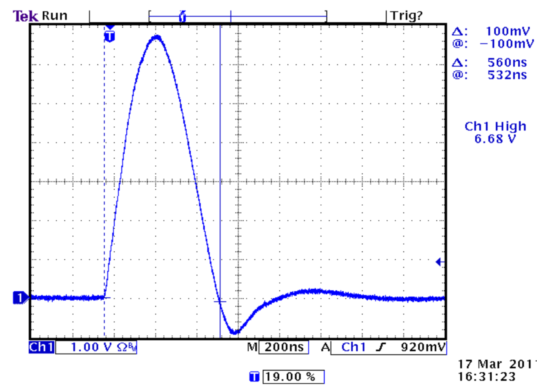

Figure 5: Measured pulse from power supply (480A/div).

For initial tests, components available in stock were used for the assembly of the pulsed supply. For example, spare 10nF/50kV capacitors and thyratron tube CX1154C were used. They are spare components of the 65 MW power modulator and of pulsed power supplies for the booster and ring kickers.

FUTURE PLANS

During the 2010 machine shutdown at the end of last year the ceramic chamber for the PSM was installed in the straight TR07. Final tuning of the sextupole design is presently being performed and the fabrication and assembly of the magnet should commence in the next weeks. The power supply will be tested with the magnet and the field characterized. The PSM is expected to be ready in the upcoming months and commissioned with the beam before the end of the first semester of 2011.

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