INJECTOR IMPROVEMENTS AT THE BRAZILIAN SYNCHROTRON LIGHT SOURCE

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Abstract

We present the results of hardware, software and operational improvements implemented at the injector complex of the 1.37 GeV electron storage ring of the Brazilian Synchrotron Light Source (LNLS) with the aim of improving injector stability and reliability, thus reducing the injection time. The improvements include changes to the 120 MeV injector LINAC RF system and high power modulators, injection automation and the implementation of a new procedure for reusing the current at the end of each user´s shifts before injection by ramping the energy back down to 500 MeV (the injection energy) without dumping the beam. All of these changes allowed us to significantly reduce the overall time from the end of a shift to the delivery of beam in the following shift with a positive impact on the reduction of injection thermal transients for the storage ring and beamlines. Further improvements are expected in the near future as a result of planned changes to the injection timing system and of the installation of a recently assembled upgrade of the 500 MeV booster synchrotron RF system.

INTRODUCTION

The injector system for the 1.37 electron storage ring at the Brazilian Synchrotron Light Source has evolved considerably since its first commissioning in 1996 [1,2]. The major milestone in injector improvements took place in 2001, when a booster synchrotron [3] was installed allowing the injection energy to be upgraded from 120 MeV (the energy of the beam from the injector LINAC) to 500 MeV. Figure 1 shows the present configuration of the injector system.

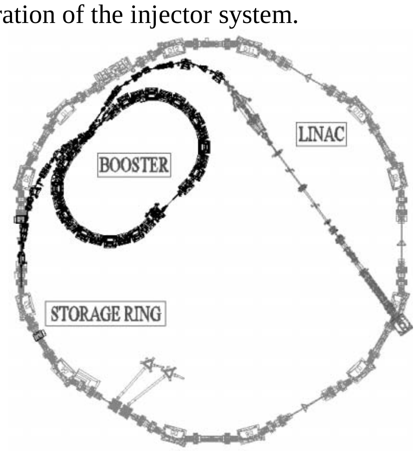

Figure 1: Layout of the LNLS light source, showing the 120 MeV injector LINAC, the 500 MeV booster synchrotron and the 1.37 GeV storage ring.

The successful installation and commissioning of the booster synchrotron represented a major improvement in light source performance, allowing the maximum amount of current that could be accumulated in the storage ring to be determined solely by the capacity of the storage ring subsystems (in particular vacuum and RF) to withstand the increased power demands and heat load and not by the limitations in injection efficiency and short beam lifetime at injection energy, which were the dominant effects when injection was performed directly from the LINAC at 120 MeV.

However, as more sophisticated and demanding applications were pursued at the LNLS beamlines over the years, the requirements on beam stability became increasingly severe and led to the need to further improve the injection system and procedures. In fact, since injection into the LNLS storage ring takes place at about one third of the nominal operating energy, every injection inevitably brings about thermal transients to the storage rings elements (due to the fast change in heat load to magnet coils and vacuum chambers) as well as to the optical components in the beam lines. The deleterious effects of these transients can be clearly seen as beam position drifts that occur particularly during the first few hours after injection (even with orbit feedback on), and which are significantly larger than the corresponding drifts that take place during the major part of the shift, associated with the slow decay of current. A program to reduce these transients was therefore considered a major part of an overall effort to improve long-term beam position stability [4].

At the start of the injector improvement project described in this work, the total injection time (defined as the time between the end of a user’s shift – when beamline shutters are closed – to the moment when full current is again stored and ramped back to high energy, all insertion devices are at minimum gap and orbit feedback is on so that beamline shutters can be opened again) was typically around 30-45 minutes and was divided into the various phases shown in Table 1.

Table 1 shows that about half the injection time is devoted to storing the beam whereas the other half is spent in ramping and performing various auxiliary operational procedures. Moreover, significant variations in injection time from one injection to another are related to injector fluctuations (in particular injector LINAC energy fluctuations) as well as to the lack of repeatability in operator actions during the various phases described above.

In order to reduce significantly the injection time, we must therefore work not only on improving the

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injection efficiency and beam storage rate but also on reducing the time and improving the repeatability of the time devoted to miscellaneous operational procedures, basically through increased automation of the whole injection process.

Table 1: Typical Injection time and phases before implementation of the injector improvements program.

Action	Time [min]	Obs
Shutters Closed		
Insertion device setup for injection	4	Open insertion devices gap
Dump beam	0	Turn RF OFF
Cycle magnets	3	Prepare for next injection
Store Beam	16	Repeat booster cycles
Prepare and Execute energy ramp	1	Send ramp tables to Local controllers. Execute Ramp
Insertion Device setup for operation	4	Close insertion devices gap
Prepare orbit corr.	2	
Shutters Open		Beam delivered to users
TOTAL TIME	30	Typical time

Reduction of the beam storage time can be accomplished through a combination of factors: improvement of the injector LINAC repeatability, increase of the amount of charge captured in the booster synchrotron per pulse and the reduction of the amount of current that needs to be stored at each shift by reusing the current remaining from a previous shift through a low energy top-up scheme.

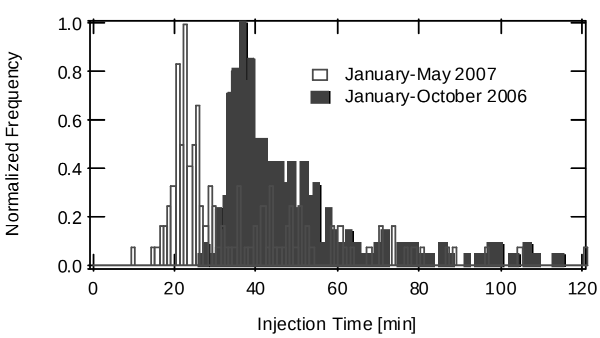

Figure 2: Histogram of injection time for all injections during user’s shifts in 2006 and 2007. The frequency of a given injection time is normalized to one in both cases: the total number of injections was 315 in 2006 and 132 in 2007.

In the following sections we describe our efforts and results in improving the repeatability of the injector LINAC by changing the triggering hardware of the high power modulators, the implementation of a low energy top-up scheme and various operational improvements which allowed us to bring the typical injection time down to about 22 minutes. Figure 2 shows a histogram of the injection time for all injections in user’s shifts during 2006 and the corresponding results obtained in the first semester of 2007, after implementation of the improvements described in this report. Finally, preliminary results of an upgrade of the booster RF system are shown. This system is expected to allow us to further reduce the injection time by increasing the amount of charge captured in each injector LINAC pulse.

INJECTOR LINAC RF SYSTEM IMPROVEMENTS

The pulse-to-pulse repeatability of the beam energy at the exit of the injector LINAC is critical to ensure high charge captured into the booster synchrotron and corresponding high charge transfer to the storage ring. In the LNLS injector LINAC, two high power modulators polarize two Thomson TV2015 B6 pulsed klystrons capable to provide 25 MW of power at 2856 MHz to feed four accelerating sections which bring the beam from a 80 keV pre-injector to the 120 MeV booster injection energy. We have found that the trigger jitter of the LINAC RF pulsed components, in particular the higher power klystron modulators were a major cause for LINAC energy fluctuations. In fact, originally the Pulse Forming Networks in these modulados were discharged by means of thyratron tubes, which in turn were triggerd by means of additional (lower power) thyratron tubes. After replacement of the low power thyratrons with a solid-state switch (see Fig. 3), the measured jitter was reduced by a factor 2 and a clear improvement could be observed in injector repeatability (Fig. 4).

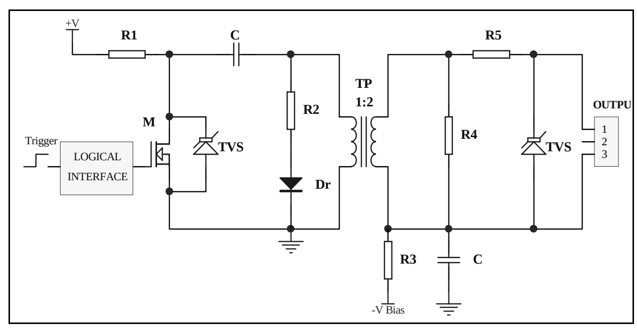

Figure 3: Block diagram of the thyratron driver

OPERATION AND AUTOMATION IMPROVEMENTS

The lifetime of the electron beam in the storage ring routinely exceeds 25 hours for currents about 200 mA. As a result, considering that the nominal beam current delivered at the start of every user’s shift is 250 mA, the amount of current still present in the machine 12 hours later, at the end of the shift is typically larger than 150 mA. The possibility of reusing that current is an obvious way of reducing the time needed to store the beam by a large factor. This procedure was implemented successfully in the LNLS machine (Fig. 5), by using the controlled ramping capability available in the Local controllers (LOCO’S) that supervise the operation of all magnet power supplies in the storage ring. Ramping tables are calculated by a client application at the high

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level control system using intermediate ramping configurations that define a *migration* route for all magnets specified in terms of normalized magnet strengths. This capability, which was already used in the original ramping-up procedure was extended to include the possibility of ramping down in energy as well as up. Tune and orbit corrections during the ramp-down is therefore accomplished by *feed-forward*, with the correction tables being determined experimentally by ramping down stepwise with beam and performing those corrections empirically and the saving the corresponding configurations for later use.

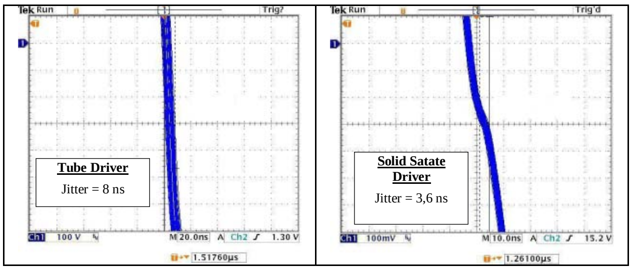

Figure 4: Modulador jitter measurement before (left) and after (right) the replacement of low power thyratron tubes with a solid-state driver.

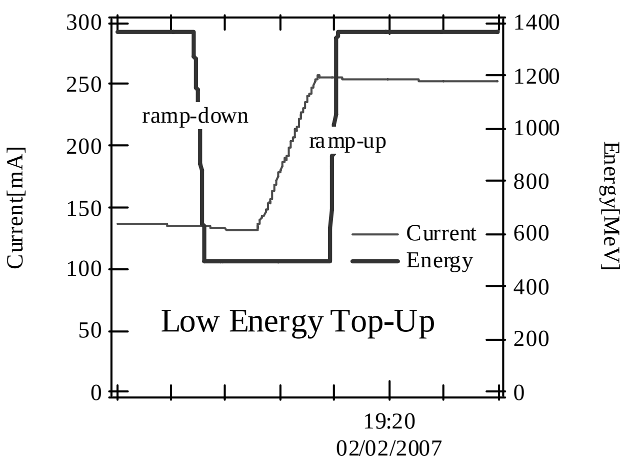

Figure 5: Low energy topping-up of the current at the LNLS storage ring.

Apart from the ramp-down, a variety of automation procedures were implemented to help operators follow a prescribed set of actions so as to speed up the whole injection process. These include automatic changes in orbit correction parameters and insertion device set-up, including the closing of the gap simultaneously with the energy ramp.

BOOSTER SYNCHROTRON RF SYSTEM IMPROVEMENTS

A 2.2 kW, 476 MHz unconditionally stable RF amplifier for CW operation has been built and tested at LNLS. The amplifier (Fig. 6,7), designed and developed in collaboration with Synchrotron SOLEIL, is made up of 9 modules, each containing one push-pull 290 W LDMOSFET equipped with a circulator and an RF termination. High efficiency, linearity, reliability and low cost are the main features we aimed at for this device. Final installation will take place next July.

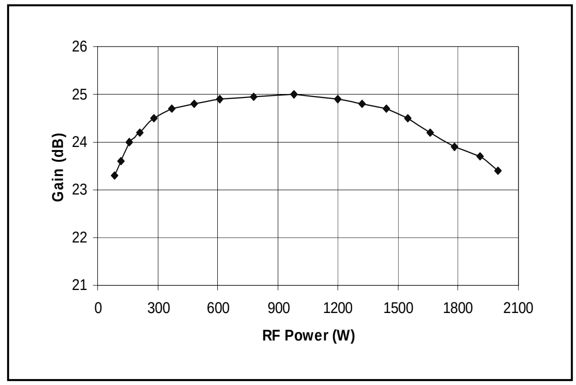

Figure 6: Gain response of the 476 MHz, 2.2 kW CW amplifier.

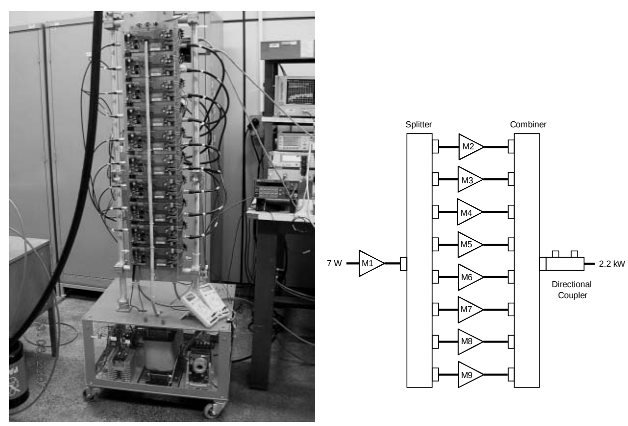

Figure 7: Amplifier assembly and block diagram.

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