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IMPROVEMENTS TO INJECTOR SYSTEM EFFICIENCY AT THE AUSTRALIAN SYNCHROTRON

M. Lafky†, M. Atkinson, L. Hearder, Australian Nuclear Science and Technology Organisation, Clayton, Australia
P. Giansiracusa, University of Melbourne, Melbourne, Australia

Abstract

The past year has seen significant improvements to the efficiency of the Australian Synchrotron's injection system. This was achieved chiefly by optimizing the linac Radio Frequency (RF) system after the installation of a new Stanford Linac Energy Doubler (SLED) cavity, and retuning the injection system's steering and focusing magnets.

INTRODUCTION

The Australian Synchrotron is a 3 GeV 3rd generation synchrotron light source in operation since 2006. The Storage Ring (SR) is a 216 m circumference electron synchrotron typically storing 200 mA of electrons for user beam. Its injection system consists of a thermionic electron gun, a 15 m long Linac, a 130 m circumference Booster Ring (BR), and the Linac to Booster (LTB) and Booster to Storage Ring (BTS) transfer lines. A bunch train of about ~70 bunches in 2 ns buckets is produced each shot for injection into the SR.

Instrumentation

The SR has a single Direct Current Current Transformer (DCCT) used for the measurement of the total current in the ring.

The injection system was built with a Wall Current Monitor (WCM) directly downstream of the gun, two fast current transformers (FCTs) at the beginning and end of the LTB, an FCT and DCCT in the BR and an FCT at the beginning of the BTS (Fig. 1).

Besides the current transformers a number of diagnostic screens are installed at various locations in the injection system.

HISTORY

Initially the facility operated only in decay mode with a peak current of 200 mA and filling about every eight hours. The injection system typically sat idle between fills, so there was little time to spend optimizing the system.

Still there were improvements. In 2010 significant work was done to optimize the Booster's combined function magnet strength ratios to avoid tune resonances in the Booster ramp [1], improving overall Booster efficiency.

The facility commenced top-up operation in 2012, and to facilitate safe operation installed a second FCT at the end of the BTS (Fig. 2). A relatively modest 60% capture efficiency was imposed as a minimum requirement for BTS FCT2 to SR efficiency, with no requirements imposed on the rest of the injection system. Initial measurements after installation gave a typical capture efficiency of ~65% [2], and the frequent injections allowed more opportunities for tuning.

In May 2017 a SLED cavity was installed in the Linac RF system, necessitating a recommissioning of the Linac and providing ample opportunity for improvements [3]. In early 2018 an Optical Beam Loss Monitor (OBLM) system was installed to provide additional independent loss measurements of the injection system [4].

In July 2018 dedicated tuning began in earnest.

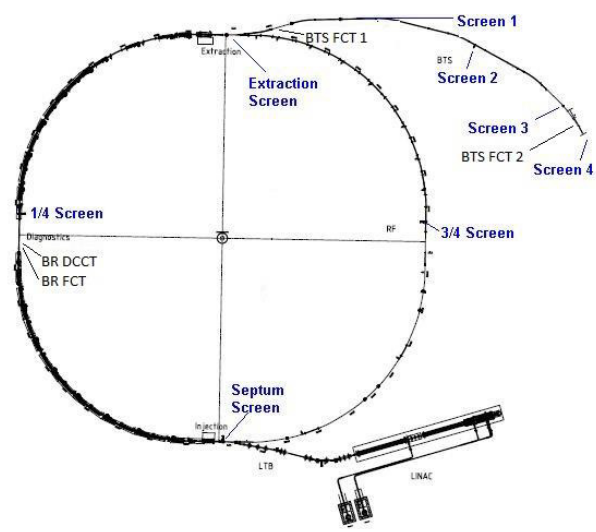

Figure 1: Booster and BTS instrumentation.

METHOD

RF Structure Optimizing

The Australian Synchrotron Linac has three pre-accelerating RF bunching structures. A 500 MHz Sub-Harmonic Buncher Unit (SBU), a 3 GHz Pre-Buncher Unit (PBU) and Fast Buncher Unit (FBU) upstream of the two main 3 GHz accelerating structures (ACC1 and ACC2). All four 3 GHz structures must have the correct forward power to correctly shape and accelerate the electron bunch train (Table 1).

Since the SLED cavity installation in May 2017 the Linac only requires one klystron to power all four 3 GHz accelerating structures. Of crucial importance is optimizing the SLED phase flip timing, which contributes to the flatness of the SLED's power output. The resolution of the facility timing system is 8 ns, so 4 rf buckets, but careful

† lafkym@ansto.gov.au

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tuning allowed for the first time the capture of the entire bunch train.

Table 1: Forward RF Power Per Structure

Structure	Power (MW)
PBU	.9
FBU	1.8
Acc 1	20
Acc 2	20

Linac & LTB magnet Optimizing

The Australian Synchrotron Linac's focusing elements consist of thirty solenoids and three quadrupoles. The solenoids provide all the focusing from the electron gun through the first 8 m of the Linac, so optimizing them is essential. The tuning method consisted of successive iterative changes to the solenoid field strengths to minimize the beam size on Linac screen four, followed by measurements of the Booster FCTs.

The three quadrupoles provide focusing between ACC1 and ACC2, and were found to be generally optimized.

Likewise careful tuning of the Linac and LTB steering magnets also improved Booster capture.

Booster magnet Optimizing

Losses in the Booster typically happen in the first 50 ms after injection, before the ramp has actually begun. Small adjustments were made to the many horizontal and vertical corrector magnet settings to improve the Booster capture. These corrections are made to the static, non-ramped correctors, and therefor only significantly alter the beam trajectory at the start of the ramp when it is at low energies.

Further improvements were made by adjusting multiple parameters in the Booster's extraction system. Booster extraction "begins" with a closed orbit bump to push the stored beam towards the extraction kicker and septum. The bump's amplitude was changed and small adjustments were made to the kicker and septum setpoints to improve Booster extraction efficiency.

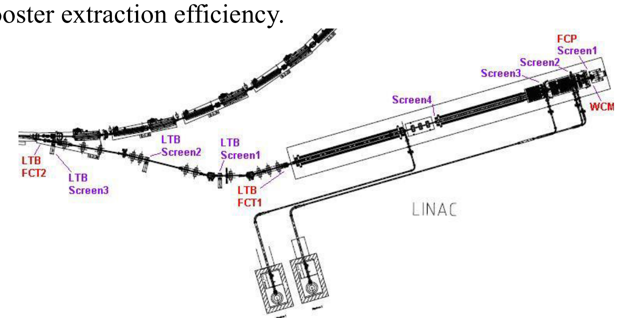

Figure 2: Linac and LTB instrumentation.

RESULTS

For results we present an averaging of two eight hour periods of user beam (Table 2). 2nd June 2018 08:00-16:00, and 12th May 2019 08:00-16:00. Each period contained 138 shots fired in top-up, the goal of each shot to provide the 360 pc (.5 mA) of beam required to maintain the SR current of 200.5 mA > I > 200 mA.

The tuning improvements have increased the overall efficiency of the injection system from ~50% to over 80%, as measured from the Linac WCM to BTS FCT2 (Table 3).

The newly installed OBLM also showed significant reduction in losses in the LTB (Fig. 3), providing independent confirmation to the FCT signals.

Table 2: FCT Comparisons Average of 138 Shots

Instrument	**Mean Charge 2/6/18**	**Mean Charge 12/5/19**
Linac WCM	-809 pC	-420 pC
LTB FCT2	-772 pC	-401 pC
BRinj FCT	-586 pC	-336 pC
BTS FCT2	-398 pC	-342 pC

Table 3: Efficiency Comparisons

ROI	**2/6/18**	**12/5/19**
Linac WCM/LTB FCT2	95%	95%
LTB/BRinj	76%	84%
BRinj/BTS FCT2	68%	98%
Lin WCM /BTS FCT 2	49%	81%

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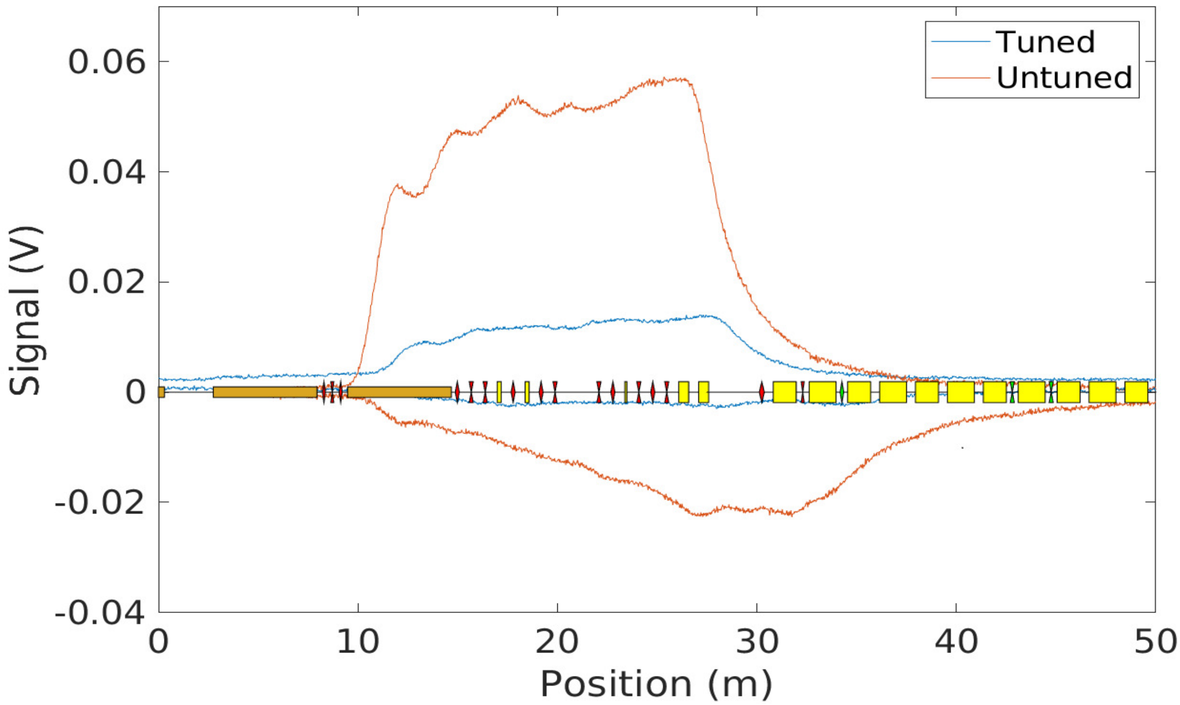

Figure 3: Linac and LTB OBLM signal. Top two traces are losses on the outside fibre, bottom two are losses on the inside fibre.

REMAINING WORK

Although significant progress has been made in optimizing the injection system, some key work remains. Most seriously, the current configuration is optimized for powering the Linac 3 GHz RF structures from klystron 2. This is the nominal operational mode, however much of the injection efficiency gains are lost if and when the Linac is powered from klystron 1, such as when faults occur on klystron 2. One would naively assume that as the power going to the various accelerating structures is the same, then surely the magnet settings can remain unchanged when switching from one klystron to the other, yet experience shows this is not the case. More puzzling is that efficiency gains are lost even briefly switching from klystron 2 to klystron 1 and then back again. The power splitter settings are different in each mode, but the fact that returning to the original settings does not yield the same results indicates a degree of mechanical hysteresis.

Additionally, only the BR and SR DCCTs have been independently calibrated. While the FCTs listed in this paper are thought to be reliable for the purposes of relative comparison, they should be calibrated against the final judgement of the DCCTs. It is also possible that the increased bunch train length is throwing off the FCT background subtraction.

CONCLUSIONS

Careful tuning of the RF structures, the linac steering and focusing elements, the Booster magnets, and the Booster extraction elements have improved the overall efficiency of the Australian Synchrotron's injection system from 50% to 80%.

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