COMMISSIONING REPORT OF THE CLS BOOSTER SYNCHROTRON

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Abstract

A full-energy booster has been produced and taken into operation for the Canadian Light Source. The Booster accelerates the beam from the injection energy of 200 MeV to a maximum of 2.9 GeV. The results of the commissioning are reported.

INTRODUCTION

A full-energy booster has been delivered to the Canadian Light Source (CLS) [1] at the University of Saskatchewan, Saskatoon, Canada by DANFYSIK A/S. The layout of the lattice is shown in fig. 1 whereas the lattice functions are shown in fig. 2.

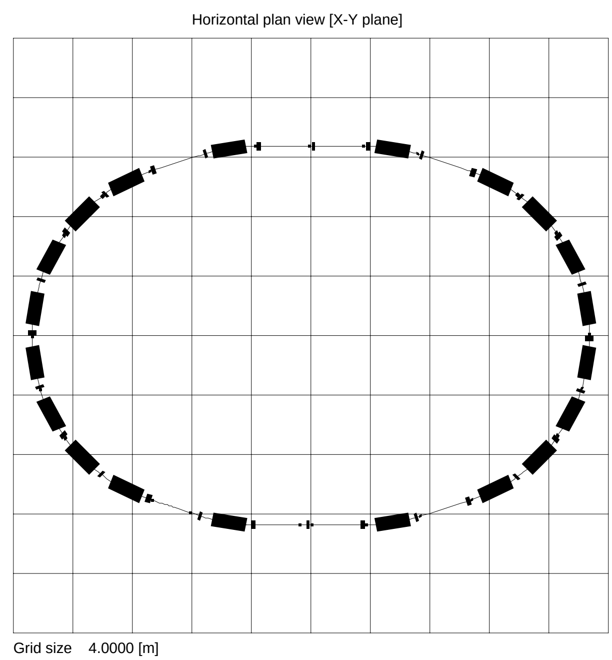

Figure 1. Footprint of the CLS Booster lattice.

The booster synchrotron is designed to deliver an electron beam with a beam energy of 1.5-2.9 GeV, a beam current of more than 10 mA, a pulse length of ~137 ns, and a horizontal emittance of 523 nm at 2.9 GeV. Details of the design and construction have been presented in [2] and [3].

BEAM CURRENT

During the commissioning an average circulating beam current of more than 20 mA has been captured by the RF system at 250 MeV. Since the transported beam current through the injection septum is typically 70 mA this corresponds to a very good capture efficiency of the RF system of 2.5*20 mA/70 mA = 71 % (the factor of 2.5 accounts for the partial filling of the booster synchrotron).

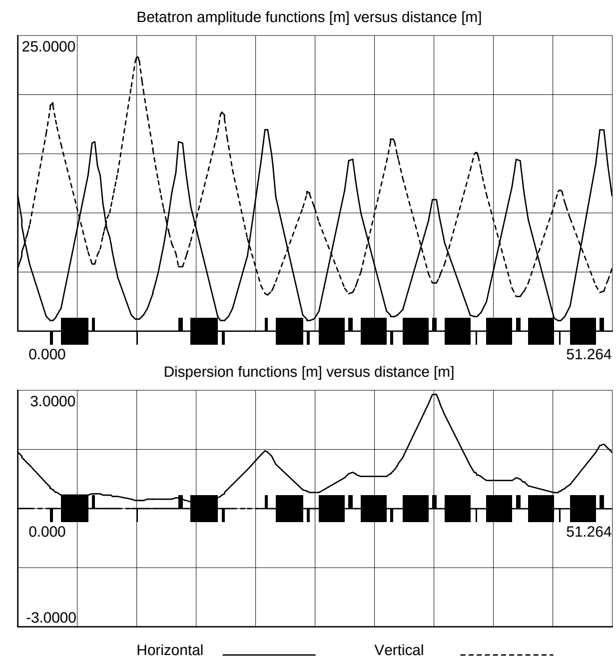

Figure 2. Lattice functions over half the circumference.

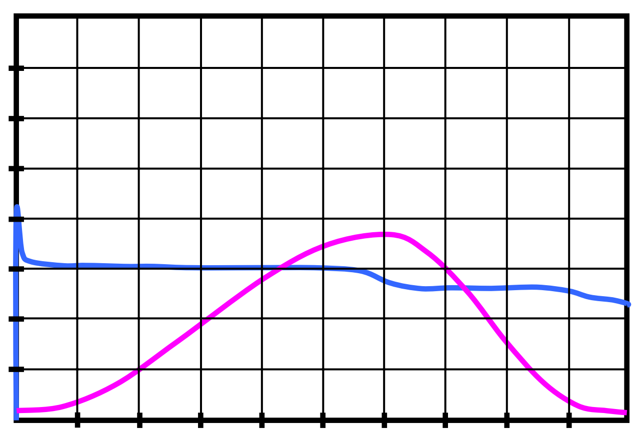

Figure 3. Blue trace: Average circulating beam current in the booster synchrotron throughout the 1 s ramping cycle (4 mA/div., 0.1 s/div.). Red trace: Beam energy.

Fig. 3 shows the average circulating beam current throughout the complete 1 s ramping cycle for an injected pre-injector beam current of 70 mA. It is observed that an average beam current of 11 mA is accelerated to 2.9 GeV; note that the beam is also decelerated. As expected in the design of the RF system there is a small reduction (less than 10 %) of the beam current close to 2.9 GeV caused by a limited quantum lifetime. The average beam current of 11 mA at 2.9 GeV is above the design value of 10 mA even though the design assumes 50 pC in each pre-injector bunch, corresponding to an injected beam current of 143 mA from the pre-injector. Finally, the captured average beam current of 12 mA by the RF system in fig. 3 is significantly lower than mentioned above. The discrepancy is attributed to a different setting of the pre-injector linac and a different matching of the beam functions of the LTB transfer line to those of the booster synchrotron. Hence, it should be possible to achieve a captured average beam current significantly above 12 mA also in ramping mode.

The extracted beam current measured with the FCT in the BTS transfer line is shown in figure 4, demonstrating an extracted beam with a current of 28 mA and a FWHM pulse length of 135 ns. The oscillating behaviour of the extracted beam current is a result of the 500 MHz bunch structure. A comparison with the FCT signal in the booster synchrotron reveals that the extraction efficiency is very close to 100 %. The average circulating beam current is 11.6 mA at 2.9 GeV.

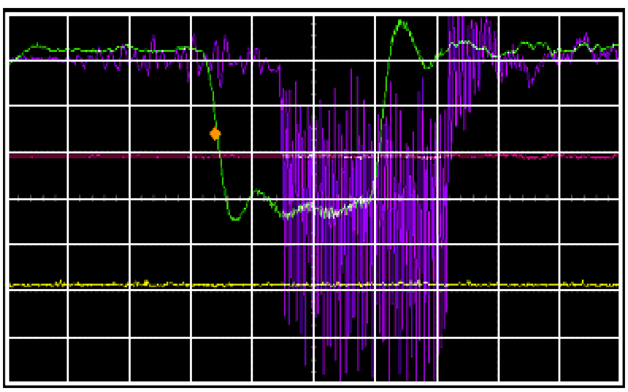

Figure 4. Yellow trace: Circulating beam current in the booster synchrotron at 2900 MeV (2 mA/div., 50 ns/div.). Green trace: FCT signal in booster synchrotron (8 mA/div., 50 ns/div.). Purple trace: FCT signal in the BTS transfer line (8 mA/div., 50 ns/div.).

BEAM LOSSES

A comparison of the beam current at the ICT just upstream of the injection septum magnet and the FCT in the booster synchrotron right after the injection septum magnet demonstrates that the transmission efficiency through the injection septum magnet is close to 100 %. A typical example of the subsequent beam loss during the first two revolutions of the beam in the booster synchrotron is shown in fig. 5.

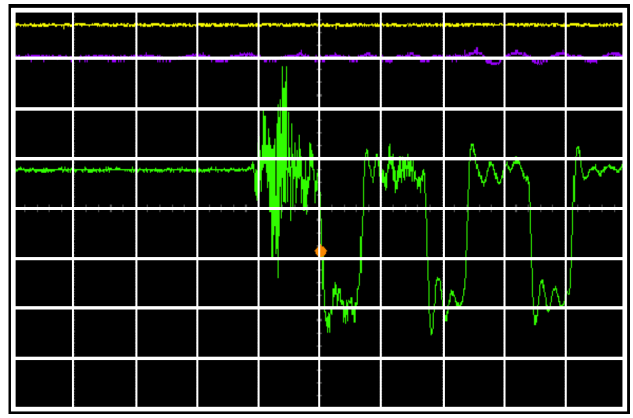

Figure 5. Green trace: FCT in booster synchrotron (20 mA/div., 200 ns/div.).

It is observed that 8 % of the beam is lost due to oscillations of the beam envelope caused by a non-perfect matching of the beam functions of the LTB transfer line to those of the booster synchrotron. According to fig. 6, 26 % of the beam is lost after 100 µs. This loss originates from a non-ideal matching and from electrons that are not captured in the RF bucket.

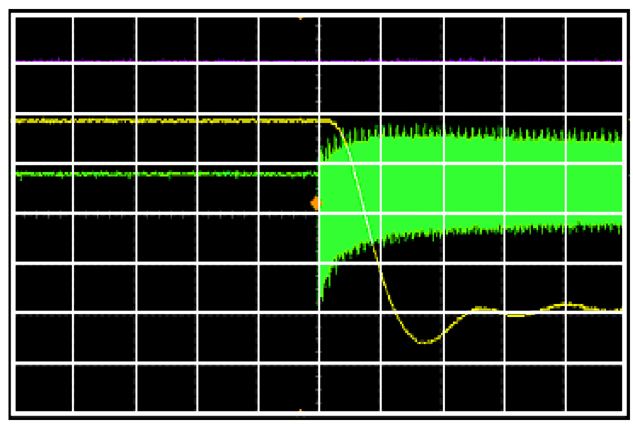

Figure 6. Green trace: FCT in booster synchrotron (20 mA/div., 0.1 ms/div.). Yellow trace: DCCT signal in the booster synchrotron with a 1 kHz bandwidth (4 mA/div., 0.1 s/div.).

The additional beam loss of 24 % after 25 ms, which is observed in figure 7, is attributed to electrons which are not captured in the RF bucket and a low elastic scattering lifetime of electrons with a large betatron oscillation. The subsequent beam loss is very small, except for the small beam loss (less than 10 %) at 2.9 GeV due to the limited quantum lifetime. In conclusion, the transmission efficiency from the LTB transfer line to the BTS transfer line is about 40 % with 90 % of the beam loss occurring around 250 MeV.

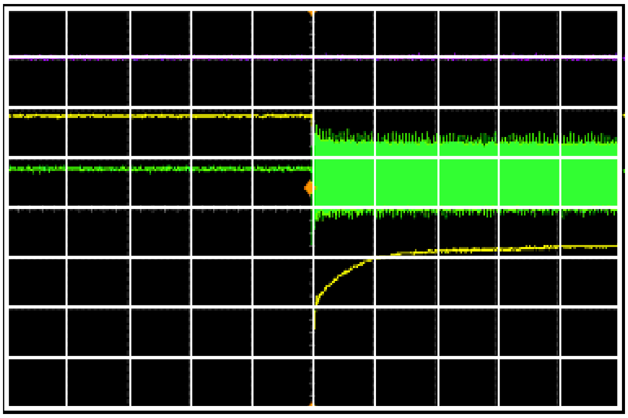

Figure 7. Green trace: FCT in booster synchrotron (20 mA/div., 5 ms/div.). Yellow trace: DCCT signal in the booster synchrotron with a 1 kHz band width (4 mA/div., 5 ms/div.).

TRANSVERSE TUNES

The fractional values of the horizontal and vertical tunes of the booster synchrotron are determined by measuring the frequency spectrum of the horizontal and vertical difference signals of the four strip-line detectors with a spectrum analyzer. It was found that the fractional part of the horizontal and vertical tunes were 0.81 and 0.78, respectively.

In order to determine the integer value of the tunes, a single corrector magnet is changed and the resulting shift of the closed orbit, the difference orbit, is measured with the button pickup monitors. The number of oscillations in this difference orbit gives the integer value of the tune. Accordingly, it followed that the horizontal and vertical tunes are 4.81 and 2.78, respectively.

The booster synchrotron can also be operated at the design working point of (5.18, 2.38). However, it is found that the average circulating beam current is larger at the new working point (4.81, 2.78). Possibly a better matching of the beta functions of the LBT transfer line to those of the booster synchrotron could significantly improve the average circulating beam current at the design working point.

RELIABILITY

In order to verify the reliability of the booster synchrotron, the machine was operated in 2.9 GeV ramping mode for 8 hours without any adjustments. The average performance of the booster synchrotron over the complete test was an average circulating beam current of 7 mA and an extracted beam of 17.5 mA. In addition, the booster synchrotron had no trips throughout the complete test.

STATUS

A summary of the booster synchrotron performance at the acceptance test is presented in table 1. Since the acceptance test in September 2002 no major changes has been made to the booster. It reliably injects a beam current of 20-25 mA at 2.9 GeV into the storage ring. The booster operates without the bumper magnets, and it is easy to extract the beam from the un-bumped orbit. The orbit correctors are only used to improve the injection efficiency and are not ramped. The beam from the booster is easily transported to the storage ring and injected into the ring with little or no beam loses in the transport line. To date the best injection efficiency into the storage ring is 77%. This is very close to the design goal of 80%.

Table 1. Summary of the CLS booster performance at the acceptance test.

	Design	Achieved
Lattice		
Horizontal tune	5.18	4.81 (5.18)[a]
Vertical tune	2.38	2.78 (2.38)[a]
Momentum compaction factor	0.051	0.055 ±0.006[b]
Max booster energy	1.5-2.9 GeV	1.5-2.9 GeV
Repetition frequency	1 Hz	1 Hz
0.25 GeV beam		
Beam current		>20 mA[c,d]
Capture efficiency		>70 %[d]
2.9 GeV beam		
Beam current	>10 mA	11 mA[c,d]
Extracted beam (2.9 GeV)		
Extraction efficiency	>80 %	~100 %
Extracted current	>20 mA[e]	28 mA[c,d]
Pulse length	137 ns	137 ns
Horizontal emittance	<600 nm	552 nm
Trips (8-hour test)	0	0

[a]The performance of the booster synchrotron is optimal at the new working point (4.81,2.78). However, the booster synchrotron can be operated at the design tunes with a lower performance.
[b]For the new working point (4.81,2.78).
[c]During the commissioning, the pre-injector linac beam current was 70-80 mA while the design of the booster synchrotron was based upon a pre-injector linac beam current of 142 mA (bunch charge of 50 pC).
[d]A 500-MHz pre-bunched pre-injector linac beam could not be provided by CLS.

REFERENCES

[1] L. Dallin *et. al.*, *The Canadian Light Source: An Update*, in Proc. Part. Acc. Conf., Chicago, 2001, p. 2680.
[2] L. Præstegaard *et. al.*, *The Booster for the Canadian Light Source*, in Proc. Part. Acc. Conf., Chicago, 2001, p. 3951.
[3] L. Præstegaard *et. al.*, *Status of the Canadian Light Source Booster Synchrotron*, in Proc. European Part. Acc. Conf., Paris, 2002, p. 611.