# STATUS OF THE CANADIAN LIGHT SOURCE BOOSTER SYNCHROTRON

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## *Abstract*

The complete 2.9-GeV full-energy booster synchrotron for the Canadian Light Source has now been constructed, installed, and the commissioning has started. The 102.5-m booster synchrotron has a FODO lattice with missing dipole magnets in order to create straight sections for injection, extraction and rf cavities. This paper describes the status of the booster synchrotron, the test of the magnets, and the installation of the booster synchrotron.

## 1 INTRODUCTION

The 2.9-GeV Canadian Light Source booster synchrotron is the full-energy electron injector for the 2.9-GeV Canadian Light Source (CLS) at the University of Saskatchewan, Saskatoon, Canada [1]. After injection of a 250-MeV electron beam from the upgraded Saskatchewan Accelerator Laboratory linac, the booster synchrotron will accelerate a beam current of more than 10 mA up to a maximum energy of 2.9 GeV and subsequently extract the beam for injection into the CLS storage ring; a sequence which is repeated with a frequency of 1 Hz. The complete booster synchrotron is designed and constructed by Danfysik A/S based on an initial conceptual design by CLS [2,3].

In April 2002 the construction and installation of the booster synchrotron was completed and the commissioning of the booster synchrotron subsystems was initiated. Presently, the full-metal vacuum system has been successfully commissioned, demonstrating a low average pressure of $\sim 2 \cdot 10^{-9}$ mbar. In addition, all power supplies have been tested and found to perform in accordance with specifications. Finally, the transport of the beam from the pre-injector linac to the injection point of the booster synchrotron and the commissioning of the rf system is in progress, and the commissioning of the beam will begin in June 2002.

## 2 MAGNET TESTS

The booster synchrotron has 20 identical H-type rectangular dipole magnets with the main parameters listed in table 1. A simulation of the horizontal closed orbit deviation caused by different field integrals of the dipole magnets shows that the rms spread of field integrals should be less than $5 \cdot 10^{-4}$ in order to ensure an acceptable horizontal closed orbit deviation (average deviation of 8 mm). Therefore, the field integral of all dipole magnets had be determined with an accuracy of at least $\sim 10^{-4}$ prior to the installation. This is achieved by measuring the induced voltage in a narrow 2.5-m long coil while ramping the dipole magnet from zero field to a specified field. During the measurement, the position of the coil is kept at the position of the beam trajectory by fixing the coil into a curved groove in a high pressure composite frame which is attached on the lower pole face of the magnet by two alignment pins. In addition, the coil can be moved horizontally in steps of 10 mm by using different holes for the alignment pins in the high pressure composite frame.

Table 1: Parameters of the dipole magnets

| | |
|---|---|
| Length | 2.28 m |
| Bending radius | 7.25 m |
| Bending angle | 18° |
| Field | 0.115-1.333 T |
| Gap | 32 mm |

According to Faraday's law of induction, the time-integrated induced voltage $V_{ind}$ in the coil from time $t_i$ to $t_f$ relates to the field integral of the dipole magnet trough the relation

$$\begin{aligned}\int_{t_i}^{t_f} V_{ind}\,dt &= \overbrace{l_{dipole}\, d_{coil}}^{\text{flux area}} N \int_{t_i}^{t_f} \frac{dB}{dt}\,dt \\ &= d_{coil} N \left( \left(\int B ds\right)_{B=B(t_f)} - \underbrace{\left(\int B ds\right)_{B=B(t_i)=0}}_{0} \right) \quad ,\end{aligned}$$

where $l_{dipole}$ is the effective length of the dipole magnet, $d_{coil}$ is the width of the coil, $N$ is the number of windings of the coil, and $B$ is the central dipole field. Hence, the field integral of the dipole magnet at a specified field in the dipole magnet $B(t_f)$ can be determined by integrating the induced voltage in the coil while ramping the field from zero to $B(t_f)$. Using this technique it is possible to determine the relative field integral of all dipole magnets with an accuracy of $\sim 10^{-5}$ ($d_{coil}$ is the same for all measurements). Figure 1 shows the found relative variation of the field integral (at the central trajectory) for one of the dipole magnets as a function of the dipole excitation current, demonstrating an iron loss of 1.2 percent at 1082 A, corresponding to the maximum specified field of 1.333 T (2.9 GeV). Furthermore, figure 2 is a plot of the relative horizontal variation of the field integral (for various dipole magnet excitations) for one of the dipole magnets.

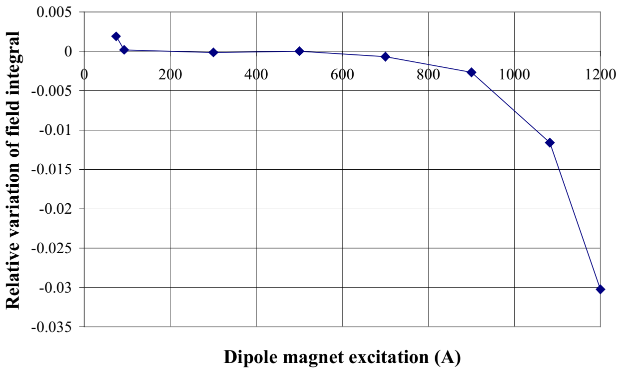

Figure 1: Relative variation of the field integral (at the central trajectory) as a function of the dipole excitation.

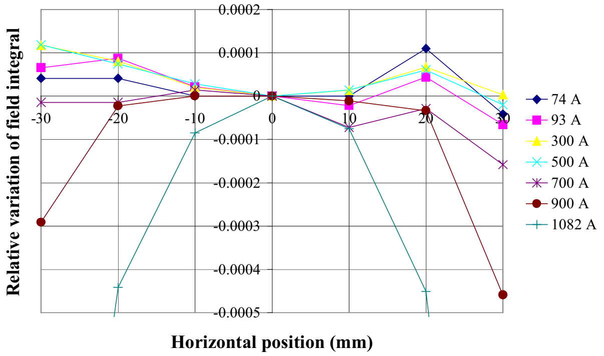

Figure 2: Relative horizontal variation of the integrated field for various dipole magnet excitations.

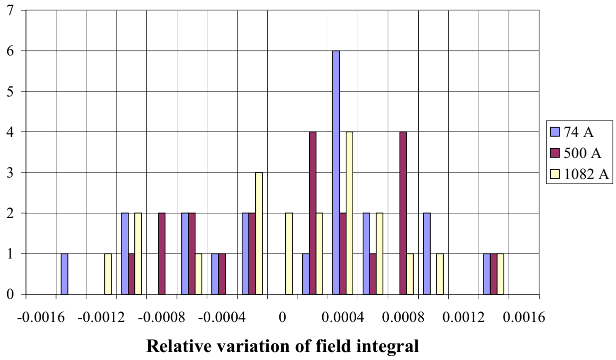

Figure 3: Distribution of the field integrals of dipole magnets (the central trajectory).

The distribution of the field integrals of the 20 dipole magnets is shown in figure 3, revealing an rms spread of the field integrals of $7\cdot10^{-4}$ over the complete dynamic range of the dipole magnets. This is slightly larger than specified, however, the knowledge of the integrated field of each dipole magnet facilitates a sorting of the dipole magnets with respect to the integrated field. The result is a maximum horizontal closed orbit deviation (caused by a spread of field integrals) smaller than 1 mm which is much better than specified.

Table 2: Parameters of the defocusing and focusing quadrupole magnets.

| **Parameter** | **defocusing** | **focusing** |
|---|---|---|
| Norm. gradient | 15 T/m | 16.4 T/m |
| Length | 200 mm | 300 mm |
| Aperture radius | 32.5 mm | 32.5 mm |

The booster synchrotron has one family of 14 defocusing quadrupole magnets and one family of 14 focusing quadrupole magnets with the main specifications found in table 2. The integrated gradient (the focusing power) of all quadrupoles have been determined by means of the rotating coil technique [4]. It is found that the rms spread of the integrated gradient is less than 0.4 percent within both families throughout the whole dynamic range of the quadrupole magnets (likely to be dominated by measurement noise), resulting in an acceptable beat of the transverse betafunctions. In addition, the iron loss at the maximum gradient is found to be 0.5 percent and 0.1 percent for the defocusing and focusing quadrupole magnets, respectively.

The half sine-pulsed injection and extraction septum magnets of the booster synchrotron have the main parameters listed in table 3. The field in the septum channel of the septum magnets have been determined by measuring the induced voltage in a coil with a known flux area. According to the measurement, both magnets successfully produce the specified field with a loss of 14 percent due to eddy currents in agreement with theoretical calculations. In addition, the leakage field in the vacuum chamber of the booster synchrotron (5 mm on the opposite side of the septum blade) is determined with the coil, revealing a very small integrated leakage field of only ~2 Gm for both the injection and extraction septum magnets. The very small leakage field is a result of the high-permeable nickel-coated iron vacuum chamber that very effectively shields against the septum magnet field.

Table 3: Parameters of the injection and extraction septum magnets.

| **Parameter** | **injection** | **extraction** |
|---|---|---|
| Bending angle | 10.4° | 7.6° |
| Field | 0.14 T | 0.78 T |
| Length | 1100 mm | 1655 mm |
| Gap | 15.25 mm | 13.3 mm |
| Septum thickness | 1.8 mm | 1.5 mm |
| Full pulse length | 330 µs | 330 µs |

## 3 INSTALLATION

The booster synchrotron is divided into 14 girders with one dipole magnet and one quadrupole magnet, and 6 girders with one dipole magnet and two quadrupole magnets. Prior to the installation, the vacuum system and all the magnetic elements were pre-assembled and pre-aligned on the girders, and the girders were shipped to CLS as complete units. At CLS each girder could be unpacked, moved to its final position in the booster tunnel on a transport cart, located on two columns, and rough aligned within ±1 mm in only two hours. Figure 4 shows one of the pre-assembled and pre-aligned girders before shipment to CLS. As a consequence all magnetic elements were installed and rough aligned at CLS within only three weeks. Subsequently, the vacuum system of the girders were interconnected and the girders were connected to the local infrastructure. A fully installed section of the booster synchrotron with 4 girders is seen in figure 5.

## 4 REFERENCES

[1] L. Dallin *et. al.*, *The Canadian Light Source: An Update*, in Proc. Part. Acc. Conf., Chicago, 2001, p. 2680.

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[3] L. Præstegaard *et. al.*, *The Booster for the Canadian Light Source*, in Proc. Part. Acc. Conf., Chicago, 2001, p. 3951.

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Figure 4: Pre-assembled and pre-aligned girder with one dipole magnet and two quadrupole magnets.

Figure 5: Fully installed section of the booster synchrotron with 4 girder.