CLS BTS1 Thick Septum Specification

CLS 4.8.31.1 Rev 0

February 23, 2001

Canadian Light Source
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REVISION HISTORY

Revision.	Date	Description	By
A	15 June 2000	Draft	Les Dallin
0	23 February 2001	Original Issue	Les Dallin

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1. INTRODUCTION

1.1. Purpose

The Canadian Light Source requires a curved septum magnet, to be designed and fabricated. The magnet will run with a DC power supply and the yoke shall be solid steel.

1.2. Scope

This document specifies the requirements for the Canadian Light Source (CLS) booster to storage ring (BTS1) thick septum magnet and details the requirements for the design and fabrication of the CLS BTS1 thick septum magnet. This work includes, but is not limited to:

- All tooling
- Materials
- Equipment
- Commercial components
- Detailed drawings
- Fabrication
- Assembly
- Testing & Inspections
- QA/QC documentation

1.3. Background

The Canadian Light Source, CLS, is a national facility in the initial phase of construction on the University of Saskatchewan campus in Saskatoon, Saskatchewan. This facility is a 3rd generation synchrotron light source, which will produce a high intensity source of infrared, visible, ultraviolet and x-ray radiation.

This facility requires a thick septum magnet to be designed and manufactured for installation into the CLS BTS1 transfer line. This line will be capable of transporting electrons with energies of up to 2.9 GeV.

References 1], 2], 3], 4], 5] and 6] provide some background information to this specification.

2. REQUIREMENTS

2.1. Functional Requirements

2.1.1. Proponent shall provide evidence to show that their proposal and designs meet all requirements in this document.

2.1.2. All specifications should be met at the nominal operating field with an excitation efficiency of 96%.

2.1.3. All requirements shall, in addition, conform to CLS General Magnet Specification 8.4.31.1, found in Appendix G. Specifications within this document take precedence over CLS General Magnet Specification 8.4.31.1.

2.1.4. Prior to commencement of fabrication, the Proponent shall issue for review and acceptance by CLS all drawings and procedures developed by the Proponent. The Proponent shall also supply the B-H curve for the proposed steel to CLS for review and acceptance, prior to fabrication material purchase.

2.1.5. Proponent shall demonstrate that the Proponent has access to the appropriate facilities to carry out the magnetic measurements.

2.1.6. Assembly

2.1.6.1. Electrical terminal blocks shall be manufactured from OFHC copper.

2.1.6.2. Electrical connections between coils and terminal blocks for power leads shall be designed to be cooled by natural convection and operate at safe handling temperatures.

2.1.6.3. Buses shall be electrically isolated from the yoke. Proponent shall specify high potential leakage test procedure for CLS review and acceptance.

2.1.6.4. Water supply and return fittings shall be clearly labelled to prevent mis-connections.

2.1.6.5. Electrical isolation between water distribution manifold and coils shall be done with non-conductive hose.

2.1.6.6. The magnet shall have 6 mounting lugs to be used in a 6 strut support method.

2.1.6.7. The terminal blocks for the power cable connections shall be attached to the yoke and designed such that the total weight of the power cable is supported by the yoke.

2.1.6.8. A field clamp shall be provided in order to limit the stray field outside the magnet as defined in Table 1.

2.1.7. Fiducials

2.1.7.1. Fiducials shall be located at positions indicated on drawing BTS1/ME/MAG/0040001 Rev C (see Appendix E).

2.1.7.2. Proponent shall provide 6 (six) fiducials accurately referenced to the entrance and exit pole ends at beam centre, as illustrated in drawing BTS1/ME/MAG/0040001 Rev C.

2.1.7.3. The fiducials shall be located using a right hand Cartesian co-ordinate system (X,Y,Z), with the origin located at beam centre in the plane of the pole face at the end with service connections, as shown in drawing BTS1/ME/MAG/0040001.

2.1.7.4. Proponent shall provide data indicating the fiducial locations on the magnet.

2.1.8. Coil

2.1.8.1. The magnet contains two (2) coils.

2.1.8.2. Coils shall be vacuum impregnated with epoxy. The epoxy composition shall be submitted to CLS for review and acceptance.

2.1.8.3. The copper thermal interlock mounting blocks and copper buses for coil to power lead connections shall be hard soldered to the conductors. A hard solder shall be selected whose brazing temperature is sufficiently high so that a lower temperature hard solder can be used for repairs if necessary. CLS shall be informed of the composition of the hard solder to be used for possible later repairs at CLS.

2.1.9. Yoke

2.1.9.1. The magnet yoke shall be made of solid steel.

2.1.9.2. Proponent shall design and fabricate proper turning and handling devices.

2.1.9.3. Proponent shall develop a procedure to fabricate the solid core. The proponent shall demonstrate to CLS that this procedure is viable by providing other magnet designs that are now in operation or provide sufficient written detail that CLS or designated other may review and accept procedure.

2.1.10. Field Clamp

2.1.10.1. The field clamp shall be made of solid steel.

2.1.10.2. Proponent shall develop a procedure to fabricate and assemble the field clamp. The proponent shall demonstrate to CLS that this procedure is viable by providing other magnet designs that are now in operation or provide sufficient written detail that CLS or designated other may review and accept procedure.

2.1.10.3. Material

2.1.10.3.1. Radiation level measurements of all material heats shall be made and recorded. No detectable radioactive contamination shall be present in steel used for the yoke.

2.1.10.3.2. The magnetic properties shall be homogeneous, with low coercivity and high induction values.

2.1.10.3.3. Steel shall be stable with respect to time in both coercivity and permeability.

2.2. Performance

2.2.1. The basic design parameters are given in Table 1 and shown in Figure 1.

Table 1. Basic Design Parameters.

Bend angle	q	8.380	Degree
Radius of curvature	r	11.3156	m
Arc length on orbit	l_0	1.6550	m
Chord length	D	1.6535	m
Pole gap (full)	g	0.020	m
Field strength at 2.9 GeV (at midpoint of l_0)	$B_y(0,0,0)$	0.8543	T
Entrance angle		0.0	Degree
Exit angle		0.0	Degree
Fringe focusing correction	k1	0.3 to 0.7	
Virtual field boundary (VFB) position on orbit	d	-2.0 to 2.0	mm
Integrated stray field (x = +190 mm)	$\int B_y(l,x,0)dl$	$1.0e^{-4}$	T-m

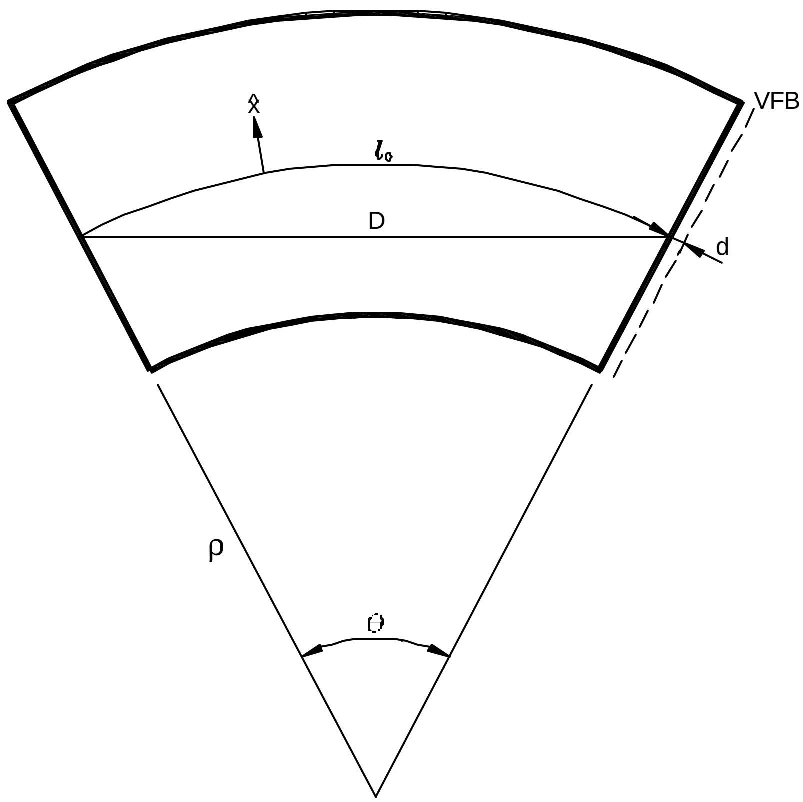

Figure 1. Thick septum magnet schematic diagram.

2.2.2. Practically, for operation at 2.9 GeV, the magnet shall meet the following criteria on orbit. The field integral shall be

$$\int B_y(l,0,0)dl = B_y(0,0,0)l_0 = 1.4139 \text{ T} \cdot \text{m},$$

where the field integral includes the fringe fields at both ends of the magnet to a point where $B_y(l,0,0)$ is 0.1% of the central field. The field integral can be made exactly the above value by adjusting the excitation current.

2.2.3. The good field region shall be defined by an ellipse normal to the beam orbit and with a major axis (horizontal) of 20 mm, a minor axis (vertical) of 15 mm, and centred on the beam orbit, as labelled in drawing BTS1/ME/MAG/0040001 Rev C.

2.2.4. Within the good field region and over the same range of integration, the magnetic field including end effects shall meet the following criteria:

$$0.998 < \frac{\int B_y(l,x,0)dl}{B_y(0,0,0)l_0} < 1.002,$$

for any fixed x position.

2.2.5. The integrated stray field at a distance of 190 mm from the pole centre and outside the septum field clamp shall be less than $1.0x10^{-4}$ T (excluding Earth's magnetic field). The integral shall be over the entire stray field taking into account end effects.

2.2.6. Main Coil

2.2.6.1. Conductor material shall be OFHC copper, or equivalent

2.2.6.2. The pressure drop across any coil shall be less than 800 kPa.

2.2.6.3. The temperature rise across any coil shall be less than 5°C.

2.2.6.4. The coil shall be designed for a nominal operating pressure of 1.2 MPa.

2.2.6.5. Preliminary coil design parameters can be found in Table 2.

2.2.6.6. The maximum current density shall be no greater than 6.5 A/mm^2.

2.2.6.7. Buses shall be electrically isolated from the core with US designation NEMA G-10, or equivalent epoxy fibreglass block.

Table 2. Reference Design Parameters.

Bend angle	8.380	degree
Nominal Field strength	0.8543	T
Maximum Field strength	0.940	T
Magnet arc length	1.6550	m
Radius of curvature	11.3156	m
Magnet gap on orbit	20.0	mm
Good field width	20	mm
Good field height	15	mm
Number of Coils	2	
Number of turns per coil	90	Turns
Max Current	89	A
Max Amp turns per coil	8000	Amp-turns
Conductor outer width	4.76	mm
Conductor outer height	4.76	mm
Conductor cooling channel diameter	3.18	mm
Conductor outer area	22.66	mm^2
Conductor cooling channel area	7.94	mm^2
Conductor area	14.72	mm^2
Conductor Length per coil	320.5	m
Total conductor length	641.0	m
Resistance per m	0.00117	Ω
Resistance per coil	0.375	Ω
Total resistance	0.75	Ω
Power per m	9.27	W
Power per coil	2.98	kW
Total power	5.95	kW
Voltage Drop per coil	33.4	V
Total voltage drop	66.8	V
Assumed delta T of water	5	^oC
Velocity of water	2.06	m/s
Flow rate of water thru coil	1.64E-5	m^3/s
	0.26	USGPM
Total Flow	4.67	USGPM
Head loss per circuit	886.7	kPa
	128.6	psi

2.2.7. Yoke

Overall physical chord length, D (Figure 1), of yoke shall be 1653.5 ± 0.50 mm.

2.2.8. Assembly

Septum magnet assembly shall consist of the following major components:

- Yoke
- Two (2) coil pancakes and support apparatus
- Electrical power bussing, thermal interlocks, and wiring
- Hydraulic assembly including input/output water manifold, hoses and fittings
- Mechanical fasteners and supports

2.2.9. Fiducials

Fiducial locations (X,Y,Z) shall be determined within $\pm$ 25 μm.

2.3. Safety and environment

2.3.1. The coils of the assembled magnet shall be blown out to insure there is no water remaining in the coils, immediately after testing.

2.3.2. The assembled magnet shall be packaged to protect the magnet against environments encountered during shipping and storage.

2.3.3. The nominal operating temperature of the magnet core is expected to be between 20°C and 40°C. The normal ambient temperature of the BTS1 tunnel is 27 °C. The expected temperature stability of the tunnel will be better than 1 °C during normal operation.

2.3.4. The assembly shall be able to withstand a relative humidity range of 0% to 95%. The expected relative humidity limits under normal operation are from 25% to 50%.

2.3.5. The magnet shall be designed for operation in a radiation environment. The vendor shall avoid materials that are subject to damage by ionizing radiation or provide adequate shielding incorporated into the design to allow for long service life of the component.

2.3.6. In the tunnel environment there will be a small amount of production of radioactive air and noxious gases. These are estimated to be:

1. N-13, O-15 and C-11: 0.0002 Bq/cc.
2. Ozone: 5.6×10^{8} mol/cc.
3. Nitrogen dioxide: 2.7×10^{8} mol/cc.
4. Nitric acid: 0.8×10^{8} mol/cc.

2.4. Applicable Codes, Standards and Procedures

Not applicable.

2.5. Quality Assurance

The Proponent shall maintain and apply a quality assurance program compliant with ISO-9001 for the design, manufacture and testing of the septum.

2.6. Inspection, Testing and Commissioning

Inspection sheets shall be filled out, signed, and dated by the technicians performing the tests and inspections listed below. The completed inspection sheet for each coil, yoke, and assembly shall be signed and dated by the technician.

2.6.1. Assembly

2.6.1.1. The Proponent shall develop an inspection sheet for the magnet assembly. This sheet shall be reviewed and accepted by the CLS.

2.6.1.2. The information contained within the inspection shall include at least the following:

- Electrical Test Results
- Measurement Test Results
- Hydraulic measurement Test Results

- Names of technicians installing coils and date
- Names of technicians assembling bus bars and interlocks, and date
- Names of technicians performing the magnetic measurements and dates
- Name of supervising technician approving the magnet for delivery and date.

2.6.2. Magnetic Measurements

2.6.2.1. Magnetic measurement data sheet shall include:

- Dates and Times (year/month/day/hour/min) measurements were performed.
- The ambient temperature (°C) during the measurements.
- Names of the technicians performing the measurements.
- Name of supervising technician approving the magnetic measurements.

2.6.2.2. All measurement results shall be filed in hardcopy, on magnetic media, and archived at the Proponent's location in duplicate.

2.6.2.3. Electronic versions of the measurement results shall include:

- Header line(s) containing measurement units, location, name of technician performing measurement, and name of supervising technician.
- Header line(s) shall be designated with a starting symbol, "#".
- Each data line shall contain the field measurement, excitation current, x, y, z location, temperature, date, and time.

2.6.2.4. Magnetic measurements shall be in reference to the origin, as defined in 2.1.7.3

2.6.2.5. Magnetic measurements shall be taken in a reasonably temperature-controlled environment at 23 °C ± 2 °C. Magnet shall be acclimatized to the measurement room environment.

2.6.2.6. Ambient temperature measurements shall recorded with 3 significant figures (0.1°C). The temperature measurement device shall be calibrated prior to and after all measurements have been taken. The calibration data shall be kept on record, and a copy sent to CLS.

2.6.2.7. The magnet shall be conditioned prior to each set of magnetic measurements.

2.6.2.8. The Proponent shall determine a magnet reset procedure. This procedure shall be used prior to magnetic measurements.

2.6.2.9. The Proponent shall develop, and implement a procedure for measuring the absolute field integral. This procedure shall be reviewed and accepted by the CLS prior to magnet fabrication

2.6.2.10. The Proponent shall develop, document, and implement procedures to measure the field integral along the nominal electron trajectory (and paths parallel to this trajectory) at the nominal field strength (0.8543 T). The Proponent shall indicate the relative accuracy and reproducibility for these measurements. This procedure shall be reviewed and accepted by the CLS prior to magnet fabrication

2.6.2.11. Proponent shall develop, document, and implement a method to measure the virtual field boundary (VFB) position (d). This procedure shall be reviewed and accepted by the CLS prior to magnet fabrication.

2.6.2.12. Proponent shall develop, document, and implement a method to measure the fringe focusing correction, k1, value on orbit, where

$$\mathrm{k1} = \int \frac{B_y(l,0,0)\left[B_y(0,0,0) - B_y(l,0,0)\right]}{g B_y^2(0,0,0)} dl \,,$$

where g is the pole gap. The procedure shall be reviewed and accepted by the CLS prior to magnet fabrication. The integral goes from the center of the magnet to an exterior point as defined in 2.2.2.

2.6.2.13. Proponent shall determine the field excitation curve for the magnet.

2.6.2.14. Current measurements shall be made to at least four significant figures (0.01 Amps).

2.6.2.15. Proponent shall develop, document, and implement a method to measure the integrated stray magnetic field outside the magnet field clamp as described in 2.2.5.

2.6.2.16. Field measurement instrument specifications shall be provided to CLS for review and acceptance prior to magnet fabrication.

2.6.2.17. Proponent shall notify CLS immediately if the field measurements, or saturation characteristics do not meet the accepted magnetic tolerances. In this case the following procedures shall be taken.

2.6.2.17.1. Proponent shall perform a detailed inspection of the core to ensure mechanical tolerances have been satisfied.

2.6.2.17.2. Proponent shall provide CLS with all measurement data and plans for any corrections as soon as possible.

2.6.2.17.3. Proponent shall implement changes, and remeasure the magnet.

2.6.2.17.4. Items 2.6.2.17.1 through 2.6.2.17.3 shall be repeated until the magnet meets required tolerances.

2.6.2.17.5. All corrections and resulting measurements shall be noted in the magnet assembly inspection sheet for the respective magnet assembly.

2.6.2.17.6. CLS shall be notified promptly if corrections do not result in a magnet that satisfies the magnetic tolerances, and plans and procedures for necessary correction shall be mutually negotiated between the Proponent and CLS. Problems that are not easily corrected may require rejection of the magnet in question, or some of its components and/or temporary suspension of a portion of the production effort until satisfactory corrective plans are developed.

2.6.3. Coil

2.6.3.1. An inspection sheet for the coil shall be designed by the Proponent. This sheet shall be reviewed and accepted by the CLS.

2.6.3.2. The information contained within the inspection shall include at least the following:

- Results of visual inspection, with technician name and date
- Measurement & Inspection results, with responsible technician name and date
- Electrical Test Results, with responsible technician name and date
- Hydraulic measurement Test Results, with responsible technician name and date
- Names of technicians winding the coil and date
- Names of technicians impregnating the coil, and date
- Names of technicians attaching interlock and terminal blocks and dates
- Name of supervising technician approving the magnet for delivery and date.

2.6.3.3. One set of measurements in hardcopy and an electronic copy on magnetic media shall be sent to CLS for review and acceptance after assembly and measurement.

2.6.3.4. The original completed and signed inspection sheet shall be kept on file by the Proponent.

2.6.3.5. A copy of the original completed and signed inspection sheet for the assembly shall be delivered to CLS with the magnet.

2.6.3.6. The original completed and signed inspection sheet shall be filed by Proponent.

2.6.3.7. A copy of the original completed and signed inspection sheet for the coil shall be delivered to CLS with the magnet.

2.7. Reliability and Maintainability

2.7.1. The expected lifetime shall be greater than 25 years.

2.7.2. Water connections shall be readily accessible for maintenance.

2.8. Layout

2.8.1. A preliminary design can be found in drawing SR1/ME/0043100 (see Appendix E)

2.9. Other Requirements and Constraints

2.9.1. Tolerances, where not defined or where difficult to achieve, are subject to negotiation.

2.9.2. Labelling & Colours:

2.9.2.1. The septum shall be affixed with a nameplate with the following format:

CLS BTS1 Thick Septum Magnet

Net Weight.:
Design Flow Rate (l/s):
Design Pressure Drop (kPa):
Design Voltage Drop (V):
Design Current (A):
Date:

Manufacturing Company Name

2.9.2.2. All lettering on nameplate shall be in 14 point font size.

2.9.2.3. The position of the nameplate shall not interfere with magnet operation.

2.9.2.4. Colour shall be RAL 5002 Ultramarine Blue.

2.9.3. Shipment and delivery preparation.

2.9.3.1. The coils of each assembled magnet shall be blown out to insure there is no water remaining in the coils.

2.9.3.2. Crate shall be designed such that it can be moved using a standard handling device (forklift or pallet jack).

2.9.3.3. The magnet shall be wrapped or covered to protect it from moisture within the shipping crate.

3. REFERENCE MATERIAL

1] L. O. Dallin, "BTS1 Septum Magnets", CLS Design Note 4.2.31.1 (formerly 2.1.41), Sept. 13, 2000 (see Appendix I)

2] J. C. Bergstrom, "The Booster-to-Storage Ring Transfer Line: Preliminary Design Study", CLS Design Note 4.2.69.1 (formerly 2.1.46), Oct. 24, 2000 (see Appendix J)

3] Drawing BTS1/ME/MAG/004001C "BTS1 8.38° Thick Septum 2D Layout" (see Appendix E)

4] Drawing SR1/ME/0043100A "SR1 Injection Straight General Arrangement Plan View" (see Appendix E)

5] CLS General Magnet Specification (see Appendix G)

6] CLS Documentation Specification (see Appendix H)