CANADIAN LIGHT SOURCE MAGNETS

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Abstract

Magnets for the Canadian Light Source (CLS) storage ring have been designed and constructed. Magnets include gradient dipoles, quadrupoles, sextupoles, orbit correctors, injection septum and kickers. The compact CLS lattice requires strong focusing and consequently field gradients approach the upper limit of conventional magnet technology. Magnets have been manufactured by industry at a variety of locations. Prototypes have been developed and measured and meet the requirements set out in the magnet specifications. A description of the CLS quadrupole, sextupole and corrector magnets and magnet measurement results will be presented.

DIPOLE MAGNETS

The CLS [1] requires 24 gradient dipole magnets. These magnets were built at TESLA Engineering in Storrington, U.K. and are described in ref. [2].

QUADRUPOLE MAGNETS

The CLS requires three families of quadrupole magnets. Two families have the same design. The third family has the same design but is about 50% longer. Parameters are given in Table 1.

Table 1 Quadrupole Design Parameters.

Name	QFA/QFB		QFC		
#Magnets	48		24		
Field (max)	22.2		22.2		T/m
Length	0.170		0.253		m
Aperture Ø	0.065		0.065		
Coils	4 Inner	4 Outer	4 Inner	4 Outer	
Turns / coil	69	35	69	35	t
Current	87.50		87.50		A
Amp turns	9100		9100		A-t
Conductor (per magnet)					
area	4.76^2		4.76^2		mm^2
cooling Ø	3.19		3.19		mm
length	180	108	226	130	m
resistance	220	132	276	159	mΩ
Voltage	19.2	11.5	24.1	13.9	V
Power	1.68	1.01	2.11	1.21	kW
ΔT of water	8.00	3.48	11.1	4.55	ºC
Water flow	3.0	4.2	2.7	3.8	L/m
	0.80	1.1	0.72	1.0	GPM

Pole tips are designed to minimize the multipole content of the magnets. Details of the geometry are given in ref. [3]. The sum of the higher order harmonics, inside a radial good field region of r < 30mm, were required to satisfy the relationship:

$$-0.002 < \frac{\sum_{n=3}^{\infty} r^{n-1} \int B_n(l)dl}{r \int B'(l)dl} < 0.002 \qquad (1)$$

where $B'(l)$ and $B_n(l)$ are the quadrupole field and the n^{th} harmonics along the magnet axis (l).

The quadrupoles have a top yoke and a bottom yoke as shown in figure 1. The yokes are joined by two non-magnetic end plates with an open-side construction that allows for a vacuum chamber with an antechamber for the passage of synchrotron light.

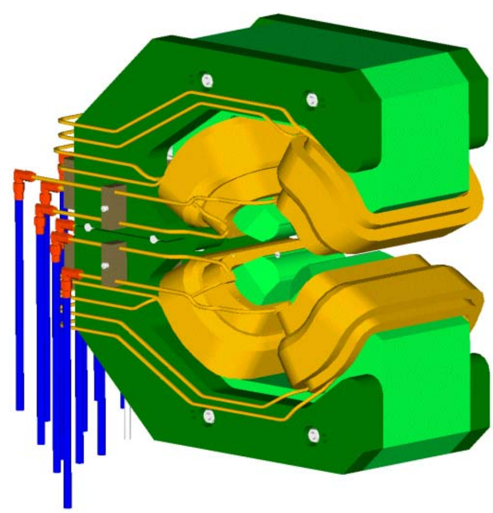

Figure 1. Isometric View of the Quadrupole Design.

The quadrupole magnets were built by SigmaPhi in Vannes, France. One of the finished magnets is shown in figure 2. The quadrupole is shown mounted on one of the CLS magnet girders. The stainless steel end plates also supply a precision interface to the machined girder for alignment.

All magnets from all three families were measured at SigmaPhi with a rotating coil assembly. Although a few of the magnets had higher order harmonics outside the specification defined in eq. (1), the average value of higher harmonics was much better than specified. Subsequent modelling of the CLS lattice with the "as-built" magnets indicated an improved lattice performance compared to the original harmonic estimates.

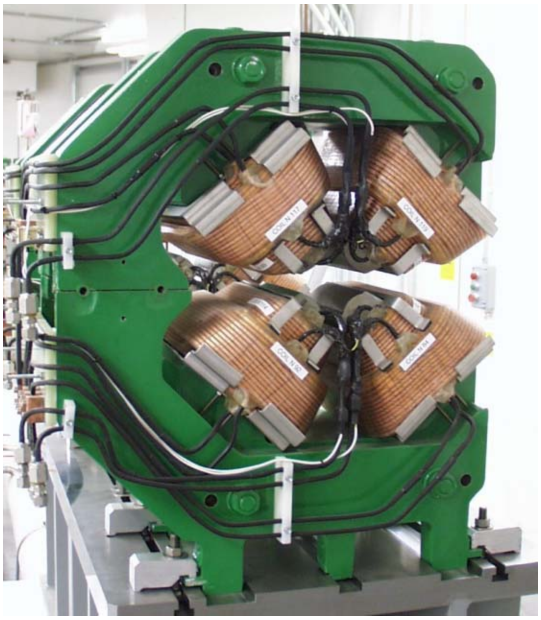

Figure 2. Fabricated Quadrupole Magnet.

For an example, the average harmonics for the QFA family of quadrupoles is shown in Table 2. In the table $I_{n/2}$ is the integrated gradient strength of the n^{th} harmonic relative to the integrated quadrupole gradient (I_2) in units of $m^{-(n-2)}$. Tilt indicates the rotation (skewness) of the harmonic in mrads [tilt=$\tan^{-1}$(skew/normal)/(n-1)].

Table 2: Measured Harmonics for Family QFA

n	3	4	5	6	7
$I_{n/2}$	0.0535	5.31	1.25E2	1.49E4	1.22E6
tilt	-297.4	-15.3	1.97	3.98	1.58
n	8	9	10	11	12
$I_{n/2}$	2.65E8	6.18E10	3.55E13	3.21E15	1.12E18
tilt	21.78	-9.34	-2.10	2.59	6.70

SEXTUPOLE MAGNETS

The CLS requires two families of sextupoles, Family 1 has 24 magnets and family 2 has twelve. The yokes, mechanical assembly and sextupole field requirements for each family are the same. Family 1 also has separate coils for each of X-corrector, Y-corrector and skew quadrupole functions. Family 2 has extra coils for skew quadrupoles. The sextupole parameters are given in table 3.

Details of the geometry are given in ref. [3]. The sum of the higher order harmonics, inside r < 30 mm, were required to satisfy:

$$-0.01 < \frac{\sum_{n=4}^{\infty} r^{n-1} \int B_n(l)dl}{r^2 \int B_3(l)dl} < 0.01 \qquad (2)$$

where B_3 is the sextupole field. Similar, but more relaxed, requirements were specified for the corrector and skew quadrupole fields.

Table 3: Sextupole Design Parameters

# Magnets	36	
Field (max)	267.8	T/m^2
Length	0.192	m
Aperture Ø	0.078	m
Coils	6	
Turns/coil	36	t
Max Current	117.5	A
Amp turns	4230	A-t
Conductor area	4.76^2	mm^2
cooling Ø	3.18	m
length	144	m
resistance	175	mΩ
Voltage	20.6	V
Power	2.42	kW
ΔT of water	8.0	ºC
Total Flow	4.36	L/min
	1.15	GPM

The sextupoles, also manufactured at SigmaPhi have a construction similar to the quadrupoles as shown in figure 3. Non-magnetic end plates support three yoke pieces each containing two poles in an open-sided assembly. The plates also serve as an interface to the girders. One of the finished family 1 sextupoles is shown in figure 4.

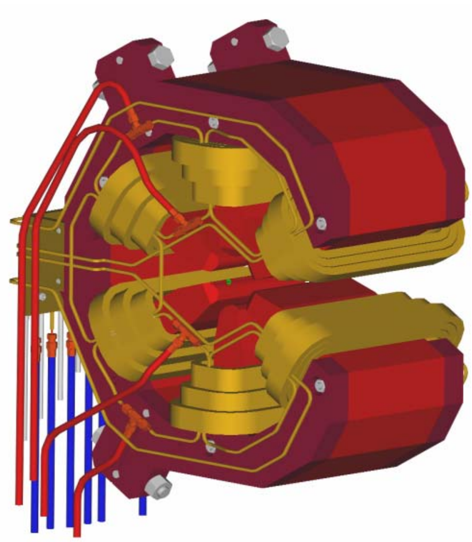

Figure 3. Isometric View of the Sextupole Design.

On average, the sextupole magnets also met the specs defined by eq. (2.). The analysis for the family 1 sextupoles is given in table 3, where the relative strengths, $I_{n/3}$ are now w.r.t the sextupole strength I_3.

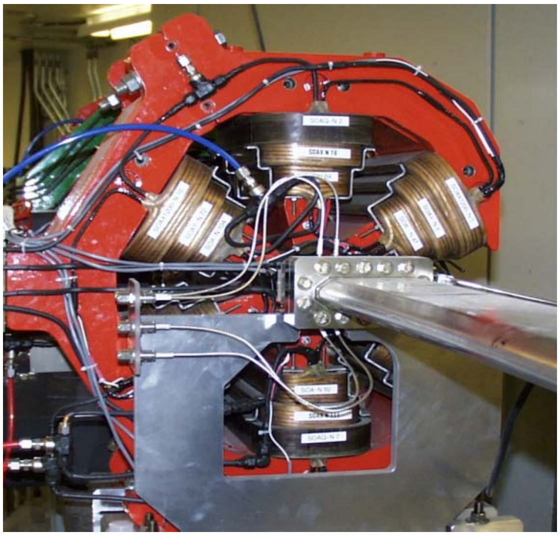

Figure 4. Fabricated Sextupole Magnet (Family 1)

Table 4: Measured Harmonics for Family 1 Sextupoles

n		4	5	6	7
$I_{n/3}$		0.0533	4.47	2.17E2	3.01E4
tilt		69.64	99.92	-25.85	23.40
n	8	9	10	11	12
$I_{n/3}$	9.51E6	1.23E9	4.03E11	8.61E13	2.74E16
tilt	-15.03	-7.95	0.02	-7.62	35.23

ORBIT CORRECTORS

The CLS requires 24 combined horizontal/vertical orbit correctors. The corrector parameters are given in table 5 and details of the design are given in ref. [4]. The correctors were built at Budker Institute in Novosibirsk, Russia. A schematic of the corrector is shown in figure 5 and the finished magnet in figure 6. The two coils on the right drive the vertical field while two sets of coils are used to drive the horizontal field. The harmonic content of the fields was required to satisfy conditions, similar to the sextupole correctors.

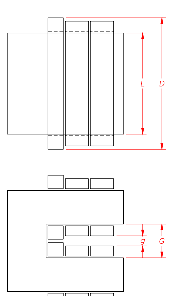

Figure 5. Corrector Schematic.

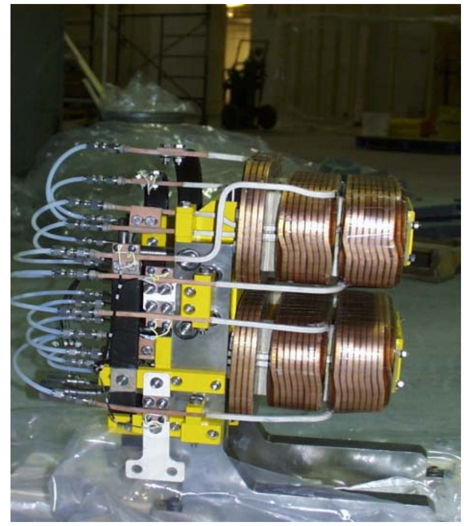

Figure 6. Fabricated Corrector Magnet.

Table 5. Orbit Corrector Design Parameters

# Magnets	24			
Yoke length	0.150			m
Gap (yoke) G	0.108			m
Gap (coils) g	0.044			m
X or Y kick	1.4			mrad
Field B_y	0.090			T
Field B_x	0.090			T
Coil Function	B_y	B_x		
# Coils	2	2	2	
Turns	24	39	36	t
Current	180	180	180	A
Amp turns	4320	7020	6480	A-t
Conductor area	6.48^2	6.48^2	6.48^2	mm^2
cooling Ø	3.18	3.18	3.18	mm
length	34.574	49.964	46.334	m
resistance	18.7	27.0	25.0	mΩ
Voltage	3.36	4.86	4.5	V
Power	605	874	810	W
ΔT of water	3.28	5.96	5.29	°C
Total flow	2.65	2.12	2.20	L/min
	0.7	0.56	0.58	usGPM

REFERENCES

[1] L. Dallin, "The Canadian Light Source", these proceedings.

[2] L. Dallin et al, "Gradient Dipole Magnets for the Canadian Light Source", EPAC 2002, p. 2340.

[3] L. Dallin, CLS tech. note 5.2.31.2 Rev. 0 - "Synchrotron Light Source Magnets", Feb. 11, 2001.

[4] L. Dallin, CLS tech. note 5.2.31.4 Rev. A - "XY Orbit Correctors", May 30, 2000.