LCLS Linac Bunch Compressor Tweaker Quadrupole Magnets Engineering Specifications

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Brief Summary: This is the Engineering Specifications Document for two weak focusing quadrupole magnets for each of the two LCLS bunch compressor chicanes.

Change History Log:

<table>
<thead>
<tr>
<th>Rev Number</th>
<th>Revision Date</th>
<th>Sections Affected</th>
<th>Description of Change</th>
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<td>000</td>
<td>10-7-2005</td>
<td>All</td>
<td>Initial Version</td>
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Check the LCLS Project website to verify that this is the correct version prior to use.
1.0 Introduction

The Linac Coherent Light Source (LCLS) project at the Stanford Linear Accelerator Center (SLAC) is intended to create a free electron laser source of 1.5 Å x-ray pulses of unprecedented brightness and short time duration. The SLAC linear accelerator must be modified in order to compress electron bunches; this document concerns two weak focusing quadrupole magnets for each of the two bunch compressor chicanes. Further information can be found at: http://www-ssrl.slac.stanford.edu/lcls

1.1 General

All communications concerning this specification shall be in English. Measurements and dimensions on drawings shall be in inch units, and may in addition be in metric units.

1.2 Scope

This document describes the technical details of a proposed fabrication order for four weak quadrupole magnets for use in the Linac Coherent Light Source (LCLS) bunch compressors at SLAC.

2.0 Deliverables

This specification is for a contract to engineer, design, fabricate, and test four identical quadrupole magnets. The physics requirements for these magnets are presented in LCLS Physics Requirements Document (PRD) 1.1-006.

The magnet assemblies comprise the following main components.

- Solid magnet iron yokes.
- Epoxy/ copper coils with electrical terminations.
- Thermal switches and wiring terminations
- Mechanical fiducial mounts
- Identification and test certification plate.
The Contractor will also provide:

- Calculations and simulations, showing expected magnetic and thermal performance
- A conceptual design review, showing calculation results, schedule, and quality assurance plan details.
- Complete set of mechanical drawings in 2D IGES (preferred), DXF, or PDF, or (3D) Parasolid (preferred) IGES, or Step formats.
- An engineering design review with SLAC before materials are ordered or machined.
- Fabrication and assembly of the magnet, and testing of components
- Electrical safety covers according to SLAC specifications in appendix
- Safe rigging mounts according to SLAC safety guidelines.
- Electrical, Magnetic, and Mechanical testing of the final assembly
- Crating and shipping

The Contractor shall comply with the specifications in the Engineering Specification Document as to packaging and shipping, and shall assume responsibility for meeting these specifications as to materials, mechanical, electrical, and magnetic tests upon delivery to SLAC. The Contractor shall create a QA traveler with each magnet, containing all documentation and test results, including:

- The materials required under this specification
- Satisfactory mechanical quality assurance results at the Contractor’s location, including thermal tests.
- Satisfactory electrical quality assurance results at the Contractor’s location.
- Satisfactory magnetic quality assurance results at the Contractor’s location.

A blank traveler document shall be prepared for presentation at Engineering Design Review.

The Contractor shall also deliver one extra set of four (4) coils that have passed all electrical and mechanical tests.
3.0 Engineering Requirements

The magnets shall be built to meet the requirements listed below. All specifications must be met. Details of process and materials may differ from those listed, but shall in each case be approved by SLAC.

3.1 Magnet Design Parameters

The basic parameters of the magnet are shown in table 1:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of magnets</td>
<td>4</td>
<td>ea</td>
</tr>
<tr>
<td>Minimum pole-tip radius (defines cylindrical stay clear)</td>
<td>30</td>
<td>mm</td>
</tr>
<tr>
<td>Maximum integrated gradient - ( \int g \cdot dl )</td>
<td>( \pm 2.1 )</td>
<td>kG</td>
</tr>
<tr>
<td>Relative variation of 4 magnets' field integrals</td>
<td>0.1</td>
<td>%</td>
</tr>
<tr>
<td>Sextupole field tolerance (@ ( r = 20 ) mm):</td>
<td>10</td>
<td>% of ( \int g \cdot dl )</td>
</tr>
<tr>
<td>Decapole field tolerance (@ ( r = 20 ) mm)</td>
<td>50</td>
<td>% of ( \int g \cdot dl )</td>
</tr>
<tr>
<td>Effective magnetic length at nominal field</td>
<td>0.1( \pm 0.01 )</td>
<td>m</td>
</tr>
<tr>
<td>Maximum current</td>
<td>12</td>
<td>A</td>
</tr>
<tr>
<td>Maximum voltage drop</td>
<td>10</td>
<td>V</td>
</tr>
<tr>
<td>Maximum current density in copper</td>
<td>1.5</td>
<td>A/mm(^2)</td>
</tr>
<tr>
<td>Maximum temp rise at coil surface at max gradient</td>
<td>10</td>
<td>°C</td>
</tr>
</tbody>
</table>

Table1: LCLS Bunch Compressor 1 Dipole Magnet Specifications.
3.2 Poles and Flux Returns

3.2.1 Design

The magnet is a normal quadrupole magnet with uniform pole cross section. It must be designed to be split about the midplane to allow assembly around a beampipe. The figure below shows a magnet of similar generic design:

Figure 1: Drawing of the magnet, showing iron poletips, poles, and flux return yoke (blue) and copper conductor coils (red). Survey tooling sockets on the top surface are shown in grey.
In the magnet design, no significant percentage of the yoke shall be driven into saturation greater than 1.5 T when the gradient is at its maximum value on axis.

### 3.2.2 Material Specification

The yokes and poles shall be made from solid, certified AISI C1006 steel, or a material equivalent or superior in saturation permeability and remnant field. These magnets will be used in a DC mode, and not for time-varying fields. Yoke parts must be machined to have gaps no greater than 0.001" across any mating surfaces.

### 3.2.3 Fasteners

Fasteners must be either non-ferromagnetic or if they are ferromagnetic, they must not contribute to remnant fields. They must be satisfactorily corrosion resistant. The contractor will consult with SLAC on the position and specifications for mounting bolt holes in the base of the magnet. The magnet shall be fitted with a non-magnetic lifting eye rated at 5 times the weight of the magnet, and a document shall be supplied showing the specification of the lifting eye. Magnet yoke components shall be pinned in such a way that the magnet meets all mechanical and magnetic specifications after disassembly and re-assembly. External brackets and fixtures are to be made of non-magnetic stainless steel or non-magnetic equivalent.

### 3.2.4 Paint

Magnets cores shall be painted with Rustoleum Industrial Choice DTM5200 water based acrylic enamel and DTM5200 primer in Safety Red. Magnet coils shall be painted with Rustoleum Sierra Performance "Beyond" Multi-Purpose Enamel in White Pastel. Fiducial surfaces and electrical contacts are not to be painted. Pole faces shall be nickel plated, and not painted.

### 3.2.5 Tooling Balls

Each magnet shall have four tooling ball sockets welded on, or machined
into the top surface. If they are machined into the surface, a 0.75" diameter spot-face is to be machined around the hole. Tooling ball holes are to be precision reamed to a tolerance of 0.2501 ± 0.0001". The tooling ball mounts should be placed in the corners of the top of the magnet, as shown in the figure above.

3.2.6 Materials Safety

Any hazardous materials involved in the fabrication of the magnet must be used with appropriate precautions, and an MSDS for any such materials must be included in the documentation for the magnets.

3.2.7 Identification

Each magnet assembly shall have affixed to the outer surface of an upper part of the yoke a metal identification plate stating:

- The identifier “LCLS Linac Bunch Compressor Quadrupole”
- Number of magnet within this production schedule
- Name of Contractor, and date of completion
- Indication of successful completion of mechanical tests
- Indication of successful completion of electrical tests
- Indication of successful completion of magnetic tests
- Total weight of magnet in pounds.

Each magnet shall also have a white painted arrow on each side pointing in the direction shown in the drawing, with ‘Beam Direction’ lettered on the shaft of the arrow (with at least 1 cm high characters), thus:

Figure 2: Beam direction arrow. Referring to Figure 1, with the magnet’s electrical connectors on the left side, the beam direction is out of the page.
3.3 Coils

3.3.1 Design

The coils are solid conductor, air-cooled, coils bonded with epoxy. The main and trim coils shall be built with copper conductors that are connected in series electrically, using this bussing scheme:

3.3.2 Requirements

All conductors shall be of solid OFE copper C11000 with at least 100% IACS conductivity, and with heavy film polyester insulation, thermal class 155 C or higher according to NEMA MW 1000 section MW35-C or MW 73-C (e.g. Superior Essex GP/MR-200)

SLAC prefers the use of Multi-Contact® connectors for high power applications. Flag type connections may be accepted with SLAC's approval. They must have two bolt holes of appropriate size and spacing. The connector design must be approved by SLAC.

The main coil terminals shall be fitted with a removable cover or covers that prevents contact with exposed magnet and power supply conductors, according to Appendix 1, below. Marathon 670A-4 type, with Marathon
CB-104D type safety covers; equivalent products from other manufacturers are acceptable both for the magnet current connections and for the thermal interlock switch connections.

Each of the coils shall be fitted with a thermal interlock switch, normally open, that is mounted to the conductor with low thermal resistance. SLAC recommends Elmwood switches, e.g. p/n 3100-3-381-L175.

The Contractor may fabricate or procure the coils required for these magnets. The Contractor will assume all responsibility for quality assurance and final inspections.

### 3.3.3 Epoxy and Ground Wrap

SLAC recommends the following technique for the application of epoxy to the magnet coils. As the conductor is wound around its winding form it is to be painted liberally with this epoxy: P.D.George/Sterling® E-300HB Thermopoxy® compound available from the P.D. George Company, 5200 North 2nd Street, St Louis, MO 63147, phone 314-621-5700 or one of their distributors. The SLAC recommended cure cycle for this (highly thixotropic E300HB) epoxy is 8 hours at 150°C. It is not necessary to cure for 16 hours, nor to do a postcure at 180 °C.

The main coils are to be ground wrapped with a 'B-stage' epoxy impregnated tape, and liberally applied with E300HB epoxy, and cured for 8 hours at 150°C. Trim coils are to be wound using wet layed-up E300HB epoxy also, but they should not be ground wrapped.

Alternative techniques, such as vacuum impregnation, may also be used; SLAC can supply detailed procedure and materials for vacuum impregnation if desired. The contractor shall supply a detailed description of the process and materials they propose for this fabrication step, as part of their response to this bid request. The processes and materials must be approved by SLAC.

### 3.3.4 Coil Tests after Final Cure
Coil resistance measurements shall be made with a micro-ohmeter resistance bridge at room temperature, with the coil temperature uniform throughout and steady state conditions prevailing. The resistance of each coil shall be within ±5% of the value calculated from the resistance adjusted for temperature, and within ±1.5% of each other.

An impulse (“ring”) test shall be performed on each coil, in which pulses of 500 volts shall be impressed across an LC circuit including the magnet, and the test shall verify that there are at least 20 oscillation peaks above noise. There must be no high frequency noise on the oscillating signal.

The Contractor shall specify his protocols for these coil tests as part of the response to this bid request.

**3.3.5 Burn-in**

After full assembly, the magnets shall be operated with coils at maximum gradient for a period of not less than 4 hours continuously. After 4 hours of continuous running, the surface temperature of the coils shall be measured and must meet the temperature rise specification in Table 1.

**4.0 Tests and Measurements**

**4.1 – Materials Qualification**

Specification data for the materials used for the ferromagnetic flux returns and poles, copper coils, and insulation materials shall be supplied.

All test results shall be recorded in the magnet traveler.

**4.2 – Mechanical Qualification**

When fully assembled, the gap between the poles shall be measured for parallelism. The gap shall vary less than ±0.001” over the entire pole faces.

**4.3 – Electrical Measurements**
After full assembly of the magnet, the main and trim coils shall be tested individually for resistance and found to be within ±1.5% of each other at room temperature. The main coils shall be hi-pot tested at 1 kV DC for 1 minute, and found to have less than 100 μA leakage to the yoke. The trim coils shall be hi-pot tested at 500 VDC for 1 minute, and found to have less than 100 μA leakage to the yoke, and to the other coils.

4.4 – Magnetic Measurements

Using a rotating coil with the largest diameter possible, but at least 25mm diameter, the integrated multipole fields shall be measured up to the dodecapole (12-pole). The rotating coil must be shown to be accurate to within 1% at the fundamental, using a calibration standard. These measurements shall be done at half and maximum field strength. The Contractor shall verify that these results meet the specifications in Table 1. The Contractor shall verify that the magnets meet these specifications both on initial assembly, and then after they are split apart and re-assembled. The results of these tests, and calibration results for the rotating coil, shall be recorded in the magnet traveler.

5.0 Measurements at SLAC

SLAC will perform quality assurance tests on the magnets upon receipt. These measurements may include testing of:

- The materials, to assure that they meet specifications.
- The mechanical construction, to assure that it conforms to design drawings.
- The coils, to assure that they meet electrical specifications.
- The magnetic fields, to assure that they meet magnetic specifications.
- Magnets that do not pass any of these tests at SLAC may be rejected or returned to the Contractor for rework, with shipping at the Contractor’s expense.
6.0 Delivery

The Contractor is responsible for timely and safe delivery of the magnets.

6.1 Shipping Crates

Magnets shall be fully assembled and packed individually in crates. The shipping crate shall be attached to a pallet so that it can be moved using standard handling devices (forklift or pallet jack). Irreversible indicators that record vertical shock loads of more than 10 G shall be attached to each crate. The Contractor is responsible for the magnet's being shipped safely to SLAC, and meeting specifications upon receipt.

6.2 Environmental Protection

The magnet shall be covered or wrapped to protect it from moisture and dust within the shipping crate. It shall be properly braced and cushioned within the shipping crate so that it will not shift within the crate during handling and shipment.

6.3 Marking

Each crate shall be labeled on the outside with:

- The identifier “LCLS Linac Bunch Compressor Quadrupole”
- the name of the receiver, Carl Rago, Bldg 26
- the address of SLAC, 2575 Sand Hill Road, Menlo Park, CA 94025, USA
- the serial number of the magnet inside
- the gross weight of each crate,
- conspicuous arrows to indicate its upright position.
Appendix 1: Magnet Terminal Cover Guidelines: SLAC-I-730-0A11S-003-R000

Purpose

The purpose of magnet terminal covers is to prevent accidental or inadvertent contact with exposed live electrical parts.\(^1\) The following recommended guidelines are for designing safe terminal covers for exposed live parts. Requirements for covering live parts are described by DOE, OSHA, NFPA, ANSI, NEMA, UL, and SLAC documents. See references for specific details.

Applicability

When the terminal voltage is over 50 volts DC, or over 50 volts AC\(_{\text{rms}}\), or the terminal has over 10 joules of stored energy, then either the terminal needs to be covered and the appropriate voltage sticker attached, or the terminal energy source must be interlocked to the PPS electrical hazard circuitry.\(^2\)

Recommended guidelines

a. Conductive covers must be grounded and have a 1/2 inch separation or more between the live part and the cover where the voltage does not exceed 250V. This spacing shall be increased to at least 1" for voltages 251 to 600 volts, nominal.\(^3\) For voltages above 600V, see NEC article 710-33. (See Figure 1.) Non-conductive covers must have at least the equivalent insulation to the conductors/ of the maximum operating voltage up to 600 volts. Conductive covers are required above 600 volts.\(^4\)

b. Any unused gap or hole in the cover shall be no greater than an 1/2 inch. This includes gaps between conductors and covers. If the distance between the opening and the nearest live part is more than 4 inches, a gap shall be no
greater than 3/4". Use Rod test as described in NEMA 250-6.2.1.2\(^5\). (See Figure 2.)

c. A WARNING - Electrical Hazard and/or WARNING - High Voltage sticker must be attached to the cover as appropriate.\(^6\)

d. The preferred cover-material is conductive and non-combustible. Conductive covers must be grounded locally. Class 1 or Class A combustible material such as fire retardant - wood, polymer, or equivalent material may be used after review by the fire protection engineer.\(^7\)

e. Temporary covers, installed for 6 months or less, must have at least the mechanical strength and electrical insulating properties equivalent to the insulator of the conductor\(^8\). For example, properly installed rubber roll and tape may be used with approval of the Accelerator Department Safety Officer (ADSO) or SSRL Safety Officer.

f. A sufficient number of fasteners must be used to mechanically secure the cover in place.\(^9\)

g. New or retrofitted covers must be inspected by the ADSO or SSRL Safety Officer before circuit operation.

h. Significant variations from the above guidelines must be approved by the Laboratory Director (the SLAC Authority Having Jurisdiction (AHJ)) with advice from the Electrical Safety Committee.
Figure 1:
- Insulated conductor
- Terminal
- 1/2 inch or more
- 1/2 inch gap or opening (maximum)

Figure 2:
- Cover
- 1/2 inch gap or opening (maximum)
- 1/2 inch diameter hole (maximum)
- 1/2 inch gap (maximum)
- Magnet
- Conductor
2 SLAC — Stanford Linear Accelerator Center: Operational Safety Policy(OSHA Electrical Hazards Related to Electromagnets in Accelerator Areas, section V - C.
3 NFPA—NEC, article 373-11 (a)(3).
5 NEMA — National Electrical Manufactures Association: Standard 250 Enclosures for Electrical Equipment (1000 Volts Max.), section 6.2.1.2.
9 SLAC – ES&H Manual chapter 8-7.3