LCLS BYKIK Pulser

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Brief Summary: This engineering specification document (ESD) specifies the system level requirements for the design, fabrication and installation of the electric pulser for the LCLS kicker dipole magnet: BYKIK

Change History Log

<table>
<thead>
<tr>
<th>Rev Number</th>
<th>Revision Date</th>
<th>Sections Affected</th>
<th>Description of Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>000</td>
<td>February 13, 2008</td>
<td>All</td>
<td>Initial Version</td>
</tr>
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</table>
1.0 Introduction

The LCLS project requires one vertical kicker magnet (BYKIK) to be installed in the LTU beamline, 260 meters upbeam of the undulator. The magnet will function to abort undesired beam from entering the undulator. Maximum LCLS beam energy at this location is 17 GeV. Once triggered, an electric pulser should provide one single-cycle sinusoidal pulse to the BYKIK magnet in order to create a maximum length-integrated magnetic field of 0.85 kG-m generated from 398 A of positive peak current. The BYKIK magnet is planned to be 2-meters long and composed of 2 identical 1-meter sections electrically connected in series. The total magnet inductance is measured to be 62µH. The total magnet resistance is calculated to be 17.5mΩ. The BYKIK pulser should be designed to fire continuously at a maximum pulse repetition rate of 120 Hz.

2.0 Scope

This document specifies the minimum system level requirements for the design, fabrication, and installation of the electric pulser for the LCLS BYKIK magnet.

3.0 Further Information

The latest versions of the following LCLS documents specify details of construction, interface, and operation of the BYKIK magnet and should be used in combination with this ESD:

- PRD 1.3-014 Requirements for the Beam Abort Magnet and Dump
- ESD 1.3-135 LCLS Kicker Magnets
- PRD 1.1-305 LCLS Timing System Requirements
- ESD1.1-312 LCLS Machine Protection System Requirements
- ESD 1.1-315 LCLS Machine Protection System Engineering Design Specifications


4.0 Ambient Conditions

The BYKIK pulser and its associated hardware will be mounted inside building 5 at SLAC. Prevailing ambient conditions are:

- Location ............... Indoors
- Temperature ........... 40 °F (4 °C) minimum to 113 °F (45 °C)
- Elevation ............... 900 ft above sea level
- Humidity ............... 10 % to 100 % relative humidity with a 50 °F dew point

5.0 Operational Requirements
Operating life shall be $\geq 20$ years (174,000 hours) at continuous full-load and pulse frequency of 120 Hz with an MTBF $\geq 40,000$ hours, exclusive of capacitors and fans, when calculated by the parts stress method of MIL-HDBK-217F.

Pulse-to-pulse stability should be better than 1% once the BYKIK magnet and its pulser have reached a thermal equilibrium.

The parameters for the operations and construction of the BYKIK pulser are listed below along with some of the characteristics of the BYKIK magnet:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>z-location of center of BYKIK magnet</td>
<td>3300.1</td>
<td>m</td>
</tr>
<tr>
<td>Maximum LCLS beam energy</td>
<td>17</td>
<td>Gev</td>
</tr>
<tr>
<td>Minimum LCLS beam energy</td>
<td>4</td>
<td>GeV</td>
</tr>
<tr>
<td>BYKIK magnet length</td>
<td>2.0</td>
<td>m</td>
</tr>
<tr>
<td>BYKIK maximum length-integrated magnetic field</td>
<td>0.85</td>
<td>kG-m</td>
</tr>
<tr>
<td>BYKIK magnet's estimated inductance</td>
<td>62</td>
<td>µH</td>
</tr>
<tr>
<td>BYKIK magnet's estimated resistance (neglecting skin effect)</td>
<td>17.5</td>
<td>mΩ</td>
</tr>
<tr>
<td>Estimated Cable Resistance (neglecting skin effect)</td>
<td>64</td>
<td>mΩ</td>
</tr>
<tr>
<td>Estimated Cable Inductance</td>
<td>29</td>
<td>µH</td>
</tr>
<tr>
<td>Estimated Cable Capacitance</td>
<td>41</td>
<td>nF</td>
</tr>
<tr>
<td>Maximum pulse repetition rate</td>
<td>120</td>
<td>Hz</td>
</tr>
<tr>
<td>Minimum spacing between consecutive trigger pulses</td>
<td>8.1</td>
<td>ms</td>
</tr>
<tr>
<td>Jitter (RMS)</td>
<td>1</td>
<td>µs</td>
</tr>
<tr>
<td>Variation in current repeatability from pulse-to-pulse</td>
<td>&lt;1.0%</td>
<td>%</td>
</tr>
<tr>
<td>Minimum &quot;flat-top&quot; duration (&gt;1% current range)</td>
<td>8.0</td>
<td>µs</td>
</tr>
<tr>
<td>Maximum Single Cycle period</td>
<td>500</td>
<td>µs</td>
</tr>
<tr>
<td>Nominal positive peak current producing maximum magnetic field</td>
<td>398</td>
<td>A</td>
</tr>
<tr>
<td>Maximum positive peak current</td>
<td>500</td>
<td>A</td>
</tr>
<tr>
<td>Maximum RMS Pulser Current</td>
<td>80</td>
<td>A</td>
</tr>
<tr>
<td>BYKIK pulser location</td>
<td>B005-L01</td>
<td>-</td>
</tr>
<tr>
<td>Pulser-magnet distance (estimated one-way)</td>
<td>400</td>
<td>ft</td>
</tr>
</tbody>
</table>

6.0 Basic Topology
Figure 1 shows the basic topology of the circuit chosen to provide single-cycle sinusoidal current pulses to the BYKIK magnet.

![Figure 1: BYKIK Basic Topology](image)

### 6.1 Theory of Operation

Referring to figure 1, capacitor bank C should be initially charged to the voltage level provided by the cap charging power supply (HVPS). Although the maximum BYKIK pulse repetition rate is 120 Hz (8.33ms), the HVPS must have enough current capacity to recharge the capacitor bank between consecutive trigger pulses spaced at a minimum of 8.1 ms.

At time \( t_0 \), a trigger pulse arrives to start the generation of one single-cycle sinusoidal current pulse to the BYKIK magnet. From this initial trigger, two one-shots will be generated: the first to turn transistor \( S_0 \) off for the duration of the single-cycle output current pulse. The second one-shot will turn transistor \( S \) on for a time slightly longer than the positive half cycle of the current pulse produced by the resonance of \( C \) with inductance \( L \). On figure 1, \( R \) represents the series resistance of the cabling and the BYKIK magnet; \( L \) represents the combined inductances of the cabling and BYKIK magnet.

At the end of the positive half cycle, \( C \) will have a negative polarity. Diode \( D \) offers a path for the remaining energy in the capacitor to be recovered through the BYKIK magnet.

Typical waveforms can be found on figures 2 and 3.

![Figure 2: Basic operation and typical waveforms](image)
6.2 Timing

The BYKIK pulser can be fired continuously at a maximum rate of 120 Hz, but the timing can be shifted onto or off the beam arrival time. Beam displacement will occur by advancing the trigger by a time on the order of a quarter of the $L-C$ resonant cycle to make the positive peak of the pulser's output current coincident with the beam arrival time as illustrated by figure 4.
7.0 Load Characteristics

The load is mainly resistive and inductive. BYKIK resistance is estimated to be 17.5 mΩ, and its inductance 62 µH. The distance from the pulser to the BYKIK magnet has been estimated to be 400 feet one-way.

The inductance and resistance of the cabling connecting the pulser to the BYKIK magnet should be taken into consideration. Also, the design and parameter specification for the capacitor and switch apparatus should be considered.

8.0 Trigger Requirements

Two trigger inputs should be made available. Whichever input receives a trigger first fires the pulser to produce the desired pulse current to BYKIK magnet. Design the circuits in such a way that once the pulser has been triggered by the trigger coming first it does not retrigger by another one arriving before the end of the recharging cycle.

Trigger input circuits should be designed to accept TTL triggers. TTL chips used as part of the triggers system should be able to accept the new low level L'TTL or standard TTL. For both standards:

- Rise-time better than 100 ns
- Jitter less than 1 ns
- Input impedance: 50 ohms

9.0 Interface

A programmable logic controller (PLC) equipped with an ENET controller will be used to interface the BYKIK chassis with the LCLS control system.
As selection criteria, it is advisable that this PLC be the same model as the one used in the multiple LCLS subsystems such as vacuum, PPS, and LLRF thus reducing the number of spares and facilitating maintenance. Additionally, using the same plc and ladder logic software will also aid in software understanding as there will now be multiple people that will have expertise in this particular language.

An Ethernet port will make it easier to download new ladder logic over the network. EPICS device and driver support already exist to allow the LCLS control system to communicate with the PLC’s ladder logic program.

The following PLC controller and associated modules should be used:

- Allen-Bradley 1756 family
- Logix 5561 Processor 1756-L61 B with compact flash

As a minimum the PLC crate should contain:
- Isolated, 12-bit minimum analog input and output modules, or a combination of both in one module
- An Ethernet module such as the 1756-ENBT
- Digital input module such as the 1756-IB16I/A
- Digital output module such as the 1756-OB16I

A panel view should be installed to allow for local control and monitoring of the BYKIK pulser basic functions. As a suggestion, PanelView Plus 600 from Allen-Bradley can be used. Its model reference is 2711P-T6C20D.

10.0 Monitoring and Feedback

Sample-and-hold circuits should provide monitoring for both:
- The positive peak current value
- The cap charging voltage value at the moment the pulser is triggered

The following monitoring should be present at the PanelView:
- Reference to the cap charging power supply
- Peak voltage at the cap bank
- Positive peak current value
- Ground current
- Other signals at designer’s discretion

The PLC should be programmed such that implementing a slow feedback loop is possible. This feedback loop will monitor peak current stability and compensate instabilities measured over several seconds by adjusting power supply voltage. Operators will have external control over when the feedback control is implemented and the range of peak current drift permitted.

A current pulse transformer should be used to make the output current waveform available for external monitoring (1V=10A, into high impedance) by the LCLS machine-protection system (MPS).
BNC connectors should provide isolated real time measurements of the following signals to the front panel:

- Output pulse current
- Voltage on the capacitor bank

### 11.0 Protections

The following conditions should halt the operation of the BYKIK pulser and turn off the cap charging power supply:

- Ground fault over 2A
- Internal over temperature
- Cap charging power supply over current (if available)
- Klixon interlock from BYKIK magnet
- Other protections at designer’s discretion

Those fault conditions should be latched and reported to the PLC’s PanelView. A reset button (on PanelView) should be made available.

In case of a power failure, the pulser should go to an OFF state and the cap charging power supply be turned off.

Given that the power supply has a rated voltage greater than 50 V dc, an automatic switch should discharge the BYKIK capacitor bank once BYKIK is turned off. Redundant bleeding resistors should be permanently connected to the capacitor bank in order to reduce the initial voltage down to less than 50 V in less than 1 minute after BYKIK has been turned off.

### 12.0 Safety Standards

At a minimum, the BYKIK pulser should be designed and fabricated according to the safety standards below:

<table>
<thead>
<tr>
<th>Standard</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>UL508A</td>
<td>Industrial Control Panels</td>
</tr>
<tr>
<td>EEIP</td>
<td>Equipment Electrical Inspection Program at SLAC</td>
</tr>
</tbody>
</table>

### 13.0 Applicable Documents and Drawings

PR 384-041-00 LCLS B005 MAG PS RACK PROFILES

EI 384-041-10 LCLS BYKIK PULSER INTERCONNECTING DIAGRAM

ID-380-201-67 LCLS PH. 3 ELECTRICAL CABLE PLANT MCC BUILDING No. 005 CABLE TRAY LAYOUT
ID 380-201-63 LCLS PH. 3 ELECTRICAL CABLE PLANT BTH WEST STA. 106+50 TO 108+00 CABLE TRAY LAYOUT

ID 380-201-64 LCLS PH. 3 ELECTRICAL CABLE PLAT BTH WEST STA. 108+00 TO 108+50 CABLE TRAY LAYOUT

SA 380-330-01 LCLS MAGNET SYSTEMS BXKIK & BYKIK MAGNET BXKIK MAGNET ASSY

Check the LCLS Project website to verify that this is the correct version prior to use.