IR Superconducting magnet quench in SuperKEKB

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KEK
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1. QCS magnet system and magnet cross section design
2. SuperKEKB beam operation and magnet quench
3. Summary
QCS SC magnet system

QCS-L Cryostat

QCS-R Cryostat

Helium Vessel

Helium Vessel

4 SC main quadrupole magnets: 1 collared magnet, 3 yoked magnets
16 SC correctors: a1, b1, a2, b4
4 SC leak field cancel magnets: b3, b4, b5, b6
1 compensation solenoid

4 SC main quadrupole magnets: 1 collared magnet, 3 yoked magnets
19 SC correctors: a1, b1, a2, a3, b3, b4
4 SC leak field cancel magnets: b3, b4, b5, b6
3 compensation solenoid

HER

LER

4 correctors
(a1,b1,a2,b4)

QC1LE

4 correctors
(a1,b1,a2,b4)

QC2LE

4 correctors
(a1,b1,a2,b4)

QC2LP

4 correctors
(a1,b1,a2,b4)

QC1LP

4 correctors
(a1,b1,a2,b4)

QC1RP

5 correctors
(b3,b4,b5,b6)

QC2RP

4 correctors
(a1,b1,a2,a3)

ESR1 Solenoid

QSRE

4 correctors
(a1,b1,a2,a3)

Leak field cancel coils
(b3,b4,b5,b6)

ESL solenoid

ESR2

ESR3

83 mrad

IP
QCS SC magnets

• Cross section design of main quadrupoles [QC1, QC2]
  – The quadrupole magnets are designed with the two layer coils (double pane cake design).
  – Inside of each magnet, 3~4 SC corrector magnets are assembled.
    • The thickness of the SC corrector is less than 1 mm. The assembled correctors are impregnated with resin. 3~4 correctors can be considered to be one block thermally.
    • Between the main quadrupole coils and the correctors, there is 1mm gap to be a helium cooling channel.
QCS operation and quench

SuperKEKB Phase2 (March 16, 2018 ~ July 17, 2018)

- During the operation, 26 magnet quench events
  - 25 events: beam induced quench
  - 1 event: ESL power supply failure

SuperKEKB Phase3.1 (March 11, 2019 ~ July 1, 2019)

- Improvement of the collimator system
- During the operation, 6 magnet quench events
  - 3 events: beam induced quench
  - 3 events: QC2LE power supply failure (IMP abnormal work)
QCS operation and quench

Collimator head damage

12 mm

D02_V1 Bottom

Beam current

Int. L [10^{32} cm^{-2} s^{-1}]

Spec L [10^{30}]

Peak L

Int. L/day

HER \( I_{\text{peak}} \): 935.0 [mA]

LER \( I_{\text{peak}} \): 829.8 [mA]

\( \beta_{x/y}^{*} \): 80. / 2.00 [mm] \n
\( n_0 \): 1576

2019/09/17

3rd-FCC-ee-MDI-WS
QCS operation and quench

Phase-2

- Quench by beam = 25, quench by power converter trouble=1
  - Collimator tuning
  - Applying a trigger signal of diamond sensors on beam abort
  - Increasing the sensitivity of the beam loss monitor for firing the trigger signal of beam abort
QCS operation and quench

Phase-3

- Quench by beam = 3, quench by power converter trouble=3
  - Increasing Collimators: LER=4, HER=1: one of collimators for LER is a countermeasure of QCS quench
  - Tuning the threshold level of the trigger signal of diamond sensors for beam abort
  - In order to measure the quench behavior of the superconducting coils, the sampling time of the data logger for the voltage signal of the SC coils was changed from 10 μs to 1μs (the loggers were upgraded).
  - For making the relation of the coil voltage signal with the beam loss monitors, the BPMs and the diamond sensors, we added the trigger signal of the abort kicker magnet to the logger.
The quenched magnets were concentrated in the QC1 magnets and the accompanying correctors.

Some magnet quenches were induced with the power supply trouble.

From Phase-3, in order to correlate the magnet quench and the beam operation, the kicker trigger signal was added to the QCS logger data, and the logger system was upgraded with the sampling time of 1 µs.

Quenched magnets by beams
<table>
<thead>
<tr>
<th>Date</th>
<th>Time</th>
<th>Quenched Magnet</th>
<th>In</th>
<th>Corrector name</th>
<th>In</th>
<th>Corrector current [A]</th>
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<tbody>
<tr>
<td>2018/4/1</td>
<td>20:54:53</td>
<td>GO1LP</td>
<td>a1</td>
<td>b1</td>
<td>a2</td>
<td>b4</td>
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<td>18:31:21</td>
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<td>b1</td>
<td>a2</td>
<td>b4</td>
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<td>a2</td>
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<td>a2</td>
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<td>CC1LE- b4</td>
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<td>a1</td>
<td>a2</td>
<td>b4</td>
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<td>CC1LE- b1</td>
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<td>a1</td>
<td>a2</td>
<td>b4</td>
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<td>a1</td>
<td>a2</td>
<td>a3</td>
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<td>a2</td>
<td>a3</td>
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<td>b5</td>
<td>b6</td>
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<td>2018/5/5</td>
<td>11:28:14</td>
<td>GO1L-b1</td>
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<td>a2</td>
<td>b4</td>
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<td>a2</td>
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<td>a2</td>
<td>b4</td>
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<td>21:11:16</td>
<td>GO1RF+ b1</td>
<td>b1</td>
<td>a1</td>
<td>a2</td>
<td>b4</td>
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</tbody>
</table>
### Checking quench condition of the correctors

- **For instance**: QC1LE correctors
  - QC1LE has the magnetic yoke (Permendur)
  - Inside the quadrupole magnet bore, a major magnetic field is generated by the QC1LE.
    - \( G = 45.3 \, \text{T/m} \) @ 1581 A
    - The correctors are assembled in the area of 28 mm < R < 33 mm.
    - The field strength in the area is 1.27 T ~ 1.5 T.
      - \( I \) for \( b_1 \) corrector = \(~ 30 \, \text{A} \) → \( T_c \) = 7.8 K
      - \( I \) for \( a_1 \) corrector = \(~ 10 \, \text{A} \) → \( T_c \) = 8.3 K
  - \( T_c \):
    - NbTi=9 K
    - Nb\(_3\)Sn=18 K

### Table: Checking Quench Condition of Correctors

<table>
<thead>
<tr>
<th>Date</th>
<th>Time</th>
<th>Quenched Magnet</th>
<th>( b_1 )</th>
<th>( b_1 )</th>
<th>( a_2 )</th>
<th>( b_4 )</th>
<th>( b_1 )</th>
<th>( b_1 )</th>
<th>( a_2 )</th>
<th>( b_4 )</th>
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<tbody>
<tr>
<td>2018/4/1</td>
<td>20:54:53</td>
<td>QC1LE</td>
<td>a1</td>
<td>b1</td>
<td>a2</td>
<td>b4</td>
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<td>a2</td>
<td>b4</td>
<td>-1.13</td>
<td>2.97</td>
<td>-0.11</td>
<td>-0.86</td>
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<tr>
<td>2018/4/9</td>
<td>17:32:41</td>
<td>QC1LE-b1</td>
<td>b1</td>
<td>a1</td>
<td>a2</td>
<td>b4</td>
<td>-92.57</td>
<td>-11.13</td>
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<td>-11.13</td>
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<td>21:42:14</td>
<td>QC1LE-b1</td>
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<td>a3</td>
<td>33.20</td>
<td>-2.22</td>
<td>-2.42</td>
<td>0.12</td>
</tr>
</tbody>
</table>

### Diagram: SC Wire Specifications

- SC wire:
  - NbTi \( \phi = 0.35 \) mm
  - Cu/SC ratio = 1
  - \( I_c = 155 \, \text{A} @ 4.2 \, \text{K and 4T} \)

- Field strength by \( A_1 \) corrector
- Field strength by \( B_1 \) corrector
QCS operation and quench

- Magnet quench data (May 28\textsuperscript{th}, 2019)
  - The origin of the trouble was QC2LE power supply failure (IPM trouble).
  - SVD had a serious damage.

Coil-voltage profiles of QC1LE and QC2LE

From the report by Y. Arimoto
QCS operation and quench

From the report by Y. Arimoto

expanded in the right plots
Summary

• The QCS system which consisted of 55 SC magnets was operated with beams in Phase-2 and Phase-3.
  – During the two operations:
    • Phase-2: 25 quench events by beams
    • Phase-3: 3 quench events by beams

• In beam induced quenches (28 events):
  – Main quadrupole + corrector : 10
  – Main quadrupole : 3
  – Corrector : 15

• Quenched magnets were focused on the area of QC1 magnets.
• With the new data logging system, the quench condition can be related with the beam operation.