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THERMAL STUDIES OF THE MAGNET QUENCHES OF THE SuperKEKB BEAM FINAL FOCUS SYSTEM

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Abstract

Operation of SuperKEKB with eight superconducting final focus quadrupoles started from 2018, and now the electron and positron beams reached 1143 mA and 1460 mA, respectively, until June 2022. The peak luminosity achieved at 4.678 $\times 10^{-34}$ cm^{-2}s^{-1} on June 8th, 2022. During four-year beam operation, the superconducting magnets in the beam interaction region experienced 171 quench events induced by the beams. For the quench events, the current sharing temperatures of the magnets at quench were studied and reported.

INTRODUCTION

SuperKEKB [1] is the particle collider of electrons (e^-) at 7 GeV (High Energy Ring: HER) and positrons (e^+) at 4 GeV (Low Energy Ring: LER), and it is the innovative collider in the luminosity frontier using the "Nano-beam scheme" [2]. The beam colliding operation of SuperKEKB started in April 2018, and now the peak luminosity has reached 4.678 $\times 10^{-34}$ cm^{-2}s^{-1}, and the beam currents of HER and LER achieved at 1143 mA and 1460 mA, respectively [3]. Figure 1 shows progress in the beam currents of HER and LER and the luminosity from February 2019 to June 2022.

During beam operation from May 2018 to June 2022, the superconducting (SC) magnets at the interaction region had 171 beam-induced quenches. The current sharing temperature (T_{cs}) of the superconducting magnets at quenches was studied, and quench occurrence at the temperature is shown to the beam current.

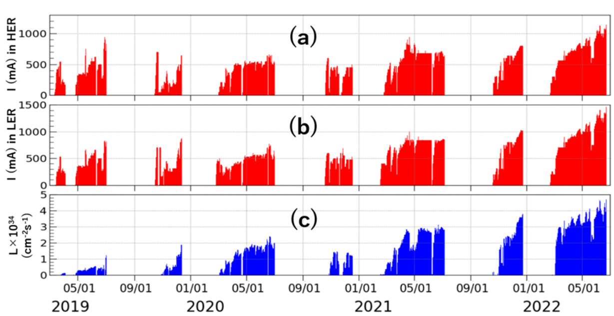

Figure 1: Progress of beam currents in HER (a), LER (b) and peak luminosity (c) from February 2019 to June 2022.

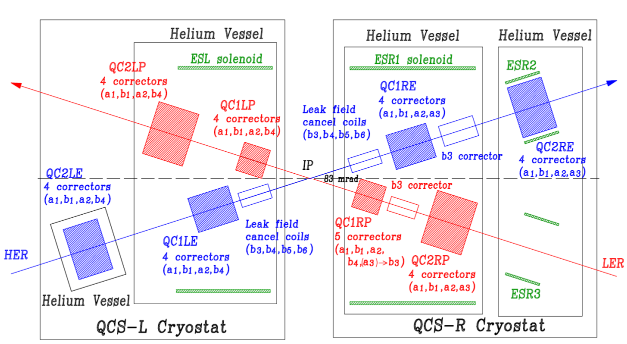

Figure 2: SuperKEKB final focus SC magnet system.

FINAL FOCUS SC MAGNET STSEM

System Layout of the Final Focus System

The beam final focus system [4] consists of the 55 SC magnets. The 25 and 30 magnets were assembled in the left and right cryostats, QCS-L and QCS-R, respectively. Figure 2 shows the system layout of the SC magnets in the two cryostats. They are classified into three types of the SC magnets: 8 main quadrupole magnets, 43 corrector magnets and 4 compensation solenoid magnets, ESL and ESR1/2/3.

The e^- and e^+ beams at IP are focused with doublets of main quadrupole magnets as shown by the red and blue boxes for LER and HER, respectively, in Figure 2. Each quadrupole magnet has four or five corrector magnets with it.

Table 1 shows the magnet parameters of the quadrupole and the corrector magnets assembled to the quadrupole magnets.

Table 1: Parameters of SC Quadrupole Magnets

Magnet	G_{op}, T/m	I_{op}, A	correctors
QC2RP	28.22	882.7	a_1, b_1, a_2, a_3
QC1RP	67.93	1601.1	a_1, b_1, a_2, b_3, b_4
QC1LP	67.82	1598.4	a_1, b_1, a_2, b_4
QC2LP	28.09	878.7	a_1, b_1, a_2, b_4
QC2LE	29.12	1001.4	a_1, b_1, a_2, b_4
QC1LE	72.29	1579.0	a_1, b_1, a_2, b_4
QC1RE	68.27	1491.0	a_1, b_1, a_2, a_3
QC2RE	30.84	1249.7	a_1, b_1, a_2, a_3

where G_{op} is the quadrupole field gradient by the operation current (I_{op}). The values of I_{op} are the magnet current on May 15, 2024.

QC1P/QC1E and Corrector Magnets

In 171 magnet quenches from May 2018, 144 events occurred in the QC1P (QC1LP/QC1RP) and QC1LE quadrupole magnets, and their corrector magnets (a_1, b_1, a_2). These magnets locate at the closest position to the interaction point in HER or LER.

Figure 3 shows the cross sections of the QC1P and QC1E magnets. The QC1P has the three corrector magnets (a_1, b_1, a_2) inside the magnet bore, and a_1, b_1, a_2 are set from the inner most layer in the corrector magnet assembly. The b_4 and a_3 correctors are assembled on the periphery of the magnet collar. The QC1E has four corrector magnets (a_1, b_1, a_2, a_3 or b_4) inside the magnet bore.

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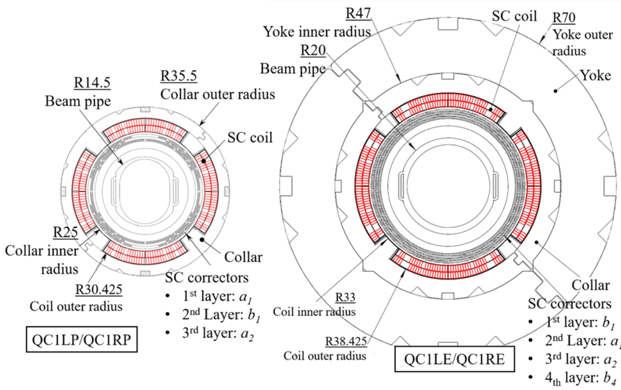

Figure 3: Cross section designs of the QC1P, QC1E and the corrector magnets.

SUPERCONDUCTING MAGNET QUENCH HISTORY BY BEAMS

Figure 4 shows the number of quenched magnets by beam for a month from April 2018 to June 2022. In April 2018, the number of the quenched magnets was twenty-six because of no fine adjustment of the collimators.

During beam operation from May 2018 to June 2022 with tuning the collimators, the number of the quenched magnet by beams was 171. In June 2022, 25 magnets were quenched because of the sudden beam loss [5].

144 quench events occurred in the QC1LP/ QC1RP, the QC1LE and their a_1, b_1 and a_2. T_{cs} of these magnets was calculated with the following equations [6].

$$t = T / T_{c0}\,, \quad (1)$$
$$b = B / B_{c2}(T), \quad (2)$$
$$J_c = [C_0/B]\, b^{\alpha} (1-b)^{\beta} (1-t^{1.7})^{\gamma}, \quad (3)$$

where t: reduced temperature, b: reduced field, T_{co}: maximum critical temperature at B=0 [K], $B_{c2}(T)$: upper critical field [T], $J_c(T,B)$: critical current density [A/m^2], C_0 : normalization constant, α=0.65, β=1.0, γ=2.3.

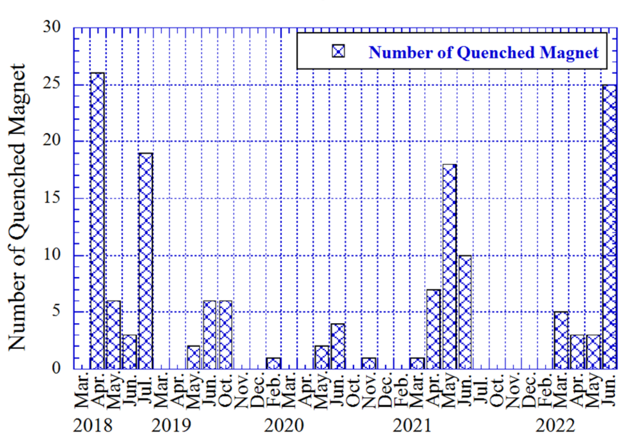

Figure 4: Number of quenched magnets by beams for a month.

For calculating T_{cs}, we use the NbTi cable short sample data as the critical current (I_c) = 3170 A at 4.22 K and 5T for the QC1P and QC1E cable and I_c = 154 A at 4.22 K and 4 T for the corrector cable.

Figure 5 shows the calculated T_{cs} for the quenched magnet shown by the red symbols, and for comparison, the T_{cs} of the non-quenched magnet in the same magnet-corrector assembly is shown in the same plot by the blue symbols.

T_{cs} of QC1LP/QC1RP is below 6 K, and the magnets quenched over the beam current over 450 mA. T_{cs} of QC1LE is 6.6 K, and five quench events were observed. When the HER beam current was 670 mA and the b_1 magnet quenched in QC1LE, QC1LE did not quench.

T_{cs} of the corrector magnets is in the range from 6.9 K to 8.0 K. In case that T_{cs} was higher than 7.5 K, the corrector magnets were insensitive to quench over the beam currents until June 2022.

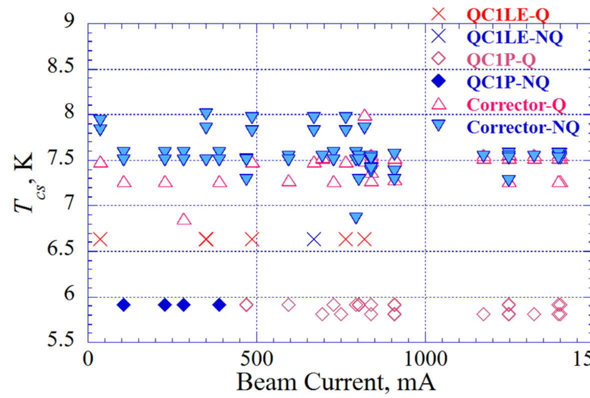

Figure 5: Current sharing temperature versus

CONCLUSION

Beam operation of SuperKEKB with the final focus superconducting magnets started from April 2018. During the operation period from May 2018 to June 2022, 171 quench events induced by beams were observed, and 144 events occurred in the QC1P and QC1E quadrupole magnets, and their corrector magnets.

From the T_{cs} studies of 144 events, the corrector magnets of which T_{cs} was higher than 7.5 K were insensitive to quench for the beam currents up to 1143 mA for HER and 1460 mA for LER.

REFERENCES

[1] T. Abe *et al.*, "Technical Design Report of SuperKEKB", `https://kds.kek.jp/event/15914/`

[2] P. Raimondi, "Introduction to Super B-Accelerators", presented at the 2nd Workshop on Super B-Factory, Frascati, Italy, Mar. 2006.

[3] Y. Ohnishi, "Recent Progress of SuperKEKB Project and Future Prospect", in *Proc. IPAC'23*, Venice, Italy, May 2023, pp. 1339-1342. `doi:10.18429/JACoW-IPAC2023-TUOGB1`

[4] N. Ohuchi *et al.*, "SuperKEKB beam final focus superconducting magnet system", Nucl. Instr. And Meth. A 1021 (2022). `doi:10.1016/j.nima.2021.165930`

[5] H. Ikeda *et al.*, "Observation of sudden beam loss in SuperKEKB", in *Proc. IPAC'23*, Venice, Italy, May 2023, pp. 716-719. `doi:10.18429/JACoW-IPAC2023-MOPL072`

[6] L. Bottura, "A practical fit for the critical surface of NbTi", *IEEE Trans., Appl. Supercond.*, vol. 10, no. 1, pp. 1054-1057, Mar. 2000. `doi:10.1109/77.828413`