# NEW SUPPORT FOR BPM TO SEPARATE FROM Q-MAGNET

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*Abstract*

In SuperKEKB, the beam orbit distortion was found to be positively correlated with the beam current. In the electron ring (HER), it was found that the injection efficiency was improved by the correction of the horizontal beam orbit in the Local Chromaticity Correction (LCC) region where a pair of strong sextupole magnets is installed. One of the possible causes is the dipole kick from the quadrupole magnet (Q-magnet), which is generated by the deformation of the beam pipe. Since the beam pipe with beam position monitor (BPM) is fixed to the Q-magnet, the position of the Q-magnet is also shifted when the beam pipe is deformed by synchrotron radiation (SR) heating. Therefore, a new support was designed for BPM to separate it from the Q-magnet. Three prototypes were produced and installed for the BPMs in the LCC region of HER. During operation from February 2024, the results showed that the new support successfully prevented the Q-magnet from moving with the beam current, which could make beam tuning easier and reduce the potential risk of beam abort.

## INTRODUCTION

In SuperKEKB, the beam orbit distortion was found to be positively correlated with the beam current, which became an obstacle to increasing the beam current [1]. It was found that in the high energy ring (HER, electron ring), the injection efficiency was improved by the correction of the horizontal beam orbit in the Local Chromaticity Correction (LCC) region, where a pair of strong sextupole magnets is installed. This implies that the beam orbit distortion did exist in this region. The magnet arrangement between these two strong sextupole magnets is shown in a top view in Fig. 1. Among them, "S" represents a sextupole magnet, "Q" represents a quadrupole magnet (Q-magnet), "B" represents a bending magnet, and "ZVQ" represents a vertical steering magnet for beam orbit correction. The outward direction of the ring is defined as +x. One of the possible causes of the beam orbit distortion is the dipole kick from the Q-magnet (which is QLY2LE.2, QLY3LE, and QLY2LE.1 in Fig. 1) generated by the deformation of the beam pipe. Since the beam pipe with beam position monitor (BPM) and the Q-magnet are connected via an aluminum L-shaped support (later referred to as "old support"), as shown in Fig. 2, the position of the Q-magnet will also be shifted when the beam pipe is deformed by synchrotron radiation (SR) heating. Additionally, the $\beta$ function in this region is large because it is close to the interaction point (IP), so even a small kick can cause a large orbit distortion. Therefore, a new support was designed for the BPM to separate it from the Q-magnet. Due to space limitations, this report will skip the details of the design process and testing without beam, focusing instead on comparing the measured displacement of the BPM and Q-magnet due to thermal deformation before and after the installation of the new support during operation.

## EXPERIMENTAL

### *New Support for BPM*

The structure of the new support is shown in Fig. 3. The lower blue trunk is composed of iron square tubes with a cross-section of 125×125 mm, and a thickness of 3 mm, and the upper silver part is made of aluminum to prevent affecting the magnetic field of the Q-magnet. During the design phase, the software Ansys was used to evaluate the strength of the support. The simulation results showed that when a horizontal force of 1000 N was applied to the BPM, the x-displacements of the BPM and Q-magnet were ~180 μm and ~100 μm, respectively, with the old support. With new support, the x-displacement of the BPM was ~70 μm, while the Q-magnet remained stationary.

### *Experiment*

**Displacement Measurement with Beam** From February to July is the first operation period of SuperKEKB in 2024. The installation of the new support can be divided into three periods, which are summarized in Table 1, and the corresponding measurement settings are shown in Fig. 4. During the first period when the old support was used, two capacitive displacement sensors with a diameter of 20 mm (φ20) were installed [2], namely BPM and

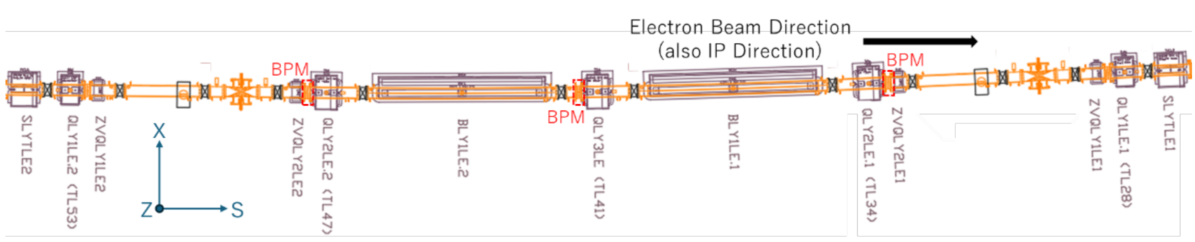


Figure 1. Magnet arrangement between two strong sextupole magnets, SLYTLE1 and SLYTLE2, in the HER (top view).

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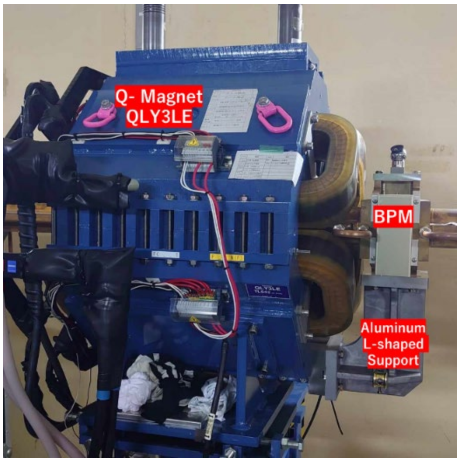



Figure 2: Original design where BPM and Q-magnet are connected via an aluminum L-shaped support.

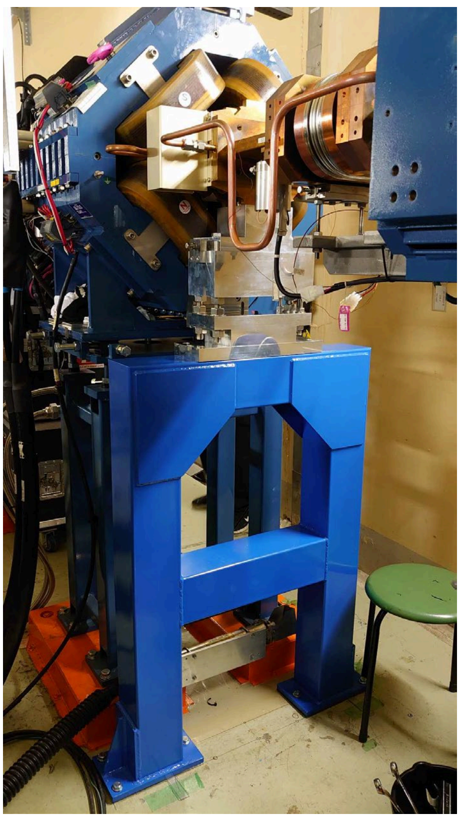


Figure 3: New Support for BPM.

QLY3LE_U, as shown in Fig. 4 and Fig. 5(a). During the second period, a new support was installed under the BPM next to QLY3LE and a new φ30 displacement sensor on QLY2LE.1_D was added, as shown in Fig. 4 and Fig. 5(b). Finally, all three BPM supports were replaced with new ones. The capacitive displacement sensor and its detector are manufactured by Sankosha Co., Ltd. The model of the detector is SKI-22181A, and its resolution is less than 0.2 μm. When using a φ20 sensor, the voltage output changes linearly from -10 V to +10 V when the gap is between 0.5 and 2.5 mm. When using a φ30 sensor, the voltage output changes linearly from -10 V to +10 V when the gap is between 0 and 6 mm. In addition, fourteen resistance temperature detectors (RTDs) were attached to the beam pipe in this region. Figure 4 only shows the six RTDs close to the displacement sensors. The ones with "SR in their names represent the side irradiated by SR.

Table 1: Three Periods of the Installation of New Support and the Corresponding Displacement Sensor

| Period | New Support | Displacement Sensor |
|---|---|---|
| 1. ~4/16 | None | BPM, QLY3LE_U |
| 2. 4/17~5/13 | QLY3LE | BPM, QLY3LE_U, QLY2LE.1_D |
| 3. 5/14~ | QLY2LE.2, QLY3LE, QLY2LE.1 | BPM, QLY3LE_U, QLY2LE.1_D |

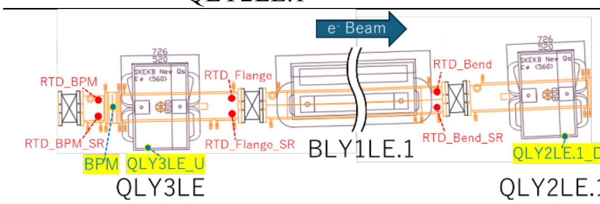
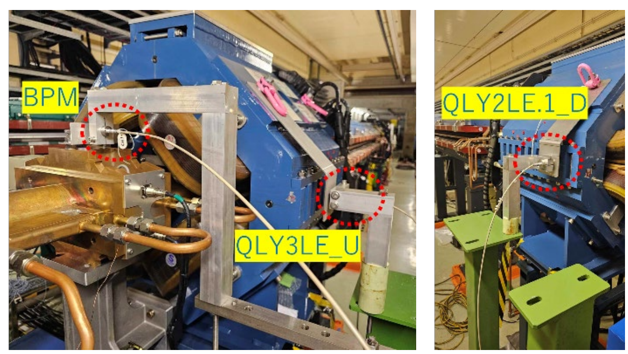



Figure 4: Top view of the beam pipe marking important measurement points in this report.




(a) (b)

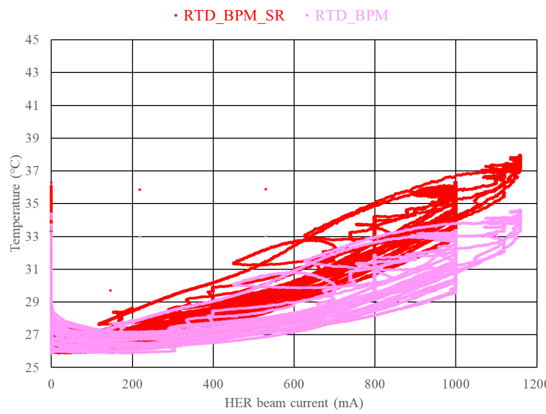
Figure 5: Photos of the three capacitive displacement sensors. (a) shows the sensors "BPM" and "QLY3LE_U". (b) shows the sensor "QLY2LE.1_D".

## RESULT AND DISCUSSION

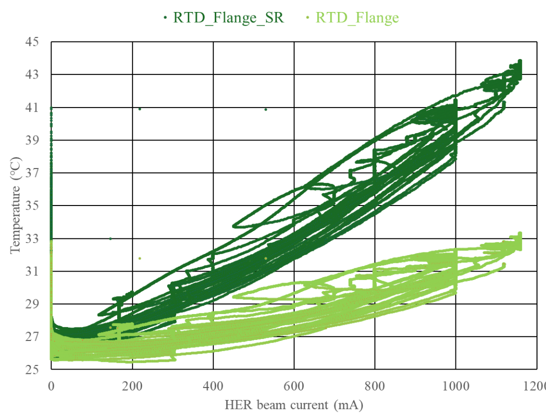
### *Displacement Measurement with Beam*

Figure 6 shows the relationship between the temperatures on both sides of BPM, Flange, and Bend and the beam current of HER from May 22nd to May 24th, 2024. When the beam current reached 1100 mA, the temperature differences between the two sides of BPM, Flange, and Bend were about 3, 10, and 13℃ respectively, and the temperature of RTD_Flange_SR reached ~43℃.

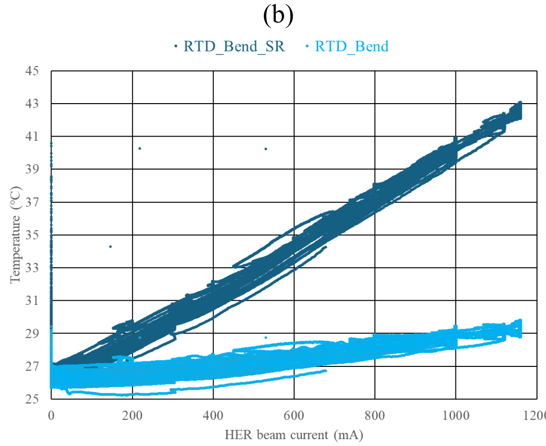
From the three periods listed in Table 1, we selected three representative days from each period: April 14th to April 16th (0414~0416), April 28th to April 30th (0428~0430), and May 22nd to May 24th (0522~0524). Figure 7 shows the relationship between the x-displacements of BPM, QLY3LE_U, and BPM, QLY2LE.1_D, and the HER beam current for these three periods. Comparing




(a)

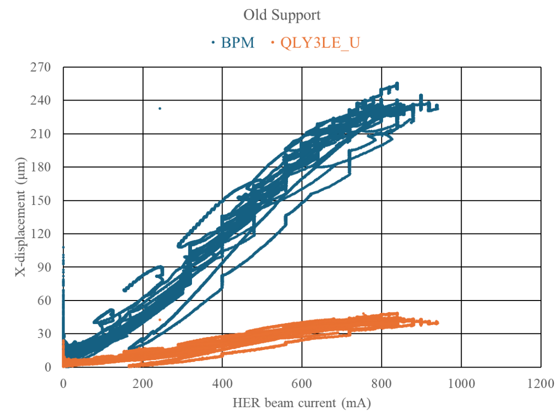



(b)

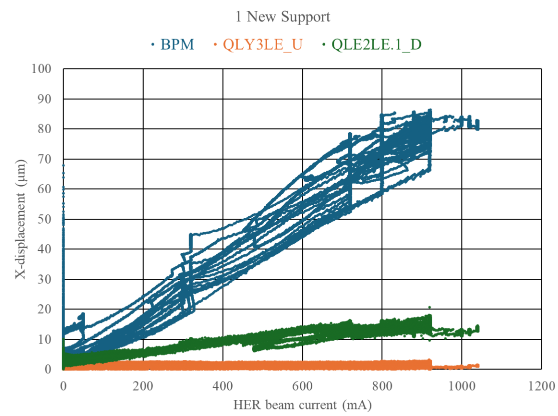



(c)

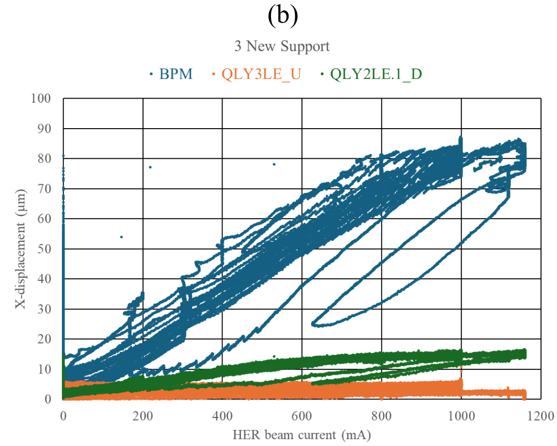
Figure 6: Relationship between temperatures on both sides of (a) BPM, (b) Flange, and (c) Bend and the beam current of HER from May 22nd to May 24th, 2024.




(a)




(b)




(c)

Figure 7: Relationship between x-displacements of BPM, QLY3LE_U, and BPM, QLY2LE.1_D and the HER beam current. (a) Old support. (b) One new support. (c) Three new supports.

Fig. 7(a) and Fig. 7(b), with only one new support installed, the x-displacement of QLY3LE_U was reduced from ~50 μm to ~5 μm at 800 mA, and the x-displacement of BPM was reduced from ~250 μm to ~85 μm. The effect of the new support near QLY3LE was significant. Comparing Fig. 7(b) and Fig. 7 (c), the effect of the two new supports next to QLY2LE.1 and QLY2LE.2 was difficult to observe from the displacement sensors near QLY3LE. Moreover, QLY2LE.1 still moved with the beam current even after being separated from the beam pipe. Possible causes include the thermal deformation of the Q-magnet due to the warm beam pipe through air convection, or a defective sensor setup, which requires further research to confirm.

### *Impact on Beam Optics Tuning*

The vertical axis of Fig. 8 is the average x-position of the beam measured by the BPMs next to the two strong

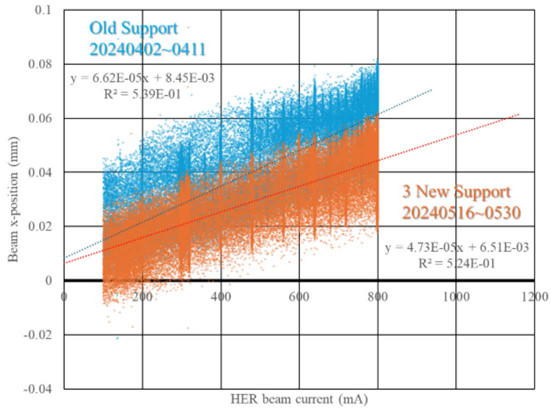



Figure 8: Relationship between beam x-position and beam current with old and new supports in HER.

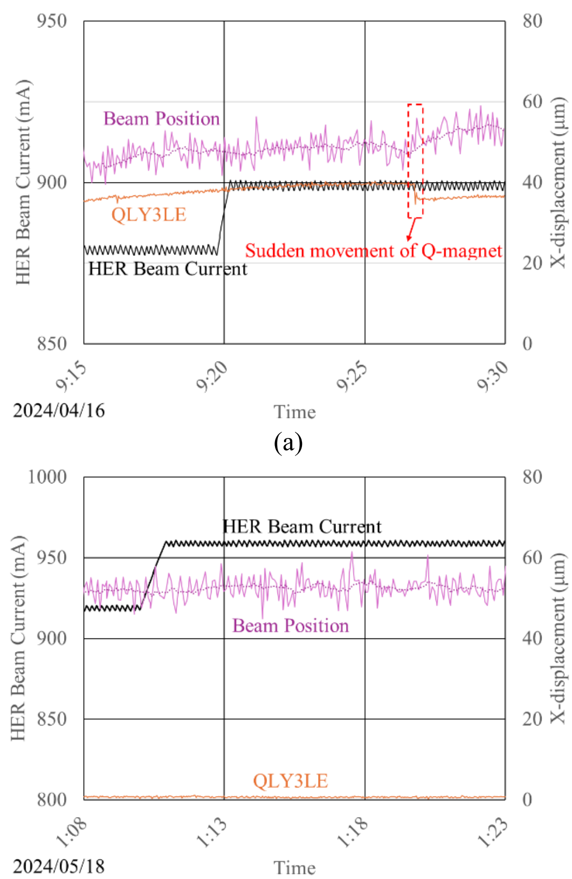



Figure 9: (a) An example of sudden displacement of the Q-magnet causing a displacement of the beam position with the old support, even when the HER current was maintained at a constant value. (b) An example of stable beam position when the Q-magnet was independent of the beam pipe.

sextupole magnets, SLYTLE1 and SLYTLE2, and the horizontal axis is the HER beam current. We selected several days each from the old support and new support periods, and took the data from beam current 100 to 800 mA to do linear fitting. The results showed that with three new supports, the change in beam position with current (i.e., the slope) decreased.

Besides, when using old support, it was frequently observed that the x-position of QLY3LE suddenly shifted while the beam current of the HER remained fixed. Figure 9(a) shows an example of such an event. It can be seen that the sudden displacement of QLY3LE caused the x-position of the beam to jump. Approximately 30 such jumps were recorded in the first half of April, all of which occurred when the beam current was above 720 mA. The sudden movement of the Q-magnet could complicate the beam tuning and has the potential to lead to a beam abort. After the new support was used to separate the Q-magnet from the beam pipe, these jump events disappeared. One example is shown in Fig. 9(b).

## CONCLUSION

A new support was developed to separate the BPM from the Q-magnet, and three such supports have now been produced and installed between the two strong sextupole magnets in the HER. During beam operation, the results of the x-displacement measurements show that the Q-magnet barely moved with the new BPM support, and the displacement of the BPM was also reduced. As a result, the beam position became more stable, which could make the beam optics tuning easier by reducing unexpected jumps, and decreasing the possibility of consequent beam abort. It is worth noting that the Q-magnet QLY2LE.1 still moved with the beam current after being separated from the beam pipe. Further research is needed to understand the cause. In the next operation, similar supports are planned to be produced and installed in the low energy ring (LER, positron ring).

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