Eddy-Current Suppression Using New Ceramic Chamber of a Pulsed Sextupole Magnet in Beam Injection

At the PF ring, a pulsed sextupole magnet (PSM) has been used for top-up injection for the first time [1]. Following its successful operation, the PSM was upgraded by introducing a ceramic chamber with a rectangular shape to strengthen the magnetic field. However, it induced a horizontal oscillation of the stored beam with a maximum amplitude of 5.0 mm at the beam injection. This oscillation was assumed to be caused by eddy currents originating from the uniform inner coating of the ceramic chamber. We, therefore, developed a ceramic chamber with a new patterned coating. The maximum amplitude was suppressed by a factor of 16 with the new chamber.

A pulsed sextupole magnet (PSM) developed for beam injection in the PF ring is a candidate as an advanced technology for realizing the top-up beam injection without causing oscillations of the stored beam (**Fig. 1(a)**). Because the magnetic field distribution of a sextupole magnet has a parabolic shape, there is a point at the magnet`s center where the magnetic field is zero and a region where it approximates to zero. If the center of magnetic field is precisely aligned with the orbit of the stored beam, the magnetic field does not affect the stored beam; it affects only the injected beam, which passes through an off-center position of the magnet. To increase the kick angle at an off-center position of the magnet, the gap was narrowed, and its shape was changed to a rectangular one to secure a horizontal physical aperture upgrading the whole of the PSM system (**Fig. 1 (b) (c)**). However, the upgraded PSM system known as PSM2 did not function as expected for the PSM1 system because of an eddy current–induced magnetic field that resulted in an unexpected magnetic field around the center of the magnet. Precise magnetic-field measurements and simulations demonstrated that the eddy currents in the uniform coating and the iron core in PSM2 were the sources of the unexpected magnetic fields around the center of magnets and that the kick angle of the integrated eddy current magnetic field explains the beam-oscillation amplitude observed during operation of PSM2.

As a countermeasure to this problem, FLiP, a new coating technology, was developed to prevent the generation of eddy currents on the surface of the coating (**Fig1. (d)**). The FLiP is one of the key technologies used in an air-core-type ceramics chamber with an integrated pulsed magnet, the CCiPM [2]. This does not generate large eddy-current loops in the longitudinal direction while providing a capacitance shape that permits the passage of the beam-wall currents.

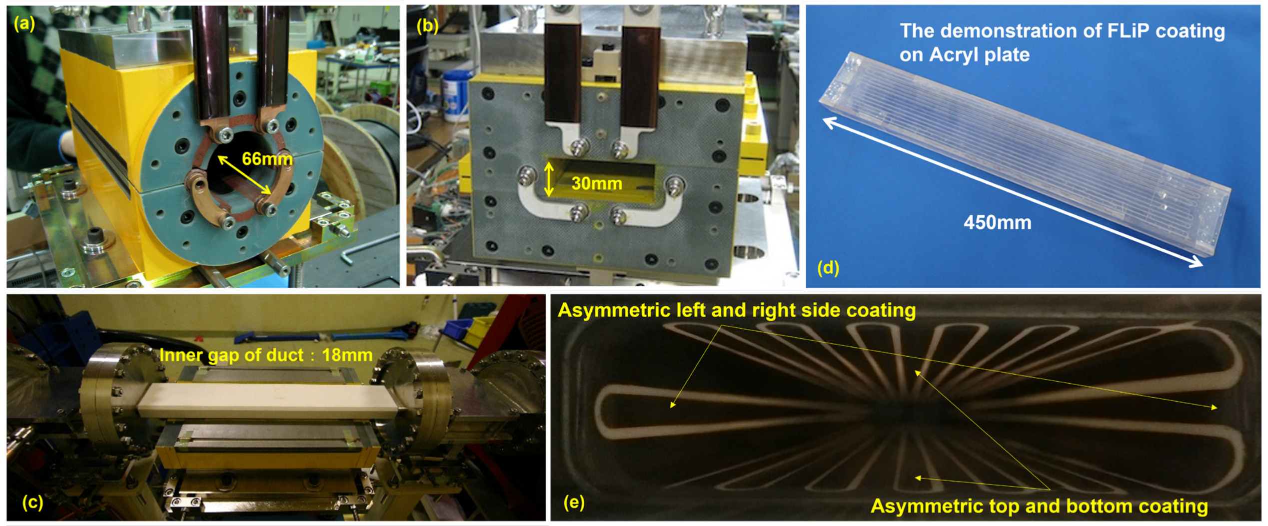

Figure 1: PSM system upgrading from picture **(a)** of PSM1 to picture **(b)** of the PSM2 in the picture. Picture **(c)** shows the ceramics duct installed into PSM2 magnet. The FLiP coating technology is shown in picture **(d)** and the coating of picture **(e)** is implemented in the PSM2 ceramics duct.

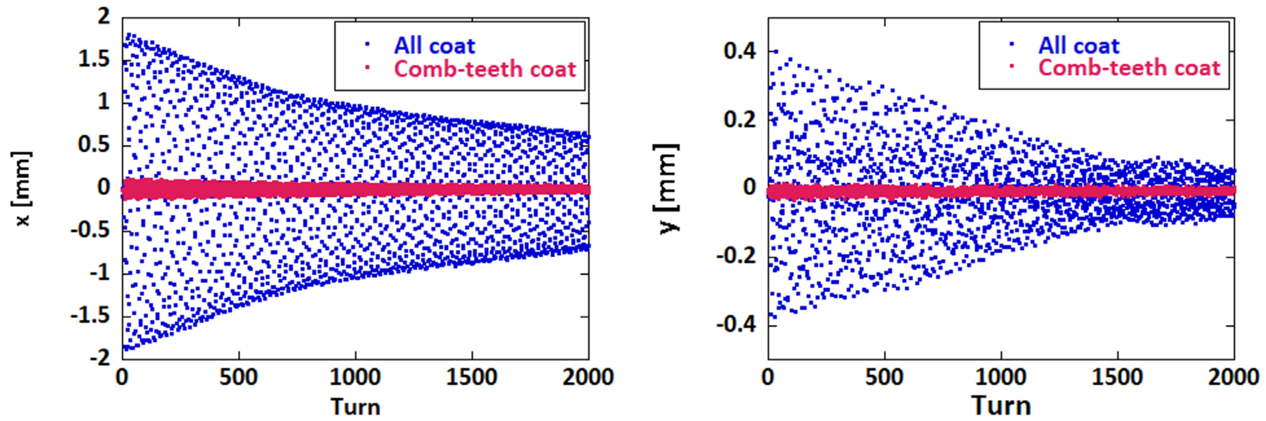

Figure 2: The experiment results of beam oscillation amplitudes for horizontal (left) and vertical (right) directions before and after installing a new duct with a comb-teeth coating.

The comb tooth–patterned coating realized by FLiP enabled us to confirm by simulation that the eddy-current magnetic field on the coating surface was suppressed by 99% and that the heat generation caused by the beam impedance of the wall current was reduced to within allowable levels. In the development of the CCiPM, a FLiP coating with comb-tooth width of 2.5 mm and a slit spacing of 3 mm between the comb-teeth was produced on the inner surface of a 30 mm diameter cylinder. Therefore, we attempted to achieve the maximum allowable setting for each parameter from the viewpoint of impedance, and we conducted a prototype test. The priority was to narrow the slit between comb teeth, with a target of 1 mm, without narrowing the width of the comb teeth to less than 4 mm. FLiP implementation of the 5 μm-thick titanium coating was successfully completed in the spring of 2020 for the newly fabricated chamber (**Fig. 1 (e)**).The new ceramics chamber with FLiP coating was replaced with the old chamber in PSM2 system in the summer of 2020.

When the beam experiments were conducted for both the case of the uniform coating and the comb-tooth coating, the results confirmed a 1/16 reduction of the beam oscillation (**Fig. 2**). The maximum temperatures measured in the MB and HB beamfilling modes were approximately 58 and 85°C, respectively; the atmospheric temperature in the accelerator tunnel was 23°C. For the HB filling mode, an air-cooling fan was used for safety after a high temperature was observed; the temperature of the fan-cooled chamber was kept below 60°C. Beam instability, which would shorten the beam life was not specially induced and was controlled under the bunch-by-bunch feedback system. In beam experiments, the eddy-current magnetic field was observed directly by examining the shape of the beam oscillation to prove the presence of an unexpected magnetic field due to eddy currents. The beam experiments showed that the eddy-current magnetic field on the surface of the coating was suppressed completely, which led us to conclude that the residual eddy-current magnetic field was generated in the iron core. For ultimate transparent top-up injection to a beamline user, an iron-core-type magnet is inappropriate. However, our experimental results showed that a ceramic chamber with a comb tooth–patterned coating can be used in practical applications for the next generation of light sources [3].

REFERENCES

[1] H. Takaki, N. Nakamura, Y. Kobayashi, K. Harada, T. Miyajima, A. Ueda, S. Nagahashi, M. Shimada, T. Obina and T. Honda, *Phys. Rev. ST Accel. Beams* **13**, 020705 (2010).

[2] C. Mitsuda, Y. Kobayashi, S. Nagahashi, T. Nogami, T. Obina, R. Takai, H. Takaki, T. Uchiyama, A. Ueda, T. Honiden, T. Nakanishi, A. Sasagawa, A. Yokoyama and T. Yokoyama, *Proc. IPAC2019, Melbourne, Australia*, 4164 (2019).

[3] C. Mitsuda, H. Takaki, R. Takai, T. Nogami, T. Uchiyama, Y. Kobayashi, T. Obina, Y. Lu and A. Yokoyama, *Phys. Rev. Accel. Beams* **25**, 112401 (2022).

C. Mitsuda, H. Takaki, R. Takai, T. Nogami, T. Uchiyama, Y. Kobayashi and T. Obina (KEK-ACCL)