Beam Test of a Newly-Developed Ceramics Chamber with Integrated Pulsed Magnet for an Accelerator Implementation

We are developing a Ceramics Chamber with integrated Pulsed Magnet (CCiPM) of the air-core type for the future low-emittance light source ring with a narrow bore. The CCiPM consists of a ceramics cylinder and four coils that are implanted deep in the through groove of the ceramics along a length of 30 cm by silver brazing. This CCiPM has a special pattern coating on the inner surface of the chamber to serve as a beam duct. We constructed a beam test line to confirm the magnetic field performance and structural durability for implementation in the accelerator in the winter of 2019. The beam test was successfully conducted during machine study time in the accelerator operation of 2019.

The CCiPM structure is able to close the gap to the beam without disturbing the beam impedance [1]. By adopting an air-core type pulsed magnet there is no limitation on increasing the order of the magnetic field and exciting a large magnetic field. Especially, the completely integrated ceramics structure is made structurally robust by implanting the coils 5 mm deep in the ceramics. This simple ceramics construction plays many roles, including as a coil-supporting jig, magnet core, coil insulation, and beam duct. Therefore, not only a highly precise magnetic field but also high operation reliability is secured against vacuum stress, magnetic force, and thermal expansion stress. The dipole-type CCiPM is thought to be the most useful kicker for advanced beam control such as turn-by-turn and bunch-by-bunch in the accelerator ring, because the simple structure and enhanced magnetic field by shrinking the bore enable it to be installed anywhere, even in arbitrary narrow spaces, in the future accelerator. This is a major advantage compared with the strip-line kicker which needs a long straight section. Furthermore, an air-core magnet can generate complex non-linear fields by supplying the current in the same direction for all coils and by optimizing the coil arrangement. The nonlinear kicker [2, 3] is thought to be one way of achieving top-up beam injection into a narrow beam dynamic aperture in an ultra-low emittance ring [4].

The CCiPM is composed of just three elements: a cylindrical ceramics chamber, coils, and flanges. A schematic view is shown in **Fig. 1**; the inner diameter is 60 mm (D60 model). This magnetic field is optimized for a dipole by arranging the coils at a 30° angle from the medium plane. In this case, the coil length is 300 mm. The ceramics chamber uses the A-479 type of fine ceramics. The coils are made of oxygen-free high conductivity copper (OFHC) of 2 mm thickness and 4 mm width.

There were two issues to overcome in achieving this designed structure. The first was to implant the coils in the longitudinal direction while keeping the vacuum seal performance. The second was to construct the connecting port of the feeder lines on the coils to supply the pulsed current. We succeeded in establishing the technologies for these issues as shown in **Fig. 2**. Additionally, the inside surface of the cylinder must be coated with some kind of metallic material so that the ceramics chamber serves as a beam duct. However, this metal coating must conduct the beam wall current while suppressing eddy currents for the main magnetic field. As a solution, a pattern coating technique was developed based on a masked blasting method after uniform coating. **Figure 3** is a picture of the inside of the completed CCiPM in the D60 accelerator implementation model. The pattern shape is a comb. The coating material is titanium, with a thickness of 3 μm.

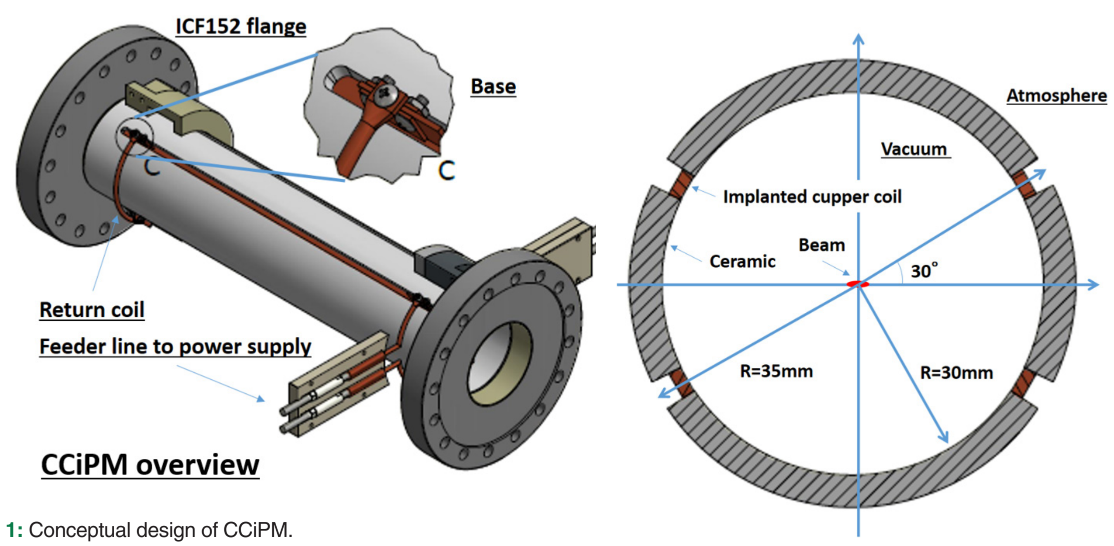

Figure 1: Conceptual design of CCiPM.

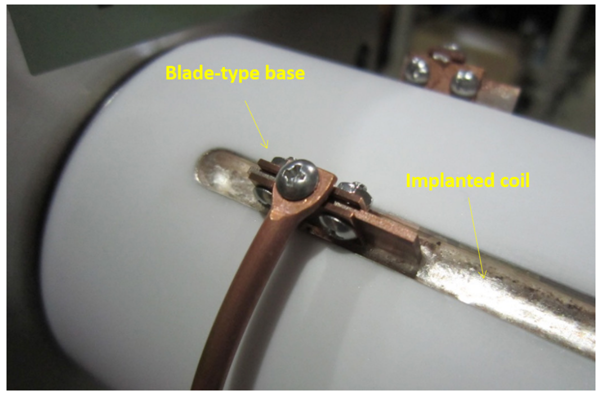

Figure 2: Implanted coils and constructed current base.

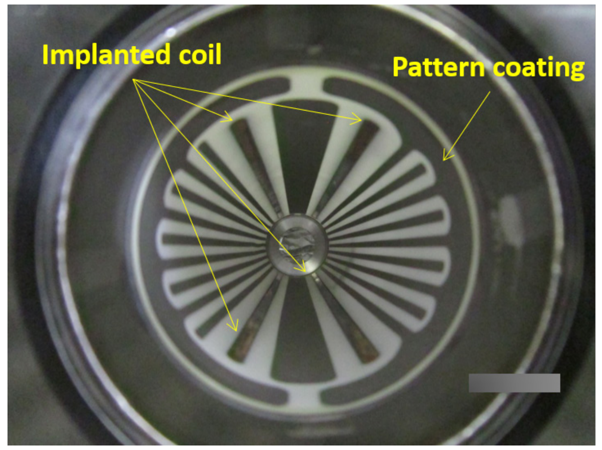

Figure 3: Inner coating of CCiPM.

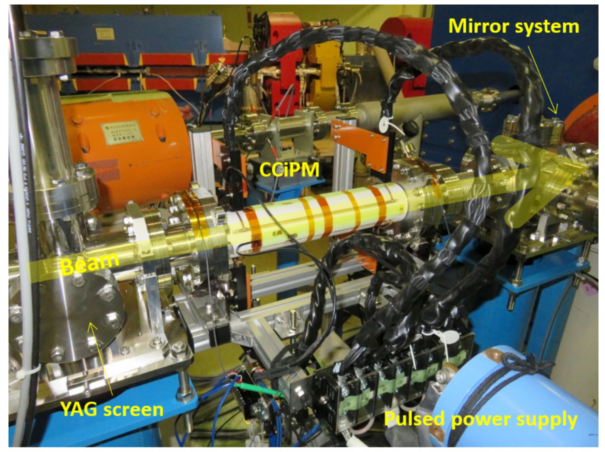

Figure 4: Beam test line for CCiPM.

The CCiPM must be operated under various stress conditions: atmospheric pressure under vacuum, magnetic force caused by the current supply, and thermal expansion stress caused by beam heat loading and current supply. The implementation model was subjected to a stress test under these conditions for 180 days continuously without any problem. In the test, the chamber was reduced to vacuum of less than 2.6×10^{-6} Pa, and a pulsed peak current of 6240 A with pulse width of 4.9 μs was supplied with 1 Hz repetition. Simultaneously, the heat cycle was applied three times a day by a ribbon heater. The flat-top of the heat cycle was kept at 120°C for 4 hours. After this baking, vacuum pressure reached 7.11×10^{-8} Pa. In the withstanding voltage test, a high voltage of 11.1 kV was applied with a pulsed peak current of 7735 A.

The beam test line of the CCiPM was constructed in the dump-line at the end of the beam transport line from the linac to the KEK-PF storage ring. The purposes of the beam test were as follows. The first was to evaluate the kicker performance precisely. The second was to prove the durability of the structure and coating by exposing it to an electron beam. Some components were newly installed in the dump-line to estimate the CCiPM performance precisely as follows: 1) a beam position monitor to observe the beam position, beam energy jitter and beam current charge in real time without beam destruction, 2) a beam profile monitor using a YAG screen system with CMOS camera just upstream of the CCiPM and dump point to compare the position and profile of the beam before and after kicking, and 3) a moving mirror system to assess damage to the inner surface coating in the CCiPM in real time. **Figure 4** shows a picture of the actual CCiPM setup in the dump-line. The first beam test was done in February 2019. The beam repetition rate was 1 Hz. There were no problems in the beam test and the basic kicker performance was confirmed to be as expected. There was no damage to the coating that was exposed to the linac beam. This beam study confirmed that the CCiPM implementation model is applicable to beam operation.

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