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ACCELERATOR IMPLEMENTING DEVELOPMENT OF CERAMICS CHAMBER WITH INTEGRATED PULSED MAGNET FOR BEAM TEST

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Abstract

We advance the development of Ceramics Chamber with integrated Pulsed Magnet (CCiPM) of air-core type as the application to low emittance of future light source ring with a narrow bore. The CCiPM consists of ceramics cylinder and four coils that are implanted into the groove penetrated on the ceramic thickness along 30 cm length by silver brazing. Additionally to this structure, we succeeded in constructing the current base on these coils to connect between the coils and power supply with feeder lines mechanically and implementing the pattern shape coating inside the ceramic cylinder. For implanting coils and constructing the current base on coils, silver brazing technique was newly improved. For inner surface coating, pattern coating was newly developed to realize both the reduction of eddy current caused by the main magnetic field and the passage of the beam wall current. We report the details about the structure performance, the new technical development on the accelerator implementation, and the beam test line construction.

INTRODUCTION

There are four subjects in iron core-type pulsed magnet. The first one is that it is difficult to shrink the magnet gap within ceramics chamber outer diameter. The second one is that it is difficult to achieve the multi-pole pulsed magnet whose filed order is higher than the sixth for a very narrow bore radius such as 30 mm because the many poles cannot be constructed in narrow bore space. The third one is that it is difficult to decrease the eddy current caused in magnet core and ceramics chamber inner coating even if the thin laminated silicon-steel and micro-order thin Titanium coating are used in order to suppress the eddy current generation. The fourth one is that the saturation effect is not negligible in huge current excitation.

The CCiPM structure [1] has a possibility of closing the gap to beam without disturbing the beam impedance. There are almost no limitations increasing the magnetic field order, suppressing the eddy current, and exciting huge magnetic field by adopting an air-core type pulsed magnet and ceramics chamber with integrated coils. Especially, the ceramics integrated structure has strong structural strength by implanting the coils into the ceramic thickness of 5 mm. The many roles are given to the ceramics in this simple construction: coil supporting jig, magnet core, coil insulation, and beam duct. Because these roles are given by the simplest feature, not only high magnetic field precision but also high operation reliability is secured for vacuum stress, magnetic force, and thermal expansion stress. The fast pulsed magnet of dipole-type CCiPM will be the most useful kicker for the purpose of advanced beam control like turn-by-turn and bunch-by-bunch. The simplest structure and strong magnetic field by closing gap enable it to install anywhere to arbitrary narrow space in an accelerator. This aspect is a great advantage comparing with strip-line kicker which needs a long straight section. Additionally to its characteristics, because the CCiPM is a lumped constant type magnet which is precisely reproduced, CCiPM makes it possible to match the impedance between a magnet or some magnets and pulsed power supply. The highly similarized field is achieved for some magnets, which are required in top-up operation using a bump orbit injection scheme [2]. In another aspect, an air-core magnet has an ability to generate complex non-linear field by flowing the current in a parallel direction and by optimizing the coil position arrangement. Utilization of non-linear kicker [3] is thought to be as one of the candidates which realize the top-up beam injection into the narrow dynamic aperture in ultra-low emittance ring [4]. In summary, CCiPM has high flexibility that CCiPM is widely used as a multi-purpose kicker [5].

ACCELERATOR IMPLEMENTATION

Coil integration development

CCiPM is composed of just three elements: a cylindrical ceramics chamber, coils, and flanges. The conceptual design is shown in Fig. 1 whose inner diameter is 60 mm (D60 model). This magnetic field is optimized for dipole by arranging the coils at 30 degrees angle to medium plane. In this case, coil length is 300 mm. Ceramics is made by fine ceramic of A-479 type. Coils are made by oxygen free high conductivity copper (OFHC) of 2 mm thickness and 4 mm width. The ceramics chamber has to be responsible for the beam duct and magnet core, and simultaneously, implanted coils have to be responsible for vacuum seal structurally. Feeder lines from the pulsed power supply are connected to coils using the current base of blade-type mechanically. By using this mechanism, there is large flexibility in the current flowing direction and connecting way of each coil. In Fig. 1, the return coils are bridged for end-parts of each coil so as to generate the dipole field in the horizontal direction.

To realize this design structure, there were two subjects. The first one was to implant coils in a longitudinal direction keeping vacuum seal performance. The second one was that

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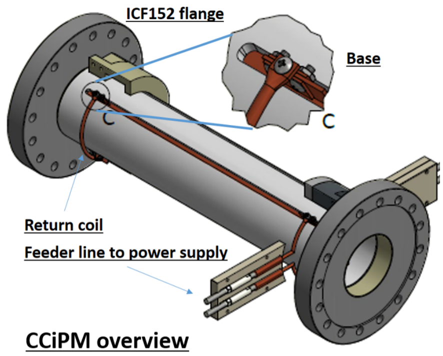

Figure 1: Conceptual design of D60 CCiPM.

connecting port of feeder lines was necessary on coils to connect the power supply system. We have succeeded in developing two kinds of technologies for these subjects.

- Slender Metal Brazing Technology (SMBT): metal blazing techniques for longitudinal direction to implant the coils into the ceramic thickness.
- High Current Base Technology (HCBT): construction techniques of the base block on the coils simultaneously with coil implanting.

In SMBT, it was difficult to add the current base block on the coils simultaneously with coils implanting because the thermal stress distribution in the longitudinal direction was different from slender metal brazing only for coils. The new metal blazing technique to combine SMBT with HCBT was achieved too through various R&D process on optimizations of base block shape and metalizing device. Fig. 2 shows the completed blade-type high current base using HCBT additionally to SMBT.

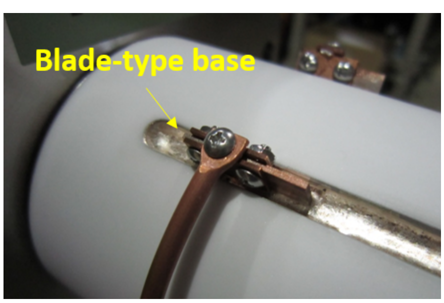

Figure 2: Implemented blade-type high current base on coils.

Coating technology

It is necessary to coat the cylindrical inner surface by some metals in order to work the ceramics chamber as a beam duct. There is a difficult issue in the metal coating; coating satisfies both performances about beam wall current passage and eddy current suppression for the main magnetic field. Thus, we have proposed to making the functional pattern coating (FPC) on the inner surface of the ceramics chamber avoiding to coat the coil surface. As the FPC design, comb-type pattern shape was adopted. The comb-pattern shape can pass the high-frequency beam wall current by its capacitance structure and can prevent the eddy current from generation on the coating surface by strip line shape.

In this FPC, there are two subjects to be solved as follows. The first one is realizing a precise and fine clear line coating to make precise capacitance structure by pattern shape. The second one is preventing an electrical discharge between the coating and implanted coils. For these subjects, we have succeeded in Fine Line coating Process (FLiP). FLiP technology was developed based on adopting a masked blasting method after uniform coating. Preventing the electrical discharge, the creeping discharge distance was exactly measured 1.17 kV/mm under atmosphere condition and the cleaning recipe after masked-blasting was established. Fig. 3 is completed CCiPM inner view in the D60 accelerator implementation model. The details about the comb-pattern shape were decided from a point of view radiation frequency characteristics of the beam wall current by using SONET simulation. In Fig. 3, the coating thickness is 3 μm and the coating material is Titanium. The measured insulation resistance was 10^{13} Ω between coating and coils. In order to get a kick angle more than 1.6 mrad for an electron beam with 8 GeV beam energy, the supplying current more than 7 kA is necessary for an impedance of Z=1.43 Ω in 4 μs pulse width. Thus, the required withstanding voltage of CCiPM is more than 15 kV at least. FLiP has a possibility to enable to increase the coating thickness and to change the coating material from titanium to copper which has high conductivity without taking care of eddy current generation in order to solve about the high impedance and heat generation by beam wall current.

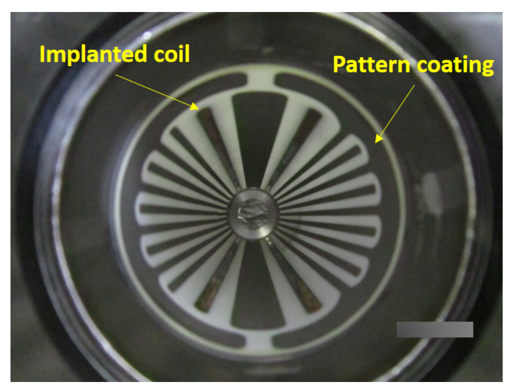

Figure 3: Completed functional patter coating on CCiPM.

DURABILITY AND PERFORMANCE

Firstly, a long-time durability test was done for a D60 accelerator implementation model in the test bench. The CCiPM will be operated under various stress conditions: atmospheric pressure by vacuuming, Lorentz force by pulsed current supplying, and thermal expansion stress of Joule heat by beam heat load and current supply. Each stress was simulated in the following ways. Vacuum evacuation system was directly connected to the flange and vacuumed less than $2.6{\times}10^{-6}$ Pa continuously. The pulsed current whose pulse width, current, and voltage were 4.9 μs, 6240 A, and 9.2 kV respectively was inputted to each 1 turn-coil by serial connection. Simultaneously, the heat cycle of three times a day was given by a ribbon heater. Flat top of heat cycle was

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kept with 120 degrees for 4 hours and not controlled ramp up·down time was about 4 hours totally. The implementation model finished the stress test of continuous 180 days without any problem.

Secondary, the reachable vacuum pressure and possibly maximum supplied high voltage without electrical discharge were verified. The measured leak rate of the implementation model was less than 1.13×10^{-13} Pa·m^3/s. After a ribbon-heater baking by 105 degrees for 48 hours, vacuum pressure reached to 7.11×10^{-8} Pa. In withstand voltage test, applying 11.1 kV high voltage was achieved with 7735 A current. The estimated withstanding high voltage is 14 kV for used coating shape. The linearity of the magnetic field is measured from 0 A to 7735 A by pick-up coils attached on the top of CCiPM ceramics. The maximum current corresponds to a 1.8 mrad kick angle for an electron with 8 GeV beam energy. Effective coil length of the implementation model is shortened from 0.3 m to 0.27 m because the high current base is connected on the slightly inside from the coil end.

Tertiary, eddy current effect was inspected by measuring the difference between CCiPM including coating and not including coating. The measured difference was less than 2% within measurement reproducibility. It is thought that the eddy current caused on the coating surface is negligible in the CCiPM structure.

BEAM TEST LINE CONSTRUCTION

The beam test of the CCiPM implementation model was planned in the dump-line at the end of the beam transport line from linac to the KEK-PF storage ring. The motivations of the beam test are as follows. The first one is evaluating the kick performance as dipole and quadrupole kicker precisely. The second one is proving the structure and coating durability by exposing to an electron beam.

Air-core type magnet enables to generate two kinds of magnetic field shape. The dipole magnetic field is generated by supplying current for each pair-coil in the same direction. On the other hand, the quadrupole-like field is generated by supplying current for all coils in the same direction: parallel current flow. The estimated kick angle is 0.74 mrad/kA for supplied current in dipole field, and 0.013 mrad/mm/kA for distance from magnet center and supplied current in the quadrupole-like field. Usually, when CCiPM is used as a dipole kicker, the return-coils are bridged for each pair-coil. When CCiPM is used as quadrupole, the 4 feeder lines are connected to each coil-end and the supplied current flow in series. The distance from dump point to CCiPM center is 3360 mm which is enough length to evaluate kick angle. Some components were newly installed into the dump-line to evaluate CCiPM performance correctly as follows: 1. beam position monitor to watch the beam position and beam energy jitters and beam current charge without beam destruction real timely. 2. beam profile monitor using YAG screen system with CMOS camera just in upstream of CCiPM and dump point to compare the beam position and profile before and after kick. 3. moving mirror system to confirm the damage of the inner surface coating in CCiPM real-timely. Fig. 4 shows a picture of the actual CCiPM setup in dump-line. CCiPM is aligned for horizontal, vertical and longitudinal positions by 30 μm and for tilting by 20 μrad at most. The pulser part of the pulsed power supply system is set up in front of the CCiPM and the power cable is connected to a terminal of CCiPM.

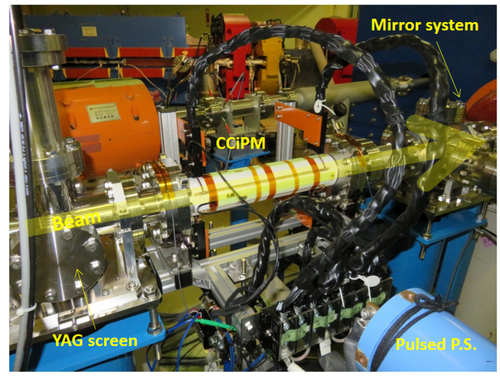

Figure 4: CCiPM installation in the beam test line.

CONCLUSION AND PREDICTION

The first beam test was done in February 2019. The beam repetition rate was 1 Hz. Any issue did not happen in the beam test and it was confirmed that basic kicker performance was not different from expectation. There is no damage on coating which was exposed to the linac beam. A more detailed beam test study is continued to evaluate the kick angle exactly.

This model will be installed in the PF storage ring to demonstrate kicker performance to stored beam in the near future. Additionally, the CCiPM with a super narrow bore of 30 mm diameter is now under development. The SMBT, HCBT, and FLiP will be established and optimized for bore narrower than 60 mm in diameter. Furthermore, the dipole-type CCiPM is planned to be expanded to the multi-pole kicker and non-linear kicker as a new injection kicker system in KEK future light source.

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