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MAGNETIC FILED MEASUREMENT AND BEAM PERFORMANCE TEST OF CERAMICS CHAMBER WITH INTEGRATED PULSED MAGNET AT KEK-PF

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Abstract

An air-core magnet named Ceramics Chamber with integrated Pulsed Magnet (CCiPM) is being developed at the photon factory (KEK-PF), which will have several applications for the future light source. One prototype has been developed as a dipole kicker whose bore is only 30 mm. Due to the type and structure, it's expected to have strong magnetic field, fast pulse, and high repetition rate. After finishing the offline measurement of magnetic field and evaluation of vacuum tightness, the CCiPM was installed in the beam transport-dump line of PF to have an online beam performance and durability test. The results of the magnetic field measurement and beam performance test will be reviewed.

INTRODUCTION

Conventional iron core-type pulsed magnet has some disadvantages such as a limitation of repetition rate, eddy current induced by iron core and inner coating of ceramics chamber, saturation effect of the magnetic field in magnet pole and so on. On the other hand, air core type magnet has a possibility to solve these problems. So, the development of Ceramics Chamber with integrated Pulsed Magnet (CCiPM) is being conducted as an idea of new air-core type magnet at KEK-PF. The structure of CCiPM is very compact and simple, which has only three parts: a cylindrical ceramics chamber, copper conductor and flanges. A prototype (CCiPM-D30) whose diameter of the bore is only 30 mm has been developed based on the technology of CCiPM-D60 [1]. Figure 1 shows the design figure of CCiPM-D30. The CCiPM just has three parts: a cylindrical ceramics chamber with super narrow aperture, coils, and flanges at end part of ceramic.

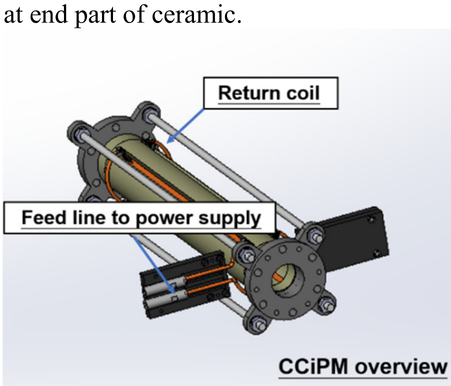

Figure 1: Design figure of CCiPM-D30.

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The material of coil is oxygen free high conductivity copper. The length of coil is 300 mm. And the angle to the medium plane is optimized for 30 degrees to generate a dipole field. Because the coil is placed inside of the ceramics, the ceramics chamber plays two roles: vacuum duct and magnet core. Due to the narrow bore, it's expected to generate strong and fast pulsed magnetic field.

Besides, due to the flexibility of current flow direction in coils, the CCiPM could also be adopted to a nonlinear kicker after the optimization of current low direction and coil arrangement, which is expected to achieve the top-up injection without the horizontal perturbation of stored beam [2].

OFFLINE EXPERIMENTS

To examine the performance of CCiPM, some offline experiments were performed before beam test experiment.

Baking and Vacuum Extraction

First, the baking and vacuum extraction were carried out to check the heat durability and vacuum tightness. To meet the requirement of installation, the vacuum should reach less than 1×10^{-7} Pa. During this experiment, the temperature and the vacuum were detected by some temperature sensors and an ionization gauge.

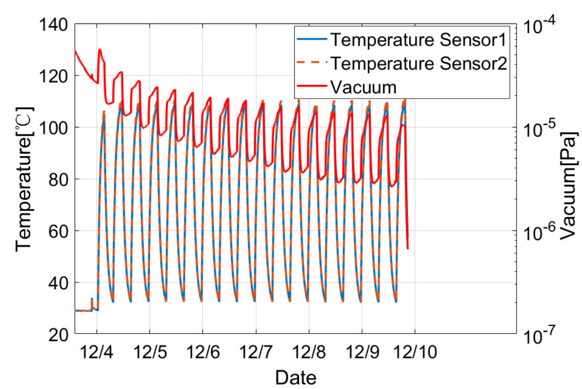

Figure 2: Record of baking condition.

Figure 2 shows a typical record of baking condition for one period. Curves of temperature and vacuum undulates regularly because a heating cycle is used as accelerated aging test to simulate a severe situation for CCiPM assuming that the CCiPM will be used in the accelerator ring. One heating cycle starts at room temperature, ramps to around 120 °C and holds for 4 h, and cools down naturally for the other 4h. The baking was controlled by an automatic timing device and continued for about 1 month.

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Finally, the vacuum could reach 3x10^{-8} Pa and leakage doesn't happen, which shows good heat durability, vacuum tightness, and its cleanliness.

Current Excitation Test

To examine the high voltage endurance, a current excitation test was performed by applying a pulsed voltage of 5 kV to the CCiPM. In the experiment, the peak current could reach to 3180 A at a repetition rate of 10 Hz and the pulse width is 3 µs. And there is no electric discharge in the experiment.

Magnetic Field Measurement.

Both DC and pulsed magnetic field were measured by a 3D mapping device. In the DC magnetic field measurement, it's measured by a hall probe and the current is set as 15 A. As for the pulsed magnetic field measurement, a special probe has been made to measure the pulsed magnetic field precisely with external noise-less condition, which is different from conventional method such as short coil or long coil [3]. The probe could help measure the pulsed magnetic field precisely, even if the useful detection area is so small. 3D mapping measurement is selected to get full information of magnetic field distribution for horizontal, vertical, and longitudinal dimensions.

Figure 3 shows the longitudinal distribution of magnetic field at x = 0 mm, which means the centre of horizontal axis. And the z means the longitudinal axis and z = 0 mm is located at the centre of CCiPM. In the pulsed magnetic field measurement, the current is observed by a current transformer and the magnetic field data are normalized under 15 A.

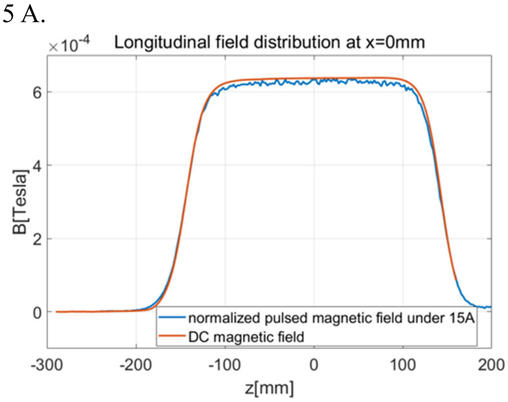

Figure 3: Magnetic field distribution along longitudinal axis.

By comparison of pulsed and DC magnetic field results, the maximum difference is only less than 4% of DC magnetic field, which is in line with expectation that magnetic field generated by eddy current is within a few percentages of main magnetic field, even if there is eddy current generation on coating surface. Although the noise in the pulsed magnetic field measurement couldn't be removed totally, the measurement is still precise within a small systematic error.

Figure 4 is the kick angle on horizontal axis calculated by the integrated-field measurement data. Although the radius of CCiPM is 15 mm, the measurement region is limited due to the width of the measuring arm, which supports the hall probe and may hit the chamber if the region is expanded too widely. And the value of integrated magnetic field could be extracted from the mapping data. The energy is selected as 2.5 GeV which corresponds to the electron energy at KEK-PF.

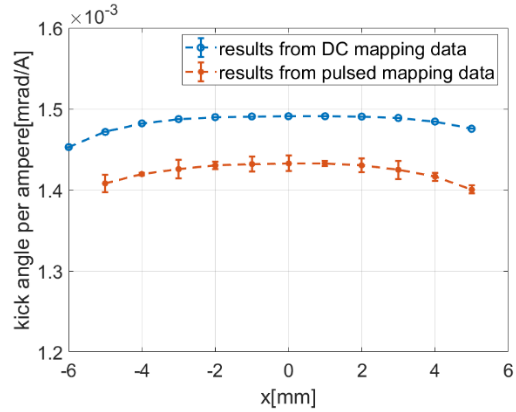

Figure 4: Kick angle calculated from DC and pulsed mapping data.

BEAM PEFORMANCE TEST

After finishing offline measurements, the CCiPM was installed at the beam transport line-dump line as shown in Fig. 5. Beam monitor system has been constructed at BT line to measure the kick angle of CCiPM [4]. And Fig. 6 shows the layout of the monitor system. In the beam performance test, a parallel beam was adjusted by bending magnet BH31, BH32 and BH41. And the kick angle could be obtained by measurement of monitor system.

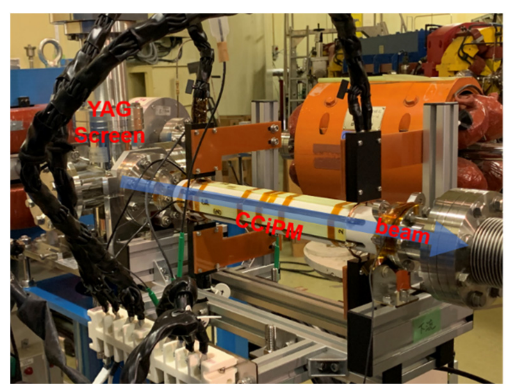

Figure 5: Installation of CCiPM at BT-dump line.

As previously mentioned, CCiPM also has good flexibility for the type of magnetic field. By changing the direction of current flow, different mode could be obtained. Figure 7 shows the horizontal magnetic field distribution of two modes in the simulation. One is the dipole mode (D-mode) if the current direction on each side is different. The other one is the Quadrupole mode(Q-mode), the current direction of four conductors is same. In the experiment, both modes were tested.

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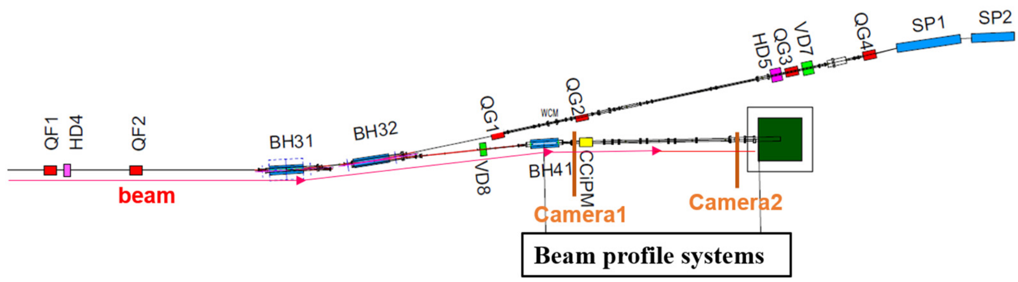

Figure 6: Layout of the monitor system at the BT-dump line.

The current excitation and horizontal survey were performed in the beam test. A parallel beam was adjusted to pass through the center of CCiPM and the kick angle was estimated under different output current. As for the horizontal survey, beam was swept along the horizontal axis, then the horizontal distribution of kick effect could be obtained to evaluate the flatness or gradient of CCiPM.

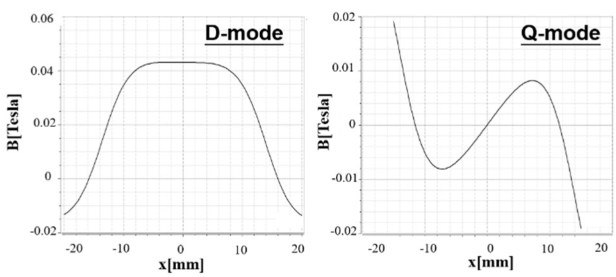

Figure 7: field distribution of D-mode and Q-mode.

RESULTS OF BEAM TEST STUDY

Figure 8 shows the measurement data of kick effect for current excitation. The kick angle is 0.0014 mrad/A from the fitting line. If the fitting error is taken into consideration, the difference of kick effect between beam test result and DC offline measurement is less than 3%, which is within the error of 5% of fitting. It proves the reliability of magnetic field generated by CCiPM.

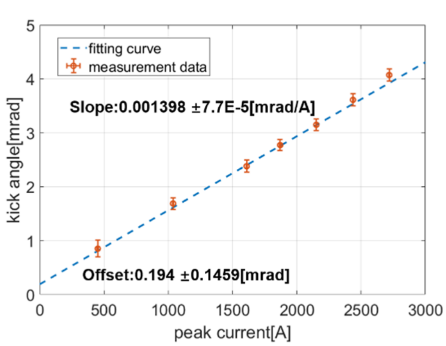

Figure 8: kick effect for current excitation of D-mode.

Figure 9 is the horizontal survey results of D-mode comparing with results of offline measurement, which has been shown in Fig. 4. The horizontal region is expanded in the beam test, but it's limited because there is a beam loss when beam is close to the vacuum duct of BH41 upstream of dump line. The performance of flatness in the beam test is in good agreement with offline-test results.

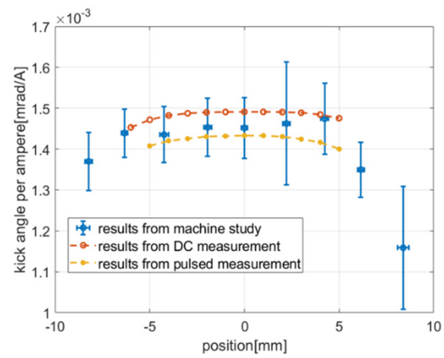

Figure 9: Horizontal survey results of D-mode.

Finally, the horizontal survey result of Q-mode is shown in Fig. 10. Generally, it shows good a nonlinearity and is consistent with the simulation result within the error. But when the beam is far from center, the kick effect doesn't match well with simulation result, which is also happen in Fig. 9. It may be due to Linac beam property and the alignment error of CCiPM setting in this time. This problem will be investigated in the future.

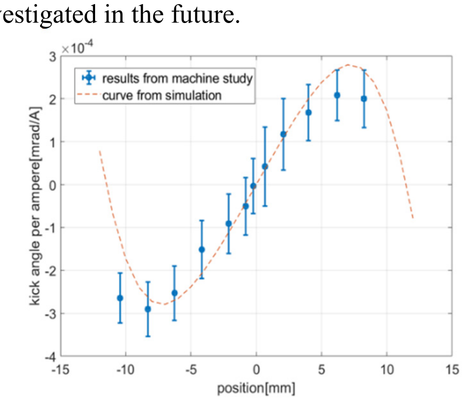

Figure 10: Horizontal survey results of Q-mode.

CONCLUSION

An air core pulsed magnet whose bore diameter is only 30 mm is being developed at KEK-PF. From the offline experimental data, the CCiPM has good vacuum tightness, heat durability and high voltage endurance, which allows it to be installed at the BT line. Performance in the beam test study is compared with offline measurement results for the application in future light source. The beam test data show good consistency with offline measurement results. And because it shows a good nonlinearity, a multipole kicker will be developed for the new injection system at KEK-PF.

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