NEW DEVELOPMENT OF CERAMICS CHAMBER WITH INTEGRATED PULSED MAGNET FOR PULSED MULTIPOLE INJECTION AT KEK-PF

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Abstract

The KEK-PF is now dedicated to the development of pulsed multipole injection scheme. An experiment of pulsed sextupole injection has been performed successfully. Although this method could inject a beam into the storage ring without large perturbation, the stored beam is still disturbed due to eddy current effects of iron core magnet and coating inside of the chamber. To suppress the perturbation completely, Ceramics Chamber with integrated Pulsed Magnet(CCiPM) of an air-core magnet, which is developed specially as fast pulsed kicker, is being expanded to multipole pulsed magnet, which could generate an Octupole-like magnetic field. To examine the performance of Octupole-type CCiPM, some preliminary experiments are conducted such as durability test, current excitation test and magnetic field measurement to evaluate the mechanical performance and magnetic field quality. The design and experimental results will be reviewed.

PULSED MULTIPOLE INJECTION

The pulsed multipole injection scheme has been developed and tested in KEK. In this case, the injection beam is injected into storage ring by one pulsed multipole magnet. And the pulsed multipole magnet provides a nearly zero magnetic field at center where the stored beam passes by. Therefore, the stored beam will not be oscillated, which means top-up injection will be transparent to users. Besides, the pulsed multipole injection scheme only needs one magnet. Compared with bump injection scheme, it is a great advantage from the point of view of space and magnetic linearity of four bump magnets

In 2008, a pulsed sextupole magnet(PSM) was installed at KEK-PF and the beam was injected successfully [1]. However, the beam oscillation still existed. In later research, it's found that magnetic field generated by eddy current induced the beam oscillation. In spite of the fact that the thickness of one lamination steel is 0.15mm, it can't suppress eddy current completely due to a 1.2 μs short pulse width of current [2]. And coating will also generates eddy current field acting on stored beam [3]. Despite the coating issue can be solved by optimizing the shape of coating, the eddy current effects of iron-core is still remained.

Although, the beam oscillation was much reduced at KEK-PF by pulsed multipole injection. It can't meet the requirements about light axis stability in next generation light source, which has much lower emittance and smaller beam size. To suppress eddy current effect completely, air-core pulsed magnet must be developed to replace iron-core pulsed magnet.

CERAMICS CHAMBER WITH INTEGRATED PULSED MAGNET

introduction

The Ceramics Chamber with integrated Pulsed Magnet(CCiPM) is developed by C. Mitsuda and KYOCERA CO from 2012 for pulsed dipole kicker at first [4]. Figure 1 shows schematic view of the initial type CCiPM-D60, whose bore diameter is 60 mm. And the copper conductor is implanted in the ceramics. Some features are listed below.

- Air-core pulsed magnet
- Apply comb coating to reduce eddy current effect
- Low impedance
- Compact and Light with structural strength
- Flexibility of magnetic field

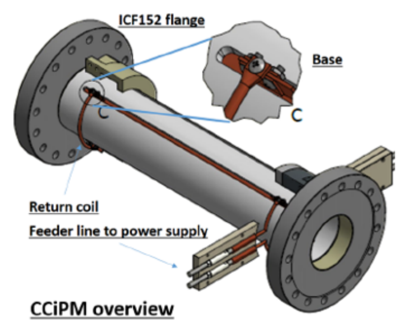

Figure 1: Schematic view of CCiPM-D60.

Based on the theory of air- core magnet which is mainly used in superconducting magnet [5], the CCiPM can generate octupole type magnetic field by placing the conductor properly and applying the parallel current flow. As shown in Fig. 2, an octupole type magnetic field can be generated by four parallel current flows in Poisson.

Thus, it's possible for performing multipole injection scheme by CCiPM.

Design and optimization

Although, in the next generation light source, the diameter of duct is usually about 30 mm, and a narrow bore type CCiPM has been developed with a 30 mm diameter [6]. Though the CCiPM technology has achieved the production of super narrow bore, to examine the injection performance of CCiPM, a prototype CCiPM-D40 has been developed to

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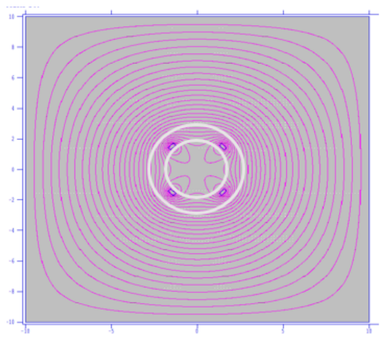

Figure 2: Octupole magnetic field by Poisson simulation.

fit the duct of PF ring. The diameter of CCiPM-D40's duct is 40 mm. And to optimize the octupole magnetic field, the angle between the conductor and the mid-plane is designed to be 45°.

The design target is that performance of magnetic strength at kick point is similar with that of PSM to replace the PSM in the ring, which means that integrated magnetic field is 0.12 mT·m for an off-axis position of x=15 mm. And the applied current is also around 3000 A.

Figure 3 shows the setup of CCiPM. At first, the terminal box was applied to change the direction of current flow. But it's found that the inductance of circuit is 11 μH measured by LCR meter.

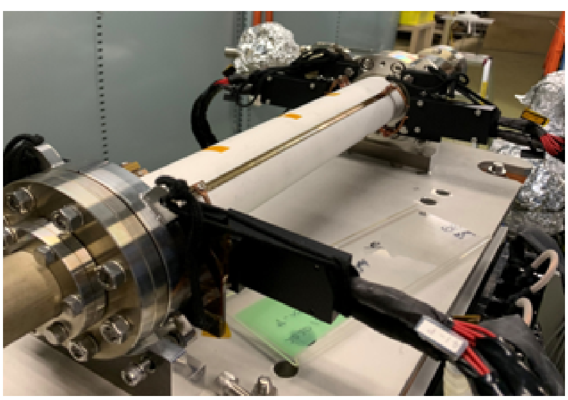

Figure 3: Setup of CCiPM.

In one-turn kick condition, the injection beam will only be kicked at the first turn. Because the revolution period of PF ring is 0.624 μs, the pulse width of power source is designed to be 1.2 μs. And the impedance will be about 30 Ω. The peak voltage will be 90 kV if necessary current is 3000 A, which indicates that the design is non-realistic. There are mainly two reasons why inductance of octupole type model is high. One is that magnetic flux is full of space so that the electromagnetic stored energy is large, which is shown in Fig. 2. The other one is the twisted cable which can reduce impedance of cable in dipole case, because the current flow directions are opposite. But in the case of octupole type CCiPM, it doesn't work because of parallel current flows so that impedance of cable can't be ignored.

To solve these issues, a new model was proposed by adding four additional conductors on the surface of ceramics. The simulation result by Poisson has been shown in Fig. 4. The current flow direction of additional conductor is opposite to the current flow direction of inner four conductors. The stored energy is reduced due to confining the magnetic flux. And the model can be also simplified. Cable and terminal box are not necessary any more for the new model, because the pulsed power supply system can be connected to the CCiPM directly just by using two feed lines.

Besides, magnetic field around kick region to injection beam is also increased. Figure 5 shows the comparison of horizontal distribution when current is 3000 A. The magnetic field at kick point of new model is 0.04 T, which is larger than that of old model(0.033T).

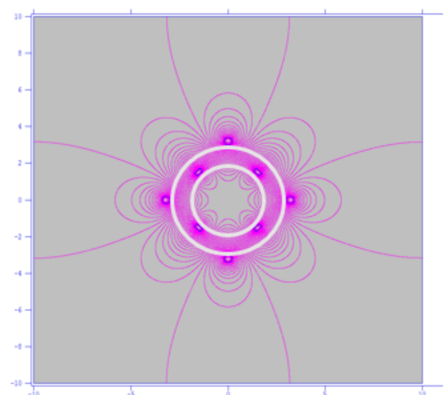

Figure 4: New model by adding additional conductors.

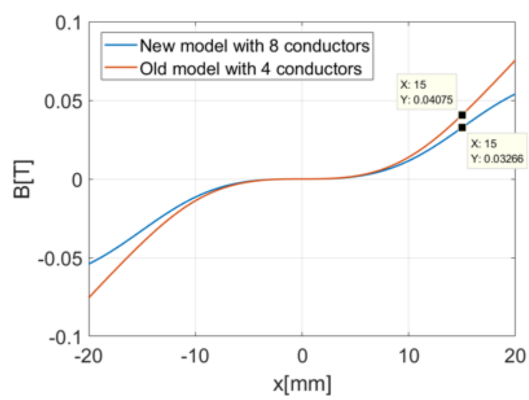

Figure 5: Comparison of horizontal distribution in different models .

And the magnetic field of the new model is also simulated by OPERA-3D, which can help optimize the structure of busbar to reduce the deformation of magnetic field along longitudinal center axis.

Figure 6 is the conductor model in OPERA-3D. The length of each conductor is 290 mm. And the gap of busbar is narrowed to reduce the deformation. The integrated field of B_y along longitudinal center axis is only 9 μT·m. And the integrated field of B_y at x = 15 mm is 11.1 mT·m when

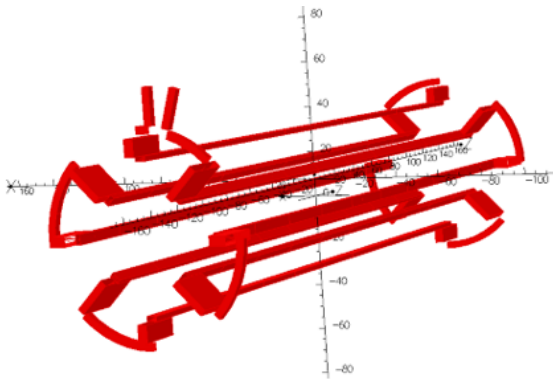

Figure 6: Conductor model in OPERA-3D.

current is 3000 A. It's less than the target value but still acceptable.

To fix the additional conductor, particular support was applied. Special jig holds the conductors precisely to keep them in correct position by using keyway. Figure 7 shows the design of 3D model. And the material of support is non-magnetic to avoid undesirable magnetic field when pulsed current is applied.

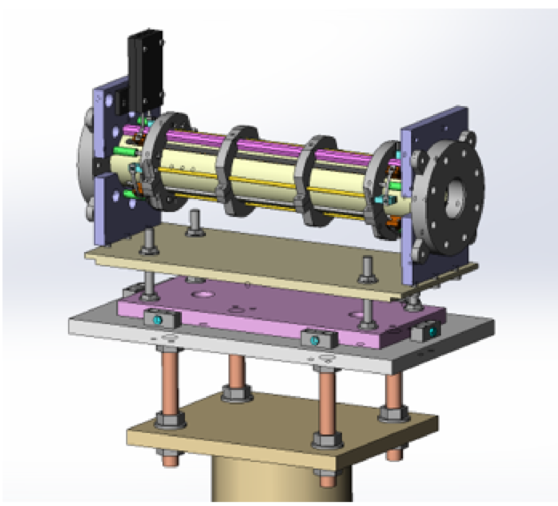

Figure 7: 3D model of CCiPM with four additional conductors.

Coating

As for the coating of CCiPM, uniform coating is applied in design instead of comb coating adopted in dipole-type CCiPM and the material is Titanium. The thickness of coating is 5~8 μm. Based on previous measurement result, the uniform coating inside of a circular chamber hardly influences the magnetic field on the longitudinal center axis. Besides, the reduction of magnetic field strength around kick region is negligible [2]. And transient magnetic field simulation was also conducted to evaluate the eddy current effects by ELF/MAGIC [7]. As shown in Fig. 8, the CCiPM model with coating is constructed in ELF/MAGIC. The gap between the conductor and the coating is 5.2 mm to avoid electric discharge. From the simulation, the magnetic field along center axis isn't distorted by eddy current effect of coating. And the reduction ratio of magnetic field at kick point is less than 1%.

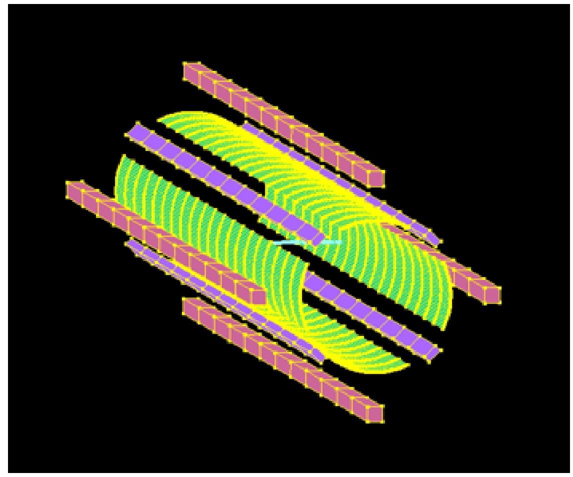

Figure 8: CCiPM model with coating in ELF/MAGIC.

PRELIMINARY TEST

To examine the performance of CCiPM, some offline experiments were performed.

Durability test

First, the baking and vacuum extraction were carried out to check the heat durability and vacuum tightness. To meet the requirement of installation at storage ring, 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.

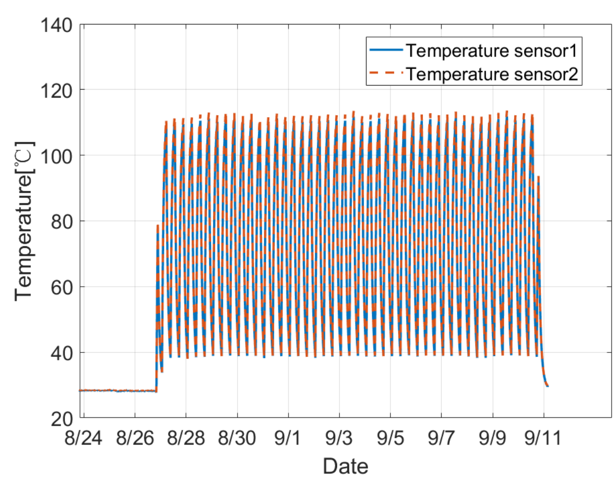

Figure 9: Record of heating cycle baking.

Figure 9 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 ℃ and holds for 4 h, and cools down naturally for the other 4 h. The baking was controlled by an automatic timing device and continued for 38 days totally.

Finally, the vacuum could reach 7.6×10^{-8} Pa and leakage didn't happen, which shows good heat durability, vacuum tightness, and its cleanliness.

Current Excitation test

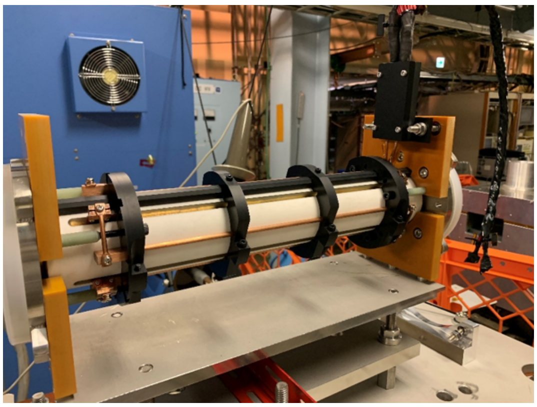

Figure 10: photo of CCiPM on test bench.

As shown in Fig. 10, the CCiPM was constructed on test bench. And the inductance is 1.45 µH measured by LCR meter, which is dramatically reduced compared with previous original model. To examine the high voltage endurance, a current excitation test was performed by applying a pulsed voltage to the CCiPM. The result is shown in Fig. 11.

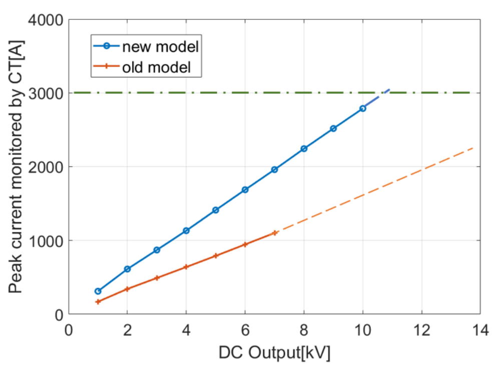

Figure 11: Result of current excitation test.

The peak pulsed current in experiment of new model is close to 3000 A with a repetition rate of 10 Hz, but there is a limitation of power source output. It also shows good linearity and the pulse width of power source is 2.6 µs. And there is no electric discharge in the experiment. And from the comparison with result of old model, the impedance of new model becomes much smaller so that the current increased much compared with that in experiment of old model.

Magnetic field measurement

Both DC and pulsed magnetic field were measured by a 3D mapping device. In the DC magnetic field measurement, magnetic field 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 with external noise-less condition, which is different from conventional method such as short coil or long coil [2]. The photo of pulsed magnetic field measurement is shown in Fig. 12.

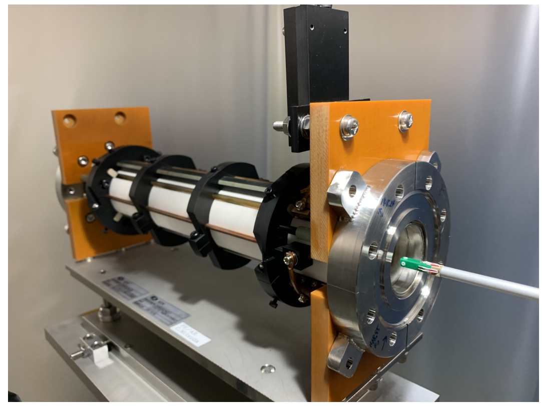

Figure 12: Photo of pulsed magnetic field measurement.

And from comparison of horizontal measurement results at center, which is shown in Fig. 13, it can be seen that DC magnetic field result is almost same with simulation, but there is a reduction in pulsed magnetic field measurement. It was though that the reduction of pulsed magnetic field was caused by the SUS stage plate, copper conductor itself and so on. These candidates as the eddy current source are removed by simulation test. More details should be investigated in the future.

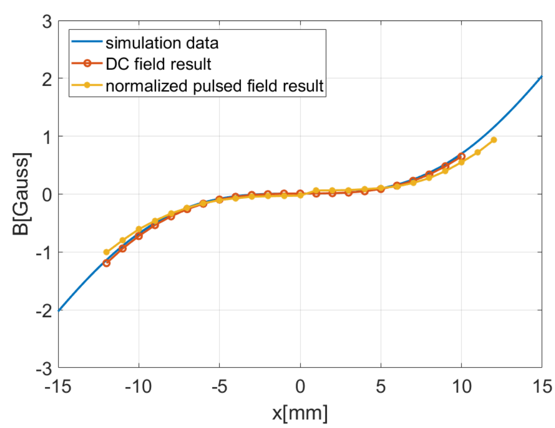

Figure 13: Comparison of horizontal distribution at center.

CONCLUSION

To solve the stored beam perturbation problem in pulsed multipole injection, air-core pulsed magnet must replace the iron-core pulsed magnet. The CCiPM, which is developed for a dipole kicker, is being developed and expanded to an octupole type pulsed magnet. A prototype of CCiPM with 40mm diameter has been made to fit the duct of PF. And additional conductors are designed to be on the surface of ceramics chamber to reduce the inductance. From the simulation, the kick effect of CCiPM is almost same with that of PSM at kick point. And some preliminary tests has been conducted to examine performance. The mechanical performance is good enough and high voltage endurance is reliable. But in the magnetic field measurement, it's found that normalized pulsed magnetic field is smaller than DC result, which is against expectation. Further investigation is needed to understand unknown issues.

ACKNOWLEDGEMENTS

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