SUPPRESSION OF BUNCHED BEAM INDUCED HEATING AT THE DCCT TOROID

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Abstract

The DC current transformer (DCCT) measuring the stored current of the PF ring encountered a heating-up problem. The temperature of the DCCT toroid increased over 70 degree C under the single-bunch operation. Large fluctuations of the measured current and some error in the absolute value frequently followed the heating-up. We made a new DCCT duct with a thin ceramic gap that had a large electrostatic capacitance. The new gap was confirmed to be quite effective to reduce the RF power invading the DCCT toroid. It becomes possible to measure the current with sufficient stability even at high current under the single-bunch operation.

1 INTRODUCTION

The Photon Factory (PF) ring of KEK is a 2.5 GeV synchrotron radiation source that has a circumference of 187 m, or the revolution frequency of 1.6 MHz. The PF ring was reconstructed to a high-brilliance lattice last year and is now operated for users at the emittance of about 35 nm rad[1].

For the convenience of various time-resolved experiments, single-bunch operation is scheduled several times each year. Before the reconstruction of the ring, we had some problems on current measurement at the single-bunch operation. When the bunch current was stored at 60 mA initially, the temperature of the DCCT toroid increased to over 70 degree C. Slow but large fluctuations in the current measurement followed the heating-up. Some error in the absolute value was also observed frequently. The source of the heating at the DCCT toroid was attributed to the eddy current loss induced by the bunched beam[2]. RF-power dissipation was occurred in the DCCT cores. There was a ceramic gap inside the DCCT toroid in order to break the vacuum tube electrically. Unnecessary high-frequency power from the beam invaded the cores through this gap. But the electric break is indispensable to stop stray current on the vacuum duct. Because the DCCT is operated with AC modulation to the magnetic core, the electric break is also important to protect the DCCT from unexpected oscillation.

In order to settle the heating-up problem, we have installed another DCCT with a thin ceramic gap that had an adequate electrostatic capacitance. In this report, we will describe the performance of the newly-installed DCCT together with some failures experienced at the current measurement using the previous DCCT. The toroidal sensors and the electronics of the both DCCT were purchased from the Bergoz Corporation[3]. The two sensors have the same dimensions, and the both electronics have the same specifications such as measurement ranges, resolution and stability.

2 INSTALLATION OF DCCT

Figure 1 shows a schematic view of the newly designed vacuum duct to install the DCCT toroid. The cross section of the duct is an octagon fit to the quadrupole-magnet bore. The electrical break was constructed by a thin alumina ceramic plate sandwiched by Kovar metal plates. The ceramic plate and the metal plates were 0.5 mm thick. At the both outsides of the metal plates, 3 mm thick ceramic plates were brazed together to protect the Kovar plates from any warp. The ceramic break was fabricated by the Kyocera Corporation. It seemed to be rather difficult to find a good condition for the brazing because of the thinness and the non circular cross section.

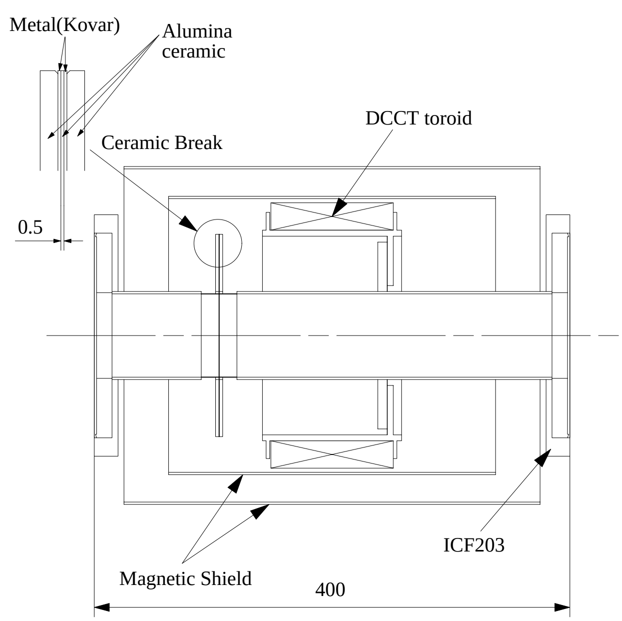

Figure 1 : A newly-installed vacuum duct for the DCCT. The ceramic break constitutes a capacitor of 2.6 nF.

The area of the capacitor with the ceramic plate as a dielectric was amount to 150 cm^2. The relative dielectric constant of the adopted alumina ceramic is 9.7. The capacitance could be estimated at 2.6 nC. This value well coincided with the measured capacitance at the frequency range from 100 Hz to 1 MHz. No frequency dependence was observed in that range. The insulation resistance and the voltage withstanding of the gap were checked using an insulation tester. There was no problem by the measurement at 2000 MOhm, 1000 VDC range.

At the outside of the DCCT toroid, two cylindrical magnetic shields of Mu-metal were placed against the DC stray magnetic fields. At this spatial configuration, the shielding factor against to the transverse field was estimated at the order of 10^2[4]. The zero drift due to the stray fields was well suppressed within about 10 micro A, even at the maximum exciting currents of the bending and quadrupole magnets.

Bake out of this duct was performed preceding the installation to the ring. The DCCT toroid and the magnetic shields could be removed at the bake-out.

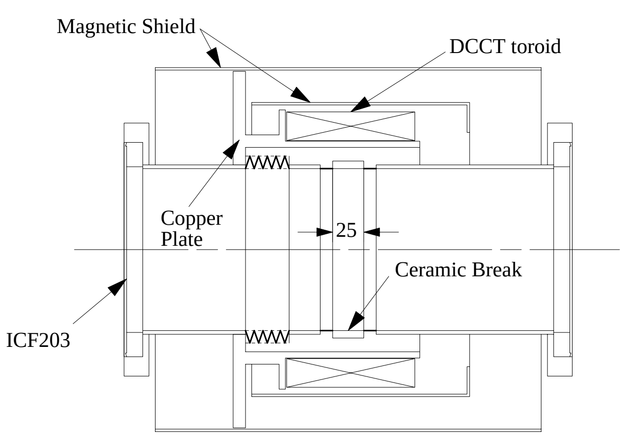

Figure 2 : Schematic view of the previously-installed DCCT duct.

In Figure 2, the previous design of the vacuum duct for the DCCT is shown[4]. This duct had a circular cross section. Except for the cross section, the major difference from the newly-installed DCCT duct was the shape of the ceramic break. The old gap was made of a 25 mm long ceramic cylinder. Because the aim of the gap was to break stray DC current, no metallic coating was given at the inside of the ceramic cylinder. This gap had only a stray capacitance of the order of 10 pF. This DCCT duct has been used about 6 years. In that period, we experienced some problems in the current measurement especially under the single-bunch operation. At present, the both DCCTs are installed in the ring at the same time. So we could compare the performance of the two DCCTs directly.

3 SOME RECORDS OF THE CURRENT MEASUREMENTS

Figure 3 and figure 4 are records of a single-bunch operation at the commissioning stage of the low-emittance lattice. In the both figures, the previously-installed DCCT is denoted as DCCT1, and the new one is denoted as DCCT2. The measured beam current by the two DCCTs are drawn. The measured temperature of each DCCT toroid and the new ceramic gap are also shown in the figures. The temperature measurement were performed using an optical-fiber thermometer that was not affected by any electromagnetic interference.

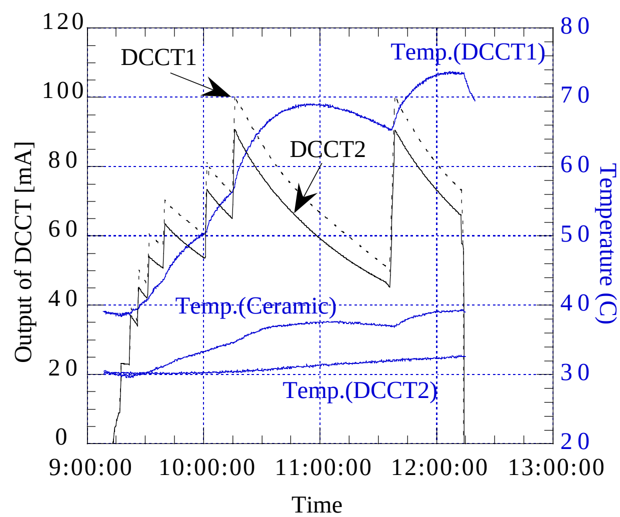

Figure 3 : A record of DCCT outputs and temperature at the single-bunch operation. No significant heating-up was observed for the newly installed DCCT2, in contrast with the previously installed DCCT1.

Firstly, it is noticeable that the temperature of DCCT1 toroid increased rapidly when the current was stored at as high as 100 mA. The maximum temperature exceeded 75 degree C in one hour, that was near the dangerous temperature affecting the magnetic characters of the cores. Previously, the maximum current stored in the single-bunch mode was mainly restricted by this heating-up problem, though some failures in the current measurements described below were also taken into account. At present, any extra cooling method is not applied because it was observed that some easy cooling introduced a larger fluctuations in the output of the DCCT. In the contrast with the DCCT1, the heating-up was not observed at all for the DCCT2 toroid. The maximum increase of the temperature was only within 3 degree C during these measurements. The power dissipation in the DCCT toroid was estimated from the rate of temperature change using a factor of 90 [degree C/h]/W[2]. At the current of about 100 mA, they were 1.3 W at the DCCT1 and 0.1 W or less at the DCCT2, respectively. It can be said that the noise power invading to the DCCT is suppressed more than one order of magnitude by introducing the thin ceramic gap. The heating-up of the ceramic break itself was not significant, too. The temperature of the old ceramic gap was observed to be rather higher than the DCCT toroid though it was not shown in the figures. Although the RF noise might be shielded by an electromagnetic shield at the outside of the DCCT, the wide ceramic gap would increase the impedance of the vacuum duct.

The usual operation mode of the PF ring is the multi-bunch (250/312-fill) with an initial current at 400 mA, typically. At the current of 400 mA, the power dissipation at the DCCT1 was estimated at about 0.1 W. At the multi-bunch mode, no failures in the current measurement were observed until now.

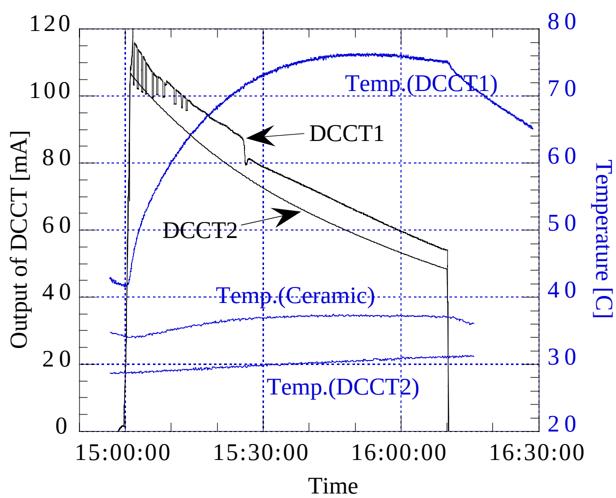

Figure 4 Another record of the single-bunch operation. The output of the DCCT1 fluctuated discontinuously at the high current.

Secondly, it was noticeable that there were some discrepancies between the outputs of the two DCCTs. In the figure 3, the outputs of the DCCT1 was larger than that of DCCT2 by a factor of about 10 %. But that factor did not reappear on another day even if the beam current was at the same value. So it was impossible to recalibrate the output for the single-bunch mode. An example that verify the lack of the reappearance is found in the next figure. In the figure 4, some discrete changes in the output of the DCCT1 was observed especially in the very high current range. The steps of the output jumps were distributed from a few mA to 15 mA at maximum. These discrete jumps obviously proved the failure in the measurement by the DCCT1.

Such discrepancies or jumps of the output did not appear under the multi-bunch operation. The outputs of the both DCCTs well coincide with each other. The difference between the two outputs was as small as 0.3 mA even at the 400 mA. This difference is the same order to the difference between the zero offset of each DCCT. Under that stable condition, the resolution of the current measurement was estimated at 2 micro A, when the data were acquired with a 20-ms integration. In the case of DCCT2, power loss in the cores was small enough at the high current under the single bunch. So we infer that the newly-installed DCCT is operating normally also under the single-bunch operation. The current limit due to the DCCT will be well relaxed to over 100 mA.

In figure 5, the fluctuations observed in the output of DCCT1 under the heating-up condition was shown in expanded axes. The characteristic time of the fluctuations was so long that usual electrical filters was not effective to eliminate them. These troublesome fluctuations could also be eliminated by suppressing the heating-up of the DCCT toroid.

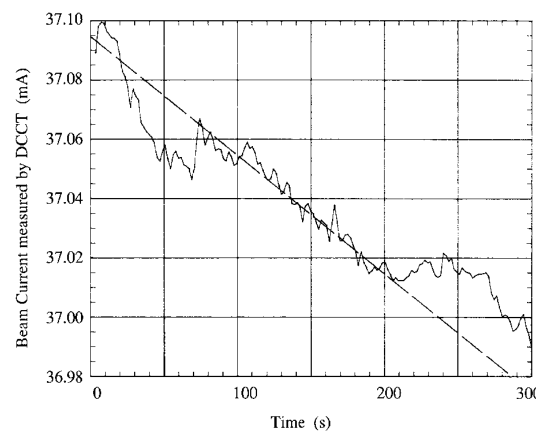

Figure 5 : Slow fluctuation observed in the output of the DCCT1 at the single-bunch operation.

4 CONCLUSION

The newly installed DCCT is working with sufficient stability and resolution under any operating conditions at the PF ring. As constructing the adequate capacitor by the ceramic gap itself, it would be effective to lower the impedance of the vacuum duct. The previously installed DCCT duct that acted as an RF noise source and restricted the maximum stored current will be removed from the ring in the near future.

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