COD CORRECTION BY NOVEL BACK-LEG DRIVE AT THE KEK-PS BOOSTER

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Abstract

The correction of closed orbit distortion is performed by using new driving system of back-leg windings. Two back-leg coils of separate magnets are connected to make a closed circuit in which the induced voltages of the two magnets have opposite phases to each other. When the current source is inserted into the closed loop, the current drives the two magnets with opposite polarities. If the pair of magnets is properly selected, the current effectively corrects the orbit distortion. The selection rule of the pair is as follows; one is the magnet at the maximum distortion and the other magnet is that separated with −90deg in betatron phase. The correction system at the KEK-PS Booster reduced the closed orbit distortion to less than 1/6 of that without correction, and increased the capture efficiency. The average beam intensity of our booster is increased from 2.0×10^{12}ppp to 2.8×10^{12}ppp.

Advantages of the drive system are as follows; (1) this scheme has no interaction between the power supply of main magnet and that of correction system, therefore (2) this scheme is very stable and reliable, (3) this reduces the cost for the orbit correction, and (4) this scheme is applicable to compact synchrotrons.

1. PRINCIPLE AND POWER SUPPLY

The KEK-PS Booster consists of eight magnets (M1 ~M8), and the magnets are separated with straight sections (S1 ~ S8) having the length of only 1.9m. Nearly all straight sections are occupied with the instruments, such as, RF systems, injection and extraction systems, and other correction magnets. That is, we have no space to install the magnets to correct the closed orbit distortion (COD). Therefore operation of the back-leg orbit-correction system is indispensable for our booster.

We use the back-leg windings of a pair of magnets, and connected them with current source as shown in Fig. 1; the two induced voltages at the back-leg windings due to the change of main magnet power supply are cancelled at the current source. Let the separation of the magnets be 90°-betatron phase angle and orbit bump at the center of magnet-2, then the current of back-leg winding at magnet-1 cancels the orbit bump at magnet-2, and the extra bending angle of the magnet-1 is cancelled by that of the magnet-2. Thus the pair of kicks minimizes the effect onto the orbit at the other position of the machine.

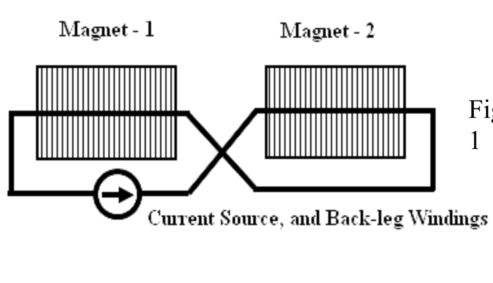

Figure 1

The second scheme is shown in Fig. 2; where windings of the three magnets are used to compensate COD.

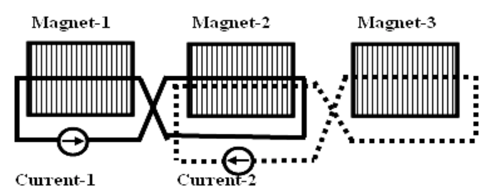

Figure 2

We installed terminal boards at the yoke of magnets. On a board eight terminals of the ends of four back-leg windings, and four terminals of four ends of cables connecting from magnet to magnet are attached. Therefore we can easily change the connection at this terminal board. For example, we selected the connection of 4-turns at each magnet for scheme-1, and connection of 2- turns for scheme-2.

The bend angle of Booster magnet is 45° (= 785.4 mrad) at 67.9kAT at the top energy, and 16.48kAT at injection. Therefore the kick angle due to the current at the back-leg winding is 11.6[μrad/(AT)] at the top, and 47.6[μrad/(AT)] at the injection. In order to compensate 0.5% of bend angle, the current of 340AT is necessary. Because we only have a COD-data at injection, we designed the power supply having output current of ±100A to make some overhead. Table 1 summarizes the constants and specifications of the power supply.

Table 1

Back-leg Coil Inductance	15.4 [μH/(turn)^2]
Maximum turn number	4
Current/Deflection at 40MeV	21.0 [AT/(mrad.)]
Current /Deflection at 500MeV	82.5 [AT/(mrad.)]
Number of Power Supply	2
Power Supply Output Voltage	±50 V
Output Current	±100 A
Response at small current	1 kHz
Loop gain at 20Hz	~70 dB
Response at maximum current.	200 Hz
Cable length from PS to Magnet.	85 m

Main magnet winding has the inductance of 24.65mH at 40-turn, this indicates that the inductance per square turn is 15.4μH/(turn^2). With assuming inductance of four turns winding and that of 100m feeder cable, the inductance seen by the power supply is nearly 0.6mH. In order to operate 100A at 100Hz (repetition frequency of Booster is 20Hz), the maximum output voltage must be larger than 38V, where the value neglects the contribution from the resistance of the load. We designed as the maximum output voltage of the power supply can be selected from the following values; ±36V, ±40V, ±45V, ±50V, and ±55V.

The band-width of the power supply for a small amplitude signal is designed to be 1 kHz. In order to increase the accuracy, the second-order compensation technique is introduced in the current feedback loop.

2. THE FIRST EXPERIMENT

At the first step, we concentrated on the correction at beam injection. Using the matrix calculation of OFDDFO lattice, we reconstructed the measured COD [1]. In the figure 3, rounds (red) at circumference points of 16, 46, 51, 91, and 106 are measured data, and square marks (blue) indicate orbit deformation produced by the pair of kicks. The pair of kicks (3mrad) is shown by delta functions at the center of the graph. Therefore, if we reverse the direction of the kicks in the figure, the COD will be reduced to the points indicated by diamonds (pink). Even at single magnet-pair correction COD can be reduced to 1/3 of that without correction.

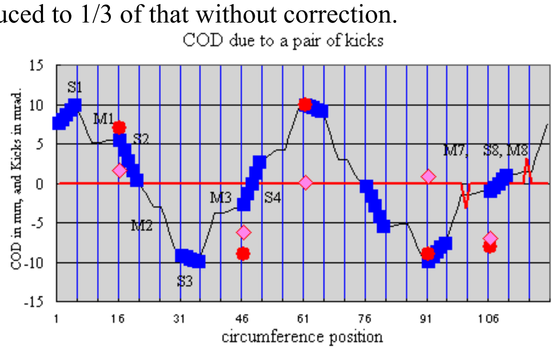

Figure 3

The kicks due to the back-leg current is introduced at the center of magnet and kick angle is just the twice of that given by the current on the winding. The reason is explained as follows; beta function at magnet center, β_H^C = 1.5m, and that averaged over the magnet, $<\beta_H>$ = 3m, therefore kick angle localized at magnet-center must be multiplied by 2 = $<\beta_H>/\beta_H^C$.

We connected the 4-turn windings of M7-M8 pair. We adjusted the current on the winding to a value where the beam loss at the capture becomes minimum value. The best operating current is 32AT. This gives a pair of kicks of ±1.5mrad which are just the expected values by our simulation. This operating mode is used from June to July 2003.

3. THE SECOND EXPERIMENT

The second experiment consists of two purposes; one is the compensation using three series of magnets shown in Fig 2, and the other is to compensate COD of entire accelerating period.

As shown in Figure 4, if we use the compensation using three magnets, COD at the beam injection can be

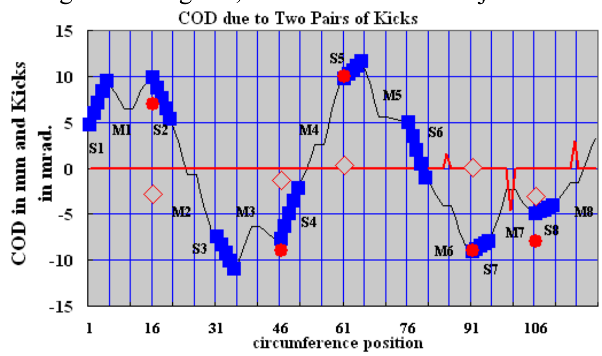

Figure 4

reduced to 1/6. The best current for M7-M8 pair is 32AT, and that for M6-M7 pair is 16AT. The best operating currents at beam injection are also the same values which are expected by the simulation.

Next step of our experiment is to reduce COD at entire accelerating period. Since we have only one position monitor, which is placed at S5, we can control the orbit during the acceleration by using this monitor.

We adjusted the compensation current to the value where aperture of the accelerator has its maximum value.

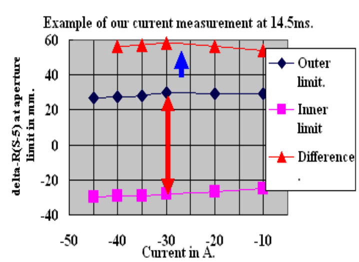

Figure 5

Figure 5 shows an example of our measurement of machine aperture at 14.5msec after beam injection. By changing the current on winding, outer and inner limits of beam position are plotted by diamonds (blue) and squares (pink), respectively. The maximum of difference of the two data (red arrow) must be the widest aperture (blue arrow).

Figure 6 shows the orbit tolerance against back-leg current at several timings from beam injection. Arrows indicate the widest orbit tolerance or widest aperture.

In the Figures 5 to 7, current value of M7-M8 pair is indicated. The current for M6-M7 pair is one half of that of M7-M8 pair.

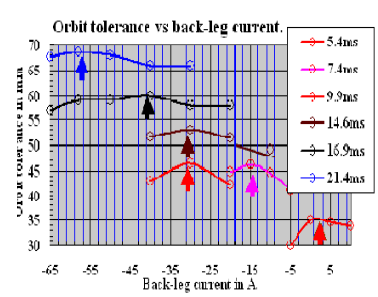

Figure 6

From Figure 6, we can determine the current pattern which gives the widest aperture during acceleration. The current pattern is shown in Figure 7. In the Figure, red squares show the current pattern which makes symmetric orbit tolerance with respect to orbit center.

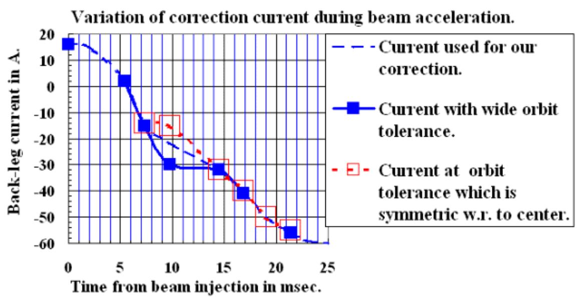

Figure 7

Figure 8 shows a photo at operation. Line at the top (pink) is the current of M7-M8 windings, and the next (light blue) is that of M6-M7 pair. At 8 ~ 10msec from beam injection, they have the influence of noise due to the beam current. The third line (dark blue) is the beam intensity for the neutron facility. In this case, apparatus to inject beam is not adjusted properly, and very fast loss at beam injection is observed in the figure.

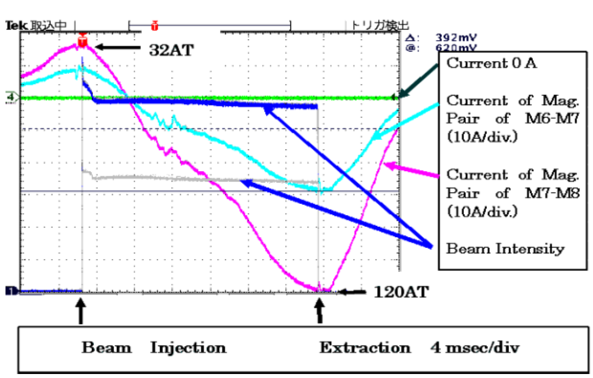

Figure 8

Technical Problem; At an early stage of our experiment, we suffered from the effect of noise due to RF component of the beam current onto DCCT which is used for the feedback control in the power supply. The noise produced large error-current at the output of DCCT. This error-current was so large to activate the protection circuit in the power supply. The effect of the noise was minimized by shielding the DCCT and its output cable. At the second stage of our experiment, we installed the shunt resistor with operational amplifier to control the current of the power supply. Even by this improvement, noise due to the beam current could not completely be suppressed as shown in Figure 8. This noise also affects on the beam orbit

Improvement of Beam-Capture Efficiency is clearly observed by the correction. Average beam intensity is increased from 2.0×10^{12}ppp to 2.8×10^{12}ppp. Beam loss at the capture process is reduced to 15% of the injected beam. This loss is not avoidable because Booster has the threshold of coupling resonance at 1.2×10^{12}ppp [1]. At a trial experiment of the superposition of the second-harmonic RF, the loss could be reduced to ~10% [2]. Further reduction of the beam loss is planning by shifting the horizontal betatron tune to avoid the resonance.

Other Effects of the Correction; (1) the orbit at extraction septum magnet is shifted to outer side by 6.5 mm, which reduced the current of bump magnets by 30%. (2) COD at the position monitor is shifted to inner side by 9 mm, which increased the extracted proton momentum by ~0.6% due to the finite dispersion at the monitor.

4 DISCUSSIONS

ADVANTAGES of the drive system are as follows; (1) this scheme has no interaction between power supply of main magnet and that of the correction system. Therefore (2) this back-leg drive scheme is very stable and reliable in real operation; whereas all back-leg drive systems using traditional scheme at the KEK-PS are failed to apply in real operation due to the troubles on drive power supplies, this new correction system is working in daily operation without any troubles from an early stage of its operation. (3) The scheme simplifies designation of the power supply, and (4) reduces practical number of power supplies for the correction. Therefore (5) it reduces the cost. In particular, if one compensates COD only at injection period, an inexpensive commercial DC power supply can be used for the current source. (6) This scheme can be applied to compact synchrotrons, which must have no space to install steering magnets [3].

DISADVANTAGE of the scheme is that the correction is not perfect, which is the result from the limited number of magnet-pairs and drive power supplies. If we increase the number of correction magnet-pairs, accuracy of the orbit correction will be increased.

Since all authors of this report are not a specialist on the transverse motion, magnet-pairs in the report were found by a primitive method. Specialists must know a more sophisticated method to select the magnet-pairs, and also they must know the way to apply the scheme to a larger accelerator.

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