IEEE Transactions on Nuclear Science, Vol. NS-26, No. 3, June 1979

CLOSED ORBIT CONTROL SYSTEM FOR MAIN RING OF KEK-PS

Kuninori Endo and Ainosuke Ando*

Summary

Closed orbit deviations of the main ring of KEK-PS are corrected at injection by supplying individual currents to 56 steering dipoles placed downstream of quadrupole magnets. Half of them are used for the correction of the horizontal orbit and the rest for the vertical orbit. Correction is made by making a local closed orbit with three successive dipoles to negate the reading of the position monitor. With this system, the same procedures are repeated for all position monitors distributed around the main ring under the manual operation mode. The system also furnishes the online correction using the accelerator control computer by taking the beam position data into it.

Introduction

An equilibrium orbit in a circular accelerator is affected by the magnetic field errors such as dipole field error, displacements of quadrupole magnets and higher order multipole correction magnets, and the stray field. In general, the equilibrium orbit suffering these fields is distorted and is different from the designed one (central orbit). Unless correcting distortion, the orbit diplaces from the central orbit by more than a few centimeters. The beam is lost if the orbit occasionally goes beyond the aperture in which the beam is allowed. To avoid the beam loss at injection when the beam size is large, the equilibrium orbit must be corrected by applying the dc dipole field.

The KEK-PS main ring has 28 cells of FODO structure. The correcting dipoles were placed downstream of the focusing quadrupole magnets to afford the efficient correction. The 28 horizontal and 28 vertical steering dipoles are installed.[1] Each dipole is controlled individually from the central control room (CCR). Practically, the orbit correction is made by superposing the local closed orbit bump established with three successive steering dipoles all around the main ring so as to negate distortions detected with the position monitors.[2] These procedures can be easily made with the closed orbit correction (COC) system at the CCR. This system is linked with the accelerator control computer (ACC) system[3] MELCOM-70 in order to correct the orbit by calculating the required currents of the steering dipoles from the data of the position monitors which is also linked with the ACC system.

Closed Orbit Control System

If the parameters among three successive horizontal (or vertical) steering dipoles are as given in Fig.1, the following relation is obtained,

$$\frac{\theta_1\sqrt{\beta_1}}{\sin\psi_2} = \frac{-\theta_2\sqrt{\beta_2}}{\sin(\psi_1+\psi_2)} = \frac{\theta_3\sqrt{\beta_3}}{\sin\psi_1}. \qquad (1)$$

In the KEK-PS main ring, $\beta_1 \simeq \beta_2 \simeq \beta_3$ and $\psi_1 \simeq \psi_2 \simeq \pi/2$, so the approximate relations are as follows,

$$\theta_1 \simeq \theta_3 \quad , \theta_2 \simeq 0 \qquad (2)$$

for the tune of ∿7.25. For the different tune, however, one should evaluate them from eq.(1). Relations among deflection angles (θ_1, θ_2, and θ_3) are treated exactly in the COC system.

The COC system can be operated by either of three modes. Usually, the manual operation or the online operation through the ACC system is used at the CCR. In the case of failures of these modes, however, an individual current can be set *in situ* under the local control of each power supply.

Layout

Layout of the COC system is shown in Fig.2 which gives the geometrical relations among steering dipoles, power supplies and the control station.

Power supplies are installed in 4 service houses (A41∿A44, each contains 14 power supplies) which are connected through the cable pits to the main ring. The 3.5 mm^2 power cables are stretched from power supplies to the nearby steering dipoles so as to save the cable cost. A control cable to control all power supplies consists of 4 sets of the 1.25 mm^2 twisted pair wires, each pair having the Cu mesh shield and moreover all pairs being surrounded with the outermost shield. Three pairs are used to transmit the timing signal, digital data of the exciting current of each

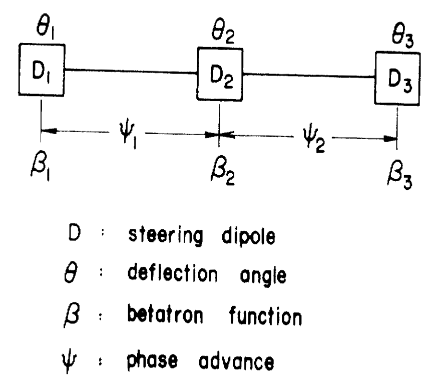

Fig.1 Parameters required to make a local orbit bump with three steering dipoles.

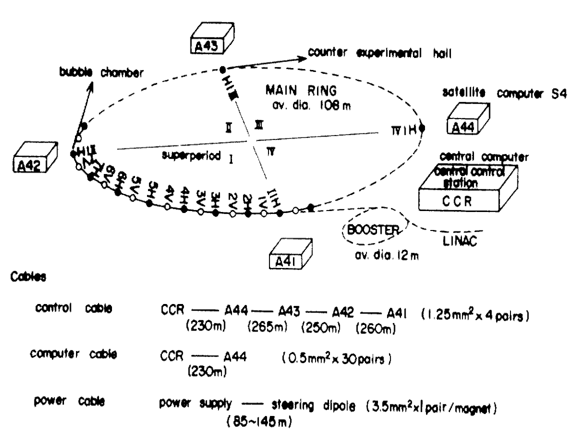

Fig.2 Geometrical view related to the COC system and cable connections.

* National Laboratory for High Energy Physics, Oho-machi, Tsukuba-gun, Ibaraki-ken, 300-32, Japan

0018-9499/79/0600-3328$00.75 © 1979 IEEE

power supply, and analog current data from power supplies to check the difference between data and real load current individually. The rest is not used at present. The control cable from the control station at the CCR is stretched to all service houses connecting all local control stations.

Linkage with the ACC system is made through the 0.5 mm^2 computer cable with 30 pairs via a satellite mini-computer S4 in the service house A44. Whole COC system is shown in Fig.3.

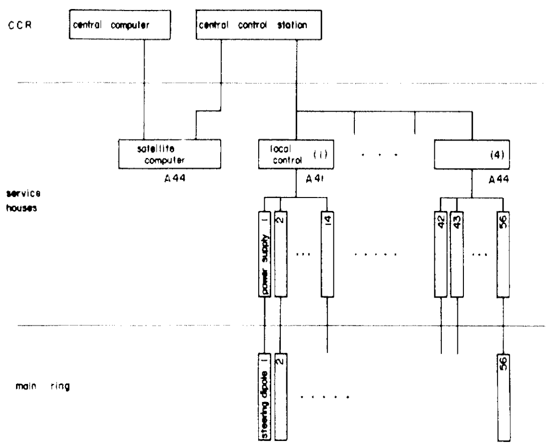

Fig.3 Whole COC system.

Current Data Generation

So far the closed orbit is corrected in many cases under the manual operation mode. By this mode currents can be set by making use of pulses from the rotary encoder which generates 1000 pulses a revolution. The block diagram for the current data generation is shown in Fig.4. Pulses are demultiplied by the preset value of the digital switch so that one revolution of the rotary encoder gives the moderate current variation. Normally the clockwise rotation corresponds to the increase and *vice versa*. But the sign can be inverted by the polarity switch which is useful when the local orbit bump is required at the tune different from the designed one.

An above description is appropriate to the occasion when the current of a steering dipole is changed (Single mode). If one wants to make the local orbit bump at an appointed place (Bump mode), the same pulses are demultiplied into three ways with three preset values of three digital switches and then counted with three up/down counters whose counts are memorized within the cycle time of the COC system (0.2 sec) after added to (or subtracted from) the old data stored in the core memory system. When the position

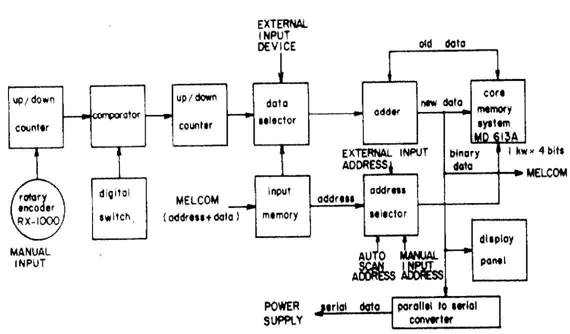

Fig.4 Block diagram showing the current data generation at the control station of the COC system.

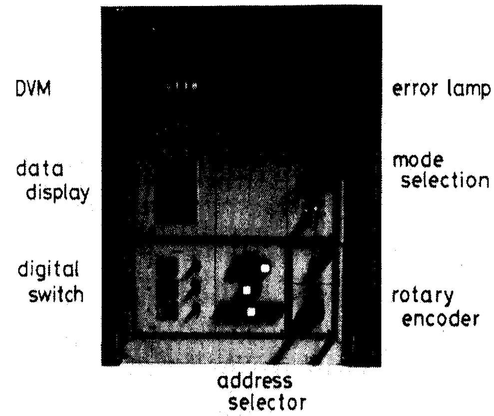

Fig.5 Control station at the CCR. Any steering dipole can be selected by pressing the address buttons.

of the local orbit bump is appointed at the control station, one steering dipole is selected and then the adjacent upstream and downstream steering dipoles are selected referring to the ROM (read only memory, IM5610). The manual control station at the CCR is shown in Fig.5.

Each steering dipole gives the orbit displacement of half an aperture horizontally (or vertically) at a cell downstream by the maximum current of 3A which corresponds to 726G for the horizontal steering dipole giving the 22 cm effective magnetic length and 293 G for the vertical one giving the 21 cm effective magnetic length.[1] The 3A is divided in 256 steps, that is, the current resolution is 12 mA (in other words, 0.3 mm a step at a cell downstream). Individual current can be expressed with 8 bits for data and 1 bit for polarity. In addtion, an address is expressed with 6 bits (2 bits for superperiods, 1 bit for horizontal or vertical, and 3 bits for position in a superperiod).

Current Data Transmission

Data stored in the core memory system of Fig.4 are transmitted sequentially to 4 local control stations as shown in Fig.6 through the transmission line (control cable) after converting the parallel data into the serial data. The local control stations distribute data to power supplies, each having a

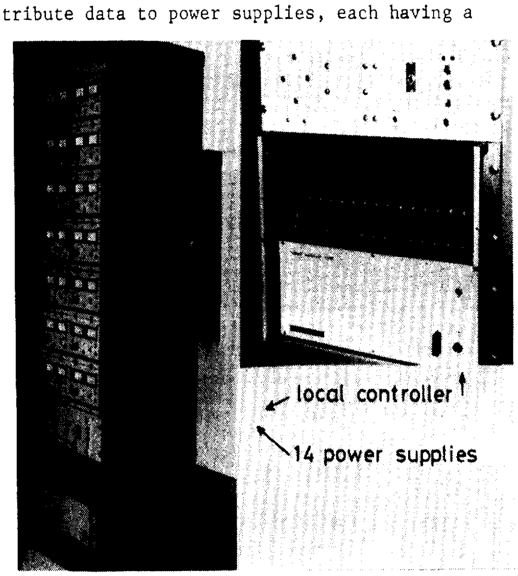

Fig.6 Local control station and 14 power supplies installed in a service house.

proper address, according to the sequential order. The current data transmission is made bit by bit in coincidence with the 5 MHz clock pulse generated by the quartz oscillator (the double current return-to-zero system is adopted for the data expression). The block diagram of Fig.7 shows the data transmission to a power supply. The timing signal in Fig.7 is used to initialize the address counters so as to accord with the data sequence. One data is composed of 16 bits (1∿8th bit for data, 9th bit for polarity, 10th bit for scanner described below, 11∿16th bit are not used).

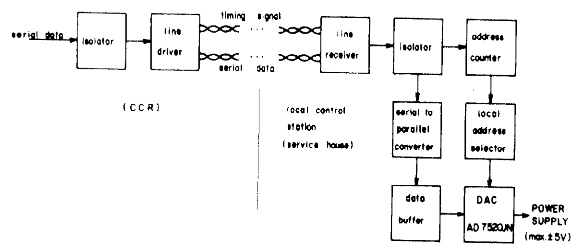

Fig.7 Current data transmission to the individual power supply from the CCR. Each power supply has a respective data buffer and a digital-to-analog converter.

Failure Detection

Real currents exciting the steering dipoles can be scanned periodically by reading the voltage developed in the shunt resistor in the individual power supply with a digital voltmeter (DVM). Each scanning time is 2.5 sec including the settling time of DVM. Timing to measure current is given by the 10-th bit of a data as mentioned above and is slow enough to watch the individual current display. Scanned current is compared with the data in the core memory as shown in Fig.8. If there is a difference more than 3 digits, the corresponding error lamp is turned on (see Fig.5).

Online Correction

To provide the easier orbit correction, the online calculation of the current data of the steering dipoles is furnished by connecting the COC system to the ACC computer. Beam positions measured with 56 position monitors (28 horizontal and 28 vertical), which are placed near the steering dipoles, are also sent to the central computer in the CCR *via* satellite computers after digitizing with the analog-to-digital converters.

The core memory system in the central control station can be accessible from the central computer

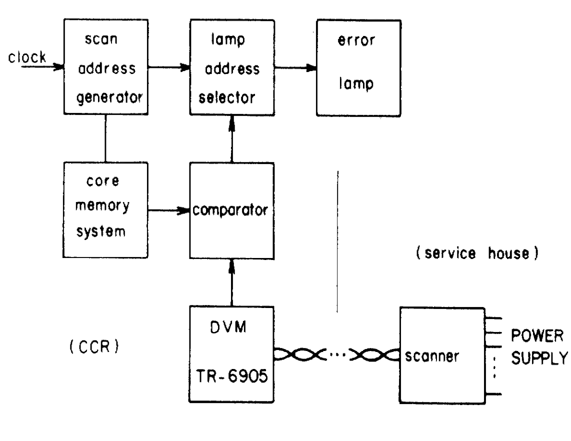

Fig.8 Failure detection of the individual power supply.

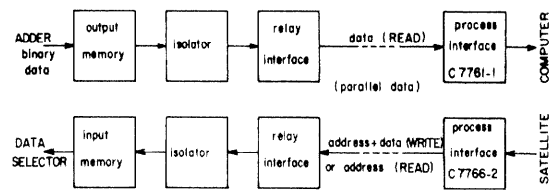

Fig.9 Current data transfer between the COC and ACC systems.

through the linkage interfaces of Fig.9. If the central computer specifies the data address of the COC system, data in the core memory system is sent back by the shake hand method (READ mode). While in WRITE mode, the increment or decrement for the old data in the COC system is sent with the instruction bit (ADD/SUBTRACT) to the adder in Fig. 4.

The online operation mode provides the quick correction when required and needs many computer memories for the matrix calculation.[5] In the case the central large computer HITAC-8800 which is linked with the ACC system through the CAMAC interface can be utilized.[6]

Acknowledgement

The authors would like to thank Prof. T. Kamei for the continuous interest during the work and the main ring magnet group personnel for their discussions and operations. They are indebted to the Digitex Lab. Co. staff for fablication of the data control system.

References

1) A. Ando, K. Endo, M. Kihara, T. Kasuga, E. Takasaki, and T. Igarashi, "Correcting Magnet System for the KEK-PS Main Ring", Proc. 5th Int. Conf. Magnet Technology (Frascati, 1975) p.63.
2) J.R. Maidment and C.W. Planner, "An Analytic Method for Closed Orbit Correction in High Energy Synchrotrons", Nucl. Instr. Methods, 98 (1972) 279.
3) T. Katoh, K. Uchino, T. Kamei, M. Tejima, T. Takashima, K. Ishii, S. Ninomiya and E. Kadokura, "Control Computer System for KEK Proton Synchrotron", IEEE Trans., NS-24 (3) (1977) 1789.
4) S. Shibata, K. Muto, H. Ishii and Z. Igarashi, "KEK Beam Position Monitor System", IEEE Trans., NS-24 (3) (1977) 1736.
5) A. Ando and K. Endo, "Correction of Closed Obrit at Injection in Alternating-Gradient Synchrotron", KEK-75-4 (1975).
6) T. Katoh, K. Uchino, M. Tejima, T. Takashima and T. Kamei, "Control Computer System for KEK 12 GeV Proton Synchrotron (in Japanese)", KEK-77-22 (1978).