ALIGNMENT OF THE BEAM TRANSPORT LINE OF KEK B-FACTORY

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1 INTRODUCTION

KEK B-factory (KEKB) is an electron-positron collider rings with asymmetric energy of 8.0 GeV and 3.5 GeV. The 8 GeV electron and 3.5 GeV positron beams accelerated with the injector linac are transferred to the rings through the beam transport line (BT) , whose lay out is shown in Fig. 1.

KEKB is constructed making maximum use of the infrastructure of TRISTAN electron-positron collider. In TRISTAN, 2.5 GeV electron or positron beam from linac was accumulated and accelerated to 8 GeV in the Accumulation Ring (AR), and injected to the Main Ring (MR). In KEKB, however, the linac was upgraded so that the beams could be injected to the rings directly. The AR was separated from KEKB accelerator complex and was dedicated to the synchrotron radiation experiment. To minimize the interference of the two accelerator system, KEKB and AR, a new tunnel which bypasses the AR and directly connects the rings was constructed. The new tunnel branches from the old BT tunnel for the AR injection and reaches the old BT tunnel for the MR injection.

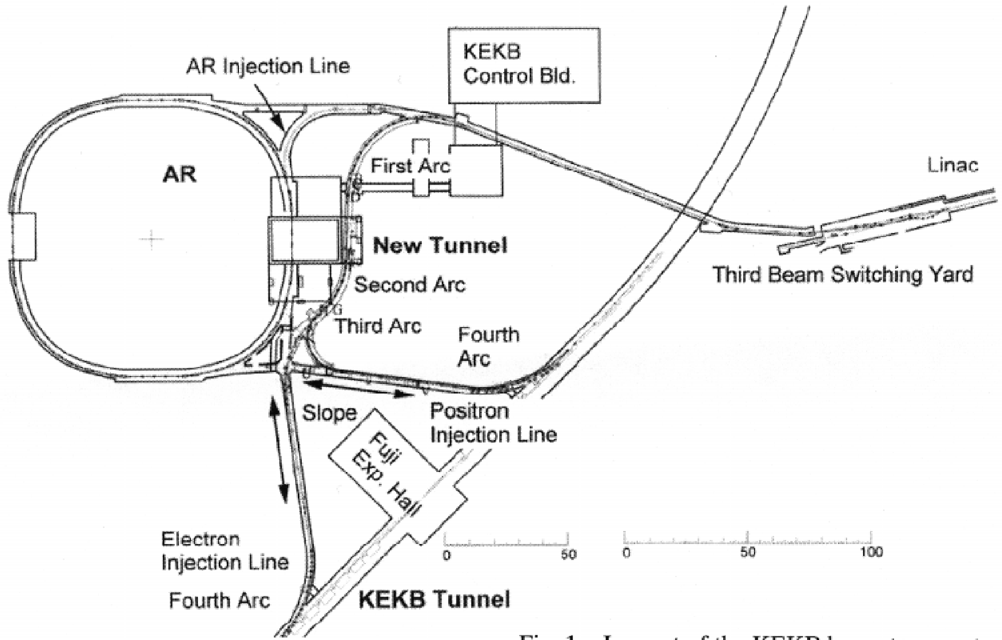

Fig. 1 Lay out of the KEKB beam transport

2 BEAM TRANSPORT LINE OF KEK B-FACTORY

The beam transport line of the KEK B-factory consists of two independent beam lines for electrons and positrons. To avoid various operational complications, the two beam lines have no common magnets except for the first magnet which separates the two beams from the linac.

Because the BT tunnel is not wide enough to lay out two beam lines horizontally, they are stacked vertically. The switch bend, which also plays a role as a part of chicane for the energy compress system of the positron beam, separates the two beams making use of different energy and charges at the Third Switch Yard in the end of linac. The height of the electron line is lowered by vertical dipoles, while the level of the positron line is kept unchanged. The horizontal dipoles guides the beams so that the positron line is placed on the top of electron line. Then the two beam lines are stacked vertically and enter the BT tunnel. Figure 2 shows the beam lines in the first arc section. The height of the positron line is 120 cm from the floor, and that of the electron line is 60 cm.

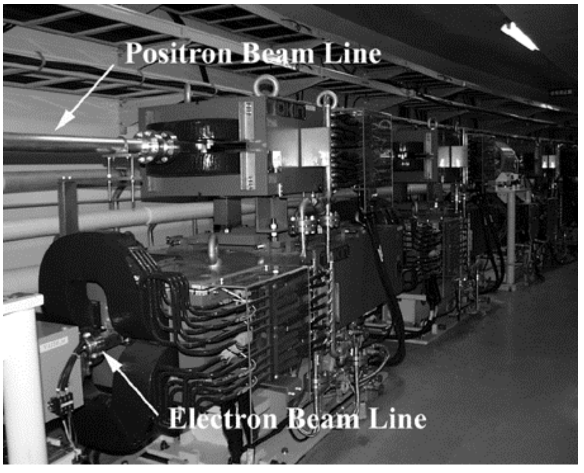

Fig. 2 First arc of the KEK BT

In the short straight section between the first and the second arc, the level of the positron line is changed such that the electron line is on the top of the positron line. As the floor level is also lowered in between the first and the second arc in order to make a enough room under the positron line, the height of the electron line is as high as 180 cm above the floor although the beam level of the electron line is not changed.

The two beam lines are separated at the beginning of the third arc. Then, passing through the downward slope, each beam line reduces its elevation to the level of the ring, and reaches the injection point. The total length of each beam line is about 460 m. In the electron beam line 129 main magnets (dipole and quadrupole magnets) are installed, and 131 main magnets in the positron beam line.

3 CONSTRUCTION OF THE BEAM TRANSPORT

Construction schedule of the BT is shown in Fig. 3. TRISTAN MR was shut down for the construction of KEKB in December, 1995. However, AR had been operated until December, 1996. The components of the old injection line of AR were removed from the end of 1996. The construction of the new tunnel began in January and completed in November, 1997. During this period, parts of old existing tunnel near junctions between the old and new tunnels were closed and not available for surveying nor magnet installation.

As shown in Fig. 3, AR was operated for synchrotron radiation experiment from March to June, 1998. Because the upstream part of the electron beam line is commonly used for the KEKB and AR injection, construction of this part of the electron line had to be completed before the start of AR operation in March, 1998. In the same time, the study of positron production and acceleration for KEKB was carried out where the positron beam was transferred to a dump temporarily placed at the first part of the first arc section. This was another reason of early construction of the upstream part of the positron line. The construction of the downstream part was carried out mainly after quitting AR operation.

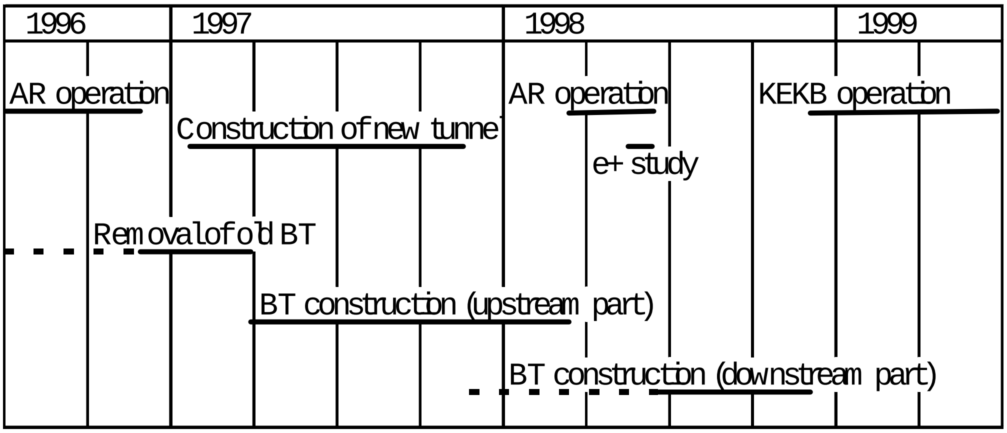

Fig. 3 Construction Schedule of the beam transport

BT tunnel are equipped with the cranes only in the slope and the fourth arc sections. Therefore, in the other parts of the BT tunnel, we should handle the magnets without making use of crane. The weight of BT magnets amounts to 5.1 t. As stated in the previous section, the electron and positron beam lines are stacked vertically. Since the space between two dipoles is not enough, as shown in Fig. 2, it is very difficult to support the upper magnet independently to the lower magnet. Therefore, we decided to support the upper magnet based on the lower magnet. On the top of the lower magnet, the support system of the upper magnet is mounted which has the mechanism to adjust the relative position of the two magnets. The total weight of the two dipoles and magnet supports is about 8 t. Air cushions were adopted to carry the magnet in the narrow BT tunnel.

Besides the difficulty in transportation, above method of magnet support brought some complications into the magnet alignment: the position of the upper magnet is disturbed by the position adjustment of the lower magnet, and the heavy weight make the position adjustment of the lower magnet much difficult.

4 FINE ALIGNMENT OF THE BT MAGNETS

Each magnet has at least two precision planes for alignment on its top, and each plane has a hole with the diameter of 20 mm. In the alignment of level, the bubble level was placed on the plane. At the survey, Talor-Hobson sphere is mounted on a socket inserted in the hole.

We adopted conventional mechanism for position adjustment of the magnet. The magnet is supported by three vertical bolts or threaded rod. The height, roll (rotation around the beam axis), and pitch (rotation around the horizontal axis perpendicular to the beam axis) are adjusted by turning the bolts or screw nuts. The adjustments of two degrees of horizontal position and one degree of rotation around the vertical axis (yaw) is carried out by using push-push screws.

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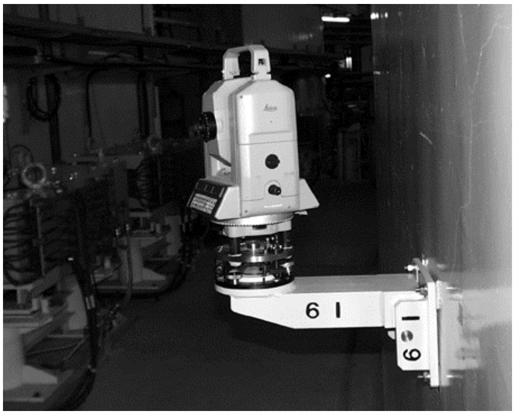
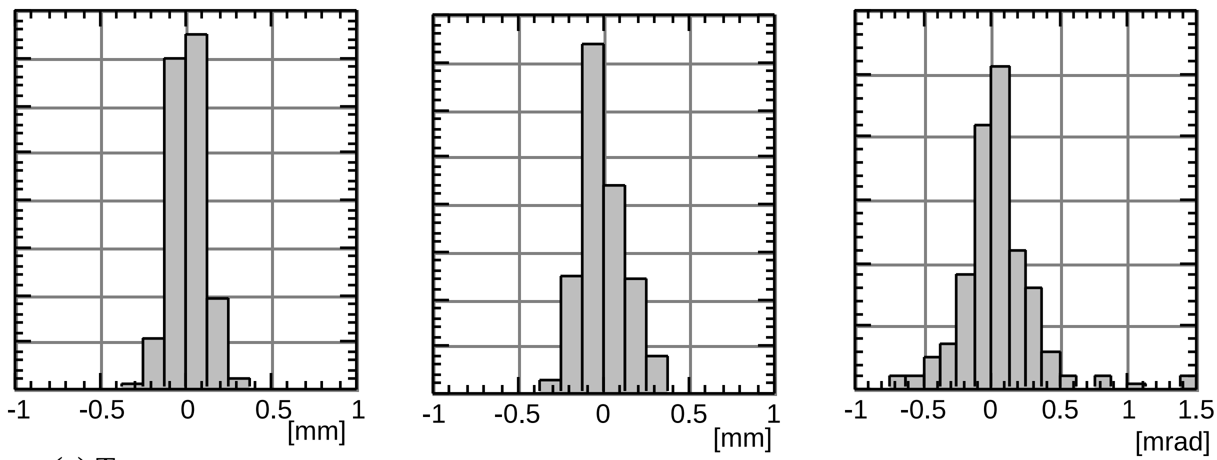


Fig. 4 Monument and theodolite with adapter

For the survey, monuments were installed on the tunnel wall, as shown in Fig. 4. Distance between the two succeeding monuments was kept below 10 m in the downstream section, and 20 m in some part of the upstream section. The positions of the monuments were obtained by traverse which was carried out using Leica TC2002 Total Station. Fine adjustment of magnet position was carried out using optical instruments. The height, roll, and pitch were adjusted with Leica N3 leveling telescope and bubble levels. Horizontal position was measured by the method of triangulation. For angle measurements, TC2002 was mounted on survey monument using an adapter (Fig. 4). The cycle of survey and adjustment was repeated until the adjustment error (difference between the design position and the measured position) became less than 0.3 mm, although the iteration was stopped in a few magnets before this criterion was satisfied because of lack of sufficient time. Figure 5 shows the adjustment errors for the magnets of the first arc and downstream section. The standard deviation of these distribution are 0.10 mm for transverse position error, and 0.13 mm for longitudinal position error. Three magnets were found having yaw error greater than 1 mrad. All of the three are short quadrupole magnets whose distance between fiducials is only 0.22 m. The standard deviation of the adjustment error of yaw was 0.29 mrad.

To obtain the alignment error, the position error of monuments should be also taken into account. The statistical errors of our angle and distance measurements are 1.8 arcsec and 0.17 mm, respectively. Using these values, the uncertainty of relative position of succeeding two monuments is estimated to be 0.17 mm. Therefore, the alignment precision of neighboring magnets is estimated to be 0.21 mm.



(a) Transverse error
(b) Longitudinal error
(c) Error in yaw

Fig.5 Adjustment error

As stated above, AR have been operated with the new injection line since March, 1998. Operation of KEKB began in December, 1998. There have been no significant degradations of beams so far which stems from the alignment.

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