MAGNET INSTALLATION AND ALIGNMENT FOR THE FUJI TEST BEAM LINE AT KEKB

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Abstract

Since the 12 GeV Proton Synchrotron ended its operation in March 2006, a GeV-class beam line for testing detectors was desired by the physics community in Japan, at least until J-PARC [1] is completed in 2009. A decision to build a new beam line which uses the electrons circulating in the KEKB [2] ring was made. The bremsstrahlung photons generated by the interactions of the electrons and the residual gas in the vacuum pipe are brought to a tungsten target to generate e+e- pairs. The electrons are then guided to the outside of the KEKB tunnel to the Fuji experimental hall by a new beam line, which has 8 dipole magnets and 4 quadrupole magnets. Due to the limited space available for extracting the beam from the KEKB tunnel, the beam line was designed to have a roller-coaster structure, with all magnets rotated in all three rotational angles, at angles of up to 40 degrees. The installation and the alignment using a laser tracker will be summarized in this report.

INTRODUCTION

KEKB is a double-ring collider with a circumference of 3016 m. The two rings are placed side-by-side in the tunnel. The KEKB tunnel consists of four straight sections, four arc sections and four experimental buildings located in the middle of each straight section. The 8-GeV electron ring (HER) and the 3.5-GeV positron ring (LER) intersect at the interaction point (IP) in the Tsukuba experimental building. The two rings cross at the opposite side of the IP, at the Fuji experimental hall as shown Fig. 1.

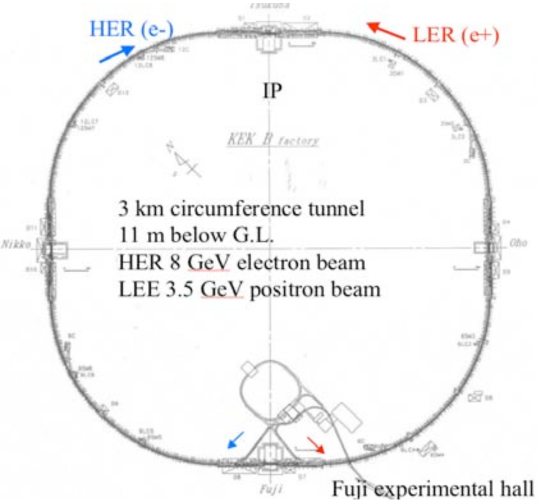

Figure 1: KEKB ring.

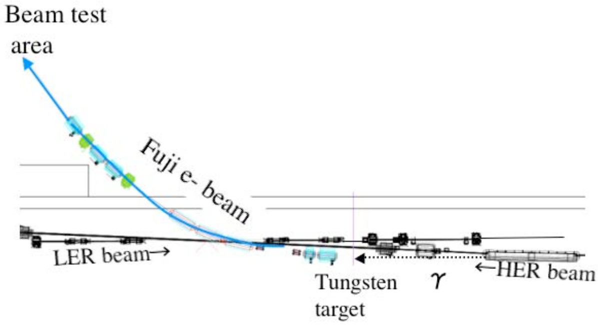

Figure 2: Fuji test beam line.

The new beam line, called the Fuji Test Beam Line (FTBL), was constructed in the straight section in the Fuji experimental hall. The bremsstrahlung photons hit the tungsten target and generate e+e- pairs. The electrons are then brought to the beam test area by the magnets, which are described in the following section , as shown in Fig. 2.

FTBL MAGNETS

In order to save construction costs, some magnets and the power supplies were recycled from old experiments. The Q3 and Q4 magnets are spare magnets used by KEKB. Fig. 3 shows the 3D view of the FTBL with magnet names indicated. Three dipole magnets, B2, B3 and B4, had to be newly fabricated since none of the existing magnets met the requirements for size and field strength. The 3D CAD played an important role in designing and modification of the FTBL magnets.

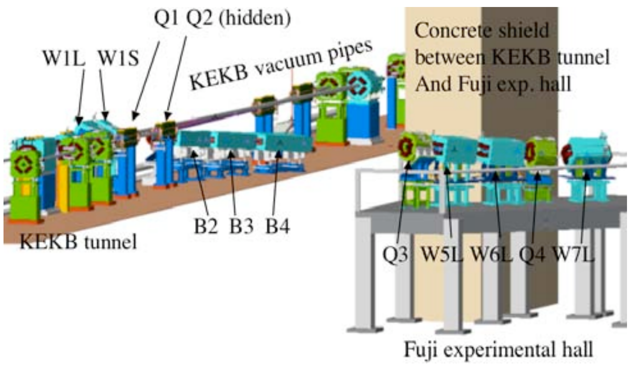

Figure 3: 3D view of the beam line. Concrete shield blocks between the KEKB tunnel and the Fuji experimental hall are shown partially. The magnets outside of the KEKB tunnel are placed on a stage made of iron.

The magnet parameters are summarized in Table 1. Due to the limited space available the magnets are arranged three-dimensionally, with rotation angles around the beam direction and tilt angles along the beam direction. The rotation angles for each magnet are summarized in Table 2. Some of the magnets are rotated by more than 30 degrees, which requires an additional stand to create the large rotation angle. Fig. 4 shows the additional magnet stand for one of the dipole magnets. The additional stand (coloured in dark blue) was placed between the magnet and the original support (coloured in light blue). Since the angles are different for each magnet, the stand was made with different tilts for each magnet.

In order to align the magnets in a three-dimensional manner, a decision to use a laser tracker was made. We used a laser tracker for the alignment in the X and Y directions, a Wild N3 for the Z (height) direction alignment and a Carl Zeiss bubble level for levelling the magnets for the KEKB main ring magnets where most of the magnets are placed two dimensionally in the horizontal plane [3]. The KEKB magnets have two reference base plates, one at the beam incoming side and the other on the outgoing side. There is a hole for a laser tracker target holder in the reference base plate. The reference base plates are welded on the magnet body. Now that the magnets for the Fuji test beam line have three-dimensional rotation angles, at least three reference (fiducial) points are needed on the magnet to define the angles and the positions. A third reference base plate was added on all magnets except for Q1 and Q2, as described in the following section. The third reference plate for Q3 magnet is shown in Figure 5.

Magnet	Type	Bmax	Imax	Leff	Weight
B1L	Recycle	1.2	300	~1	3400
B1S	Recycle	1.2	300	0.513	1800
Q1	Recycle	16	50	0.525	390
Q2	Recycle	16	50	0.525	390
B2	New	1.2	500	1.64	2800
B3	New	1.2	500	1.64	2800
B4	New	1.2	500	1.64	2800
Q3	Spare	3.8	300	0.584	2070
B5L	Recycle	1.2	300	~1	3400
B6L	Recycle	1.2	300	~1	3400
Q4	Spare	6.3	500	0.584	2070
B7L	Recycle	1.2	300	~1	3400

Table 1: Magnet parameters. The units for the maximum magnetic field strength B_{max}, are [T] for B1L,B1S,B2,B3,B4,B5L,B6L and B7L and [T/m] for Q1,Q2,Q3 and Q4 magnets, respectively. Leff represents the effective length in meters and the weight is in kilograms. Imax is the maximum current for each power supply in amperes.

Magnet	Rotation	Chi3
B1L	-30.246	0
B1S	-30.246	0.13908
Q1	-59.511	0.3147
Q2	-54.202	0.3147
B2	-0.315	0.3147
B3	-1.087	1.0865
B4	-1.847	1.8473
Q3	-59.712	2.5970
B5L	-2.597	2.597
B6L	-3.091	3.0910
Q4	-31.486	3.5818
B7L	38.173	3.5818

Table 2: Magnet angles in degrees. Rotation is the angle around the beam direction. Chi3 is a parameter defined in SAD[4] which represents the angle between the beam motion (β-oscillation) and the global coordinate. The rotation angle in the global coordinate is given by the sum of rotation and chi3.

Figure 4: Additional magnet stand to create large rotation angles, around and along the beam directions. Two new reference plates were added on the magnet support.

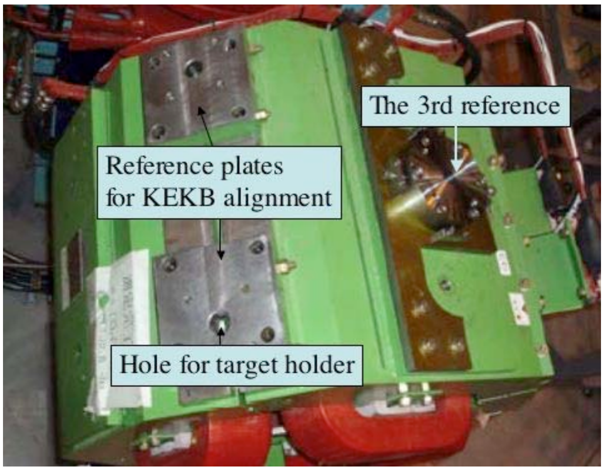

Figure 5: A top view of the quadrupole magnet. Three reference points are needed for the 3D alignment. An

additional reference plate was added on the magnet to define the rotation angles. Each magnet has its own combination of angles.

ALIGNMENT

The FTBL had to be completed during the summer shutdown of just two months. This means that not only installation of magnets but also other systems such as cooling water system, power supply systems, etc. had to be completed in two months. It was important to come up with a strategy which minimized the time spent on the magnet installation and alignment in the KEKB tunnel. The magnet installation work was done in two steps: (1) pre-alignment outside of the KEKB tunnel before the summer shutdown, and (2) the actual installation in the tunnel.

Pre-alignment

The third reference base with a hole was placed in the desired position using a scale and an auto-level. The tracker measurement later confirmed that the third reference was placed with 0.1 mm accuracy by this "scale and auto-level" method. When the magnets were equipped with three reference points, they were placed on the tilted stands designed for each magnet. A laser tracker was used to measure the three reference points. The absolute heights of the magnets were not adjusted in this pre-alignment. Only the relative heights of the three reference points were adjusted to give the desired angles using the adjusting bolts of the magnet support. The absolute height of the magnets had to be determined from the KEKB beam line, which could only be done in the KEKB tunnel. Fig.6 shows the pre-alignment of one of the quadrupole magnets. When the magnets were tilted to the design angles, the new reference plates on the magnet support (see Fig. 4) were adjusted level using Carl Zeiss bubble level for use in the actual installation in the FTBL.

Figure 6: Pre-alignment of Q4. Pre-alignment was done in one of the experimental halls, not in the FTBL.

Drawing of the beam line

The KEKB tunnel at the Fuji straight section is covered by concrete shield blocks as indicated in Fig. 3. These blocks needed to be removed before the vacuum chamber removal and the magnet installation. The position of a 100 mm ϕ hole for the beam passage was required to be determined and marked before the removal of the concrete shield blocks. The positions of the FTBL magnets were drawn on the KEKB tunnel floor using a laser tracker. The height of the hole was calculated using the height of the KEKB quadrupole magnets and the entering and exiting positions were marked on the corresponding block. Fig. 7 shows a top view of the FTBL indicating where the hole should be drilled. The marked block was removed after the KEKB beam operation stopped for the summer shutdown and brought to the area next to the Fuji experimental hall where a hole was drilled (Fig.8).

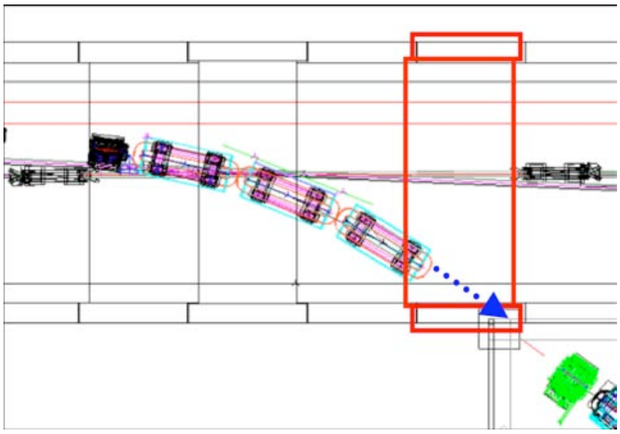

Figure 7: FTBL top view. The squares in red indicate one concrete shield block where a hole needed to be drilled. Each block measures ~2 m in width and weights ~ 40 tons.

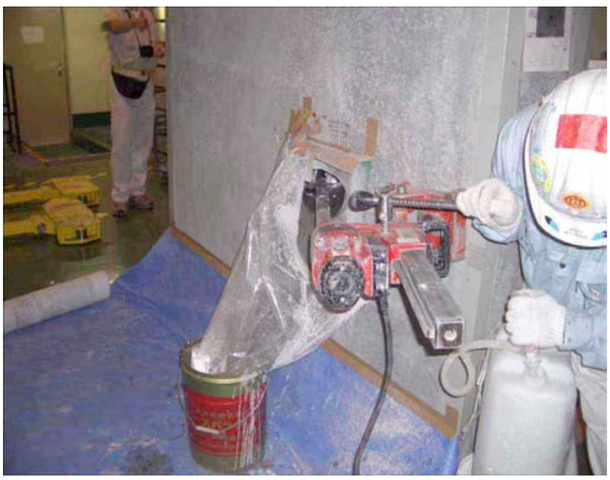

Figure 8: Drilling a hole through the concrete block.

Modification of the KEKB quadrupole magnet and the vacuum chamber

The bremsstrahlung photons generated in the Fuji srraight section hits the vacuum chamber. In order to pass the photons, the vacuum chamber in the dipole magnet had to be replaced by a new chamber with a window. Also the quadrupole magnet downstream of the dipole magnet needed to be replaced by the same type magnet with two rectangular holes (10 mm x 30 mm, each) in the iron yoke as the photons travel straight and hit the magnet yoke as indicated in Fig. 9. One hole would have been sufficient for the photon passage. The second hole was made to maintain the magnetic field symmetry.

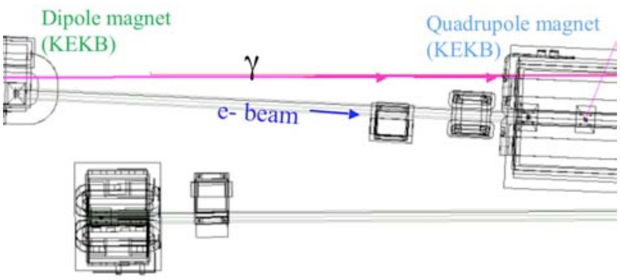

Figure 9: Photon passage is indicated by a line (magenta). The KEKB quadrupole magnet needed to be replaced by the one with a hole in the iron yoke for the photons to go through.

The strength of the quadrupole magnet with a hole was measured by a harmonic coil system as shown in Fig.10. There was no significant effect of the hole on the magnetic field strength.

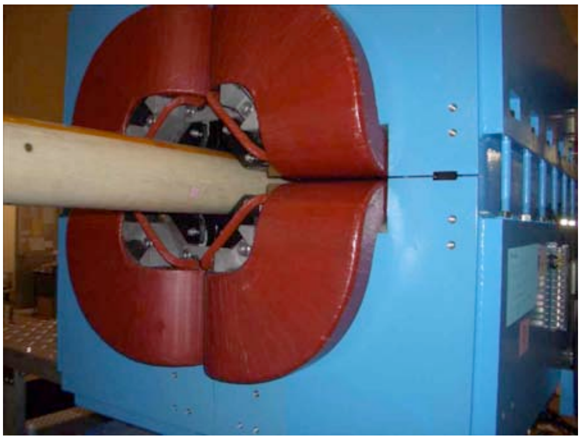

Figure 10: Quadrupole magnet, which has a rectangular hole in the iron yoke, being measured by a harmonic coil.

Magnet Installation and Alignment

Since the magnets have large tilt angles, special care was needed in the installation. A sufficient number of chemical anchor bolts with proper lengths was needed to support the tilted magnets in the KEKB tunnel. A stage made of steel was prepared as a foundation structure for the FTBL magnets outside of the KEKB tunnel. Iron plates of 10~20 mm thickness were used as base plates for the magnet stands.

A laser tracker was used to measure the KEKB quadrupole magnets, which defined the KEKB coordinates including the level. Table 3 summarizes the alignment tolerance. The FTBL magnets have three fiducial points to define the magnetic plane, except for Q1 and Q2. The Q1 and Q2 magnets have two fiducial points on the beam axis, which were used to align the magnets along the beam line. Since the magnets are rotated, we need to confirm that the magnet bore center is on the beam line in addition. In order to align the magnet bore center to the beam line, a transit was used to align the center of the target placed on top of the magnet, the center of the bar inserted in the magnet bore and the beam line projected on the floor as shown in Fig. 11. The global alignment of Q1 and Q2 was done by measuring the positions of the magnet fiducial points on the magnets with the laser tracker.

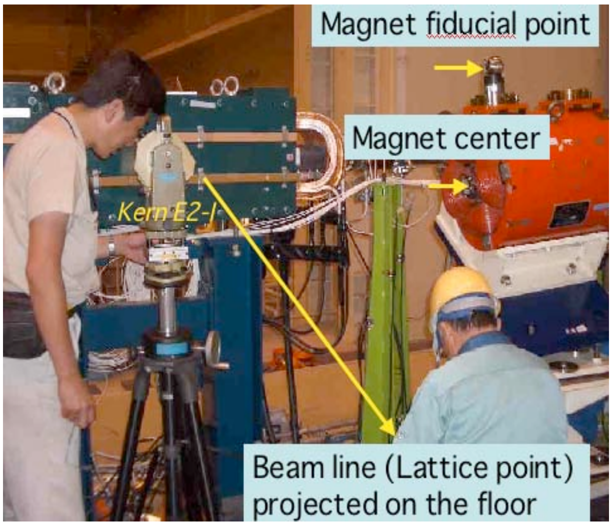

Figure 11: Aligning the magnet center of Q2 using a transit (Kern E2-I). The fiducial point placed on top the magnet, the central point of the rod inserted in the magnet bore and the beam line projected on the floor have to be aligned.

Figure 12: An iron rod for Q1/Q2 alignment. The rod center is marked to be viewed by the transit.

Position along the beam line	0.5
Relative height of 3 fiducial points for Bmag	0.1
Relative height of 3 fiducial points for Qmag	0.1
Qmag center, perpendicular to the beam line	0.15

Table 3: Alignment tolerances in σ (mm).

Fig.13 summarizes the deviation of each fiducial point from the FTBL beam line. A set of three fiducial points define the rotation angles of the magnet.

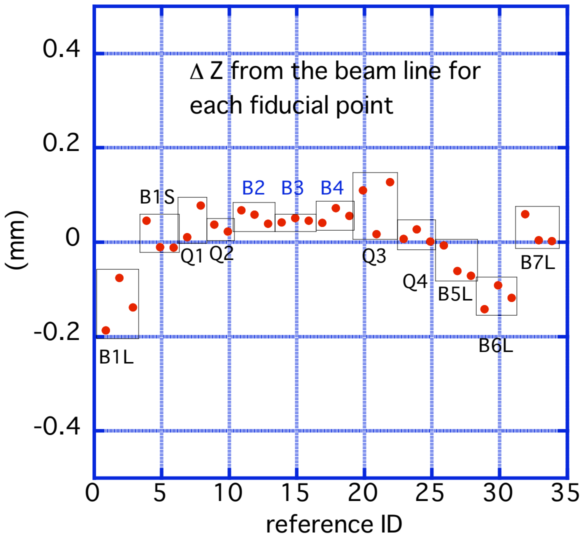

Figure 13: Residual from the beam line level.

The residuals in the transverse directions X and Y for all magnets are summarized in Fig.14. The laser tracker was placed so that the X is almost parallel to the KEKB beam line, Y pointing away from the KEKB beam line at the final measurement. Larger deviation from the target values comes from dipole magnets B1S and B5L, where the alignment tolerance in the horizontal direction is not too tight. Residuals of the quadrupole magnets on the other hand, are contained in the two central bins, satisfying the requirements given in Table 3.

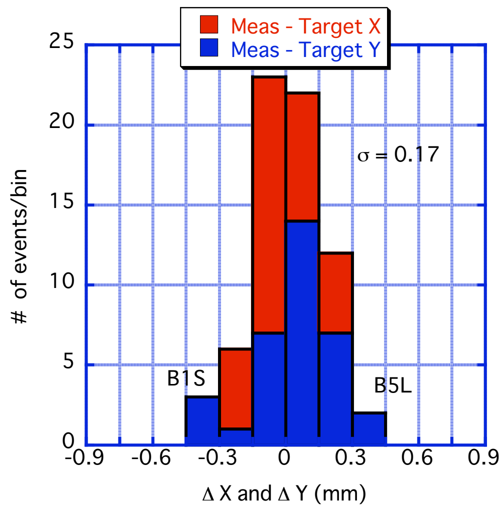

Figure 14: Alignment error in horizontal direction.

FTBL COMMISSIONING

The FTBL magnets were turned on and set at the design currents on Oct.12, 2007 during the KEKB luminosity run. The first beam was observed when the magnet currents were set at the design values. There was no need for tuning the magnet strength in order to obtain beam at the end of the FTBL. Fig. 15 shows the signals from lead glass counter placed at the end of the FTBL when the magnet strengths were varied from their 3 GeV settings to their 2 GeV settings. A clear separation is seen.

One of the requirements that the FTBL has to satisfy is that the FTBL commissioning should not interfere with the KEKB beam operation, i.e. both FTBL use and KEKB luminosity run must coexist. Fig.16 shows the KEKB beam currents and luminosity when we ran KEKB and FTBL simultaneously on Feb.14, 2008. The red and blue lines indicate the KEKB beam currents in the LER and HER, respectively and the orange line represents the luminosity. The green line indicates a counting rate measured by a lead glass counter place in the FTBL. The event rate varies with the HER current as expected.

The event rate obtained at the end of the FTBL turned out to be lower than simulation for the vacuum level in the KEKB HER chamber. The KEKB HER beam orbit is speculated to be the cause of the lower event rate, which needs further beam study.

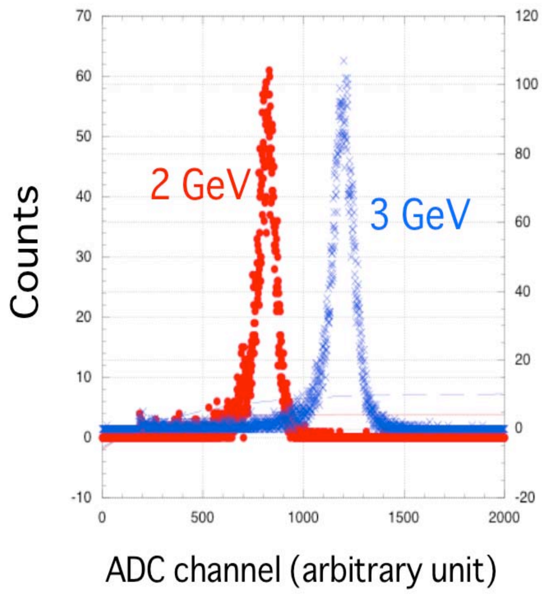

Figure 15: Signals from lead glass counter for different beam energies. A clear separation is seen.

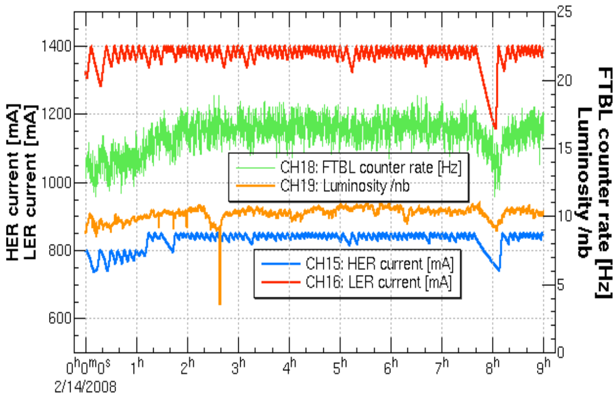

Figure 16: FTBL event rate measured by a lead counter, KEKB luminosity, and HER and LER beam currents.

SUMMARY

The Fuji Test Beam Line (FTBL) was proposed to provide a GeV-class test beam following the shutdown of the KEK 12 GeV PS. The facility is based on the use of bremsstrahlung photons created by scattering 8 GeV electrons off residual gas in the HER Fuji straight section. The photons are converted to e-/e+ pairs in a target creating electrons with a sharp forward peak, sufficient for a test beam of a few GeV/c.

The FTBL was designed to re-utilize as many components as possible, in particular spare magnets from KEKB, recycled magnets from Tristan, and power supplies from the PS beam lines. However, a new, purpose-designed vacuum chamber was required. A peculiarity of the line is that the magnets are tilted up to 30° so the layout and magnet supports had to be designed carefully. Construction began in 2006 and was completed in September 2007.

The 3D CAD was an indispensable tool when designing and modifying the magnets to fit in the very limited space of the KEKB tunnel. A beam line which has a roller-coaster structure, with all magnets rotated in all three rotational axes, can be constructed if a set of proper fiducial points is provided.

The first test beam was observed on October 12th, soon after the KEKB operation started in October 2007. The FTBL has started operation with test beams and FTBL commissioning will be continued. The Fuji Test Beam will be an important facility for developing new detectors.

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[3] "Installation and alignment of KEK B magnets", R. Sugahara, M. Masuzawa, Y. Ohsawa, M. Sakai and H.Yamashita,KEK-PREPRINT-99-131, Nov 1999. 7pp.

[4] SAD (Strategic Accelerator Design) http://acc-physics.kek.jp/SAD/