Positioning the SPring-8 Magnets with the Laser Tracker

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The storage ring of third-generation synchrotron radiation source is much sensitive to magnet misalignment, especially quadrupole misalignment. To reduce this sensitivity, the magnet alignment for the SPring-8 storage ring is divided into two stages: magnets are aligned within units of about 5 m with RMS accuracy less than ±50 μm, and the units are aligned along the storage ring of 1436 m in circumference with relative accuracy of ±0.2 mm. The two-stage alignment method will reduce the amplitudes of the orbit distortions induced by the quadrupole misalignment [1].

For the alignment of the SPring-8 storage ring, various methods are investigated. The laser tracker is for the first time employed in the measurement of storage ring networks. Optimized alignment network makes the position displacements of the magnets to a very low value.

The laser tracker SMART 310 is a dynamic measurement system which consists of a laser interferometer, a rotating mirror on two axes with two angle encoders and servo motors, a position diode etc. Return-ing beam from retro-reflector is partly divided to the position diode (Fig.1).

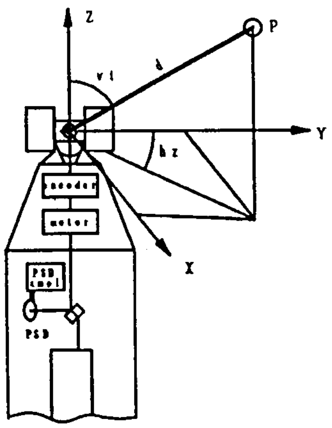

Fig.1 Principle of the laser tracker

Through a servo loop the offset on the diode corrects the angles of the mirror to keep the beam on the target. The tracker gives 3D spherical coordinates of a target in space with a distance re-solution of 1 μm, an angular resolution of about 1 arc sec..

Many factors may influence measurement accuracy of the laser tracker: the calibration, atmospheric conditions, and the way laser tracker been used, mainly its accuracy is restricted by the angular resolutions of the encoders. To realize the accuracy it can achieve, the laser tracker was checked under various condition such as different measurement angles and encoder positions, as well as two faces of its measuring head. Also it is compared with HP 5527A interferometer. Experiments show the laser tracker has a distance accuracy of 0.001+0.2ppm L(mm) and an angular accuracy of 10 μrad. This accuracy will result at least 7.3 mm traverse disclosure for the storage ring orbit if the laser tracker is simply used for coordinate measurement.

The networks for the SPring-8 storage ring include a primary control network of trilateral for monument survey and a secondary network for magnet alignment. The monuments are buried at the intersection points of the straight lines at both sides of the bending magnet. These monuments are surveyed before building construction and before the bending magnet installation with a survey accuracy better than ±1 mm. The monuments are used as the references for individual unit installation before employing final precise magnet alignment. After this, the primary control network is abandoned. The secondary network is employed in the magnet precise alignment.

Secondary alignment network for the SPring-8 storage ring is designed as a distance-only trilateral network. Several aspects are optimized. The laser tracker has different accuracy for distance measurement when its position changes in respect to measuring targets. To reduce the influence of angular error, the laser tracker's positions within network are chosen by checking the distance accuracy it results:

$$M_f=\sqrt{\left(\frac{l_1-l_2\cos\alpha}{l}\right)^2 m_{l_1}^{\ 2}+\left(\frac{l_2-l_1\cos\alpha}{l}\right)^2 m_{l_2}^{\ 2}+\frac{1}{\rho^2}\left(\frac{l_1 l_2\sin\alpha}{l}\right)^2 m_\alpha^{\ 2}}$$

where l is the length between two measuring points, α, l_1, l_2 are angle and lengthes from laser tracker to these points, m_α, m_{l1} , m_{l2} are their measurement accuracy respectively. The laser tracker gives the most precise distance when it is placed at the extension line of two measuring points, where it can eliminate the calibration error of absolute distance and reflector eccentricity. The distance from the mirror to the target is also precise on the condition that the laser tracker is well calibrated. For this purpose, a calibration stand is being made to compare it with HP 5527A interferometer.

The network precision depend on both the accuracy of laser tracker and the ratio of measurement length to the width of the net. Measurement lengths are optimized by simulation study of error accumulation. The results show that this ratio less than 5:1, that is, measurement length shorter than 15 m (1/2 cell) has least error accumulation rate along the ring. Distance longer than one cell is not beneficial for control radial deviation of the magnets.

The secondary alignment network is composed of 288 quadrupole fiducial points and 96 auxiliary brackets on inner wall. What makes this network particular is the laser tracker positions directly compose the knots of network. Over 50 percent distances are measured directly by laser tracker interferometer (Fig.2).

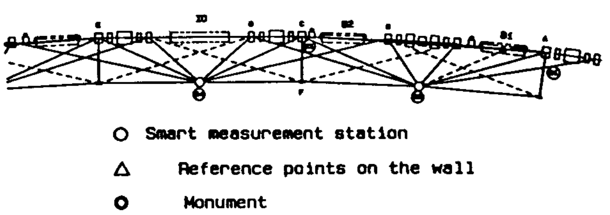

Fig.2 Alignment network for SPring-8 storage ring magnets.

Precision for magnet positioning is estimated on the assumption that the distance errors have a Gaussian distribution. Error ellipse analyzing shows that maximum position displacement of magnets in respect to geodetic coordinate less than ± 1 mm, relative displacement between adjacent units of ± 0.05 mm are expected (Fig.3). Twenty times simulations are executed. The results well coincide with precision estimation.

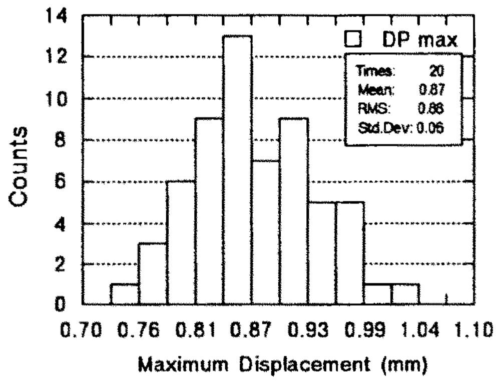

Fig.3 Maximum magnet displacement of twenty time simulations

Two iteration adjustments for magnet positions are needed. In the first iteration, the monument positions in respect to the alignment network are also measured with the laser tracker. Units are adjusted to a best-fitting orbit of these monuments. The secondary iteration will abandon the monuments. Relative positions between units are emphasized.

References

[1] H. Tanaka, N. Kumagai, and K. Tsumaki, Nucl. Instr. and Meth. in Phys. Res. A313 (1992) 529-545.