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Accurate Geodetical Settlement of Reference Points for HIMAC Synchrotrons at NIRS

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Abstract

Elements of HIMAC synchrotrons are aligned on straight lines connecting between reference points. The points are settled accurately by means of a lattice formed by 19 points consisting of 12 reference points and 7 supplementary points. Measured distance data between the points are stored in a computer and are processed by a software for network calculation to give probable distances between points and probable positions of the points. Positioning of the reference points is repeated to reach at acceptable tolerances. Achieved accuracy of the reference points is a displacement within 0.26 mm from theoretical value and a standard deviation of error ellipse within 0.05 mm.

Introduction

Main part of the NIRS medical accelerator, HIMAC, consists of two identical synchrotron rings installed at upper and lower underground floors of the building. It is essential for high beam quality to exactly position such ion optical elements as dipole magnets, quadrupole magnets, and beam position monitors with respect to a closed orbit in synchrotrons. Specification of overall alignment tolerance has been optimized so that specification of a gap of the dipoles, an aperture of the quadrupoles, a measuring accuracy for beam position, and an alignment method has been taken into account, because the specifications of them are related to each other. The present alignment method is based on a reference point method in which the points are settled outside the ring elements.

This paper briefly describes main feature of geodetical settelment of reference points for accurate alignment of synchrotron elements together with instrumentation and software.

Determination of tolerance

A tighter alignment tolerance leads to a narrower gap of the dipoles and a smaller aperture of the quadrupoles due to a smaller closed orbit distortion (COD), which has been simulated on an assumption of deviation of the dipoles and quadrupoles from theoretical positions. In addition, a COD correction has been incorporated with the assumed measuring accuracy of 1 mm of beam position including displacement of the beam monitors themselves. The tightest alignment tolerance for the elements is required to the quadrupoles. Vertical COD correction, however, turns out ineffevtive because the realistic accuracy of 1 mm is not sensitive enough to improve the distortion. Thus, no vertical correction magnets are brought in the rings for the initial construction phase.

Taking into account of specification of elements due to the COD value, we have decided specification of the overall alignment tolerance for a radial direction as 0.1 mm, a vertical direction as 0.1 mm, a beam direction as 0.3 mm, and a tilt as 0.2 mrad.

Choice of alignment method and reference point method

As seen from the above alignment tolerance, required accuracy for the beam direction is less tight than that for both radial and vertical directions. Such alignment is achievable by the measurement for angle when elements are positioned on the basis of well positioned reference points which are precisely settled on extension lines of the beam direction. In this alignment concept, we have considered that a measuring accuracy for angle possibly exceeds that for distance within the same expense. This alignment method is also advantageous so as to give an easy positioning procedure for the dipoles because of no reference points on them. However, it requests several careful operations to handle the instruments well because no numerical data on alignment error is available.

In order to realize highly accurate positioning of the reference points by means of an instrument having its own measuring accuracy, a lattice consisting of the reference points and supplementary points is formed. These points are thus settled by measurement of distance only, which is observed by an electromagnetic distance meter (EDM) with the help of iterative calculation described later. Positioning of the reference points themselves is repeated until the displacement from theoretical value becomes acceptable. The reference points forming double hexagons are settled on extension lines of the beam axis for the dipoles as shown in Fig.1.

After the settlement of the reference points, a single dipole is first positioned by measuring instruments for angle, theodolites, from two directions formed by two crossing lines based on reference points. This alignment significantly eases positioning of the dipoles because of no distance measurement. For the final check, however, distances between the dipoles are measured by EDM.

After the distance check between the dipoles, the quadrupoles are positioned in combination of the angle measurement with the theodolite located at the reference point and the distance measurement with EDM located at a central target of the dipole. Referring the exactly positioned quadrupoles, other elements such as sextuple magnets and the beam position monitors are positioned in combination of the same angle measurement and distance measurement with an inside micrometer or with a 3-dimensional measuring system. The alignment method is preferable because all the neighbouring elements within the same straight section are well aligned on the single straight line.

Along this alignment concept, most of all elements such as the quadrupoles, the sextupoles, the beam position monitors, an electrostatic inflector, and electrostatic deflectors have two target stations on its upper plane for the beam direction : while the dipoles have three target stations for two directions. These stations are also machined to have a flat surface for a tilt measurement.

Lattice design for reference points

In order to position the reference points accurately, the lattice is formed by 19 points consisting of 7 supplementary points in addition to 12 reference points for the alignment, as shown in Fig. 1. On the basis of the choice of the alignment method, 12 reference points are positioned on extension lines of the beam axis for the dipoles. Since the extension lines form double hexagons of which radii are different depending on short and long straight sections of the ring, tops of each hexagon are the unique positions for the reference points. Six (denoted as BS's in Fig. 1) of them are just positioned at tops of a regular hexagon corresponding to the long straight sections. The other six are planned at tops of another regular hexagon corresponding to the short straight sections, but two of the lower ring or one of the upper ring (denoted as SE's in Fig. 1) of them are shifted from the tops because of space interference with the building wall or such facility as air-conditioning package. Because the reference points (denoted as BHS's in Fig. 1) opposite to the shifted points SE's are exactly positioned at the top, the correct beam axis around the shifted points is formed by means of an angle shift from the reference points positioned at the tops exactly. The shifted amount is 5 degrees.

The supplementary points are efficiently introduced to strengthen the network calculation in order to give more accurate values for position of the reference points.

Instrumentation and software

Measurements for settlement of reference points and alignment of synchrotron elements are made on direction, distance, angle, height, and inclination. Instrumentation is listed in Table 1.

Precisely adjustable 2-dimensional stages with a centering plate (Kern) having a tolerance of 30 μm are mounted on pillars for the reference points. The pillars are demountable but are fixed during a period for the measurement and the alignment for each ring. Supplementary points are fixed on tripod mounting during a period for the measurement.

Table 1 Geodetical instruments

quantity	instrument	model	accuracy
direction	theodolite	Wild T-3000	0.1"
distance			
up to 4 m	micrometer		0.1mm
4 to 50 m	EDM*	Kern MEKOMETER ME5000*	0.2mm 0.2ppm
4 to 50 m	3-D system	PASCO	
plumbing	plummet	Wild ZNL	0.02mm
inclination	1st order level	Wild N3	0.02mm/m

* EDM: Electromagnetic Distance Meter with control software PASMEKO by PASCO

Target stations have precsie holes for mounting of optical targets and other measurement targets. Several types of target (invar staff for height, targets for direction and plumbing) are prepared according to types of measurement.

A distance between two points is doubly measured from both directions. Concerning a given point, several distances relating to the point are measured. Total number of the measured distances is 240 for 19 reference points. Many measured distance data are stored in a computer, and a probable distance between two points and a probable position of each reference point are then calculated in two steps, respectively, by a software, PAG-U.

Main feature of PAG-U is summarized as follows. All the measured data are managed for data base. A probable distance called corrected distance is calculated on the basis of a net adjustment by a least square method in order to give confident and plausible value for the distance within a given accuracy of the measuring instrument. A probable position is then calculated together with a displacement from theoretical value and a standard deviation of error ellipse through the network calculation based on the corrected distances.

A new program, FREENET, is developed and is useful to find the best position of the double hexagons for the lattice. Because movement of the building was noticed after the initial installation of the ring elements had been done and the injection and extraction beam lines had been fixed, it was required that reference points are again to be settled to minimize the displacement of the elements while keeping specified hexagonal shape among reference points. Main feature of the program is to search such minimum displacement in addition to the same functions of PAG-U.

Building movement and settlement of reference points

The reference points for the rings had been once positioned in September, 1992 just before the delivery and the initial installation of ring elements. The points for two rings were positioned to agree in size and direction at that time. After the initial installation of the ring elements, positions of the points were measured in January, 1993. Apparent deviation of about 1.5 mm was observed within a ring itself and between two rings, and seems to be due to such uniform movement as rolling and pitching of the

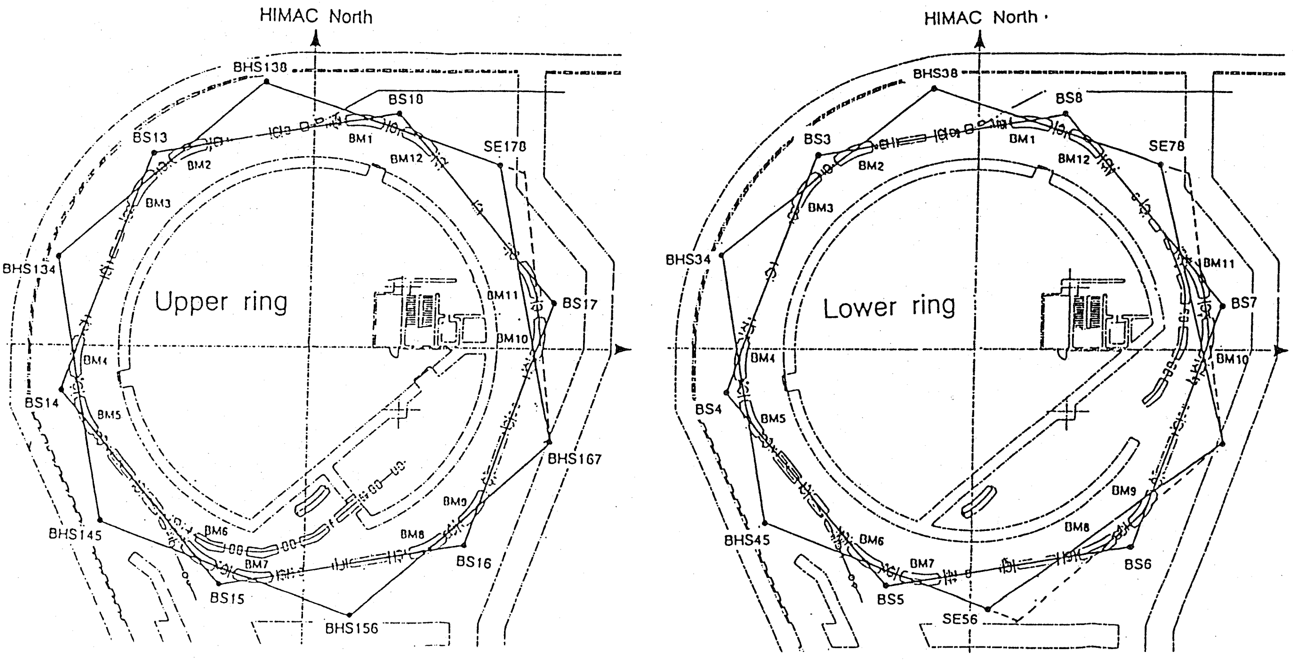

Fig. 1 Lattice of double hexagons for reference points for alingment: dotted lines show the beam axis for the shifted points.

Table 2 Measured deviation of position of reference points

Lowrer ring						Upper ring					
	displacement		error ellipse				displacement		error ellipse		
	Azi(deg)*	L(mm)	Azi(deg)**	a(mm)	b(mm)		Azi(deg)*	L(mm)	Azi(deg)**	a(mm)	b(mm)
BS3	305	0.12	136	0.02	0.02	BS13	15	0.17	100	0.03	0.03
BS4	118	0.17	79	0.03	0.02	BS14	223	0.08	75	0.05	0.03
BS5	162	0.06	4	0.02	0.01	BS15	208	0.15	14	0.03	0.02
BS6	147	0.05	150	0.02	0.02	BS16	166	0.05	158	0.03	0.03
BS7	231	0.18	87	0.03	0.02	BS17	114	0.09	88	0.04	0.03
BS8	349	0.09	15	0.03	0.02	BS18	345	0.18	45	0.04	0.03
BHS34	78	0.22	110	0.04	0.02	BHS134	179	0.21	107	0.06	0.03
BHS38	9	0.26	169	0.05	0.02	BHS138	199	0.11	167	0.07	0.04
BHS45	247	0.09	49	0.04	0.02	BHS145	109	0.02	49	0.07	0.03
SE56	157	0.13	0	0.04	0.02	BHS156	241	0.12	174	0.06	0.03
BHS67	264	0.01	107	0.04	0.02	BHS167	254	0.03	110	0.06	0.03
SE78	261	0.14	51	0.05	0.02	SE178	58	0.22	47	0.10	0.03

* Azim: direction of displacement vectors to HIMAC north, L: length of vectors

** Azim: direction of great semiaxis vectors to HIMAC north, a: great semiaxis, b: small semiaxis

building as a whole. Because the accurate alignment of the injection and extraction beam lines had been finished, we abandoned the agreement in vertical direction between two rings because of no enough margin for the shift of rings as a whole, while the size of them is kept at the same value because of rather uniform movement.

The final positioning of the reference points for two rings has been made for each ring itself. However, rotation and shift of the lattice between two rings are required to match the existing injection and extraction beam lines on the basis of the FREENET calculation.

Results

Results based on the final measurement of positions of the reference points for the upper and lower rings are summarized in Table 2. A displacement is within 0.26 mm and a standard deviation of erorr ellipse is within 0.05 mm. An average of all the measured distances is 17 m and a standard deviation of the corrected distances is 0.09 mm while the maximum correction of all measured distances is 0.28 mm.

The dipoles are then aligned on the straight lines connecting between reference points. Distances between center targets of the dipoles are then measured to check the accuracy before the final alignment of other elements. The distance data along short and long straight sections are summarized in Table 3. The largest deviation in distances within a ring is 0.9 mm for both short and long straight sections. This deviation is considered to come from both direction and amplitude of the achieved displacement of reference points from the theoretical values because of geometrical configuration between the lines and the dipoles.

On the other hand, preliminary measurement shows that other elements such as the quadrupoles and the beam monitors on the same straight section are exactly aligned with tolerance of both radial and vertical direction within 0.1 mm, beam direction within 0.3 mm, and a tilt within 0.2 mrad. These values are satisfactory due to the present alignment method.

Table 3 Measured distance between dipoles

	Upper ring (mm)	Lower ring (mm)
Short sections		
BM2 - BM3	5,480.28	5,479.65
BM4 - BM5	5,480.04	5,479.31
BM6 - BM7	5,480.81	5,479.40
BM8 - BM9	5,479.91	5,479.43
BM10- BM11	5,480.55	5,479.59
BM12- BM1	5,480.42	5,479.88
Long sections		
BM1 - BM2	16,278.81	16,279.64
BM3 - BM4	16,279.17	16,279.54
BM5 - BM6	16,279.04	16,279.62
BM7 - BM8	16,279.56	16,279.76
BM9 - BM10	16,278.68	16,278.85
BM11- BM12	16,278.84	16,278.86

Summary

In order to achieve accurate alignment of the elements for the HIMAC synchrotron rings, we have chosen the alignment method so that the dipoles are aligned with a theodolite on two straight lines connecting between the reference points. The settlement of the points is made by the lattice with help of the distance measuring instruments and the computer system. The measured positions not only of the reference points but also of the dipoles are satisfactory because the neighbouring elements are accurately positioned in both radial and vertical directions, although positions of the dipoles themselves in beam direction deviates slightly due to the geometrical configuration between the reference points and the dipoles. The present method is useful because of easy positioning procedure for the dipoles and other elements.

Acknowledgement

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