GEODETIC NETWORKS OF HESYRL AND MAGNETS' PLANAR POSITIONING

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Abstract

This paper presents a review of the survey and alignment methods and techniques in positioning the beamcarrying elements of the HESYRL. For the emphasis of machine alignment was laid on the components' planar positioning in the horizontal plane, the author describe mainly the geodetic networks for this purpose as well as their accuracy computations and processing procedure. The instrumentation employed in the assembly is also illustrated. These experiences are useful when a new machine is to be constructed.

1. Introduction

The National Synchrotron Radiation Laboratory (HESYRL) is the first dedicated synchrotron radiation light source in China. It mainly consists of a 200MeV electron linac, a beam transport line, and a 800MeV electron storage ring (Fig. 1)[1].

The main part of the linac is an accelerating system which includes preinjector, accelerator units and beam diagnostic segments etc. The linac is built in the tunnel and 3.2 meters below the orbit of the storage ring, and It covers a length of 70 meters, including 35 meters for possible energy extension to 400 MeV.

The beam transport line is designed to transport linac electron beam to the 800 MeV storage ring or to a nuclear physics hall and covers a length of about 80 meters.

The storage ring has 12 dipoles, 32 quadrupoles and 14 sextupoles as well as 2 injection, 3 kicker magnets etc. about hundred componenta, which are distributed separately along 66.13 meters circumference. According to particle dynamics computations these components must be in a strict relative position. The positional accuracy of some magnets in relation to the theoretical orbit are shown as follows.

Table 1 Positional accuracy of some magnets (mm)

	Radial Δr	Vertical Δz	Tangential Δs
Dipole	1.00	1.00	0.30
Quadrupole	0.15	0.15	1.00
Kicker	0.25	0.50	1/4000 (Tile)

It is evident that the challenge to geodetic scientists is to under engineering measurement conditions obtain an accuracy of metrology.

2. Alignment networks

Alignment of small ring is distinct from large circular accelerator. The latter generally adopts frame net or offset method while the former usually adopts polar-coordinate net. The alignment networks for HESYRL synthesize both methods of them and, in the meantime, make some changes.

The first **order** control net is composed of 6 reference stakes. The second order nets are 24 measuring points on 12 dipoles in the storage ring and 2 measuring points in the linac respectively (Fig. 2). In addition, the control network of storage ring is both closely interrelated to the first order net and relatively independent of it. In the primary stage of the magnet positioning, the origin and orientation axis of the storage ring net were determined by the first order control net considering the large deviations of the components. In the precise adjustment stage of the magnets, to insure the relative accuracy between components the storage ring net is transferred to the 'gravity center' of the magnets to meet the optimum coordinate fitting. Under this circumstance the storage ring net is an independent, moveable control net. We chose dipoles as our references for the alignment and installation although their positional accuracy is not the most critical, because all other components that situate between dipoles on straight sections are easily aligned from two adjacent dipoles and, what is more, can be precisely installed according to the computation results of the control net even if the dipoles were not adjusted to their ideal positions.

3. Alignment of the LINAC

The beamcarring elements in the Linac are mounted on ϕ **350mm,** 6.2 meters long aluminum pipes, 6-meter segments. The aluminum pipes serve as the support girders and the path for the laser beam simultaneously. The 6- meter segments are prealignment using a pair of optic alignment devices which are composed of a four-microtelescope station and a four-target stand. The alignmemt of one segment used in take four or five days to get the stable dimensions of the elements before the segment is installed onto the linac. During these days the components are made necessary adjustments and get the positional accuracy within ± 0.03mm. The alignment accuracy of the accelerator units and the beam diagnostic segments are ±0.25mm and ±0.12mm respectively.

The control network for the linac consists of two reference stakes and this auxiliary reference line is measured by a Laser Alignment System. The laser alignment system developed for HESYRL linac is a Fresnel- zone alignment system (Fig. 3). It includes a light source of 2 mW He-Ne laser, eighteen Fresnel- zone plates made of chromium coated glasses with crisscross pattern, and a detector of four-quadrant silicon cell with the amplifier and the micrometers. For the purpose of diminishing the orientational drift of laser beam, the laser unit was designed several times better than a normal one. In the practical alignment and installation of the HESYRL linear accelerator, the alignment accuracy of

±0.10mm/80m and the sensitivity of ±0.02mm have been obtained. Figure 4 gives the installation results measured with the laser alignment system after the linac was assembled.

4. Accuracy computations of the control networks

The configuration of the first order net is that P25-P28 are the curvature center of the three dipoles in their each quadrant, P5 and P6 are the transfer points from the surface to the tunnel, i.e., from the storage ring to the transport line and the linac. The first order net as well as the storage ring net is composed of distance measurements only and performed with the DISTINVAR. Accuracy estimation shows that the standard deviations of the points P6, P6 are the most, for their bad geodetic figures[2]. To enhance the two points accuracy, one consideration is to add two offset measurements in triangles $\triangle P_5P_{27}P_{28}$, and $\triangle P_6P_{25}P_{28}$. The following table gives the standard deviations of the first order control net before and after adding offset measurements in the condition that the unit standard deviation of DISTINVA is ±0.03mm:

P_{25}:	$m_{p25} = \pm 0.039mm$,	± 0.034mm
P_{26}:	$m_{p26} = \pm 0.026mm$,	± 0.025mm
P_{27}:	$m_{p27} = \pm 0.041mm$,	± 0.038mm
P_{28}:	$m_{p28} = 0$.	
P_5:	$m_{p5} = \pm 0.116mm$,	± 0.047mm
P_6:	$m_{p6} = \pm 0.247mm$,	± 0.092mm

As stated in the precedence, the storage ring control net is a relatively independent or free net. Here twelve dipoles are distributed along a 66.13 meter circumference. Each dipole has two reference points for measurement. The three dipoles in the same quadrant have a coincident curvature center where is also set up a reference point. Therefore there are 28 knots in the network. To enhance the accuracy of the magnet positioning, the geodetic figure is composed of distance measurements only and is stiffened between magnets intentionally.

In the installation of the magnets a rational and flexible computation program occupies a decisive position. Our program includes the following functions:

(1) calculating the coordinates of the magnets reasonably, providing positional accuracy and relative positional accuracy of the magnets.

(2) Analyzing the distance values, helping to diminish measurement errors.

(3) Providing a plan that with mininum magnet adjustments to insure magnet relative accuracy.

(4) Any kinds of geodetic figures that composed of distance measurements can be calculated.

The control net for storage ring as showed in the figure has 86 distance measurements and 56 unknown coordinate parameters. The ratio of measurements to unknown parameters is 1.54. In the computation equations there are 86 error equations, one limitation equation of the orientation axis, and 139 parameters. According to the method of least squares, we evaluate the coordinates that make the sum of distance compensative values to the second power the least. That is,

V^TPV-Minimun (under the limitation equation)

P: Matrix of weight coefficients

V: Matrix of distance compensative value equals the most probable values minus the measurement values.

The accuracy computation of the control net gives the standard deviations of the storage ring magnets as follows:

Dipoles: $m_{pmax}=\pm 0.081mm$

Quadrupoles: $m_{pmax}=\pm 0.095mm$

Relative accuracy of dipoles: $m_{pr}=\pm 0.062mm$

The parameters of the error ellipse and the relative error ellipse between two adjacent dipoles are:

$m_{max}=\pm 0.075mm$, $m_{min}=\pm 0.030mm$

$m_{rmax}=\pm 0.056mm$, $m_{rmin}=\pm 0.026mm$

The accuracy estimation show that the least positional deviations of the quadrupoles caused by the control net occur in the middle of the straight sections with the most occur at the two ends. therefore the positional deviations of the quadrupoles equal the reference errors of the dipoles plus the positioning errors from the dipoles.

The distance compensative values fully reflect the precision of distance measurements. Frequently appeared measurement errors are systematic errors such as the calibration errors of the invar wires, the tolerance on fit of the measuring sockets etc.. The effect of three errors can be reflected on the distance compensative values. Wherever v values of distances are large, there must be problems in the measurements of these wires or related wires. In this consideration, we found many measurement errors in the installation.

To smooth the path of electron beam the relative positional accuracy between magnets should be as high as possible. For this purpose, in the precise adjustment stage of the magnets, we transfer the storage ring net to the ‘gravity center’ of the dipoles. That is, eventhough magnets have definite coordinates in relation to the first order control net, they are not installed according to this coordinate system, but to a new one in which twelve dipoles are adjusted to their ideal positions with minimum shift. i.e., let

$$S=\sum[(X_i(x_o,y_o,\theta)-XT_i)^2+(Y_i(x_o,y_o,\theta)-XT_i)^2]$$

$$\frac{\partial S}{\partial x_0}=0,\quad \frac{\partial S}{\partial y_0}=0,\quad \frac{\partial S}{\partial \theta}=0$$

XT, YT: theoretical coordinates of the reference points

x_o, y_o, θ: shift parameters of the coordinate system

The points with large deviations, which should be adjusted anyway, are not included in the optimum coordinate fitting.

5. Installation results of the magnets

From November to December, 1988 the storage ring magnets were adjusted three times. Fig.5 shows the absolute error ellipses and the relative error ellipses, and Table 2 the positional deviations of the dipoles after the twice adjustments. The standard deviations of the magnets show obviously symmetric nature, and in radial and tangential directions the deviations are follows:

Dipoles: $m_r=\pm 0.08mm$, $m_s=\pm 0.21mm$

Table 2 The position of bending magnets after the coordinate optimum fitting

POINT	*X* adjustment	*Y* adjustment	*DX*	*DY*	*DP*
B 1	4300.09	9576.00	−.05	−.13	.14
B 2	3520.81	10025.96	.01	−.11	.12
B 3	449.82	10848.70	−.14	−.21	.25
B 4	−450.07	10848.76	−.11	−.15	.18
B 5	−3520.76	10025.93	.04	−.14	.15
B 6	−4300.07	9576.02	.07	−.11	.13
B 7	−9576.07	4300.06	.02	−.14	.14
B 8	−10025.99	3520.62	.12	−.12	.17
B 9	−10848.79	449.94	.12	.01	.12
B10	−10848.74	−499.90	.17	.03	.17
B11	−10025.91	−3520.68	.17	.11	.20
B12	−9576.01	−4299.99	.11	.16	.19
B13	−4300.02	−9575.93	.14	.18	.22
B14	−3520.74	−10025.98	.04	.11	.12
B15	−449.98	−10848.70	.00	.21	.21
B16	449.93	−10848.73	−.05	.18	.19
B17	3520.77	−10025.91	−.02	.17	.17
B18	4300.08	−9575.89	−.07	.22	.23
B19	9575.98	−4300.11	−.10	.10	.14
B20	10026.05	−3520.68	−.07	.05	.09
B21	10848.81	−449.95	−.10	−.03	.11
B22	10848.80	449.84	−.11	−.08	.13
B23	10026.02	3520.66	−.08	−.10	.13
B24	9575.98	4299.98	−.12	−.20	.23
P25	−.01	3027.98	−.01	.01	.01
P26	−3028.08	.07	−.11	.07	.13
P27	−.17	−3028.01	−.17	−.04	.17
P28	3027.94	−.07	−.03	−.07	.08

$x_0 = .10$ $y_0 = .02$ Thita = .0010 $DP_{max} = .25(M_3)$

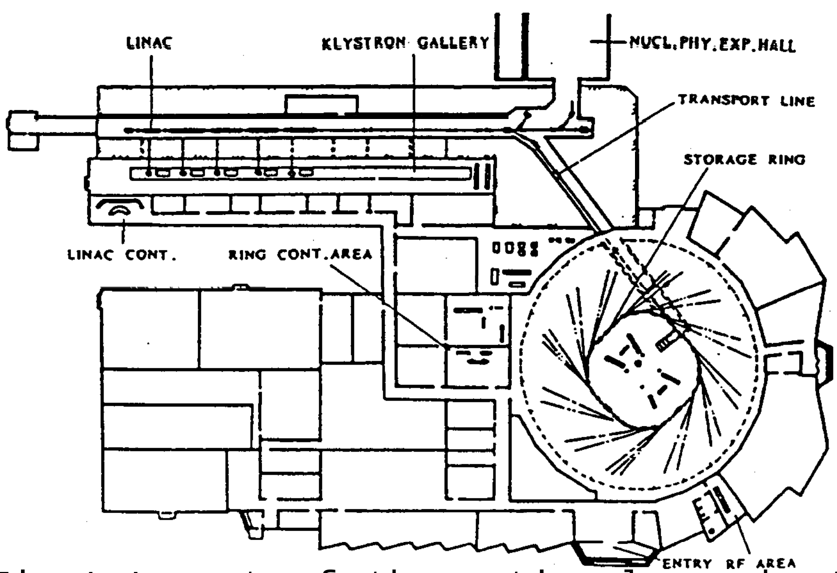

Fig.1 Layout of the national synchrotron radiation facility

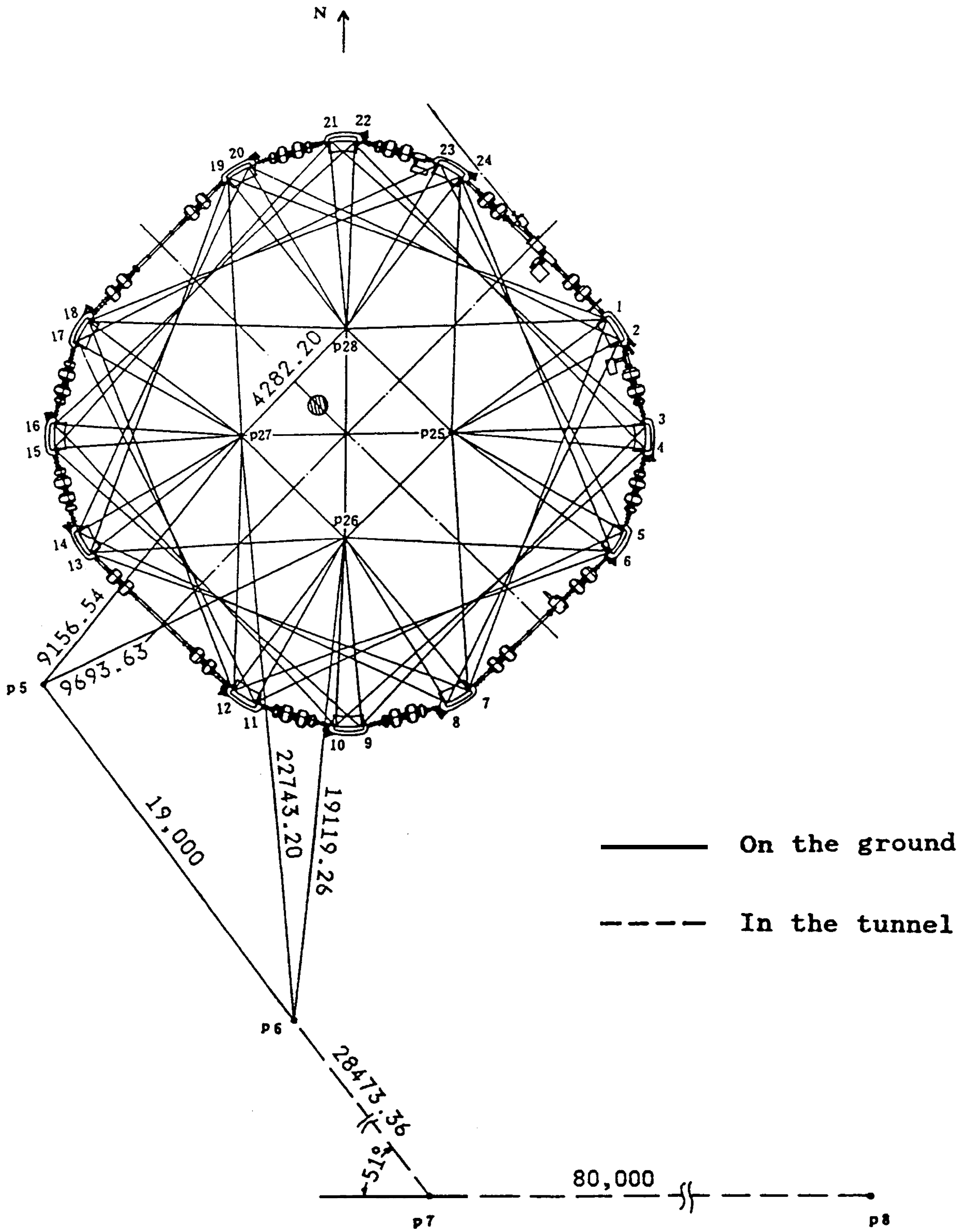

Fig.2 Control networks for the HESYRL

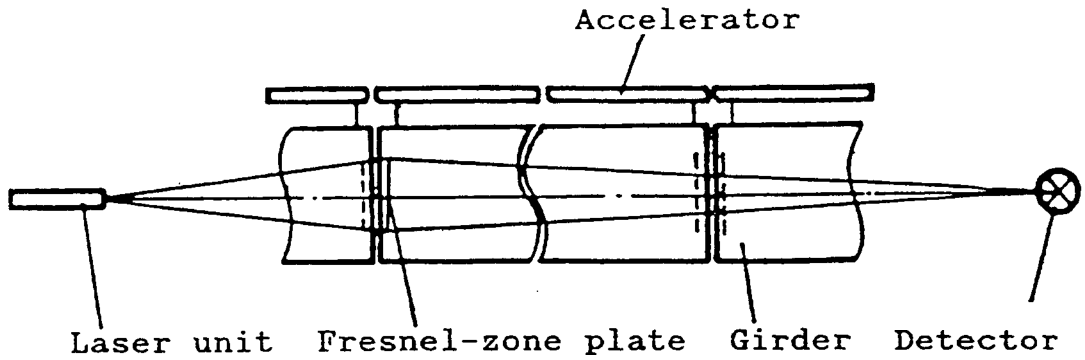

Fig.3 The sketch of the laser alignment system

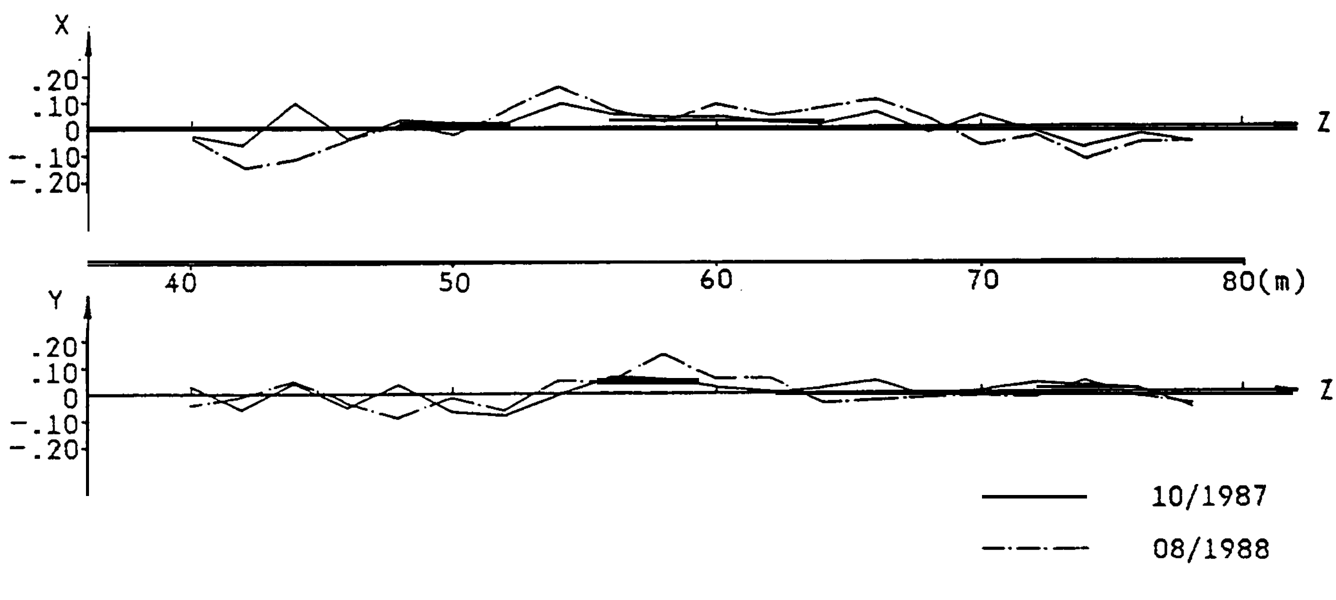

Fig.4 Installation results after the linac was assembled

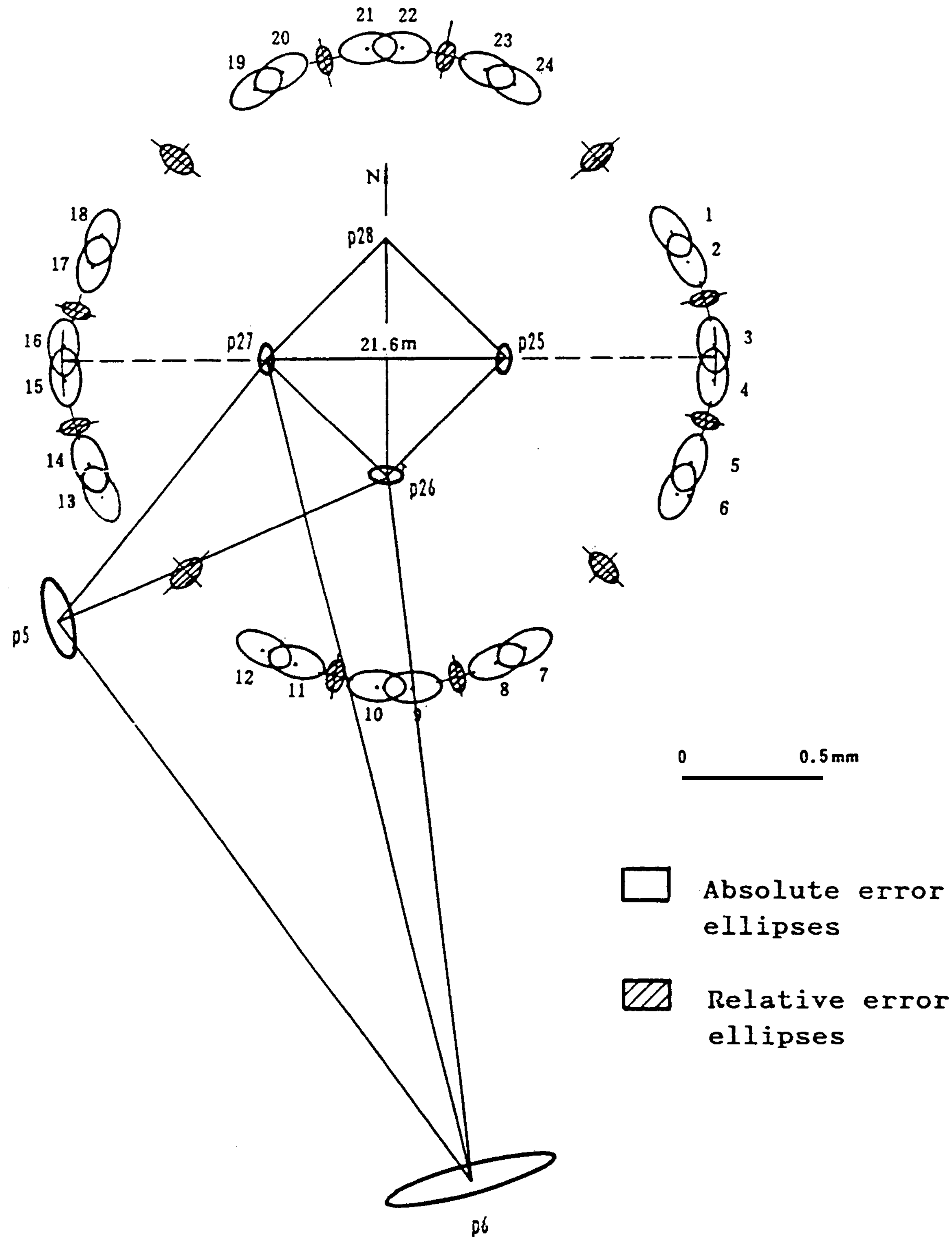

Fig-5 Error ellipses of the control networks

Quadrupoles: $m_r = \pm 0.10mm$, $m_a = \pm 0.54mm$

Relative deviations of dipoles:

Long straight sections: $m_r = \pm 0.16mm$, $m_a = \pm 0.07mm$

Short straight sections: $m_r = \pm 0.11mm$, $m_a = \pm 0.07mm$

In the performance of the distance measurements with the DISTINVAR, the unit standard deviation was ±0.08mm. Though the extension coefficient of invar wire is very low, its sensitivity to vibration can not be ignored, and, Moreover, its calibration should be much careful. In the operation, the following experience were summarized.

(1) The laser beam of the interferometer employed in calibration should be as close as possible to the invar wire.

(2) Each invar wire that has just made a periodic measurement along the ring circumference, should be checked up by remeasure the first pair of reference points.

(3) The tolerance on fit of the measuring points as well as the elastic deformation of the measuring points supports should be compensated.

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