Optimum Adjustment of Q Magnets' Horizontal Place in Storage Ring

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In an accelerator or a storage ring, Q magnets are used as focusing units. If their horizontal places deviate the designed ones beam orbit deformation will occur. A method that how to fit the orbit and how to make the adjusted Q magnets' number and the adjusted amount of the displacement in the radius directions as little as possible, after get the horizontal deviation of the Q magnets by horizontal network surveying, is discussed. It has practical significance in the aspects of alignment survey of displacement and adjustment on storage ring.

Key words: fitting; coordinate; datum point; Q magnet; B magnet

1. INTRODUCTION

Q magnets (Quadrupole electromagnets) restrain electron beam in two perpendicular directions to keep the beam in lest size, the process of which is called focus. If the position of Q magnet deviates the designed one, this displacement will combine with the magnetic field gradient to form an additional bending field, which will make the real beam orbit deviate the designed one and produce an orbit distortion. This distortion could influence the normal commissioning of storage ring. The displacement could be caused by assembling and alignment error. It could also be caused by the magnets' sedimentation, driftage and deformation. So it is very important to monitor the displacement of the magnets by the method of precise engineering survey. If the position of some magnets goes beyond the limit they must be adjusted.

But in accelerator, the relative positions among magnets are more important the their absolute ones. If we keep continuously adjust every magnets to their designed positions, the workload is very heavy, and it needs much time, and the more important is that it is unnecessary. Before adjusting the place of magnets in a accelerator, by reasonable fitting calculating, we can find a fitting orbit in which the relative positions among all the magnets are acceptable, and find the Q magnets whose displacements are largest. By this way, the number of the magnets having to be adjusted become much less as well as the adjusting quantity.

Because the survey and adjustment in vertical direction are easier, this paper mainly discusses the adjustment in the horizontal direction.

Here the Hefei Light Source is given as the example. The plane deformation-monitoring network of the Storage Ring in Hefei Light Source is used to monitor the displacement of every magnet. There are 12 B magnets in the ring and there two datum points on every B magnet. By measure the distances among these points we establish the plane deformation-monitoring network. After adjustment calculating we can get the adjusted coordinates of every point. The line linking the two neighboring points on the neighboring B magnets is used as reference line. By measuring the distances of every Q magnets to every reference line can be gotten, which is the horizontal displacement in the radius direction of very Q magnet. We concern the positions of Q magnets but the ones of B magnets. The purpose is to find which Q magnets have relative large displacement in radius direction and adjust them.

2. KNOWN CONDITION

An original coordinate system was established with the center of the storage ring as its origin. The X-axle and Y-axle are the symmetry axles of all the magnets. A Q magnet in quadrant I is given as an example to discuss how to calculate its coordinates from the known coordinates of the datum points on the neighboring B magnets. The example is shown in Fig.1. The suffix with "0" represents the designed position. A_0 and B_0 are the neighboring datum points on the neighboring B magnets. Q_{i0} is center position of a Q magnet between the B magnets. The line linking A_0 and B_0 is a reference line. Theoretically Q_{i0} should be on the line. The angle between the A_0B_0 line and the X-axle is α_0. The distance from Q_{i0} to the point A_0 is L_{A0}. The theoretical coordinates of the two datum points and the Q magnet are (x_{A0}, y_{A0}), (x_{B0}, y_{B0}), (x_{i0}, y_{i0}). α_0 and L_{A0} can easily be determined and they are known parameters.

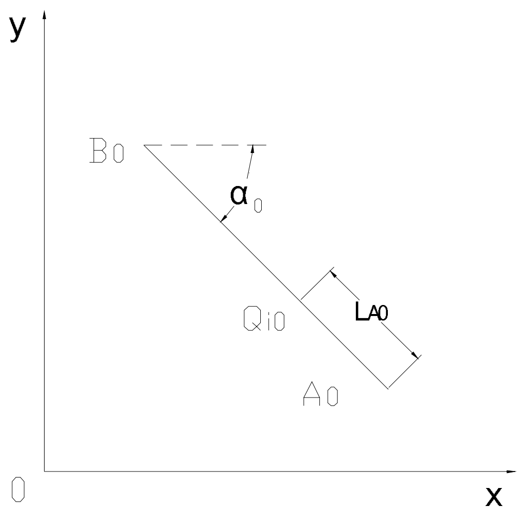

Figure 1. Sketch map of the theoretical position of Q magnet in quadrant I

After surveying and calculating, we can get the adjusted coordinates of the two datum points. A and B represent them and their coordinates are (x_A, y_A), (x_B, y_B). The surveying result of the distance from the Q magnet to the line AB is h_i. The relative positions are shown in Fig.2. If the Q magnet displaces outside the ring, the value of h_i is positive.

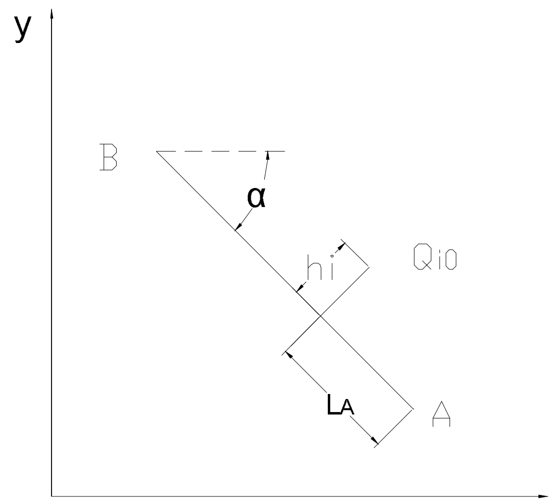

Figure 2. Sketch map of the actual position of Q magnet in quadrant I

Then the actual coordinates of the Q magnet (x_i , y_i) and the angle between the reference line and X-axle α respectively are

$$\alpha = tg^{-1}\left(\frac{y_B - y_A}{x_A - x_B}\right) \tag{1}$$

$$x_i = x_A - L_{A0}\cos\alpha + h_i \sin\alpha \tag{2}$$

$$y_i = y_A + L_{A0}\sin\alpha + h_i \cos\alpha \tag{3}$$

Here the diversity between the actual L_A and the theoretical L_{A0} is neglected because it is very small and its influence on the calculating result can be neglected.

3. ALTERNATION OF FITTING COORDINATE

Because there is diversity between the actual position and the theoretical position of the datum points on B magnet, the surveyed h_i is actually not the displacement must be adjusted in the radius direction. Another coordinate system is imagined, which is alternated from the origin one, e.g. the O—XY coordinate system is alternated to a new one $\tilde{O}-\tilde{x}\tilde{y}$. See fig.3. The alternating principle is that in the new system the difference between the coordinates of Q magnet $(\tilde{x}_i, \tilde{y}_i)$ and the theoretical coordinates (x_{i0} , y_{i0}) is as small as possible. Then in the new system the displacement of Q magnet is analyzed. After the alternation the orbit including the centers of Q magnets and the lines linked the datum points on B magnets is the fitting one.

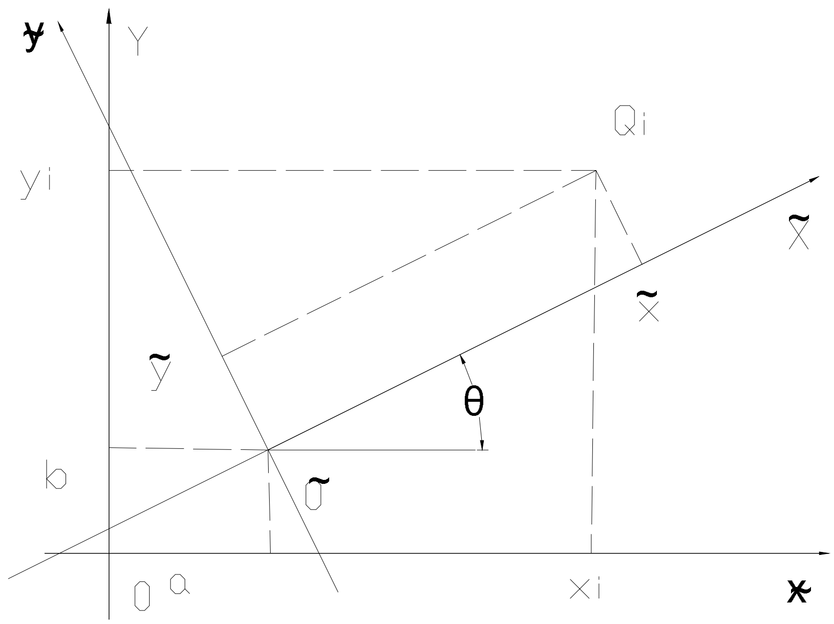

Figure 3. Coordinate alternation

Now the alternating process is discussed. The coordinates of the origin of the new system $\tilde{O}$ in the original system are （a，b）. The angle between the axle $\tilde{O}\tilde{x}$ and axle Ox is θ. The alternation includes rotating and parallel shifting. The coordinates of Q magnet in the two coordinate system are （x_i, y_i） and $(\tilde{x}_i, \tilde{y}_i)$. Then

$$\tilde{x}_i = (x_i - a)\cos\theta + (y_i - b)\sin\theta \qquad (4)$$

$$\tilde{y}_i = -(x_i - a)\sin\theta + (y_i - b)\cos\theta \qquad (5)$$

In new system the ideal position of Q magnet also is （x_{i0}，y_{i0}）certainly, and it is unnecessary to use other symbols to distinguish. So in new system the diversities between the actual coordinates and the ideal ones are

$$\Delta\tilde{x}_i = \tilde{x}_i - x_{i0} \ , \quad \Delta\tilde{y}_i = \tilde{y}_i - y_{i0} \qquad (6)$$

Using $\sum_i$ represents add. For Hefei Light Source there are 32 Q Magnets so i=1~32. To add all the squared diversities of the coordinates in two directions up

$$\begin{aligned} f &= \sum_i (\Delta\tilde{x}_i^{\,2} + \Delta\tilde{y}_i^{\,2}) \\ &= \sum_i \{[(x_i - a)\cos\theta + (y_i - b)\sin\theta - x_{i0}]^2 + [-(x_i - a)\sin\theta + (y_i - b)\cos\theta - y_{i0}]^2\} \\ &= \sum_i \{(x_i - a)^2 + (y_i - b)^2 + x_{i0}^2 + y_{i0}^2 - 2\cos\theta[x_{i0}(x_i - a) + y_{i0}(y_i - b)] \\ &\quad + 2\sin\theta[y_{i0}(x_i - a) - x_{i0}(y_i - b)]\} \end{aligned} \qquad (7)$$

In order to get the least f value, least square method is used to choice the parameters of a、b and θ. Then a、b and θ must conform to

$$\frac{1}{2}\frac{\partial f}{\partial a}=\sum_i\{a-x_i+x_{i0}\cos\theta-y_{i0}\sin\theta\}=0 \qquad (8)$$

$$\frac{1}{2}\frac{\partial f}{\partial b}=\sum_i\{b-y_i+y_{i0}\cos\theta+x_{i0}\sin\theta\}=0 \qquad (9)$$

$$\frac{1}{2}\frac{\partial f}{\partial \theta}=\sin\theta\sum_i[x_{i0}(x_i-a)+y_{i0}(y_i-b)]+\cos\theta\sum_i[y_{i0}(x_i-a)-x_{i0}(y_i-b)]=0 \qquad (10)$$

Using symbol " $\langle\ \rangle$ " represents the average value, then equations 8 and 9 can become

$$a=\langle x_i\rangle-\langle x_{i0}\rangle\cos\theta+\langle y_{i0}\rangle\sin\theta \qquad (11)$$

$$b=\langle y_i\rangle-\langle y_{i0}\rangle\cos\theta-\langle x_{i0}\rangle\sin\theta \qquad (12)$$

Equation 10 can be alternated as

$$\begin{aligned}&\sin\theta[\langle x_{i0}x_i\rangle+\langle y_{i0}y_i\rangle-a\langle x_{i0}\rangle-b\langle y_{i0}\rangle]\\&=\cos\theta[\langle x_{i0}y_i\rangle-\langle y_{i0}x_i\rangle+a\langle y_{i0}\rangle-b\langle x_{i0}\rangle]\end{aligned} \qquad (13)$$

From equations 11, 12 and 13，the following one can be gotten

$$\sin\theta[\langle x_{i0}x_i\rangle+\langle y_{i0}y_i\rangle-\langle x_i\rangle\langle x_{i0}\rangle-\langle y_i\rangle\langle y_{i0}\rangle]=\cos\theta[\langle x_{i0}y_i\rangle-\langle y_{i0}x_i\rangle+\langle x_i\rangle\langle y_{i0}\rangle-\langle y_i\rangle\langle x_{i0}\rangle]$$

So

$$\theta=tg^{-1}[\frac{\langle x_{i0}y_i\rangle-\langle y_i\rangle\langle x_{i0}\rangle-\langle y_{i0}x_i\rangle+\langle x_i\rangle\langle y_{i0}\rangle}{\langle x_{i0}x_i\rangle-\langle x_i\rangle\langle x_{i0}\rangle+\langle y_{i0}y_i\rangle-\langle y_i\rangle\langle y_{i0}\rangle}] \qquad (14)$$

From equations 14, 11 and 12 the values of a and b can be calculated.

For the ideal coordinate system, which the origin is the center of storage ring, the X-axle and Y-axle are the symmetry axle of the ring, the calculation can be easily simplified. In this kind of system

$$\langle x_{i0}\rangle=\langle y_{i0}\rangle=0$$

So

$$\theta=tg^{-1}[\frac{\langle x_{i0}y_i\rangle-\langle y_{i0}x_i\rangle}{\langle x_{i0}x_i\rangle+\langle y_{i0}y_i\rangle}] \qquad (15)$$

$$a=\langle x_i\rangle \qquad (16)$$

$$b=\langle y_i\rangle \qquad (17)$$

Not only the equations is simpler but also the physics' meaning of the parameters is clearer.

Combining the calculated values of a and b with equations of 4,5, and 6, the coordinates of Q magnet in new system, $\tilde{x}_i$ and $\tilde{y}_i$, can be calculated.

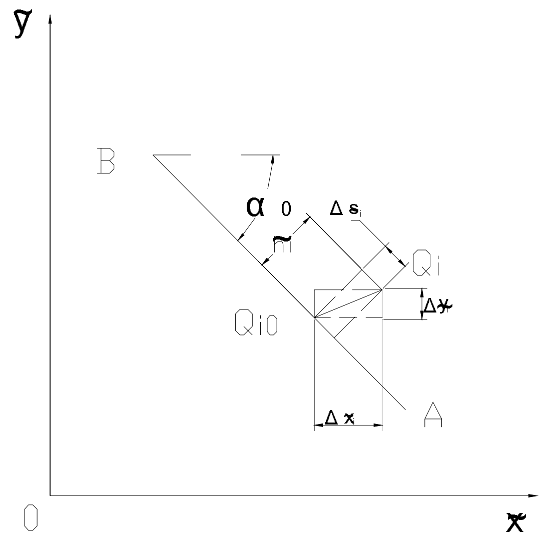

Figure 4. New coordinate of Q magnet

Factoring the displacement of every Q magnet into two directions of lengthways and radius, it is easier for adjusting. See Fig.4.

The displacement in the direction of radius is

$$\tilde{h}_i = \Delta\tilde{x}_i \sin\alpha_0 + \Delta\tilde{y}_i \cos\alpha_0 \quad (18)$$

The displacement in the direction of lengthways is

$$\tilde{s}_i = \Delta\tilde{x}_i \cos\alpha_0 - \Delta\tilde{y}_i \sin\alpha_0 \quad (19)$$

Where α_0 is the angle between ideal reference orbit and the X-axle. Using tabulation or plot to show the calculated values of $\tilde{h}_i$, it is easy to know its changing situation. Based on its values and the commissioning situation of accelerator to determine whether adjusting the place of magnet or not. $\tilde{h}_i$ is the adjustment value. If the largest value of $\tilde{h}_i$ or its is less than a standard (0.1mm, for example) it is not needed to adjust。

4. COCLUSION

Computer can do all the calculating process. We have used the method discussed above in our alignment and adjustment of the storage ring.

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