STRUCTURES OF QUADRUPOLE MAGNET CORE

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Abstract

In general, there are two different quadrupole core designs: two pieces (up half and low half cores) and four pieces (four quarter halves). Both structures work on those quadrupole magnets in different accelerators around the world. There is no certain standard about which design is good for what machine, it is most likely defends on the engineer's preference and the coil size. There are advantages and disadvantages with both structures. However, the disadvantage of four pieces design is rather visible. It is the goal of this paper to study those advantages and disadvantages of two types of core structure from manufacturer's point of view and the perturbations of the magnet field.

RIGIDITY COMPARISON OF TWO STRUCTURES

Figure 1 below is the prototype of LEB, SSC quadrupole magnet which was built at LBL. Its core was built by four quarter cores and the quarter core was stacked and glued by laminations. In addition to gluing laminations together and tightening the pole by a bolt in a stacking fixture under the pressure, a tight bar was welded on the back of the core. This prototype was checked at LBL and then shipped to SSC by air. After the shipment, the gaps between the poles and the diameter of the aperture were all shifted and were out of the tolerances.

Figure 2 below is a quadrupole magnet of SPEAR3, SLAC. Its core was built by two half cores. The half core was glued by laminations as well. Rather than a tight bar, laminations were tightened by four bolts in addition to gluing laminations together and tight bolt at pole. The quadrupole magnets were built at IHEP, China and inspected and measured there and then shipped to SLAC by boat. Some of those magnets were re-measured at SLAC. The results were correspondent with what IHEP people obtained, which indicated that the quadrupole rigidity is very good and the structure of the core experienced all sorts of impact during the shipment.

These two examples mentioned above demonstrated that a two piece core is more rigid than a four piece core.

But one may notice that the coil dimension of LEB SSC quadrupole made it impossible to be installed into a two piece half core. An engineer must examine the size and the shape of the coil carefully and make sure it will be installed into the half core without trouble should a two piece core structure is selected.

Figure 1: SSC, LEB Quadrupole

Figure 2: SLAC, SPEAR3 Quadrupole

COMPARISON OF GLUED CORE AND WELDED CORE

Figure 3 below is a half core of SPEAR3 quadrupole magnet. It was glued by laminations. Figure 4 below is a half core of LER, PEPII quadrupole, it was laminated as well, but was welded as one piece by angle plate instead of gluing.

Glued Core

The first problem with a glued core is an environment issue. The workers smell epoxy directly which is different from the case of coil impregnation. The later one is processed under the vacuum. In most case, the workers do not feel comfortable to work under a strong smell working place. The second problem with a glued core is that the cleaning work after core curing is a quite involvement. The cleaning work actually can be limited when the thickness of the epoxy layer is adjusted very carefully. But it is not an easy task, if the gluing machine is old and the roller of it is not built with very tight tolerance. The third problem with a glued core is that it leaves almost no room for re-adjusting after curing if the dimension(s) shifted during the curing by some reason(s). The advantage of gluing procedure is that it will avoid from deformation caused by welding, especially for a

long core. A core longer than 750mm, usually it is difficult to control the welding deformation and its sugariness is very much rely on the skill of welder(s).

Welded Core

A welded core does not have those problems a glued core has. But it will involve solid end plates and angle plates in most cases. When an accelerator has a very tight placement, which leaves a very small room between magnets, additional solid end plate may cause problem. Also, the angle plate is a rather costly part, it will involve heating treatment, forming and machining. Sometimes, one maybe surprised by the cost of the angle plate comparing with other main components of a magnet.

An advantage of the welded core is that it can be re-adjusted almost as many times as it needed after welding until reach the tolerance requirement. A very skilled technician can pick up the right spot(s) of a welding seam based on the dimension that is out of the tolerance and hammer it (them) to release welding strength at point(s). The welding deformation will be then corrected sequentially. But this procedure involves high man skill and it can not always work if the core is very long and the deformation is big.

Figure 3: SPEAR3 Quadrupole Glued Half Core

Figure 4: PEPII LER Quadrupole Welded Half Core

Should a core be welded or glued, is a comprehensive decision. An engineer shall consider available fabrication fixture of the selected manufacturer, the environment code of the place where it located and also its workers' workmanship, allowed magnet dimension and cost, etc.

PERTURBATIONS [1]

In general, there are four factors which cause perturbations of a quadrupole magnet.

A. Excitation Error $\varepsilon_j=\Delta j/J$: caused by coil design position or fabrication and installation error or caused by length or magnetic property of half core.

B. Radial Offset $\varepsilon_{rd}=\Delta x/r$: caused by horizontal shift of the pole(s) (shown in figure 5).

C. Azimuthal Offset $\varepsilon_{az}=\Delta y/r$: caused by vertical shift of the pole(s) (shown in figure 5).

D. Pole Rotation $\varepsilon_{rot}=\Delta$Ang: pole(s) rotated (shown in figure 6).

The core assembly of four quarter structure involves three factors among those mentioned above: B. C and D. Furthermore, each pole of quarter core can be offset individually (shown in figure 7). While, a two half core structure, during the assembly can reduce the effort of adjustment of factor B, C and D significantly comparing to four piece core (shown in figure 8).

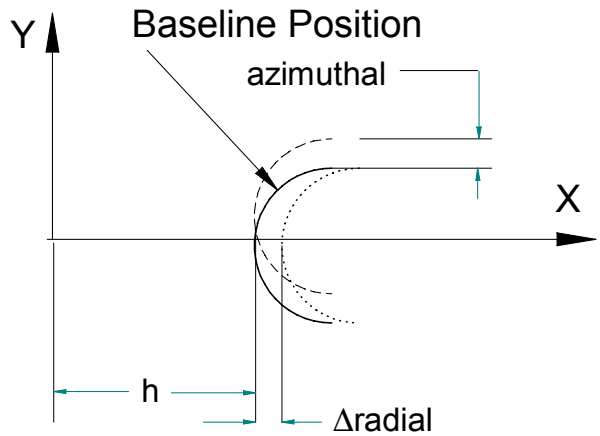

Figure 5: Case B and C

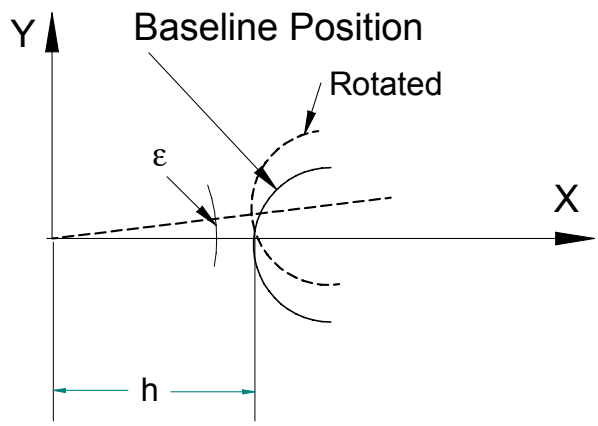

Figure 6: Case D

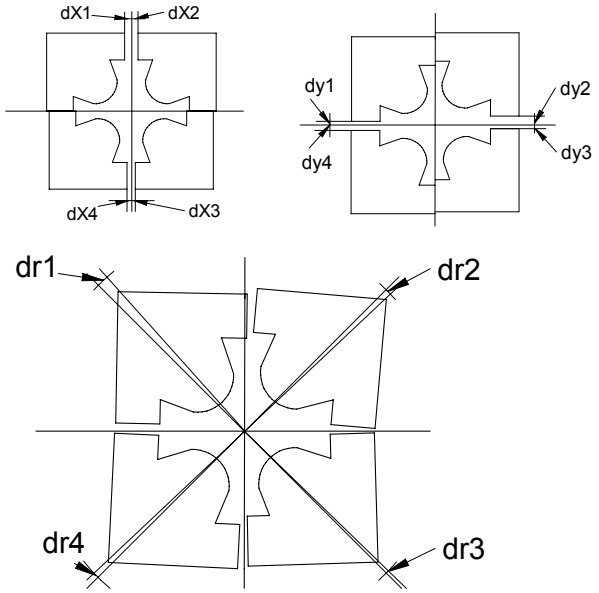

Figure 7: Four Piece Core Assembly Errors

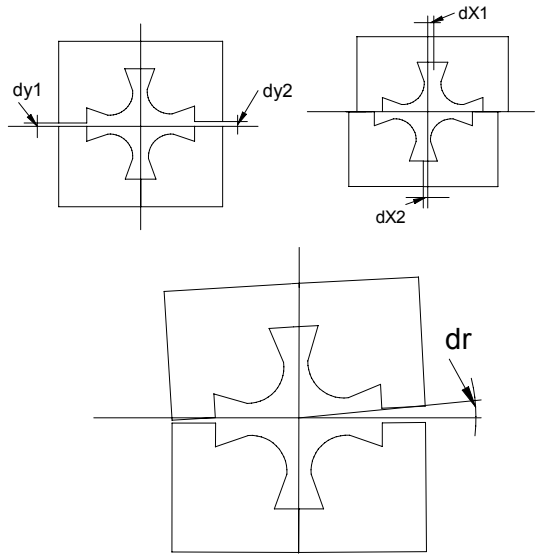

Figure 8: Two Piece Core Assembly Errors

CONCLUSIONS

Based on the discussions above, a core with two half cores shall be a first choice of an AC quadrupole magnet design. An engineer shall make the coil dimension easily install in between two poles. If the magnet shall be operated under DC current, usually, the core is built as a solid piece rather than laminated core. In this case, a four piece core is recommended, because that the machining tolerance is the direct proportion of the part dimension. A quarter half core will reduce machining cost significantly.

REFERENCES

[1] Jack T. Tanabe "Iron Dominated Electromagnets" Published by World Scientific Publishing Co. Pte. Ltd.