# PRELIMINARY DESIGN OF MAGNET SUPPORT SYSTEM FOR CEPC

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*Abstract*

Magnet support system is important for CEPC. For the 100 km design of CEPC, there will be thousands of magnets and their supports in both collider and booster. Especially, the booster ring is above the collider in the space, the magnets are hung by the supports. The goals of magnet supports are simple and flexible structure, minimizing the magnet deformation, good stability, low cost and so on. This paper will describe the preliminary design of magnet support system, the optimization to minimize the magnet deformation and the topology optimization of the frame structure in booster.

## INTRODUCTION

Circular Electron Positron Collider (CEPC) which was proposed by Chinese scientists after the discovery of Higgs at LHC is under R&D now. The perimeter of the collider is 100 km in recent design [1]. The two rings (collider and booster) are in the same tunnel, the booster ring is above the collider in the space. There will be thousands of magnets and there supports for such a big facility, so the stability, flexibility and cost must be taken into consideration in the R&D stage.

For cost consideration, the current design uses manual mechanisms for the supports adjusting. Each magnet is supported, fixed and adjusted separately. The requirements of support system in both ring are as follows:

- Range and accuracy of adjustment are showed as Table 1.
- Stability with large time constants, avoiding creep and fatigue deformation.
- Simple and reliable mechanics for safe mounting and easy alignment.

Table 1: Range and Accuracy of Adjustment

| | Range of adjustment | Accuracy of adjustment |
|---|---|---|
| X | ≥±20mm | ≤±0.02mm |
| Y | ≥±30mm | ≤±0.02mm |
| Z | ≥±20mm | ≤±0.02mm |
| Δθx | ≥±10mrad | ≤±0.05mrad |
| Δθy | ≥±10mrad | ≤±0.05mrad |
| Δθz | ≥±10mrad | ≤±0.05mrad |

## OVERALL DESIGN OF MAGNET SUPPORTS

For the collider ring, each support contains the pedestal (concrete), magnet mounting plate and adjusting mechanism (push-poll bolts).

For dipole magnets, four magnet modules of length 4500 mm each are connected to become a unit of magnet, total length 18000 mm. The supports for each magnet module is called support module. To avoid deformation, each support module contains two main supports and two auxiliary supports, as shown in Fig. 1. The main support is for support and adjustment (6 DOFs), while the auxiliary supports are only for support (1 DOF).

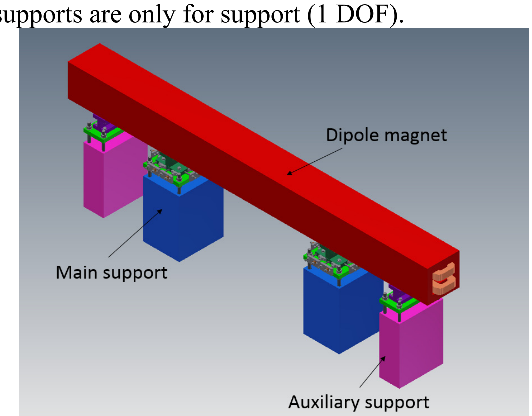


Figure 1: Dipole magnet supports for each module.

The quadrupole magnets are 2000 mm long, supported by two supports, as shown in Fig. 2. The sextupole magnet is 670 mm or 370 mm long, supported by one support, as shown in Fig. 3. The supports are similar to the main supports of the dipole magnet.

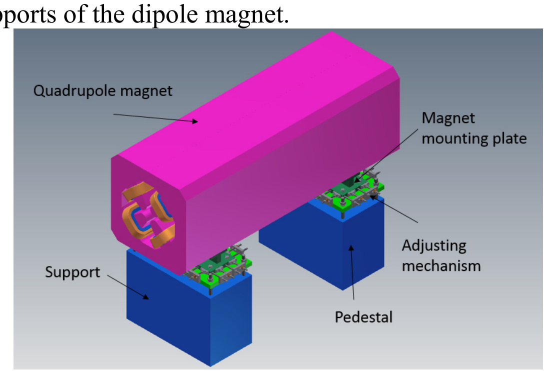


Figure 2: Quadrupole magnet supports.

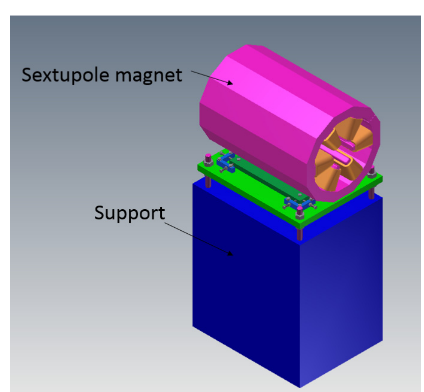


Figure 3: Sextupole magnet supports.

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For the booster ring, the supports are similar, except the pedestals are made of steel frames. The preliminary supports design for both rings are shown in Fig. 4.

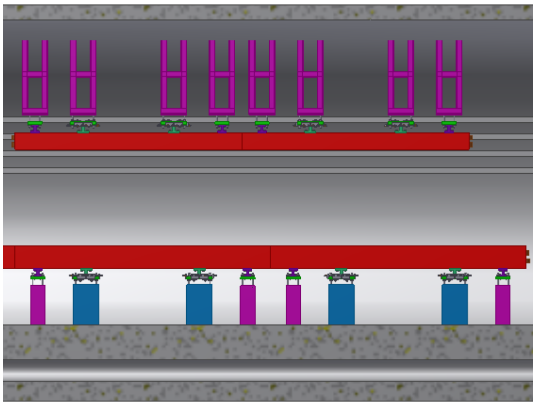

Figure 4: Longitudinal cross section of the tunnel.

## DISTRIBUTION OF SUPPORT POINTS FOR DIPOLE MAGNETS

As described above, there are four support points for a dipole magnet module. This is mainly for minimize the deformation of the magnet. In this section, the location of supporting points will be discussed.

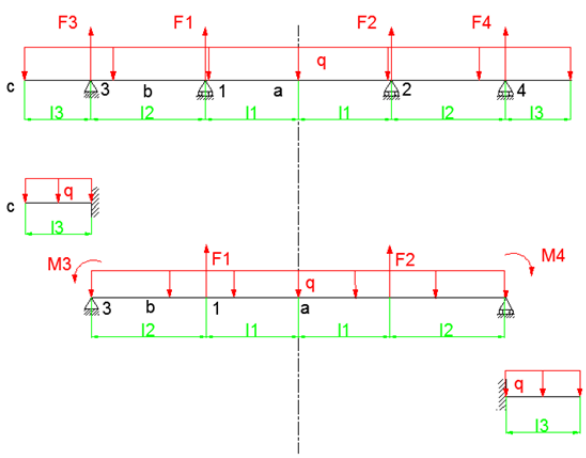


Figure 5: Force diagram of 4 support points beam.

Supposing the 4.5 meters or 4 meters dipole magnet module as a slender beam, the force diagram of the beam is shown as Fig. 5. Because of the symmetric structure, we can obtain that

$$F1 = F2, F3 = F4 \quad (1)$$

$$F1 + F3 = q(l1 + l2 + l3) \quad (2)$$

$$\omega 1 = 0 \quad (3)$$

$\omega 1$ is the deflection of point 1. From Eq. (1) ~ (3) F1 and F3 can be expressed by $q$, $l1$, $l2$ and $l3$. In Fig. 5, point a is the middle point of the beam, point b is the point which has the largest deflection between point 1 and point 3, and point c is the end point of the beam. Then, the deflections of point a, b, and c can be expressed by $q$, $l1$, $l2$ and $l3$, as described in Eq. (4) ~ (6), in which $\omega_{aq}$ means deflection of point a caused by q, and similarly $\theta_{3M3}$ means bending angle of point 3 caused by M3.

$$\omega_a = \omega_{aq} + \omega_{aF1} + \omega_{aF2} + \omega_{aM3} + \omega_{aM4} \quad (4)$$

$$\omega_b = \omega_{bq} + \omega_{bF1} + \omega_{bF2} + \omega_{bM3} + \omega_{bM4} \quad (5)$$

$$\omega_a = \omega_{cq} + l3 \cdot (\theta_{3M3} + \theta_{3M4} + \theta_{3q} + \theta_{3F1} + \theta_{3F2}) \quad (6)$$

To obtain a common result, the beam length is uniformed to 1 m. Using MATLAB for optimization calculation, the aim is minimize the maximum value of deflections of point a, point b and point c. Figure 6 is the contour result. When *l1* equals 0.132 m and *l2* equals 0.263 m, the maximum deflection of the calculated three points is minimum. This optimization is also checked by Response Surface design in ANSYS Workbench, the results is *l1* equalling 0.133 m and *l2* equalling 0.263 m, almost the same as the former one. The deflection distribution of the beam is shown as Fig. 7.

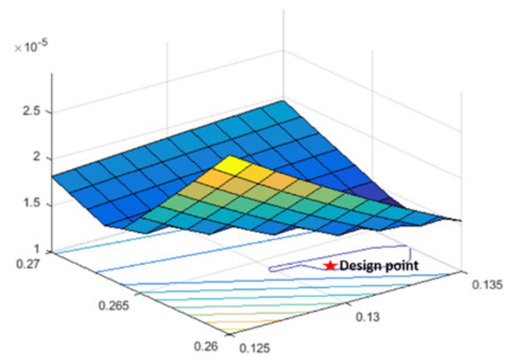


Figure 6: Contour result of distribution of support points along beam

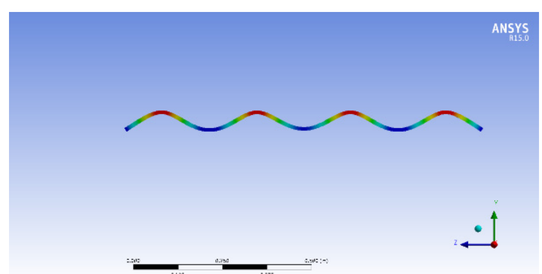


Figure 7: Deflection distribution of optimized support locations of slender beam.

The current designs of dipole modules are 4.5 meters long in collider and 4 meters long in booster, the supporting points can be obtained by multiplying module length. If the module length changes, the supporting locations can change easily according to the calculation above.

## TOPOLOGY OPTIMIZATION OF MATGNET SUPPORTS IN BOOSTER

In the pre-CDR stage, three schemes of booster supports were considered, which are shown in Fig. 8 [2]. The first two schemes were given more consideration because of independent supports. But where should the supporting points be needs further consideration.

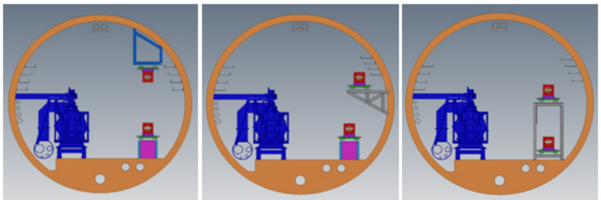

Figure 8: Three schemes of booster supports in pre-CDR.

Topology optimization is used for the supporting points design. According to the preliminary design, the radius of the tunnel is 3250 mm, the dimensions of dipole magnet core in booster is 235mm in width and 260 mm in height. The mounting and adjusting mechanism is about 200 mm high.

Firstly, the optimization in the plane perpendicular to the beam is done. Supposing there are two supporting points at the wall of tunnel, the angle of each point varies from 0° to 90°. The topology optimization is carried out by using the volume as the constraint and the structure supple degree as the objective function.

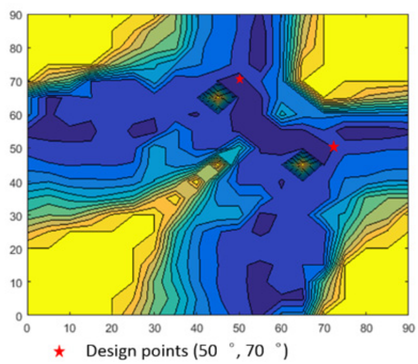


Figure 9: Contour of Structure supple degree.

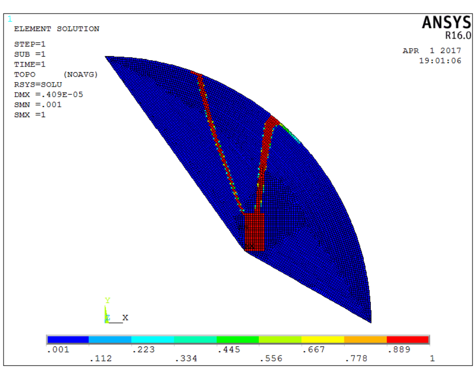


Figure 10: Mesh density in the plane perpendicular to the beam.

The contour of structure supple degree is shown as Fig. 9. The minimum structure supple degree happens when the two angles are 50° and 70° separately, and the mesh density distribution is shown as Fig. 10. The red ones have the higher mesh densities and should be reserved.

Secondly, the 3D-optimization is done. According to the support points designed above, a roughly 3D-model is built. Then topology optimization is carried out again, also use the volume as the constraint and the structure supple degree as the objective function. The optimized elements distribution is shown in Fig. 11.

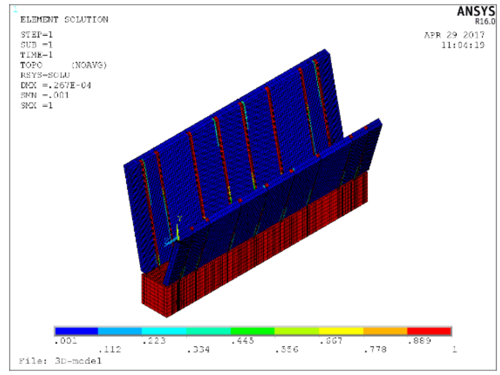


Figure 11: Distribution of the 3D mesh density.

The final frame structure of the supports can be designed according to the red elements in Fig.11, and also should consider other details, like welding, mounting and so on.

Similarly, the support structure of other kinds of magnets can be designed. And once the dimensions or locations of the magnets changed, the optimized structure can be changed conveniently using the same method.

## CONCLUSION

The preliminary structure design of the support system for CEPC are done. The supports use manual adjusting mechanism for cost consideration. The locations of support points for the dipole magnet modules in both collider and booster are optimized to minimize the deflection. Besides, topology optimizations of the frame structure of supports in booster are done to minimize the structure supple degree.

## REFERENCES

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