CBETA

Engineering review report : C-Beta hybrid magnets

Date: September 12, 2016
Reviewers: T. Tanabe (chair), M. Anerella, C. Cullen and G. Ganetis
Participants: S. Peggs, K. Smolenski, G. Mahler, J. Tuozzolo, P. Wanderer, F. Willeke, H. Witte

Engineering review for C-Beta hybrid magnets was conducted from 2pm to 5pm on September 12, 2016. Here are charge questions:

1. Are the techniques for modeling and analysis sufficient for the hybrid magnet design?

2. Will the prototype magnets accurately represent the final product, and use sufficiently detailed material properties?

3. Is the temperature compensation scheme sufficiently proven? Should additional tests or alternate approaches be considered (for example heaters with temperature controllers)?

4. Does the engineering design faithfully reproduce the required magnet physics design? Have issues of mechanical stability and rigidity been considered?

5. Considering that hundreds magnets need to be produced, are there techniques or solutions to reduce the cost or complexity of the magnet, in order to reduce manufacturing costs?

6. Does the design lend itself to tightly controlled magnet-to-magnet variations, through either the design or the manufacturing process?

7. Are there aspects of the design that demand extremely challenging tolerances or assembly requirements (precision sorting, critical material specifications)?

8. Should additional features be added to the magnet to accommodate mounting the correctors and for mounting or positioning the magnets on the girders?

1. **Are the techniques for modeling and analysis sufficient for the hybrid magnet design?** **Magnetics → Yes, Structural → No**

Comments:

- 3D magnetic analyses appear sufficient for magnetic performance. However no structural analysis was presented. It is preferable to check the mechanical deformation due to force with ANSYS or other software and compare it to the values measured in a proto-type.
- The analysis is sufficient; but, what was presented was Holger's work. A recommendation would be that an independent analysis be done to confirm this work. N. Tsoupis may have already done this. Also it should be checked with the machine physics group - again this may have already been done.
- The modeling and analysis seem sufficient, but the building and testing of a proto-type is required to confirm the magnetic field and temperature coefficient of the magnet to the calculation.

2. **Will the prototype magnets accurately represent the final product, and use sufficiently detailed material properties**? **No**

Comments:

- The "fast track" prototype which is currently being built will not accurately represent the final product. PMs to be used are smaller than the final design and therefore have less attractive force, making the assembly process seem easier than it will be for the final product. In addition, steel being used is not of the same magnetic quality as the material being specified for the final product. It is important to expedite the orders for the proper steel and the proper PMs.
- From the information presented the temperature coefficient of the permanent magnet material used in the proto-type could be different from the production run. There seems to be a wide variation between batches. There are provisions in the magnet design to accept some variation but it may not be sufficient. I would recommend working with the permanent magnet vendor in developing a testing process on the formulation of the material to ensure the temperature coefficient is within the range the magnet design can accept.
- The only concern expressed in the review is that a small order of permanent magnet material may have slightly different properties than the production order. This should not delay proceeding with prototypes with different materials.
  - Finding: There was not a cohesive plan presented for how the prototype magnets will be tested. One magnet is being built; but, there is concern about cross-talk between the adjacent magnet in a doublet and cross talk between doublets.
  - Recommendation: A plan for testing/magnetic measurement of these pairings needs to be developed, a plan for building x number of additional prototypes implemented, and additional material needs to be ordered quickly.

3. **Is the temperature compensation scheme sufficiently proven? Should additional tests or alternate approaches be considered (for example heaters with temperature controllers)?**
   ➔ **Almost. An additional test to estimate the variances of temperature coefficient of NdFeB magnets is recommended.**

Comments:

- Temperature compensation has been demonstrated on a “C-magnet”. If possible these tests should be repeated on a prototype magnet
- The amount of NiFe seems to be determined by a test. It should be confirmed that no big variations of required amount is expected by estimating the variance of the temperature coefficient of a sample of magnets.
- Once the prototype is tested at different temperatures I believe the design should be validated. The potential problem will be the temperature coefficient of the production permanent magnets. Sample testing at the manufacturer should be required. Any active temperature control scheme will need a thorough understand of the requirements and may have to be incorporated in to magnetic field testing.
- It won't be proven until the prototype magnets are tested. Testing the first prototype should indicate whether alternate approaches are needed. The additional prototypes noted in item 2 should also be tested to confirm that success of prototype 1 is not an anomaly. There is limited time and manpower - working on alternate approaches should only start if it is necessary.

4. **Does the engineering design faithfully reproduce the required magnet physics design? Yes**
Have issues of mechanical stability and rigidity been considered? Not enough

Comments:

- The engineering design faithfully reproduces the required magnet physics design, including issues of mechanical stability and rigidity. However, complete determination of reproduction of the design with repeatability cannot be assessed until mechanical assembly (i.e. final machining) drawings are reviewed.
- Mechanical rigidity and stability have been considered in the assembled state. Stability of the laminations during assembly has been considered, but needs to be proven during the prototype assembly.
- First question: yes similar to the question 1. Second question: The magnet is not large and appears to be well designed. There was not detail on stability or rigidity presented; but, it does not appear to be an issue. The forces present when installing the blocks and the method for installing the laminations shows that permanent magnet assembly problems were considered. The method pinning for alignment has been well proven on conventional magnets here at C-AD.
- The magnet looks like it should meet the physics requirements as long as the shimming and shunting schemes work as presented. Not a lot of analysis was given in regard to mechanical stability. However from the description of the keying plan for the magnets should make them reproducible. The stability should be testing by repeated assemblies and disassembles of the prototype.

5. **Considering that hundreds magnets need to be produced, are there techniques or solutions to reduce the cost or complexity of the magnet, in order to reduce manufacturing costs?** **Yes**

Comments:

- The cost and complexity of the magnets can be reduced by simplifying the shapes of the clamps which hold poles against the magnet back legs, and by removing excess mounting holes between the PM grids and accompanying back legs.
- Instead of stacking individual laminations, pre-fabricated pole of glues laminations precisely machined can be used to improve accuracy and repeatability. This procedure may require a special assembly tool to be fabricated.
- The magnet design is efficient. The tooling design for assembly needs to prove that assembly can be performed handling the laminations without jamming and with stability. Because of the large number of laminations, approximately 50,000, the efficiency of assembly will be a significant cost driver of the magnets.
- A lot of thought has gone into how to assemble these magnets based on experience building Halbach magnets, building permanent magnets at C-AD for the RHIC IPM's, and the magnet division first prototype quad. None of those magnets were built in large quantities and world wide experience is limited. George Mahler has spent a lot of time considering assembly forces and presented a potential vendor with an approach that is workable.
- It is hard to say what would help cut cost at this stage and for me (G.G) to suggest anything at this time. The assembly of the prototype will be critical to determine the overall process.

6. **Does the design lend itself to tightly controlled magnet-to-magnet variations, through either the design or the manufacturing process?**
   ➔ Not enough. Needs a tolerance analysis

Comments:

- Since the magnet poles are made from 2 mm material, the yoke weight variation will be proportional to ± 1 mm of pole length in each of the 4 poles. This effect on magnetic properties must be calculated.
- The laminations should be uniform due to the manufacturing process (stamping). The steel back leg should be easy to control due to the simple design and fabrication processes. That said, a tolerance analysis of the pole position should be performed if it hasn't already.
- As stated earlier the shimming and shunting schemes are critical to the magnet performance. Every magnet may need to be tested for the magnetic field and temperature coefficient. A rotating coil test bench with capabilities of changing the magnet temperature may be required.
- Variations discussed included:
  • permanent magnet material property variations - they will ordered when large mixed lot and measure (not sure if it will be samples or all).
  • machining tolerances - the outside frame is simple to construct, align, and pin. Accurately, machined aluminum sections will be used to align the laminated pole tip instead of the permanent magnet blocks, simplifying the design.
  • laminated quadrupole poles: stamped laminations will provide tight tolerances and shuffling laminations will provide consistent field properties.

7. Are there aspects of the design that demand extremely challenging tolerances or assembly requirements (precision sorting, critical material specifications)?
→Needs further analysis on tolerance build-up.

Comments:

- The design is suitable but relies on very tight mechanical tolerances of all parts – pole laminations, back leg steel plates and all the aluminum spacers that separate poles from back legs. In addition, the mechanical design and assembly process result in alignment of the poles indirectly through and accumulation of all these tolerances. The tolerance buildup should be analyzed to determine if the effect is acceptable. Alternately an active alignment feature which directly contacts and positions poles during assembly should be added to the assembly process.
- The temperature coefficient of the permeant magnets seems to be the biggest issue. Effort should be made to get the manufacturer to develop a process or recipe to get the final production permanent magnets within an acceptable range for the magnet design.
- Material requirements, machining tolerances, assembly techniques are all challenging; but, they are not beyond present technology. They will require attention to detail, tight QA control, and magnet measurement of each magnet.
- The temperature coefficient of the permeant magnets seems to be the biggest issue. Effort should be made to get the manufacturer to develop a process or recipe to get the final production permanent magnets within an acceptable range for the magnet design.

8. Should additional features be added to the magnet to accommodate mounting the correctors and for mounting or positioning the magnets on the girders? →Not presented

Comments:

- The magnet needs both features to install and align correctors and to be installed and aligned on the girder. These features were not yet developed.
- This was not presented or discussed in detail. Detailed design of the girder and magnet mounting and alignment methods was not presented.
- There was not enough level of detail presented at this review. With that said there should be features built into the design to allow for mounting the corrector onto the magnets and to allow for positioning of the magnets on the final girder.

Additional comments:

- The design is in good shape, but the methodizing for assembly needs to be proved that it can be done economically.
- It is prudent to build a series of preproduction magnets at BNL to resolve all outstanding technical issues and to establish repeatability of magnetic field, crosstalk effects, etc. Once built, these magnets make a powerful statement to potential vendors regarding the proper methods of construction and the quality to be expected, eliminating potential delays further on.
- K. Smolenski comment – “this is the only design review”. Disagree. This is only PDR (Preliminary Design Review). Essential to have FDR (Final Design Review), including responses to action items from today, plus more in-depth look at mechanical features, results from imminent magnet assembly, etc.
- 5-6 month lead time for full batch of PMs ARO per HW/GM (independent MA information – 5 month minimum lead time for Armco yoke steel.) Essential to initiate purchase orders as soon as possible.
- Magnets can be assembled to 150 µm pole accuracy, not 25 µm. (correction to HW slide)
- $50 per PM = $1.5M total (independent MA estimate, balance of parts ~ $1M. $2.5M in material excludes correctors, girders.)
- HW: must characterize all PMs prior to assembling 1st magnet. GM: not necessarily. Needs to be resolved.
- Scott Berg – correctors are attached to magnets after construction. Need to incorporate correctors into production plan.
- Installing individual PMs requires 2 hands and proper tooling for smaller demonstrator size PMs. Tooling needs to be identified and tested for larger PMs.
- Parts (grids, standoffs) appear to not be optimized and are unnecessarily complicated/costly – GM reports that this is a temporary issue due to a late magnetic design change and will be rectified – needs follow-up.
- When commercial vendors are used, add extra schedule float to their schedules. They tend to be intentionally optimistic to obtain a contract.