Magnet Review

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Introduction

- Engineering review: C-Beta hybrid magnets
  - Date: September 12, 2016
  - Reviewers: T. Tanabe (chair), M. Anerella, C. Cullen and G. Ganetis

Charge

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?

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

- Magnetics → Yes, Structural →No
- 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.
  - **Response: An ANSYS simulation has been carried out; no issue was found (max. deflection um level).**
- A recommendation would be that an independent analysis be done to confirm this work.
  - **Response: An OPERA simulation has confirmed the results obtained by COMSOL.**

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

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- Also it should be checked with the machine physics group - again this may have already been done.
  - **Response: The magnet design was developed in close collaboration with members of the Accelerator Physics group, led by Chris Mayes. There is frequent contact, usually daily.**

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

- 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.
  - **Response: A fast-track prototype has been constructed. The magnetic performance agrees well with measurements. The magnetic shunting scheme, used to balance poles, was demonstrated on the prototype as well. The measurements confirm the simulation results.**
    The fast track prototype magnet will be upgraded to a full size prototype magnet, on which the temperature compensation scheme will be demonstrated. The temperature compensation scheme worked well already on smaller test magnets, so we do not expect any changes to the design.

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

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- → No
- 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.
  - **The purpose of the 'fast-track' prototype is to verify the higher order harmonics and to vet the magnetic shunting scheme; the simulations agree well with the measured values. The fast-track prototype magnet (contrary to the original plan) used full size PMs (but fewer of them). The fast-track prototype magnet will be upgraded to a full-size prototype magnet; based on our experience we do not expect any difficulties.**

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

- 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.
  - **In tests conducted at BNL only one company delivered sample magnets that showed a higher temperature coefficient than expected. Permanent magnet companies that were recommended to the CBETA collaboration (internally and externally) in tests showed the anticipated temperature coefficient. These companies refer to the temperature coefficient as a material constant and have agreed to guarantee the temperature coefficient. We intend to source permanent magnets from one of these suppliers. There is no evidence so far for batch-to-batch variation.**

- There was not a cohesive plan presented for how the prototype magnets will be tested. [...] 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.
  - **A cohesive plan has been developed and is available to the reviewers.**

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

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- → Almost. An additional test to estimate the variances of temperature coefficient of NdFeB magnets is recommended.
- 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.
  - **The amount of NiFe required can be calculated from the (known) material properties of the NiFe alloy and the temperature coefficient of NdFeB. The temperature coefficient is guaranteed by at least two manufacturers. During production samples of the permanent magnets and NiFe will be taken to verify no change in properties.**

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

- 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.
  - **Presently no manufacturer of permanent magnets has been identified that offers, or is capable of, measuring the temperature coefficient on-site during production. However, two manufacturers are happy to guarantee the temperature coefficient. An active temperature control system could be developed, but would delay the CBETA project.**

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

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- → Yes / Not enough
- 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.
  - **Stability of the laminations during assembly was tested on sample laminations, and will also be tested during the assembly of the prototype magnet.**

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

- The stability should be testing by repeated assemblies and disassembles of the prototype.
  - **Response: It is planned to disassemble and re-assemble the prototype magnet, to ensure that the harmonics do not change.**

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?

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- → Yes
- 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.
  - **Response: Post-production analysis is planned, to identify possible manufacturing production improvements.**

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

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- → Not enough. Needs a tolerance analysis
- 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.
  - **A tolerance study of the effect of different pole lengths was carried out. A 1mm length change of one pole causes a small change in quadrupole strength (8 units) and a 1 unit change in the 12-pole component (both at R=35mm). Both are not a concern. There are several ways to prevent different pole lengths in production, for example by using a few thinner laminations, or by adjusting the thickness of the 8 mm end lamination of each pole.**

- That said, a tolerance analysis of the pole position should be performed if it hasn't already.
  - **Response: Results of the pole position tolerance studies were presented at the review. The investigations are continuing.**

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

- 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.
  - **Response: It is planned to measure every production magnet using BNL's rotating coil setup. Discussions with permanent magnet vendors indicate no or insignificant variation of the temperature coefficient. In addition, it is planned to test samples of permanent magnets and NiFe during production, which can be tested in c-core magnets. CBETA is investigating the possibility of carrying out temperature controlled measurements on BNL's rotating coil setup.**

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

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- →Needs further analysis on tolerance build-up.
- The tolerance buildup should be analyzed to determine if the effect is acceptable.
  - **Response: A tolerance buildup study was carried out and was found to be acceptable.**
- 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.
  - **Response: CBETA has been in continuous discussions with manufacturers. The CBETA magnets are designed to accept standard PM specs from these vendors.**

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

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- →Not presented
- Response: CBETA is presently working on the engineering design for the correctors and girders. Presently this is manpower limited.