U.S. MAGNET DEVELOPMENT PROGRAM

Preliminary Feedback from MDP Technical Advisory Committee

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Opening

- Sincere Congratulations !
- As in the past MDP Collaboration annual meeting, the TAC has been:
  - captured by the diversity array of thought-provoking R&D,
  - extremely impressed by the progress achieved,
  - refreshed on the breath of the program, from scientific work on basic components and simulations to the forefront achievements in the challenges of putting together complicated objects such as high field magnets.
- Summarizing feedback from an intense collaboration meeting is a challenge:
  - We are *eavesdroppers* in a working and information exchange environment
  - Presentations are “designed” to transfer info among colleagues, not to provide answers to Charge Questions or inquiry from TAC members
- In the following, please find some some preliminary feedback.
  - Much of this feedback is based on our impressions, concerns and open questions

Charges

- **TAC Charge:**
  - *Are the MDP priorities being followed? Are the Areas monitoring and prioritizing their milestones?*
  - Yes, all Areas are monitoring and prioritizing their milestones. The newly released P5 report will require a timely re-consideration in the next year
  - *Is each Area properly leveraging the capabilities within the collaboration to achieve their goals?*
  - Partially yes. Areas for improvement: take full advantage of modelling capabilities to understand and correct observed magnet performance limitations
  - *Is the MDP appropriately identifying, leveraging and developing synergistic activities, such as SBIR, DOE-FES, NP?*
  - Yes

Charges (cont.)

- **TAC Charge:**
  - *Is MDP community involvement appropriate, i.e. in the US HEP planning process and in the context of international collaborations? Are there further avenues that should be pursued?*
  - *Mostly Yes. MDP was very involved in the US HEP planning process. International Collaboration on IMCC and Eu-HFM are being discussed/established*
  - *Are the plans to develop updated MDP Roadmaps consistent with the P5 report?*
  - *Yes. The plans to update the roadmap (to be completed by ~Nov '24) with enhanced focus on central P5 themes (Performance, Cost Reduction, Sustainability) are reasonable.*

General remarks

- MDP has an impressive range of expertise and performs activities covering all aspects of magnet development for future colliders
- Strategic priorities for the current plan:
  - Probing stress management structures
  - Hybrid HTS/LTS designs
  - Understanding and impacting the disturbance-spectrum
  - Advancing both LTS and HTS conductors, optimized for HEP applications
- Despite a welcome increase in funding in FY2023 (~20% plus more than doubling of conductor procurement funds) there has been a schedule disconnect between real progress and many of the 2020 Updated Roadmaps milestones.
  - In general, progress seems slow in most areas, requiring an update of the roadmap and milestones in light of present progress and updated knowledge of performance limitations.

General remarks

- Any design and technology proposed for development eventually need to meet the fundamental requirements for collider magnets. Ideally the core elements required for a successful operation in the accelerator should be addressed from the beginning and not left to be considered at some later point.
  - Examples include compatibility with length scale-up, quench protection, electrical integrity, materials radiation tolerance etc.
- We encourage continued growth in collaboration among laboratories and with international partners
  - The TAC is particularly impressed with far reaching collaborative initiatives that have brought to the program additional intellectual or technical expertise from US and non-US institutions
- MDP is doing an excellent job recruiting and training students and post-docs, there may be the possibility to further expand the collaboration with university groups in areas that do not require significant magnet infrastructure. Possibilities include magnet design, simulation and modelling, instrumentation, protection, etc.

Nb_3Sn magnets & SC

- Congratulations on the overall progress and tests of SMCT and CCT magnets. MDP reached a sweet-spot of at least ~2 tests/year on Nb_3Sn models.
  - SMCTM1a reached a field of 12.7T, a very good result for this configuration.
  - Unfortunately, the performance of SMCTM1a/b, showed some unexpected (for Nb_3Sn) limitations such as lack of memory between thermal cycles and observations of large voltage spikes during the test.
    - Degradation of Superconductor or Stresses management must be investigated
    - Source of voltage spikes must be understood
    - Insufficient axial support of the inner coil appears to be the cause of the limitations, but it should be supported by test data
    - Alignment features between the inner coil, outer coil and the magnet structure were not clear
  - In general, for SMCT and any other magnet test presented, performance of coils and splices was not validated with a hold current during test. This step should be part of every test process

Nb_3Sn magnets & SC (cont.)

- In view of the post-mortem for the SMCTM1a/b, the group should take full advantage of the modelling and diagnostic capabilities available to the program to understand the observed performance limitations and point to the most promising design improvements
  - Specifically, 3D simulation should be used to assess limitations introduced during the pre-load of the coils in SMCTM1a/b

- Several design criteria for the Nb_3Sn portion of the 20T Hybrid magnet need further definition
  - Target field for HTS insert
  - Max. acceptable peak stress (to insure appropriate margin) for the Nb_3Sn portion

HTS magnets & SC

- Maintaining a High Field Dipole component in the program is existential for the MDP, for the US community and the world-wide HEP collaborations.
- Fully qualify and model HTS (REBCO CORC and STAR) cables and coils to understand if these cable geometries are the most suitable for use in high field accelerator quality magnets. Identify advantages and limitations. Elaborate a R&D roadmap with milestones and decision points

- Design studies of 20 T collider magnets
  - The design study assumes that 2212 wire is used for the HTS portion. A conceptual design effort for a 20 T REBCO/hybrid magnet is needed to provide guidance and feedback for conductor and small coil development
  - The 20T study shows significant challenges to meet basic requirements
  - Max acceptable prestress on HTS must be defined
  - Define achievable Field Quality for REBCO/STAR cables
- Investigate whether expanding the study to other possible uses of HTS (e.g. lower field with higher operating temperature) may provide an attractive goal for the collider application while driving the study toward new approaches in magnet design and conductor development. Such a significant change (i.e. all HTS) need to be made within consideration of any major programmatic changes decided to be compatible with the P5 strategy.

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HTS magnets & SC (cont.)

- Several HTS coils tested recently had limited performance
  - STAR wire tested under SBIR phase I had very poor performance. Conductor likely damaged before coil winding. MDP needs to make sure new STAR wire and coil design and fabrication methods are sound for Phase II SBIR manufacture and test
  - CORC conductor performance in BNL Hybrid test was poor.
  - COMB test at FNAL had lower performance than expected
- It is recommended that a *post-mortem diagnostic workshop* is run by MDP to brainstorm on best tools to understand sources of limitations
- 6-Layer C3 coil being developed with CORC. Good bend performance but use of 3 layers from AP tape and 3 from HM tape complicate the ability to understand any performance limitations
- COMB-CORC experience at FNAL demonstrated usefulness of LN2 test on HTS conductor before winding. This experience should inform initial elements of QA/QC program for acceptance of all future REBCO conductor for winding

HTS magnets & SC (cont.)

- There is strong competition for limited supply of LTS and HTS superconductors, but use of inferior quality conductors creates difficulties in evaluating results of conductor, coil, and magnet tests. This can be mitigated by proper characterization of SC used in the cables.
- While it is nice to see the conductor procurement coordination within MDP, there might be benefits or interests for CPRD to reach out to other fields who are also interested in superconducting magnet development to coordinate superconductor needs. For instance, light-source community is interested in superconducting undulator in particular HTS based technology
- Similarly, the international fusion community is procuring large amounts of REBCO at large quantity discounts. CPRD might be able to somehow take advantage of these larger procurements and take a lead in characterization activities

Technology

- As usual, the presentations on Technology development have shown a great breadth of good ideas and initiatives. On the other hand, a re-assessment of the various efforts to establish their “applicability” to MDP progress might be advisable.
- The program may benefit from additional investments in specific fabrication and test infrastructure. Some impact on near-term R&D effort would be acceptable to allow faster progress in the longer term.
  - For example, maintain efforts to invest in facilities and infrastructure to facilitate hybrid magnet testing
- Carefully consider the implication of abandoning thermoplastic R&D
- Use of Gd as high C_p material must be carefully evaluated since it has large cross section for thermal neutron and emits gamma ray.
- Successful results in TELENE gives a good example of impregnation material properties studies. The approach could also be used to further the search for other candidates.
- MQE test of TELENE with various fillers indicate that good thermal conductivity is better than high C_p. Consider using just AlN and avoid Gd

MDP & 2023 P5 Report

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- The current MDP roadmap was updated in 2020, and milestones are well aligned with the 2023 P5 report in particular 100 TeV CM proton-proton collider
- As the Muon Collider is now implied by the 2023 P5 report, there is an opportunity to evaluate progress on the established plan and whether any adjustments would be useful to best support the HEP priorities
  - MDP presented a plan to develop a new strategy following the DOE presentation at HEPAP (May 2024). The program is planning to conduct a vigorous internal discussion over the next ~6 months to converge on an updated plan. As an example, a potential partial redirection of technology development toward solenoids design might be necessary and needs to be assessed vis-a-vis the desire to maintain a scientific leadership.
- Renewed MDP focus on 2023 P5 themes (Performance, Cost Reduction, Sustainability) is welcome and necessary before the "blooming" of Targeted R&D Programs. It must be expected that development of such goals in the new MDP plan might require resources that will be redirected from more conventional MDP goals

MDP & 2023 P5 Report (cont.)

- Consider opportunities for closer collaboration with groups looking at accelerator design, for example in the context of HFM for FCC and the Muon Collider
- Continue to research fundamentally new concepts to lower cost including both capital and operation

- To promote sustainable accelerators in the context of MDP, identify energy efficient accelerator technology
- Consider developing or widening collaborations with fusion community lab, university, and industry members to take advantage of experience with high field, large bore solenoids in high radiation environment.

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Simulation & Modeling

- While the simulation capabilities for the understanding of superconducting magnet behavior are outstanding and well aligned with MDP's milestones in magnet science, there appears to be a lack of fully shared simulation approach. For instance, the LBL simulation is specific for CCT and has 3D capability while there wasn't a detailed presentation about the Fermilab simulation on understanding the SMCT degradation and loss of training memory.
- The simulations studies for the 20T Hybrid design are impressive and very important to converge on a feasible design. The studies should be continued with different impregnation materials and temperatures in a systematic way.
- The work on the BELFEM program is impressive and efforts should be made to integrate this type of detailed analysis of the HTS conductors with the coil design, analysis and simulation.