EPFL

SWISS PLASMA CENTER

MEETING MINUTES

To: All participants *From:* Xabier Sarasola	*Date:* April 2nd, 2020 *Subject:* EDIPO: Engineering Design

1. Participants

- *CERN:* Luca Bottura, Douglas Martins Araujo, Juan Carlos Pérez, Gijs de Rijk.
- *EPFL-SPC:* Pierluigi Bruzzone, Xabier Sarasola, Evgeny Solodko, Kamil Sedlak.
- *F4E:* Alfredo Portone, Luigi Reccia, Pietro Testoni.

2. Meeting documents

- Meeting documents are uploaded to the following Indico site: https://indico.psi.ch/event/8809/

3. Agenda

3.1. Welcome and goals of the meeting

- The goals of the meeting are:
  1. Signal the transition from the Conceptual Design to the Engineering Design of the magnet.
  2. Introduce Evgeny Solodko. He joined SPC last month, and since then, he works full-time in the engineering design of EDIPO.
  3. Introduce the role of Juan Carlos Perez as responsible and single point of contact from the CERN side.
  4. Establish a functional structure for the engineering design. Identify key actors in both organizations and set up a work plan.
  5. Give an overview of the design and analysis at CERN since the decision on the 6-coil baseline.

3.2. Engineering design: existing models and geometry

- E. Solodko showed the geometry of the existing models in CATIA: both the EDIPO test facility and the new magnet assembly.
- The engineering activities are not only limited to the magnet assembly: a vessel for the liquid helium bath is also required, including interfaces with the cryogenics and sample environment, feedthroughs for the current leads and instrumentation. The experience of CERN might be also useful for the design of He vessel. The cryoplant at SPC supplies supercritical helium at 10 bar.
- The current geometry of the magnet assembly in CATIA corresponds to that of Summer 2019. E. Solodko requests the latest version of the magnet models from CERN.

3.3. Conceptual design activities at CERN

- D. Martins presented the status of the activities at CERN, focusing on the winding trials and the conceptual design of the magnet.

- Based on the existing winding tool for FRESCA2 cables, new tooling has been developed at CERN for the EDIPO winding trials. The parameters explored include different tilt angles of the flared heads (at least, 10 and 17 degrees), radii of curvature at the ends, and winding tension. A new procedure based on a laser inspection method was also developed to identify potential deviations from the ideal cable geometry (e.g., pop-out strands or dishing at the ends). The data analysis is still ongoing, but based on the preliminary results, there is a moderate to high degree of confidence among the participants in the winding tests that the cable can be wound as required.
- An overview of the evolution of the magnet design was presented. CERN has recently devoted a fair amount of time and effort on the optimization of the 4-coil design. The results of this alternative design are compared with the baseline (6-coil) design and can be shown in the slides uploaded to Indico. The conclusions emphasized:
    - The better behavior of the 4-coil design in the presence of misalignments during assembly, thanks to the thick steel plate between coils #1 and 2. Magnet protection (quench) must be investigated, including an evaluation of the effect of E&M loads at fast discharge.
    - The reduced number of coils and tooling of the 4-coil design compared to the current baseline. This is considered an advantage in terms of time and material by CERN.
- A few ideas that were discussed during the presentation of the conceptual design of the magnet (and might be object of further analyses) are:
    - The use of detachable poles. The local contact pressure between the titanium pole and coil #1 is well beyond 20 MPa in tension in the region close to the upper corner of the Ti pole. With the current criterion of pre-load, the epoxy bond will most likely break there during operation. This criterion must be reviewed if detachment is to be avoided. This has major impact on the location and amplitude of the peak stress. R&D at CERN is ongoing to investigate the use of "non-bonded" poles.
    - The elimination of the titanium pole. The coil might be wound in a "dummy" pole and then transferred and installed in direct contact with the test well. This alternative might result in a more efficient use of the conductor, since the coil windings may be closer to the aperture (i.e., less ampere-turn, and lower peak stress)
    - The inner corner radius of the titanium pole is larger in the 4-coil design compared to the baseline, which affects the comparison of peak stress in both designs. The 4-coil design has been optimized to take into account the Ti pole deformation at cold. This optimization results in a larger aperture and a larger inner corner radius compared to the baseline design. Both solutions seem to be able to accommodate the test well inside. However, an equivalent optimization of the Ti pole geometry is still missing in the baseline design, and should be the object of future studies.
    - SPC reminds the boundary conditions for sample insertion:
        - The clear aperture inside the test well shall be 94 mm × 144 mm with an inner corner radius of 3 mm. This is a fixed boundary condition.
        - Insertion of SULTAN samples occur when the magnet is cold, but not powered.
        - If a 3-mm-thick test well is assumed, the outer dimensions of this rectangular pipe shall be 100 mm × 150 mm with an outer corner radius of 6 mm.
- CERN informs that based on experience with other coils, the assumed thickness of conductor insulation in the models has been increased from 150 to 200 µm.

3.4. Manufacturing considerations, based on the experience from FRESCA2

- J. Pérez will be the contact person at CERN during the EDIPO engineering design activities and made a presentation on the experience during the manufacturing of FRESCA2. Required R&D, overview of the construction activities and share of the workload between CEA and CERN during the

FRESCA2 project were the main topics of the presentation, which can be downloaded from the Indico site.

- J. Pérez reminds that the complexity of tooling and assembly of the baseline (6-coil) design is greater than the 4-coil solution. The 6-coil configuration will require one extra tooling for winding and one for reaction (which will increase the price of tooling by around 30%).

3.5. Status of strand procurement and cabling activities

- L. Bottura reported on the procurement of the 1.1 mm strand. 60 km of strand have been already received at CERN. This should be enough to wind approximately one magnet pole. However, CERN does not consider additional procurement of strand until the cabling activities start at LBNL.
- Cabling testing activities with RRP strand were planned at LBNL, but have been postponed.

4. Next steps

- The input presented by CERN regarding the 4-coil design has been received at SPC. So far, no showstoppers have been identified for the baseline design. The analysts of the team are invited to complement the open issues quoted in section 3.3 (which were already the object of investigations in 2018), mainly: the impact of bonded/sliding assumption of the poles, the removal of the titanium pole, and the effect of E&M loads at fast discharge in the steel plate between coils #1 and 2.

  The studies should not be limited to the 4-coil design, but shall also include the study of open issues regarding the baseline design already identified in November 2019, namely:
  - The axial pre-load of the coils. It does not seem to be sufficient to avoid pole detachment.
  - The aperture after cool-down seems to be slightly smaller than required.
  - The wedge shows a large peak of stress
  - Concentration of stress has been identified in coil #1 when the wedge opens.

  A confirmation/update of the baseline design is urgent with respect to the engineering design activity, and should be scheduled within three months (hopefully, as an in-person meeting as soon as the Covid situation subsides).
- The engineering design continues at SPC based on the current baseline design and available boundary conditions. The activities will start, as far as possible, from the areas and components less affected by the winding layout.
- SPC will propose a work plan, including:
  - Definition of the required R&D. It is crucial to distinguish between “accompanying R&D”, to be done in parallel with the engineering design and procurement, and “critical open issues” affecting the design since the beginning. For the latter, a decision shall take place at an early stage.
  - Detailed schedule of the engineering design and rough schedule of the whole project. The schedule shall not be an informal “internal” document, but it shall reflect the commitment of the team to the funding partners: EUROfusion, EPFL, and (maybe) CHART.
  - Identification of key actors (both for the magnet design and the He vessel). Securing procurement sources and manpower is mandatory for the project. It is desirable to identify a “plan B” whenever a critical supplier/lab may become unavailable (e.g. for strand, cabling or winding)

  The work plan will be circulated with CERN and will be the subject of the next video meeting (preliminary scheduled for the last week of April).