WP 2: Cavity design and beam-cavity interaction (DRAFT)

1. Cavity design for FCC-ee

Description of work

Define viable cavity designs for the FCC-ee RF systems to cover the requirements for both high accelerating gradient and very high beam currents.

Cavity impedance and HOMs are expected to be a major issue at the Z pole, and may dictate to a large extent the RF system design. Therefore, comprehensive impedance estimates for the different cavity layouts and staging of the RF system, HOM characterization and power calculations including tapers and other cold to warm transitions are necessary. The conformity of the RF structures within the stability limits with adequate HOM damping should be verified.

1.1: Study and optimization of RF cavities for high energy operation (Rostock)

Develop a cavity design optimized for the Higgs operation at 120 GeV beam energy.

- Define the appropriate shape from RF and mechanical aspects.
- Verify the choice of frequency.
- Make a choice on the number of cells per cavity based on the required voltage and available input power. Define a minimum/optimum distance between cavities to minimize cross-talk and to limit HOM effects.
- Evaluate loss factor and HOM power in the cavities and evaluate HOM coupler power limitations.
- Study the HOM damping scheme using superconducting filters and propose an optimum configuration

Description of Work

The delivered document contains the following items:

Task 1: Preliminary cavity design description

- Overview and description of cavity design
- Evaluate loss factor and HOM power in the cavities and evaluate HOM coupler power limitations.
- Beam loading aspects to define the input power requirements.
- Input power requirements.
- Maximum number of cells per cavity
- Appropriate damping scheme to define the minimum/optimum distance between cavities, which correspond to the established limits for loss factor and HOM power.
- Verification of the choice of frequency for the accelerating cavities. Calculated HOM damping with SC filters.

Task 2: Detailed EM design including HOM couplers

- The delivered document contains the following items:
- 3D cavity shape and aperture of the cavity, optimization based on preliminary design

- Information required for CERN to be able to develop a mechanical design with final cavity aperture and transition section with considerations of RF, mechanical and thermal aspects.

Task 3: Cavity design and HOM damping design report

- The delivered document is a textual description and conceptual drawings of the cavity design. It summarizes the results and possible limitations of the cavity design and layout choices.

1.2: Study and optimization of RF cavities for high intensity operation (CERN)

Develop a cavity design optimized for the Z operation at 45.5 GeV beam energy and 1.5 A beam intensity.

Description of work

Task 1: Study and optimization of cavity design

- Verify the choice of frequency and number of cells for high beam current operation at the Z-pole.
- Verify the feasibility of a single cavity design optimized for the needs of an FCC-ee and FCC-hh RF system.
- Develop a preliminary design for the shape and aperture of the cavity
- Decide on a preliminary cryomodule layout with optimum distance between cavities
- Evaluate higher order mode spectra including tapers and cryomodule layout.

1.3: Higher order mode damping scheme for high intensity operation (CERN/MEPhI?)

Propose an HOM damping scheme optimized for the Z operation with up to 1.5 A total beam intensity.

Task 1: Design of the HOM damping scheme for high intensity beams

- Given:
  - an initial cavity design with its associated higher order mode spectra
  - a stable set of beam parameters (number of bunches, bunch intensity, bunch length)
  - a set of representative filling patterns
  - impedance budgets for single- and coupled-bunch stability
- Evaluate HOM power levels
- Study the available HOM damping schemes (loop couplers, waveguides, warm absorbers) and propose a damping scheme which satisfies the requirements of
  - power handling
  - beam stability criteria
  - cryogenic load
  - overall mechanical length

2. Cavity design and HOM damping for FCC-hh

Task 1: Study and optimization of the RF cavities

- cavity material
- cavity design constraints (number of cells, loss factor, frequency)
- number of cavities
- fixed or variable coupling, Q_L
- power budget

- HOM coupler design
- cryomodule design constraints:
    - beam separation requirements
    - spare part exchange
- total cost estimate

3. Beam dynamics

3.1 Beam stability considerations for FCC-ee (J. E. Mueller, E. Shaposhnikova)

- beam parameters (bunch length, emittance, intensity, filling pattern) required for stability (single and coupled bunch)
- budget for broadband and narrowband longitudinal impedances

3.2 Beam stability considerations for FCC-hh (E. Shaposhnikova)

- beam parameters (bunch length, emittance and intensity) required for stability (single and coupled bunch)
    - budget for broadband and narrowband impedances
    - analysis of the need of a harmonic RF system and/or a longitudinal damper

4. Low Level RF (RF-FB)

4.1 LLRF for FCC-ee

- Propose a scheme for beam loading compensation compatible with high intensity operation
- requirements for fixed or variable Q_L fundamental power couplers taking into account steady-state and transient beam loading
- Evaluate the requirements for longitudinal feedback based on coupled-bunch instability growth rates and radiation damping.
- Evaluate the need for longitudinal feedback on modes other than the fundamental

4.2 LLRF for FCC-hh

- Determine limits on acceptable RF noise level
- Bunch length control for stability by controlled longitudinal emittance blow-up and bunch shaping
    - during the acceleration ramp
    - to counteract bunch shortening in physics
- Requirements for cavity impedance control at the fundamental based on growth rates and Landau damping
- Requirements for beam control loops (phase/radial/synchro)
- RF synchronization with injectors