PSI-COFUND Proposal
The Conceptional Design of a new PSI Ring Flattop Cavity & Investigation of Plasma Phenomena in the Ring Cyclotron

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1 Problem domain

The PSI High Intensity Proton Accelerator (HIPA) facility is leading for many years the field of medium energy proton facilities with an average power of 1.4 MW on target. An average availability of $> 90\%$ ensures satisfactory user operation over 9 months per year. In 2008, the last 50 MHz Ring aluminium cavity was replaced by a copper cavity and at the same time a 10th harmonic re-buncher was installed in the transfer line between Injector 2 and the Ring cyclotron. Two new Injector 2 cavities are also ready for installation. Aside from the magnets, the last large part of the Ring Cyclotron – from 1978 – is the 150 MHz aluminium flat-top cavity.

Despite the fact of the high availability, several problems around the cavity systems had a considerable impact on the performance within the last few years:

1. plasma phenomena in the Ring, caused by coupled rf power into the vacuum chamber
    - negative effect on the extraction elements due to increase of dark current
    - negative effect on the diagnostic due to increase of background
    - kind of the plasma and location of ignition: *unknown*
2. multi-pactingand voltage limit of the 150 MHz flat-top cavity
    - structural damages of the rf coupling window, the rf contact fingers and the rf power coupler in 2013 due to multi-pacting
    - the intensity of the Ring cyclotron is limited due to the resulting thermal heat load on the flat-top cavity

In the near future, these two problem complexes will have a significant impact on the reliability and performance of the facility. In this research project, we will address both of the challenging problem in the following way:

a) electromagnetic design of a new Ring flat-top cavitywith emphasis on

- minimising multi-pacting
- minimising rf-coupling into the vacuum chamber, caused by geometrical asymmetries (obtaining mechanical tolerances from shape deformation studies)
- maximise the achievable voltage

c) full electromagnetic simulation of all Ring cyclotron cavities including the vacuum chamber

- investigation of the observed plasma in the Ring, by establishing an energy density map of the entire vacuum volume
- experimentally characterisation of the plasma by the use of optical sensors (cameras) and existing captive pickups

1.1 Electromagnetic design of a new Ring flat-top cavity

In this research project, we will create the electromagnetic design of a new flat-top cavity for the PSI Ring Cyclotron. The emphasis will be on minimising multi-pacting [4] and the rf-leakage into the adjacent vacuum chamber. In order to increase the beam-intensity even further, the peak voltage of the flat-top cavity must be maximized. The question of copper vs. aluminium must be answered fulfilling boundary conditions such as: space- power- and cooling-limitations, secondary emission yield, forward and backward power flow. Mechanical tolerances, crucial for the manufacturing process, will be obtained by a shape deformation analysis. Besides traditional goals such as: frequency stability and higher order modes damping, the quantification of the rf-power coupled into the vacuum chamber will makes this analysis challenging and unique.

ANSYS [5] can be used for the electromagnetic and mechanical design of the new flat-top cavity. The final, precise electromagnetic fields and the shape optimisation studies will be calculated by FEMAXX [6], and for predictive multi-pacting simulations [9] we will use OPAL [2].

With the new cavity configuration and a possible higher flat-top cavity voltage, a new theoretical intensity limit will be established based on the model in [3]. This model is capable to match measured losses in the order of 10^{-4} of the charge density at the extraction septum, which is one of the most limiting factors of the PSI Ring Cyclotron.

1.2 Full electromagnetic simulation of all cavities including the vacuum chamber

Since the replacement of the aluminium main cavities in the PSI Ring Cyclotron rf-leaking is experimentally observed [8]. This leaking of rf-power seems to trigger plasma phenomenas in the vacuum chamber. So far,

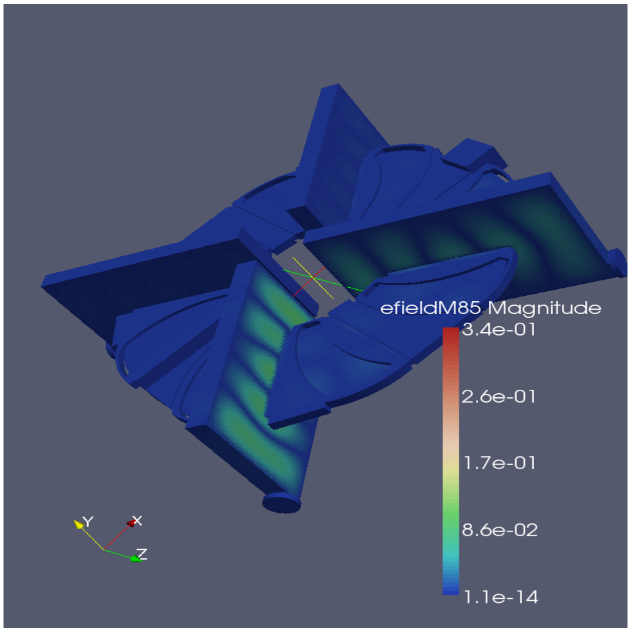

Figure 1: Electromagnetic simulations of the full PSI Ring Cyclotron vacuum volume with old aluminium cavities but without the flat-top cavity.

we did not see an impact on the beam dynamics, however a clear disturbance of diagnostics elements and an increase of the dark-current in the electrostatic devises can be observed. We already started with a proof of principe calculation (Fig. 1), showing that an Eigenmode calculation, taking into account the full vacuum volume is feasible with FEMAXX [6]. We will extend this model with the new flat-top cavity and the actual configuration of the main cavities. In the new version of FEMAXX [7], we are also able to include losses which potentially have a non negligible effect on the field distribution.

Characterising the plasma experimentally is a very difficult task. Direct observation using one camera outside of the Ring vacuum chamber was already proven to be feasible. The availability of different view-ports, could allow us to get an idea on the spatial localisation of the plasma. Capacitive pickups, located at various position around the PSI Ring Cyclotron enables us to precisely determine the temporal behaviour of ignition, related to other measurable parameters such as mean pressure and cavity voltages. We will combine these experimental data in order to obtain a clearer signature of the plasma.

From the Eigenmode calculation, an electromagnetic field distribution in the full vacuum volume of the PSI Ring Cyclotron will be available. Different plasma model can then be evaluated and constrained with the experimental data, in order to select the most probable one. This will be the first step towards counter measures to eventually eliminate the disturbing plasma problems.

2 Scientific Impact

High power Cyclotrons getting recently attention w.r.t. Neutrino physics [1]. A 800 MeV machine is proposed [10], mainly in the context of ADS systems. The better understanding and further development of HIPA, the leading facility of the field, will pave the road for more cyclotron proposals, and at the same time develop a better understanding of ultimate limits w.r.t. rf-power and intensity.

3 Impact for PSI

In order to mitigate the risk of a long term downtime of HIPA, resulting from a failure of the flattop resonator, the construction of a new resonator must be prepared. This study represents a first step in this direction by considering several conceptual design choices for a new resonator. It will provide the basis for an engineering design. In addition the study will establish a better understanding of the observed plasma phenomena that periodically interfere with the operation due to interaction with diagnostics and the electrostatic injection & extraction devises.

4 Foreseen Papers

Besides conference contributions, the following refereed papers are foreseen:

- NIM - A or Phys. Rev. STAB: Minimising Multipacting and RF-Leakge in the New Flattop Cavity of the PSI Ring Cyclotron

- NIM - A: A New Intensity Extrapolation of the Ring Cyclotron taking into account Rf-Leakage and Particle Losses

- Phys. Rev. STAB or Appl. Phys. Letters: Investigation of Plasma Phenomenas in the PSI Ring Cyclotron

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