UPGRADE CONCEPTS OF THE PSI ACCELERATOR RF SYSTEMS FOR A PROJECTED 3mA OPERATION

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Abstract

To run the SINQ facility at its design current of 2 mA, the primary beam current of the PSI cyclotrons has to be increased to 3 mA – assuming a transmission factor of the target E of 67%. In the context of a feasibility study on how to accelerate such a beam, we present the necessary upgrade steps for the different RF systems.

1 INTRODUCTON

The challenges facing RF systems in high current cyclotrons are twofold:

- Space charge effects at higher beam currents call for higher acceleration voltages to reduce the turn number and increase the turn spacing at extraction [1].
- Beam loading (the part of the total RF- energy fed to a cavity that is delivered to the beam) is no longer negligible, although not yet in the range seen in some other accelerator designs (synchrotrons, linacs). This calls for very high power amplifiers, capable of handling large RF power swings and input impedance variations. [5,6]

The main ring cyclotron at PSI [1,3] routinely accelerates a 1.8 mA proton beam to 590 MeV, employing four 50 MHz acceleration cavities and one 150 MHz flat-topping cavity. All of them are operated close to their thermal limit.

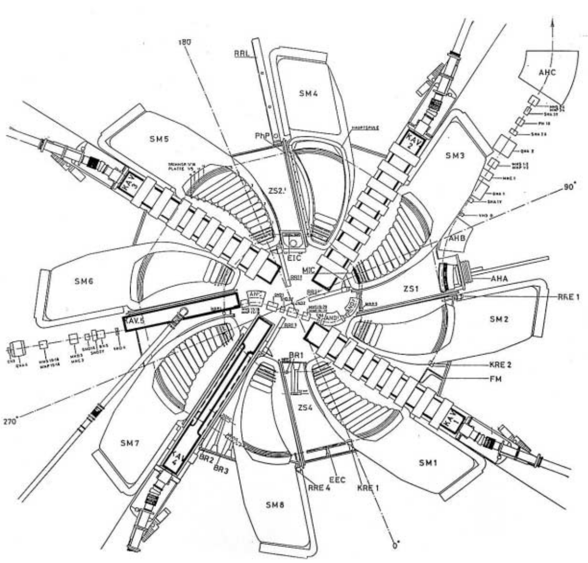

Figure 1: Layout of the Main Cyclotron (590 MeVp)

The 72 MeV injector cyclotron (Injector 2) [7] has demonstrated the capability to accelerate and extract 2.2 mA; its RF system consists of two double-gap acceleration cavities (50 MHz) and two smaller 150 MHz cavities, which were originally used as flat-topping cavities, but are now operated in the acceleration mode.

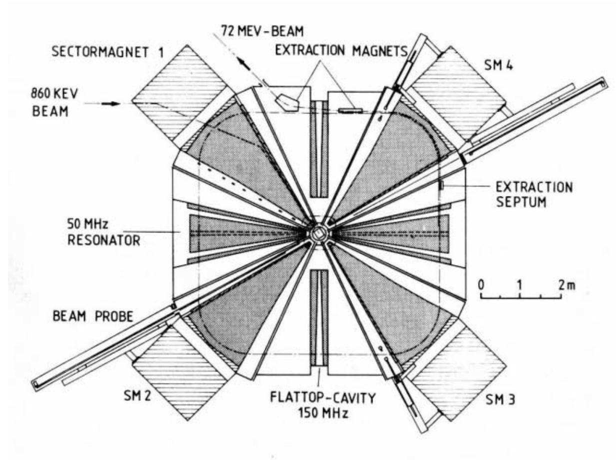

Figure 2: Layout of the Injector Cyclotron (72 MeVp)

The characteristics and limits of the two main accelerators are so different that each machine has to be considered separately for the upgrade program. The ion source and pre-accelerator, at present a Cockcroft-Walton 870 keV DC proton generator, will eventually also have to be replaced, probably by a RFQ.

A key parameter of all RF systems is the accelerating voltage, which is required to produce a beam with tolerable extraction losses. For our two machines we get:

- Measured values at extraction from **Injector 2** indicate, that compared to the operating conditions of today, the bunch width at 3 mA will widen by approximately 35% [1]. To maintain the turn separation at the same value, the accelerating voltage *at extraction* has to be increased by about the same factor, which means - in absolute terms - 300 kV_p.
- Extrapolating the V^3 scaling law [1,2] for the **Main Cyclotron**, an energy gain of roughly 3 MeV per turn is needed to accelerate a 3 mA beam. Assuming the same ratio between fundamental and third harmonic accelerating voltage, this requires a gap voltage of 910 kV_p for each of the 50 MHz cavities and 640 kV_p for the 150 MHz cavity.

CP600, *Cyclotrons and Their Applications 2001, Sixteenth International Conference,* edited by F. Marti

2 INJECTOR 2 UPGRADE

Looking at possible ways to increase the acceleration voltage (energy gain/turn) in the injector cyclotron, we see that the options differ from those of the ring cyclotron. As fig. 2 shows, the sectors containing the 150 MHz cavities are 'underused' in terms of their contribution to the energy gain/turn; however, they contain essential injection- and extraction components that should not be touched. Three solutions present themselves:

- The lowest cost version – but with the smallest contribution – would consist of increasing the acceleration voltage in the existing 150 MHz cavities, by adding two new final amplifiers (increasing P_{max} from 10 kW to ≈ 30 kW each). This (estimated) upper power limit is given by the fact that these cavities are convection cooled only, and that the cooling of their tuning system must probably be redesigned. This step would lead to a moderate increase of the average acceleration voltage of ≈ 7 % (reducing the number of turns from 81 to 76). Advantage: this could be tried out within one year, because we could rig up a provisional test set-up. We plan to install the necessary RF transmission lines and power splitter for a hook-up of an existing 60 kW 150 MHz experimental power amplifier to the two cavities in the Injector 2 cyclotron, to confirm the calculated contribution of the voltage increase.
- Another possibility – the redesign and replacement of the two existing double gap acceleration cavities, allowing us to increase their acceleration voltage – is a more difficult one, because we would like to retain the existing voltage distribution vs. radius. Since the thermal load on the resonator stem towards the machine centre is already high, a very refined cavity design would be called for, probably requiring full power testing of a prototype – an expensive and time-consuming procedure. In contrast, we feel that replacement cavities (next paragraph), integrated into the existing flat-topping sectors, can be built, tested and inserted in one step.
- A potentially much more promising route would be to replace the existing 150 MHz cavities, and install new, 50 MHz single gap cavities in their place; that is, in fact redesigning the two sectors. This type of cavity has several advantages: the single gap design leaves the location of critical injection- and extraction components untouched; at the same time, it allows a voltage distribution along the acceleration gap which increases towards higher radii, and lastly, much higher voltages are obtainable (up to 50 % increase of the average acceleration/turn). Note: because of anticipated strong interference with the beam phase measurement equipment in the cyclotron, 100 MHz cavities are not even considered.

The third alternative was studied in some more detail: a cavity shape was found, where the space requirements along the central plane (as well as the location and dimension of the acceleration gap) remain the same as in the existing design (fig. 3). As mentioned, a 50 MHz cavity was chosen because it allows the desired acceleration voltage increase towards extraction radii. (see fig. 4)

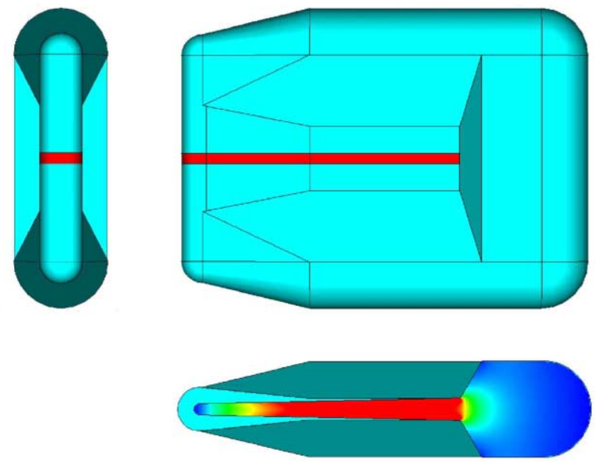

Figure 3: Proposed 50 MHz cavity for the Injector 2. Above: side and front view of the cavity. Below: the accelerating field distribution in the beam plane.

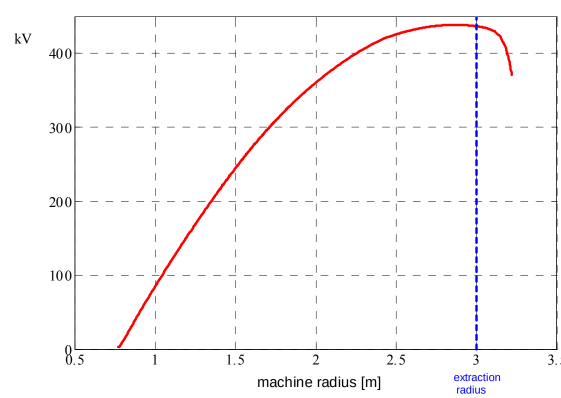

Figure 4: Radial Distribution of the Gap Voltage. The values correspond to a dissipated RF power of 100 kW in the cavity.

3 MAIN RING UPGRADE

3.1 Acceleration Cavities

The existing 50 MHz cavities in the main ring cyclotron cannot be operated at an accelerating voltage of 910 kV, as would be required for the targeted 3mA beam current. As reported earlier [4], a first prototype cavity (compare fig. 5), capable of generating a gap voltage in excess of

1 MV, is now under construction and will be available in 2003. By then replacing all four old cavities, the required acceleration voltage per turn can then easily be obtained.

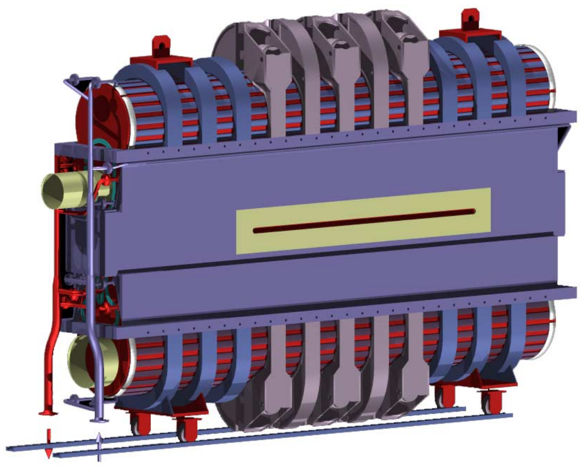

Figure 5: 50 MHz prototype cavity. The RF wall is made of 8 mm copper sheets. The support structure consists of stainless steel. The cavity can dissipate 500 kW of RF power and has a calculated shunt impedance of 1.8 MΩ.

At 3 mA beam current, the RF power feed line between final amplifier and cavity, will have to handle 700 kW of RF power. This is just within the specifications of the presently installed type of our coaxial transmission lines, which are 25 to 40 m in length, depending on cavity location.

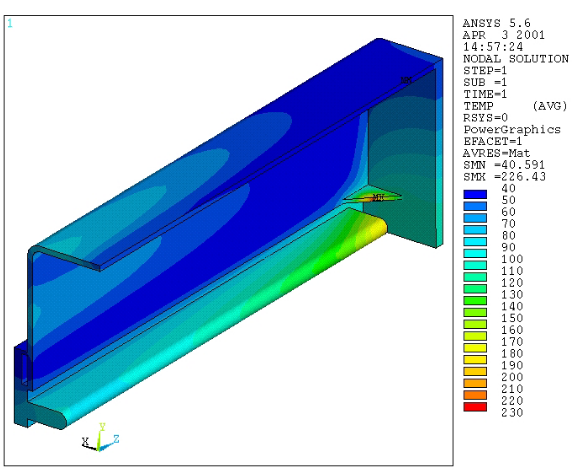

Figure 6: FEM analysis of the flattop cavity. The temperature distribution corresponds to a gap voltage of 550 kV_p (Dissipated RF power of 95 kW).

3.2 Flat-topping System

Already at today's beam currents of 1.8 mA, the flat-topping cavity is operated close to its tuning limit. (see fig. 6). A study is now under way which will lead to a better understanding of the thermo-mechanical behavior of the cavity, and to assess some upgrade possibilities.

The control system, as well as the power amplifier, is also way out of the ordinary: for the cavity voltage and phase control system, the bandwidth varies widely and the system has to shift – under power – from power delivery to power absorption mode, while maintaining amplitude stability to $< 10^{-4}_{pp}$ and phase noise below $0.05°_{pp}$. In principle, this is an expansion of our existing concept, but some careful analysis and redesign, as well as some testing, will have to be carried out, before a 3mA beam with the required quality will successfully be extracted from the ring cyclotron. [6]

4 CONCLUSIONS

To go from 2 mA to 3 mA in beam current for the PSI accelerators – as seen from the viewpoint of an RF designer – is a very costly and complex project. Both accelerators require at least *some* new cavities, furthermore, a considerable additional investment in new RF power equipment, like amplifiers, high voltage power supplies, transmission lines, cooling systems, etc., is required.

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