DEVELOPMENT OF THE NEW 50MHz RESONATORS FOR THE PSI INJECTOR II CYCLOTRON

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Abstract

In the framework of the high intensity upgrade of the PSI proton accelerator facility, it is planned to replace the two existing 150 MHz resonators of the injector II cyclotron by two new 50 MHz resonators. This will make the injector II cyclotron ready for an increase of the current intensity from now 2 mA to about 3 mA in the year 2011. The rf-design of the resonator, fine-tuner and inductive coupler was carried out with the eigenmode solver of the ANSYS multiphysics program. Despite the limited available space for the resonator, it was possible to find an rf-geometry which should allow to reach a maximum gap-voltage of 400 kV at rf wall-losses of about 45 kW. A coupled rf-thermo mechanical simulation was performed for the design of the support structure and the cooling system.

INTRODUCTION

The RF system of the 72 MeV Injector [2] consists currently of two double gap-acceleration cavities (50 MHz) and two smaller 150 MHz cavities, which were originally designed as flat-topping cavities. Since the proton bunches are only about 5° long, flat-topping is not efficient and the 150 MHz cavities are therefore operated in the acceleration mode. The 72 MeV injector cyclotron has already demonstrated [3] the capability to accelerate and extract 2.2 mA. However, in the framework of the high intensity upgrade [3, 4] to 3 mA, it is planned to replace the 150 MHz cavities by new, more powerful 50 MHz cavities. The additional energy gain per turn will help to reduce the total number of turns and also increase the turn separation at extraction location. This will reduce the extraction losses and therefore allow the acceleration of higher beam currents [3].

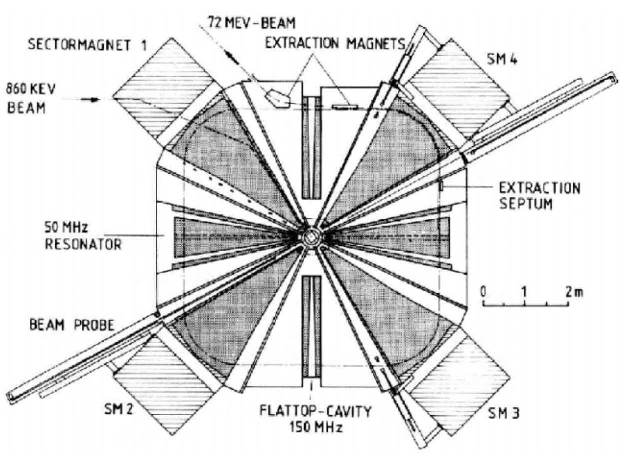

Figure 1: Layout of the Injector Cyclotron (72 MeV).(Top view on cross-section at beam-plane)

Figure 2 shows the design view of the new cavities to be built by SDMS ”la chaudronnerie blanche” in France. The order has recently been placed and the first cavity will be installed in the year 2010 in the injector cyclotron. The inner geometry of the cavity is indicated in Fig. 4 and Tab. 1 shows its main parameters.

Aluminum is chosen as cavity material due to economic reasons because the other cavities of the injector cyclotron are also made of Aluminum. The same cooling circuit can then be used for all cavities of this cyclotron.

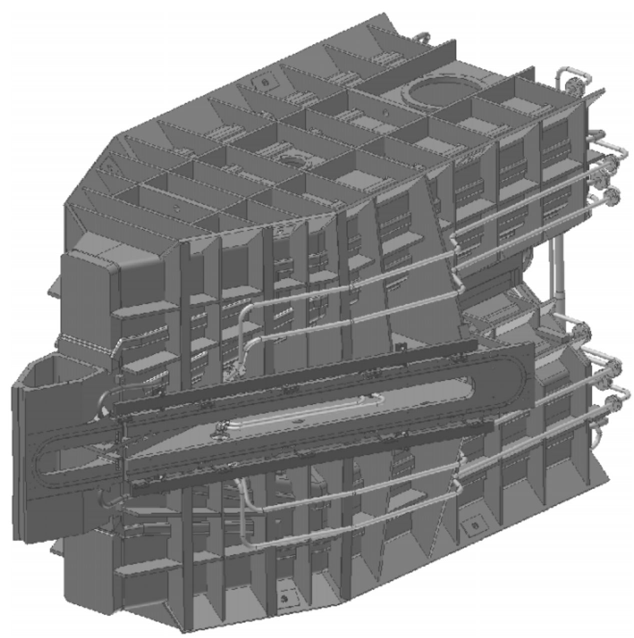

Figure 2: The new 50 MHz cavities for Injector 2. The beam slot is seen in the center. (CAD by SDMS)

Table 1: Operation Parameters of the new cavities

Gap Voltage	400 kV
Wall Losses	45 kW
Quality Factor	28’000
Vacuum	10^{-6}mbar
Material (rf walls)	Alu. EN AW 1050
(support structure)	Alu. EN AW 5083
Dimensions (l,w,h)	ca. 5.3 m, 3.3 m, 3.0 m
Weight	ca. 6 t

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MECHANICAL DESIGN

The mechanical construction was analyzed with the multi-physics program ANSYS [1], using a coupled rf thermo mechanical simulation method.

Detuning due to air pressure

The inner geometry (vacuum) was created first, discretised and the rf eigenvalue problem solved. About 0.8 million second order elements of ANSYS type 10 Node HF119 were used for this calculation. It gave directly the electric and magnetic fields for the fundamental mode and radio-frequency parameters such as frequency, acceleration voltage and wall losses for the case of the initial geometry.

A mechanical model of the support structure was then created, using about 4.5 million tetrahedral elements of type 10 Node SOLID187. The vacuum deformation due to the air-pressure load of 1000 mbar on cavity walls was then calculated. This deformation was interpolated onto the grid used for the previous rf simulation and then the new eigenfrequency calculated. The detuning due to pump-down is estimated to about -75 kHz, as illustrated in Tab. 2. Fig. 3 illustrates the deformation of the vacuum volume, due to air-pressure load, compared to the outline of the initial geometry.

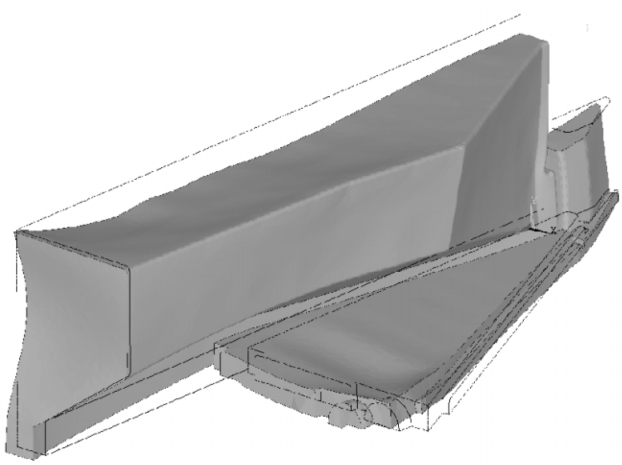

Figure 3: Deformations due to air-pressure load (pump-down). View on deformed rf geometry. Because of the vertical and horizontal symmetries, only one fourth of the geometry is simulated. The maximum deformation is 1.8 mm.

Detuning due to thermal deformation

The power density distribution on the wall, as calculated in the initial rf simulation, was applied as new boundary condition to the mechanical structure. The temperature distribution was then calculated, using about 4.5 million tetrahedral elements of type 10 Node SOLID87. As illustrated in Fig. 4, the maximum temperature of $76.5\,^{\circ}C$ for a total power dissipation of 100 kW is localized around the tip of the electrodes. With this data, the simulation of the thermal deformation was performed. Fig. 5 illustrates the deformation of the vacuum volume, due to thermal load, compared to the outline of the initial geometry.

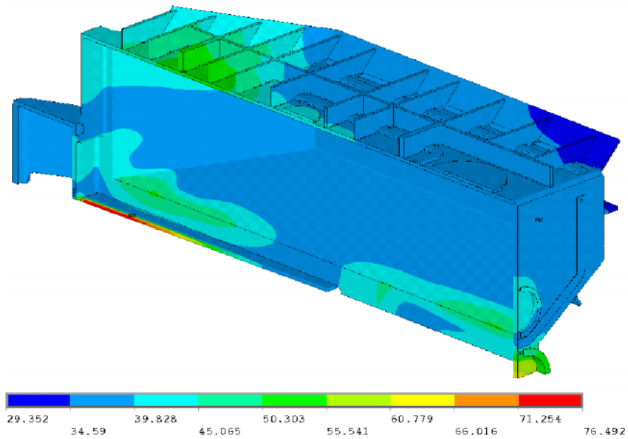

Figure 4: Temperature Distribution (Pw = 100 kW). View from outer part on cut at mid-planes. Because of the vertical and horizontal symmetries, only one fourth of the geometry was simulated.

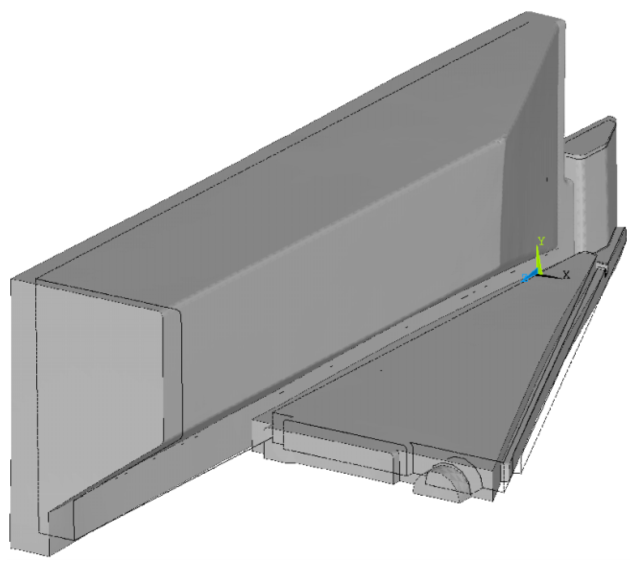

Figure 5: Deformations (Pw = 100 kW) due to thermal load. View on deformed rf geometry. Because of the vertical and horizontal symmetries, only one fourth of the geometry was simulated. The maximum deformation is 1.7 mm.

The resonance frequency can now be calculated again and determines the minimal range for the tuning system. A frequency drift of -32.57 kHz was found.

The "Worst Case"

In order to get the sensitivity of the design on the model parameters, a "worst case" simulation was performed. The "worst case" corresponds to higher power dissipation in the cavity walls and pessimistic assumptions for all of the thermal input parameters, as illustrated in Tab. 2.

Table 2: Parameters and results for Design- and ”worst case” simulation. The forced convection cooling parameters depend on the location in the cooling channel.

Case	**Design**	**”Worst”**
Power dissipation	100 kW	200 kW
Forced convection cooling α_k	7000-11000 W/m^2K	3500-5500 W/m^2K
Natural convection α_{kn}	5 W/m^2K	2.5 W/m^2K
Cooling water temp.	35°C	40°C
Ambient air temp.	25°C	40°C
Uniform start temp.	25°C	20°C
Max. temperature (on Electrodes)	**76.5°C**	**148°C**
Freq. drift vacuum	**-75.2 kHz**	**-75.2 kHz**
Freq. drift thermal	**-32.6 kHz**	**-58.7 kHz**

The results show that operation at 100 kW should be possible even under pessimistic assumptions.

RF DESIGN

The rf analysis was performed with the electromagnetic eigenvalue solver in ANSYS [1]. The cavity is operated at the fundamental mode and its gap-voltage increases therefore almost linearly from 0 kV at injection to the maximum value at extraction location [3]. This has the advantage of high energy gain at higher energies and therefore helps to increase the turn separation at extraction. In order to achieve the required maximum gap-voltage of 400kV, the cavity dissipates about 45kW of wall losses.

The maximum local electric field of 3.9 MV/m for a gap voltage of 400 kV was found at the tip of the electrodes. The maximum local magnetic field reached then a value of about 67 A/cm at the other end of the electrodes.

Tuning

During the fabrication process, there are two coarse frequency adjusting possibilities of the cavities. The total length of the cavity can be adapted in the range of about 5 cm for a first coarse tuning before the end-wall is welded to the cavity. Later, the position of the electrodes can be slightly adjusted in order to compensate the remaining fabrication tolerances and to achieve the correct starting frequency. Therefore, the tuner needs to correct mainly for the thermal drift when the cavity is switched on and off. The desired fine tuning range was therefore set to 200 kHz and three possible tuner locations were investigated.

One plunger of 26 cm diameter located on each of the upper- and lower cavity walls would require an insertion depth of about 50 cm for the required tuning range of 200 kHz.

On the other hand, one single plunger with diameter 27.2 cm located at the end-wall and centered in the beam plane would require an insertion depth of only 15 cm. At a gap-voltage of 400 kV, the rf-contacts of the plunger would have to conduct current density up to 35.5A/cm.

If two plunger of diameter 50 cm were installed on the end-wall, each at a distance of 60 cm from the beam plane, the insertion depth would be slightly longer (18 cm), but the maximum current density on the rf-contacts could be reduced from the 35.5 A/cm, in the case of one single plunger, to about 14.5 A/cm. The choice of such a big diameter has also the advantage that the plunger ports could also be used as access holes during fabrication and maintenance.

Inductive Coupler

The size of the inductive coupling loop was investigated with Balleyguier’s method for the calculation of external quality factors [6]. ANSYS’ eigenmode solver was used for the simulation of the partial solutions. Preliminary investigations showed that the coupler used in the cavities of the 590 MeV cyclotron could be adapted for the operation in the new cavities of the injector cyclotron. The design of the coupler could be identical, but with a reduced loop length to about 4 cm.

CONCLUSIONS

The simulations showed that the new cavity for the injector cyclotron can be operated safely up to wall losses of 100 kW. In the case with two tuners at the end-wall of the cavity, the rf-current densities on the plunger can be reduced to half. At higher power levels, the maximum gap-voltage will then be limited by the temperature on the electrodes, the current densities on the rf-contacts of the plunger and the maximum electric field.

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