DEVELOPMENT OF A NEW HIGH POWER CAVITY FOR THE 590 MeV RING CYCLOTRON AT PSI

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Abstract

The cavity development is done in two steps: The design concept is first verified with a fully operational model cavity and then, based on this experience, a 1:1 scale prototype cavity is constructed and fabricated. Right now we are in between the two steps. This paper presents the proposed layout for the new full scale cavity and summarises the results gained with the model cavity. Special emphasis is given on the transient behaviour of the tuning system under large load changes.

1 INTRODUCTION

The main cyclotron at PSI [1] routinely accelerates with four 50 MHz RF cavities a 1.5 mA beam up to 590 MeV. Each cavity dissipates 300 kW of RF power and generates a peak voltage of 730 kV. To allow the acceleration of even higher currents this voltage has to be increased. Due to limitations in the cooling system and the tuning range of the cavity [2] this requires a new design. It was decided at PSI to build a new cavity, which can produce stable accelerating voltages of up to 1 MV and dissipate 500 kW of RF power [1]. Such a cavity would also serve as a prototype for the driver cyclotron of an energy amplifier or transmutation machine [3].

2 CAVITY LAYOUT

Table 1 lists the main parameters of the new cavity in comparison with the existing one.

Table 1: Cavity parameters

	EXISTING CAVITY	NEW CAVITY
Frequency	50.6 MHz	50.6 MHz
Shunt Impedance	1 MΩ	1.8 MΩ
unloaded Q	30000	48000
Dissipated Power CW	300 kW	500 kW
Accelerating Voltage	730 kV	1 MV
RF-Wall Material	Al	Cu
Mech. support structure	cast Al	stainless steel

Figures 1 and 2 depict the proposed layout for the 1:1 scale prototype (for the results with the 1:3 model see section 3).

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This new design will allow:

- an operation with an accelerating voltage of up to 1 MV, or with the "standard" voltage of 730 kV but decreased energy consumption.
- the cavity to stay tuned all the time. (e.g. when the input power trips due to a spark in the cavity.)
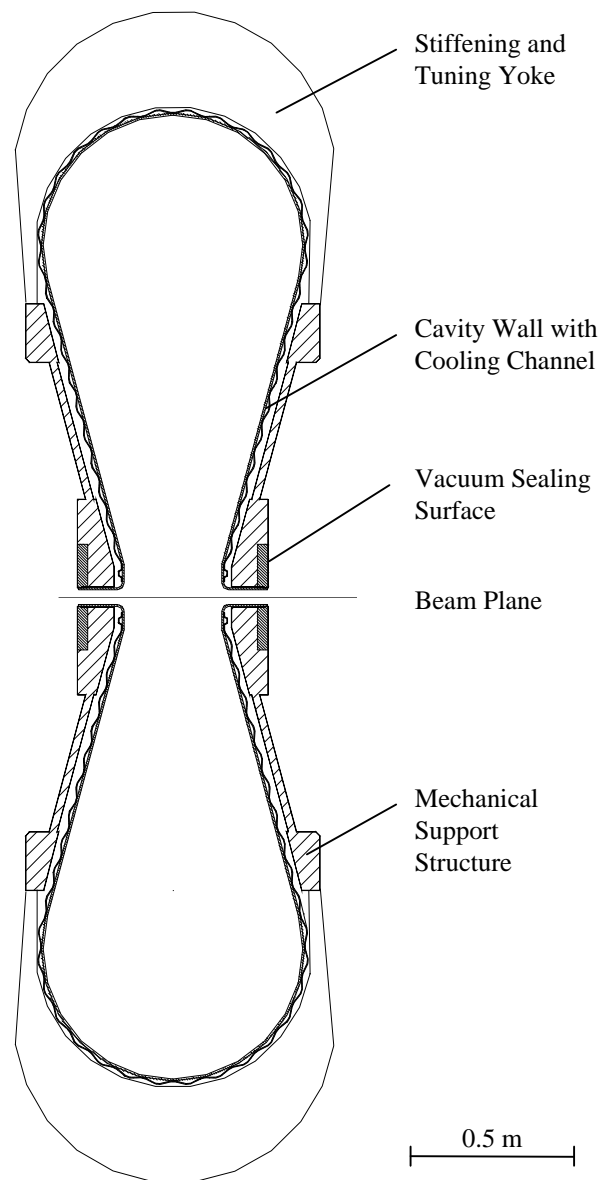

Stiffening and Tuning Yoke

Cavity Wall with Cooling Channel

Vacuum Sealing Surface

Beam Plane

Mechanical Support Structure

0.5 m

Figure 1: Cross section of the proposed 1:1 scale cavity

The main features of the cavity layout are listed below:

- The cavity wall consists of an inner liner of a 6 mm copper sheet, directly electron-beam welded onto a corrugated stainless steel sheet, forming the outer shell. The large number of channels generated hereby provide a very efficient water cooling of the entire cavity surface with very small thermal gradients.To facilitate the welding process, the copper sheets have to be as thin as possible.
- The shape of the cavity is optimised for a maximum shunt impedance with the constraint that the whole structure has to fit into an existing sector of the ring cyclotron.
- The end sections of the cavity serve to connect to the water feed lines and to distribute the cooling water into the individual channels. Integrated into the end sections are the ports for the vacuum pump and the RF-window.
- To prevent the structure from collapsing under atmospheric pressure, a solid and stable stainless steel frame is built around it. This support structure is constructed such that it can be separated from the cavity shell at any time. It also provides the necessary vacuum flange connections in the beam plane and a good sealing surface because it's built from stainless steel .
- The tuning system is integrated into the support structure and consists of a fast and a slow system (see section 3.2).
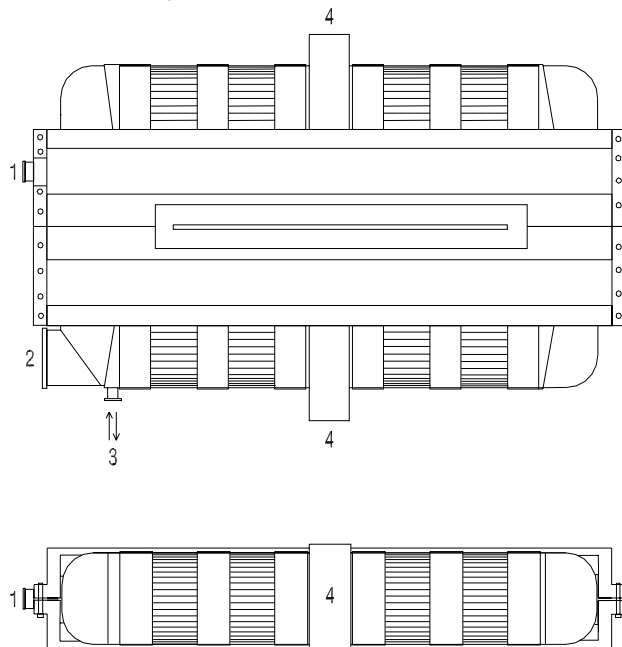

Figure 2: Side and top view of the proposed 1:1scale cavity.

1:opening for the RF coupling loop
2:vacuum pumping port
3:cooling water inlet/outlet
4:stiffening and tuning yoke

3 MODEL CAVITY

To be able to study all aspects of such a high power cavity, we have built a model on a 1:3 scale and which is able to dissipate at least 100 kW of RF power (see Figure 3). The scale factor of 1:3 comes from the fact that we have a high power amplifier available operating at 150 MHz.
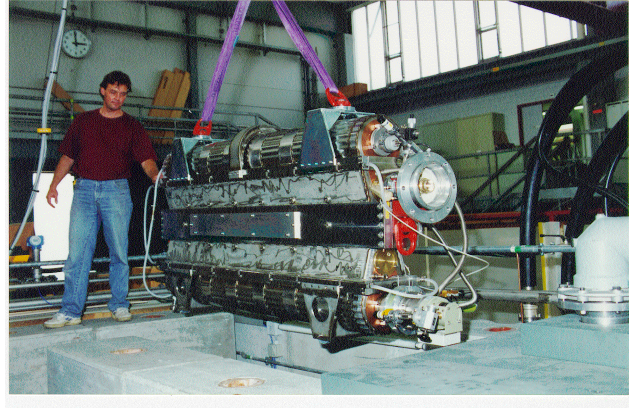

Figure 3: 150 MHz 1:3 scale model cavity before installation in the testing vault.

The model allows us to
(i) Experiment with new design ideas.
(ii) Test fabrication techniques.
(iii) Study the tuning behaviour in the case of large load changes.
(iv) Validate simulation models which are necessary to predict the behaviour of the full scale cavity.

3.1 Cold tests

Using this design concept, copper and stainless steel have to be joined together. After having had great difficulties with these welds we can now maintain a vacuum pressure better than 10^{-5} mbar in the cavity.

Table 2: RF parameters of the evacuated 1:3 scale cavity

	calculated	measured [1])
Frequency in MHz	151.834	148.951
unloaded Q	27550	24750
Shunt Impedance in MΩ	1.084	1.064[2])

[1]) without the stiffening yokes

[2]) measured in air

The difference between calculated and measured values in table 2 is mainly due to the larger than expected mechanical deformations caused by the atmospheric pressure, and due to the fact that the cavity shape had to be slightly deformed in order to fit into the mechanical support structure.

Up to now we did not try to get closer to the nominal frequency, because the bandwidth of the amplifier chain is large enough to drive the cavity. Since we have to 'hit' the

exact resonance frequency with the full scale cavity, the model contains an adjusting mechanism, with which enables us to do so.

3.2 Power tests

When feeding RF power to the cavity for the first time, virtually no multipacting could be observed and the incident power could be increased almost instantaneously to the limit of the amplifier chain (80 kW CW).

We could show that the foreseen tuning system based on thermal expansion and acting on the support structure neither could provide the necessary tuning range nor the required speed.
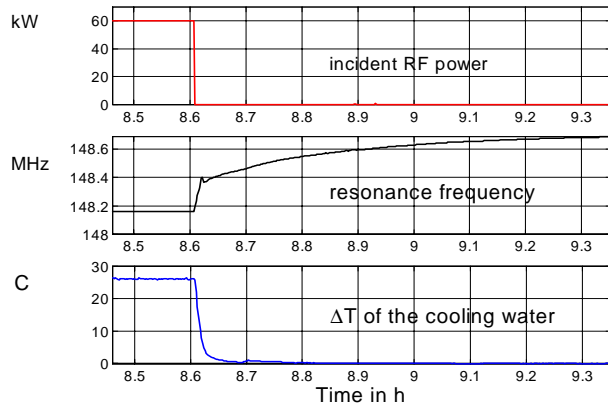
Figure 4: Cavity response to a step in RF input power.
The oscillator is following the resonance frequency of the cavity with the tuning system switched off.

The second trace in figure 4 shows that the resonance frequency of the cavity changes roughly by 0.5 MHz when the incident RF power goes from 60 kW to zero. About half of this large detuning is caused by an unwanted residual thermal coupling between the cavity wall and the mechanical support structure. We believe that we can remove it to a large extent by changing the layout of the cooling channels around the beam plane.

The resonance frequency can, as finite element calculations (see figure 5) and experiments [4] show, be changed over more than 1 MHz by intentionally heating (or cooling) part of the mechanical support structure. This effect allows to compensate for the slow drift.

To cope with the fast changes of the resonance frequency, we will build into the stiffening yokes a hydraulic adjusting mechanism which is at least an order of magnitude faster than the slow system.

Figure 5: Deformation of the mechanical support structure due to thermal expansion.
The temperature of the upper rod is raised by 60°C above the rest of the support structure. This deformation would yield in a change of the resonance frequency of 1.4 MHz.

4 THE NEXT STEPS

To come up with a working full scale cavity, we are planning the following steps:

1. Already under way are tests of the tuning system on the model cavity.
2. Learn how to reproducibly join copper and stainless steel.
3. Mechanically design and fabricate the prototype cavity together with a partner in industry
4. Test the prototype cavity in our 1 MW testing installation, which is now being set up.

5 REFERENCES

[1] U. Schryber et al.,*"High Power Operation of the PSI Accelerators"*, Proc. 14th Int. Conf. on Cyclotrons and their Applications, Cape Town (RSA), Oct.1995

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