SUPPRESSION OF RF RADIATION ORIGINATING FROM THE FLATTOP CAVITY IN THE PSI RING CYCLOTRON

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Abstract

In the PSI Ring cyclotron, protons are accelerated from 72 MeV to 590 MeV. In several upgrade programs, the beam current was increased from the initial design value of 100 µA up to 2.4 mA. The rf-system of this separated sector cyclotron consists of 4 copper cavities running at 50 MHz for the main acceleration. For the purpose of increasing the phase acceptance of the Ring, an aluminum flattop cavity is operated at a gap voltage of 555 kVp at the 3rd harmonic frequency.

As a result of the progressively increased flattop voltage, this cavity was pushed toward its mechanical and electrical limits. As a consequence, rf-power is leaking into the cyclotron's vacuum space and is causing several problems. A visible effect was the formation of plasma in the vacuum chamber [1].

In the last shutdown, an attempt was made to reduce the radiated rf-power. On the vacuum sealing between the flattop cavity and sector magnet 6, a shim was installed which reduces the gap for the beam from 60 mm to 25 mm in height. Results of this intervention will be presented and compared with finite element model simulations.

INTRODUCTION

The flattop cavity in the Ring cyclotron is located between Sector Magnet 6 (SM6) and Sector Magnet 7 (SM7) as shown in Fig. 1. AS2 and AS3 are rf-radiation probes.

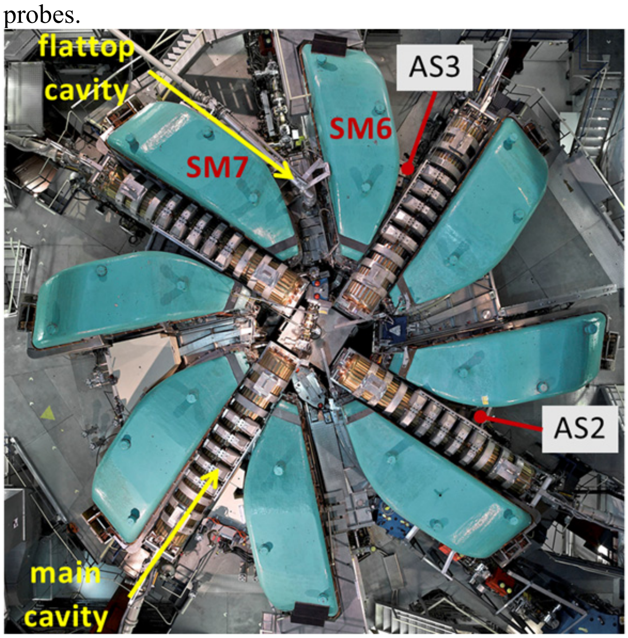

Figure 1: The PSI Ring cyclotron.

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The FT cavity is directly attached to the vacuum chamber on the SM7 side by an O-ring. However, an expandable sealing (see Fig. 4) is installed between the cavity and SM6. This expandable sealing is an O-shaped bellow made of aluminum, holding an O-ring on both sides. For a vacuum tight connection it is pressurized by air to 0.7 Bar. For installation in the machine, the expandable sealing is shrunk by applying vacuum. This sealing has a vertical gap size of 60 mm.

Simulations showed that the radiated power of the flattop cavity could be reduced, by adding a metal shim (25 mm vertical gap size, 102 mm length) outside the cavity into the beam aperture from 11.9 kW to 3.3 kW. This is a reduction of 8.6 kW or 75% [2].

It turned out to be difficult to add such a shim on the flattop cavity towards SM7 because a mechanical support holding the shim is needed. Additionally, for the installation of such a shim the cavity would have to be taken out of the ring cyclotron.

A much easier way to install a shim was to reduce the gap in the expandable vacuum sealing on the SM6 side of the flattop cavity. Figure 2 shows a cross section of flattop cavity, expandable vacuum sealing with shim, and vacuum chamber of sector magnet.

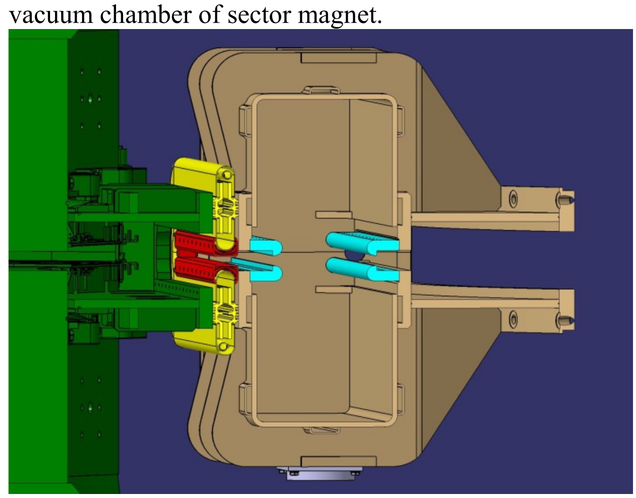

Figure 2: Cross section of flattop cavity (beige) with electrodes (cyan), expandable vacuum sealing (yellow) with shim (red) and vacuum chamber of sector magnet 6 (green).

SHIM

The design of the new shim was straight forward. The gap size should be lowered to 25 mm and the maximum length is given by the space between SM6 and flattop cavity such that the sealing could still be installed. We decided to use an aluminum sheet of 4 mm thickness which is formed into a U-shape (see Fig. 3). The expand-

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able sealing's top and bottom inside radius have this U-profile. For a good rf-contact to the sealing the U-shape was changed to a C-shape with a sharp corner pressing into the sealing. On both sides we added a block of aluminum to get the 25 mm distance between the upper and lower profile. As fixation for the shim on the sealing over a distance of 180 mm, clamps were added. We could tighten the C-profile with screw to get a smooth contact to the vacuum sealing. The clamps on the ends of the profile were used to center the shim vertically in the gap.

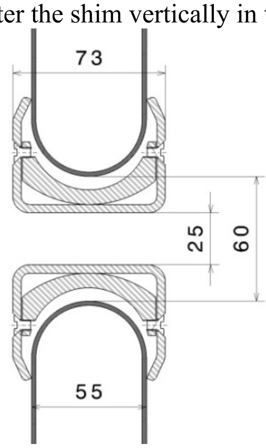

Figure 3: Cross section of expandable sealing with shim. Dimensions of vertical gap and length in mm.

It was difficult to find a manufacturer who was able to bend the aluminum sheet into the C-profile with the expected tolerances over a length of 2.72 m.

TESTS

In January 2016 we received a window of 2 weeks for tests during the shutdown. Two different setups were tested. The first one was to collect data without shim, so as to have measurements during normal operation with the standard expandable sealing. After 1 month shutdown of the cyclotron is was important to have actual reference data.

Then the cyclotron was vented and the vacuum sealing was taken out to install the shim on it. The shim could not be mounted on the expandable sealing on the first attempt because some welded joints were thicker than expected. After some mechanical fine tuning on the shim, which did not affect the principal geometry, we managed to finish the installation. Figure 4 shows a photo of the vacuum sealing with the installed shim.

To avoid multipactoring in our shim we decided to paint the surfaces with “Aquadag 18 %” [3]. This gives a thin layer of graphite on the aluminum surface and lowers the secondary emissions coefficient of electrons.

Then we reinstalled the sealing in the cyclotron and after applying vacuum and conditioning we made our second measurements. Each of those two iteration lasted for about one week.

We expected to see a difference in the power fed into the cavity at the same gap voltage, because less power should be radiated into the machine. On the other hand we used some pickups installed in the vacuum chambers to measure the rf-signal. Such as AS2 is an inductive pickup near the main cavity 2 and AS3 is a capacitive pickup near cavity 3 (see Fig. 1).

MEASUREMENTS

Parameters were measured as a function of the gap voltage. We started on the highest gap voltage and then lowered it in steps of 50 kVp. From point to point it took about 15 minutes to have stable thermal conditions of the flattop cavity. During measurements the main magnets were on and the main cavities were off.

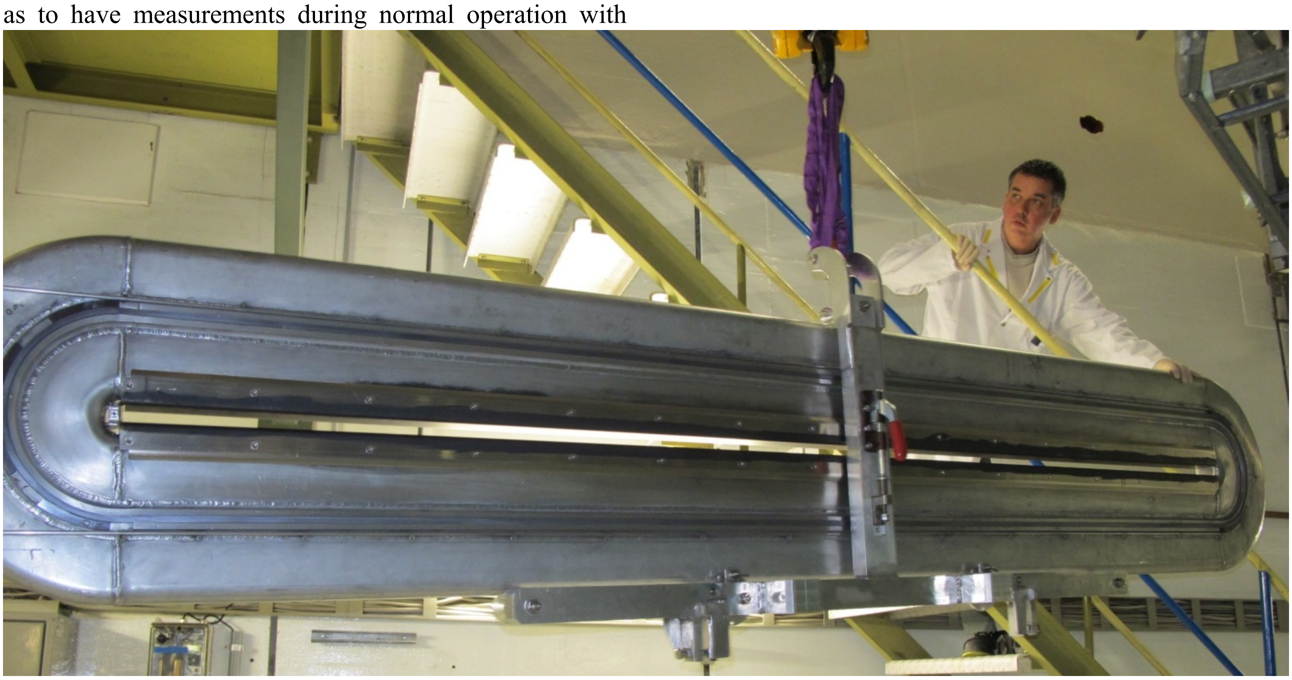

Figure 4: Transport of expandable sealing with shim for installation into the Ring cyclotron.

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Power Versus Gap Voltage

Figure 5 shows the power fed into the cavity versus the gap voltage. Contrary to the simulations, which showed a difference of 8.6 kW at 500 kVp gap voltage, with and without shim the same power was needed during both tests.

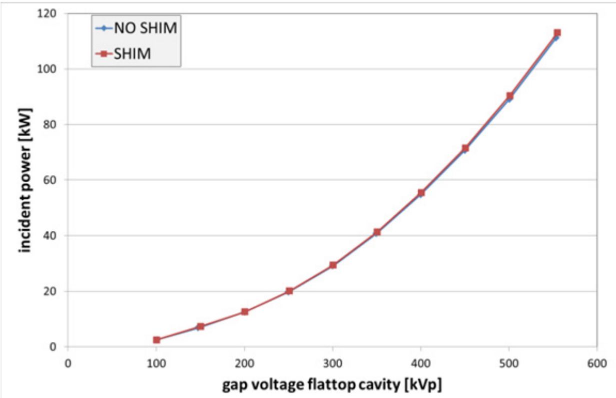

Figure 5: Incident power versus gap voltage of flattop cavity.

Normally the flattop cavity is fed with 102 kW to achieve the 555 kVp. During the two tests, the power was 112 kW for the nominal gap voltage. The additional 10 kW must be fed into multipactoring around the flattop cavity. Higher levels on the ionization chambers are another indicator for this. The same effect was observed after the shutdown 2015 and could be solved by painting several surfaces around the flattop with Aquadag. Such an intervention would have needed at least another week, which was not possible during the assigned test time.

Pickup Signals

The pickup signals were measured by using a spectrum analyzer. In Fig. 6 the signal of the pickup at 151.9 MHz versus the gap voltage is presented. At the probe AS2 the signal was about 4.5 dB lower with the shim. At AS3 a reduction of about 6 dB was measured.

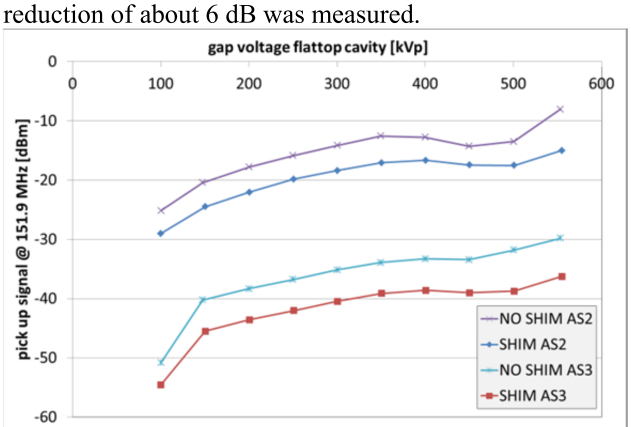

Figure 6: Pickup signals versus gap voltage.

Measurements with Main Cavities

At the end of each test, data was taken with all cavities on normal operation voltage. Table 1 compares those values.

Table 1: Pickup Signals with all Cavities on Nominal Voltage

	NO SHIM	SHIM	difference
AS2 @ 50.6 MHz	1.03 dBm	1.03 dBm	-
AS2 @ 151.9 MHz	-17.90 dBm	-23.86 dBm	-5.96 dB
AS3 @ 50.6 MHz	-44.81 dBm	-44.87 dBm	-
AS3 @ 151.9 MHz	-27.84 dBm	-32.88 dBm	-5.04 dB

CONCLUSION

A metal shim was successfully installed on the expandable sealing for the tests during the shutdown 2016. The pickup signals measured during power tests were 5 to 6 dB lower compared to the setup without shim. This is in the range of the estimated results from the simulations. Nevertheless the expected reduction of the power fed into the cavity was not observed during the tests.

The shim is an improvement to reduce the radiated power from the flattop cavity, but does not solve all the plasma problems observed in the PSI Ring cyclotron. Unfortunately there was no pickup on the SM7 side of the flattop cavity, to see if the power leakage increased at the SM7 side as a result of the reduction on the SM6 side. Further investigation will be needed. A measurable reduction in power might be seen, if the shims are located on each side of the cavity.

The installed shim reduces the vertical gap to 25 mm. Because there is no protecting device to avoid that the beam hits the shim, it was taken out of the machine after the tests.

During both runs more power was needed for the nominal cavity voltage. This could be temporary solved by excessive painting in and around the flattop cavity with Aquadag in the shutdown after the test.

ACKNOWLEDGEMENT

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