# DISTURBANCE EFFECTS CAUSED BY RF POWER LEAKING OUT FROM CAVITIES IN THE PSI RINGCYCLOTRON

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*Abstract*

While commissioning the PSI high intensity proton beam facility after the shutdown 2010, direct and indirect phenomena of interaction occurred between the RF power leaking out from the cavities and the electrostatic septa at the injection and extraction region in the Ringcyclotron. As an indirect influence RF fields outside the cavities generate plasma clouds in the peripheral area of magnet poles. Accelerated plasma ions sputtered metallic atoms from the vacuum chamber wall, which then covered the insulator surface with an electrically conductive layer. The septum therefore had to be replaced. Directly, RF power dissipated from the 150 MHz flattop cavity was redirected by a beam stopper in such a way, that a linear correlation between the RF pick up signal monitored at the extraction septum (EEC) and the leakage current across the septum insulator could be observed. As an instant mending action the beam stopper, which is not permanently used, has been removed. The long term attempt to minimize these disturbing effects will be an asymmetrical setting of the hydraulic cavity tuning system and an effective RF grounding of build in components.

## INTRODUCTION

In the Ringcyclotron of PSI's high intensity proton facility, the amplitudes in the RF cavities have been raised from 760 MV in 1998 to 860 MV nowadays. In lockstep with this RF upgrade the electrostatic elements had to be modified to meet the new requirements.

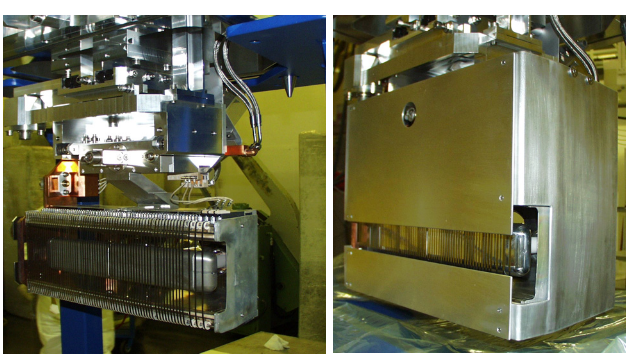

Figure 1: Electrostatic injection channel of the PSI Ring-cyclotron without shielding (left) and shielded (right).

That bundle of measures succeeded to maintain their reliable operation. As an example, the RF shielding of the electrostatic inflection channel, added in 2006, is shown in Figure 1. Despite these efforts, the septa belong to the most critical parts of the cyclotron. In particular their behaviour during the first few weeks after the annual shutdown is a cause for concern. Several times, shortly after the start up of the facility, one or even both of these elements were seriously damaged and had to be replaced.

## INVESTIGATIONS IN 2010

In 2010 once more, shortly after the facility commissioning the electrostatic extraction septum EEC lost its electric field strength. The examination of the dismounted EEC septum has exhibited traces of damaging effects. The outer face of a shielding plate at the beam exit side showed a staining on its surface and one of the insulators was contaminated with a strip of conductive material.

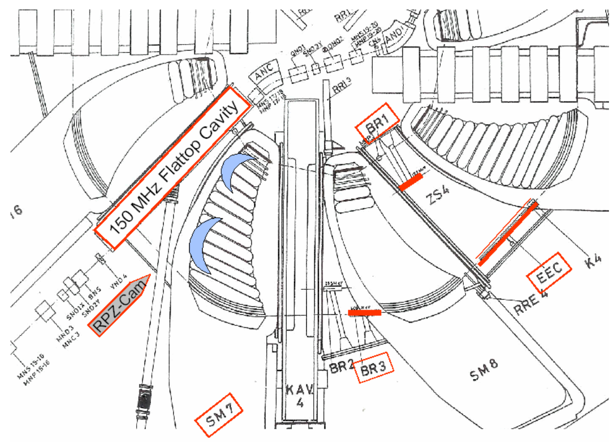


Figure 2: Layout of the PSI Ringcyclotron. The blue coloured patches represent the plasma clouds monitored by the CCD camera in the RF on, beam off state.

After the replacement, various efforts were tackled to get more insight into the damaging incidents that had happened. The scheme in Figure 2 shows coloured in red the cyclotron components involved in them. The experiments uncovered peculiar observations inside the vacuum chamber of the Ringcyclotron.

### *Interaction of RF with BR1, BR3 and EEC*

The two beam stoppers BR1 and BR3 are used for commissioning and tuning purposes. In the beam production state of the machine they are moved out and parked off the beam path. Since years it was a well known fact, that whenever BR1 was set in beam stopping position, BR3 measured a virtual proton beam current of up to 50 µA. The current readout evidently was unreal, since no protons could transit the active stopper BR1. It instead was depending on the voltage level of the flattop cavity. While until the end of last year this fake current signal vanished when BR1 was parked, after this year's shutdown it remained present, independent of the BR1 position. During the shutdown BR1 had undergone modifications. Its unfavourable side effect was that its carrier arm, formerly effectively RF grounded when parked, had lost its conducting connection to the ground.

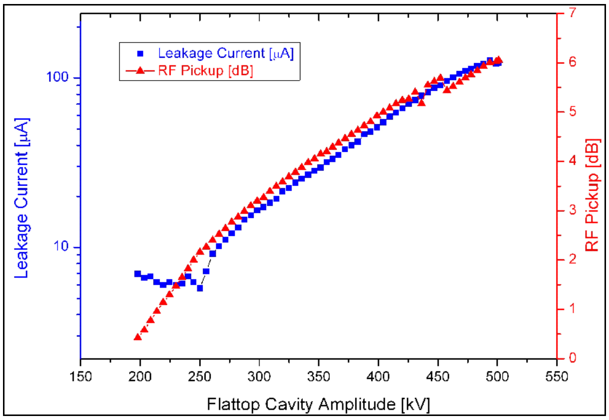


Figure 3: RF pickup and leaking current versus amplitude of the flattop cavity. The logarithmic current scale allows a direct comparison with the RF pickup in dB.

A similar impact of the flattop cavity on the EEC septum could be observed even more precisely. The EEC is protected by the control of the leakage current across the insulators and by six metal strips which collect aberrant protons. For test purposes the second strip was connected to an RF pickup device. Figure 3 displays the leakage current and the signal recorded by this device as a function of the amplitude of the flattop cavity. Above 270 kV the leakage current signal raises strictly proportional to the RF pickup, BR1 obviously acted as an RF antenna which absorbed the RF field decoupled from the flattop cavity and reemitted it radially towards the EEC septum and the stopper BR3.

### *Plasma Clouds Created by Flattop Cavity*

A RDZ security camera, placed in front of a window in the vacuum chamber wall revealed an explicit glowing in the sector magnet SM7 near the exit gap of the flattop cavity. The ignition, shown in Figure 4, could reliably be reproduced by raising the voltage of the RF amplitude above 490 kV and expunged again by lowering the voltage below 400 kV. The ion density could be measured by means of a vacuum gauge in the cyclotron centre region. Up to 490 kV the vacuum pressure remains stable around 0.1mPa. At 490 kV, it raises sharply, indicating the dramatic ion fraction growth of the residual gas.

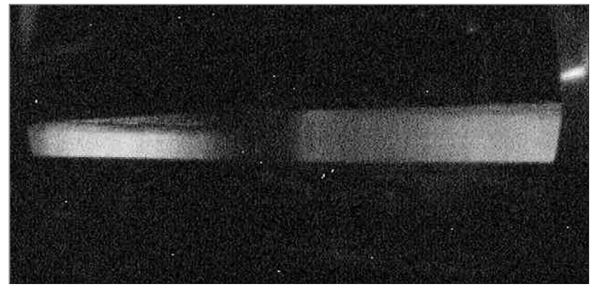

Figure 4: Plasma glowing in the pole region of sector magnet SM 7 as seen by the CCD camera.

In Figure 5 this devolution is plotted (peak A) and compared to the development of the EEC leakage current. Up to 240 kV the current stays constant. At 240 kV a splay (B) induces a sudden boost, followed by a quadratic growth as a function of the RF amplitude. The sudden increase of charged particles observed in the EEC region, is similar to the one, the vacuum gauge recorded from the plasma cloud at SM7. Though not fully proven, most probably the RF power, redirected to the EEC septum, ignites here another plasma cloud. Due to the more complicated structure of the surroundings, 240 kV RF amplitude suffice to ignite it, whereas in the almost empty region at the flattop cavity at least 490 kV are needed. Since the plasma cloud directly wraps the EEC, ions are travelling to the corresponding electrodes, yielding a rise of the leakage current proportional to the plasma concentration.

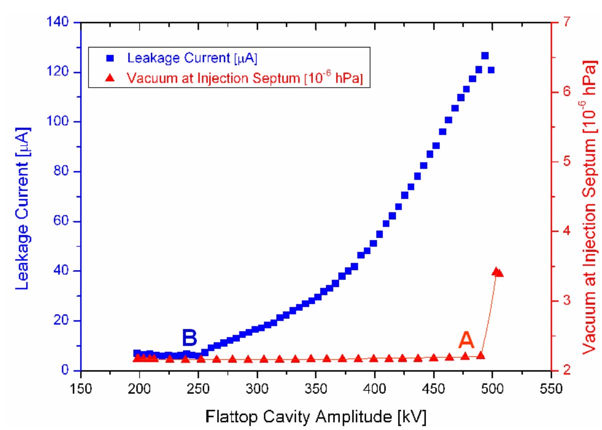


Figure 5: Residual gas pressure of the vacuum gauge and the EEC leakage current as a function of the amplitude of the flattop cavity. Plasma ignition occurs at the rib A and eventually at the splay B.

Accelerated ions sputter metallic atoms from the electrodes or the framework. These atoms then settle down on what ever surface present in the surroundings and therefore among others, on the insulators that serve as support of the EEC cathode. Sooner or later this deposition lowers their resistivity.

## MENDING TASKS

It is well known, that vagabonding RF can ignite plasma clouds [1]. But these as a fact are not mandatory harmful. The presented effects show a case, where by interaction with devices, the RF field moves an existing cloud to a sensitive place or generates it there, which then deploys its destructive potential.

### *Short and Intermediate Term Mending*

With the intent to damp the RF power decoupled from the flattop cavity, a first attempt was to install an RF absorber at the exit gap of the flattop cavity. Unfortunately the marginal effect predicted by simulation was confirmed by reality. The absorbing effect did not exceed a few percentage. By withdrawing the stopper BR1 it was possible to avoid the redirection of the RF power decoupled from the flattop cavity towards the EEC element. So both effects, the direct influence of the RF power on the stopper BR3 as well as the generation of the plasma cloud at the EEC septum were eliminated. This intervention has set the facility in the condition required for a successful beam production. Since the removal of the BR1 stopper three month ago, a proton beam of up to 2.2 mA was routinely extracted.

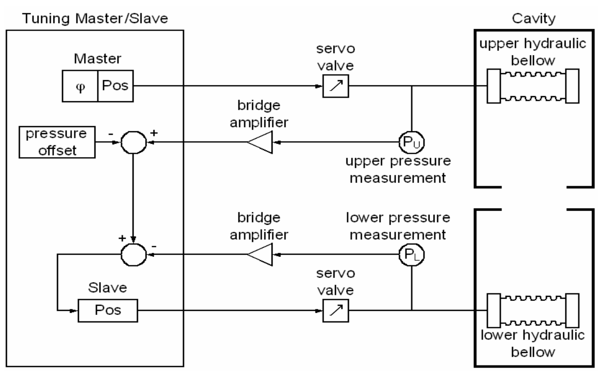


Figure 6: Block diagram of an independent pressure system for the upper and lower flattop cavity box part.

### *Long Term Repair of the Disturbance*

This measure will nevertheless only be a short term solution, as the lack of BR1 could cause problems in case of a more complicated machine setup. As well the decoupled RF and the plasma clouds still exist in the cyclotron an may damage at another place if prospective modifications of machine elements promote it. Investigations for a low rest gas pressure and an effective RF grounding of the components inside the vacuum chamber remain important, but the minimization of the decoupled RF power became a main task. The leaking out of RF power from a cavity is known to depend on vertical asymmetry. Positioning deviations, geometrical asymmetries, or partial coating on the inside walls of the cavities may add a vertical component to the regularly horizontal oscillation plane. As a correction of the oscillations slant several compensation mechanisms are known. N. Sakamoto has presented a system with movable panels to be an efficient approach [2]. Since in the PSI cavities the resonance of the RF is tuned by a hydraulic pressure system, the approach at PSI will be the installation of a separate tuning system for the upper and the lower box part. An upgrade of the flattop cavity in this regard is under way, see Figure 6.

### *Clue about the Septa Reliability Cycle*

Once the startup after a shutdown has succeeded, the key data of the electrostatic elements continuously improve. Some weeks after the successful first commissioning the number of voltage breakdowns drops significantly and the leakage currents reduce and get increasingly smooth. During the last quarter of the year before the annual shutdown the beam availability therefore often exceeds 95%. This observation adds another evidence for the key role decoupled RF plays in the reliability of the electrostatic elements. During the shutdown servicing and upgrading activities require an opening of the ring vacuum chamber for weeks sometimes. In this time all inner surfaces undergo contaminations with breathable air and humidity. So after the shutdown accidental partial coating of the surfaces yield a higher rest gas pressure and an enhanced amount of decoupled RF power. During production time the surface contaminations shrink bit by bit resulting in a reduction of the preconditions for ion generation and as well of decoupled RF power. Thus the irritation of the electrostatic septa is reduced.

## CONCLUSIONS

In addition to a shielding of the electrostatic septa, an effective system to minimize the RF power decoupled from the cavities is mandatory to operate the Ringcyclotron reliably at a beam current up to 3 mA. The PSI approach will be an independent tuning system for the upper and the lower cavity box part.

## ACKNOWLEDGEMENTS

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