DEVELOPMENTS AT PSI (INCLUDING NEW RF CAVITY)

H. Fitze, M. Bopp, A. Mezger, J.-Y. Raguin, P. Schmelzbach, P. Sigg, PSI, Villigen, Switzerland

Abstract

For a few years now the main activities for the PSI cyclotron complex are devoted to increase its availability and to reduce the number of serious and long breakdowns. This stems from the fact that on the one hand some components have been running for more than 30 years, and on the other hand today's users ask for more than 90% of the scheduled beam time. In this context a replacement program of the accelerating cavities in the 590 MeV ring was started, which will not only reduce the risk of an unscheduled shutdown but will also increase the current limit of the cyclotron. The prototype cavity was installed during the shutdown 2004 and runs smoothly since then. The manufacturing of the remaining three cavities has been started and the installation in the ring cyclotron will be finished by the year 2008.

BEAM TIME STATISTICS

Since 2001 the average availability of beam on target is between 86% and 89%. Looking at preliminary data of 2004 it seems to be very difficult to reach better values. A compilation of statistical data on the operation of the facility is presented in the tables 1 and 2.

Table 1: Production hours of the **590 MeV cyclotron**

	2001	**2002**	**2003**
production for experiments	4520	5030	4790
setup	120	152	150
beam development	210	272	120
unscheduled outage	440	192	240
service	190	248	320
shutdown	3360	2784	3025
standby	50	110	110

Table 2: Production hours of the **injector II cyclotron**

	2001	**2002**	**2003**
production for experiments	4520	5100	4890
setup	120	200	200
beam development	210	400	320
unscheduled outage	440	160	140
service	190	320	250
shutdown	3360	1540	2825
standby	50	1000	320

The low energy facility (injector I) is operated on a reduced basis with several longer shutdown and standby periods. Beam is preferably delivered to the OPTIS facility.

Table 3: Production hours of the **injector I cyclotron**

	2001	**2002**	**2003**
NE-experiments	4170	2440	1640
OPTIS	350	400	460
setup	780	200	120
beam development/ training	250	80	100
unscheduled outage	330	150	80
service	420	180	150
shutdown	1350	2660	3530
standby	1110	2600	2430

ACTIVITIES

Proscan

In 2003 the preparation of the technical infrastructure of the Proscan facility was nearly completed. The installation of the superconducting cyclotron started in summer 2004 and is practically finished. Commissioning of the RF system is starting now. For detailed information see [1] and [2].

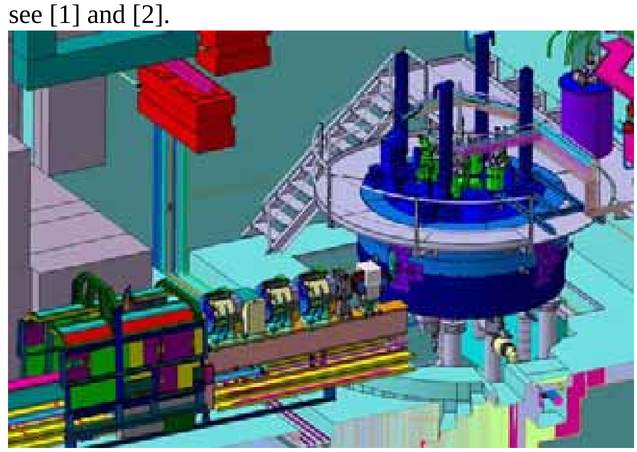


Figure 1: Superconducting cyclotron for Proscan

Injector II

By rearranging power amplifier chains in 2001, the accelerating voltage in injector II could be raised by about 3%, resulting in an improved vertical beam emittance. As a consequence a substantial reduction of critical losses in the extraction region of the 590 MeV ring could be achieved. This modification was essential among others to raise the beam intensity towards 2 mA.

The envisaged current upgrade from 2 to 3 mA requires an increase of the accelerating voltage of the 50 MHz cavities and as a consequence of the 150 MHz flat-top cavity as well. The tuning and cooling systems of the flat-top cavity are already running close to their limits. In order to preserve the transmission of the machine while relaxing the high demands on the flat-top system, it is conceivable to install a buncher in the 72 MeV injection line between injector II and the 590 MeV ring.

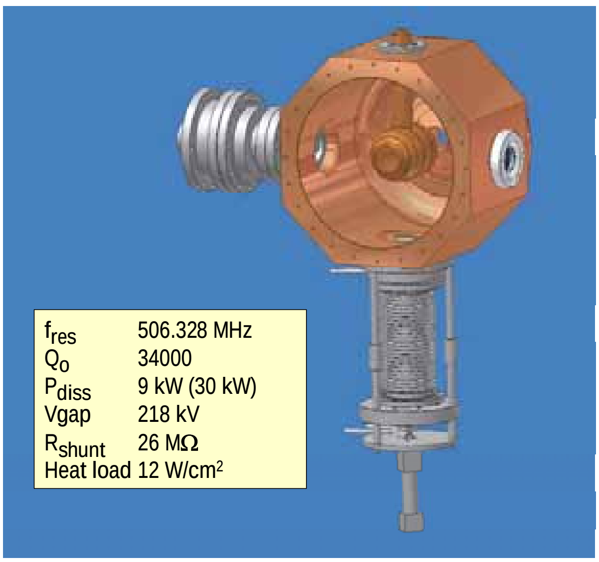


Figure 2: CAD model (with front cover removed) of a Rebuncher at the 10th Harmonic.

RF design of a two-gap drift-tube cavity and beam dynamic studies [3,4] are done and a prototype is expected to be ready next year.

590 MeV Ring

The vacuum seals between the aluminium cavities and the vacuum chamber show increasing leak rates, making it more difficult to maintain the desired vacuum quality in the cyclotron. A grinder/polisher device has been designed and built which will allow a speedy reconditioning of the cavity sealing surfaces.

Figure 3: Grinder/polisher module

During the shutdown 2002 the beam line in the centre of the cyclotron was reconstructed, leading to:

- A reduced risk of unscheduled downtime.
- A much faster replacement of failing components (better accessibility and no necessity to ventilate the whole cyclotron).
- A reduced dose load of the personnel.

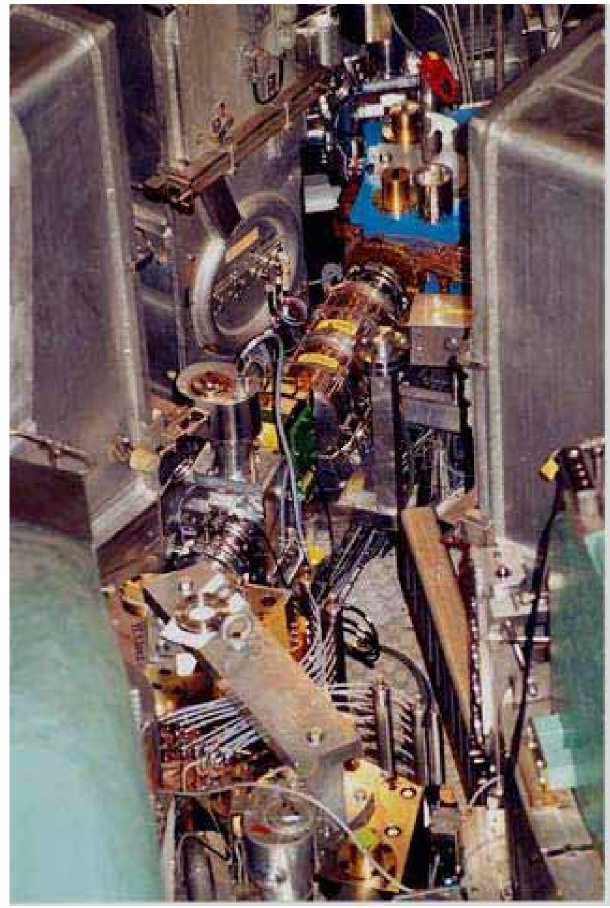


Figure 4: Beam line section in the centre of the 590 MeV cyclotron

NEW RF CAVITY

Each aluminium cavity of the 590 MeV ring dissipates 300 kW of RF power and generates an accelerating voltage of 730 kV. To produce beam currents above 2 mA this voltage has to be increased. Due to limitations in the cooling and tuning systems of the cavity this requires a new design. It was decided to build a new cavity that can produce stable accelerating voltages of up to 1 MV and dissipate 500 kW of RF power [5,6].

Cavity layout

The main features of the cavity layout are:

- The cavity wall consists of an 8 mm copper sheet on which cooling channels are directly TIG brazed. The large number of channels provides a very efficient water-cooling with very small thermal gradients.

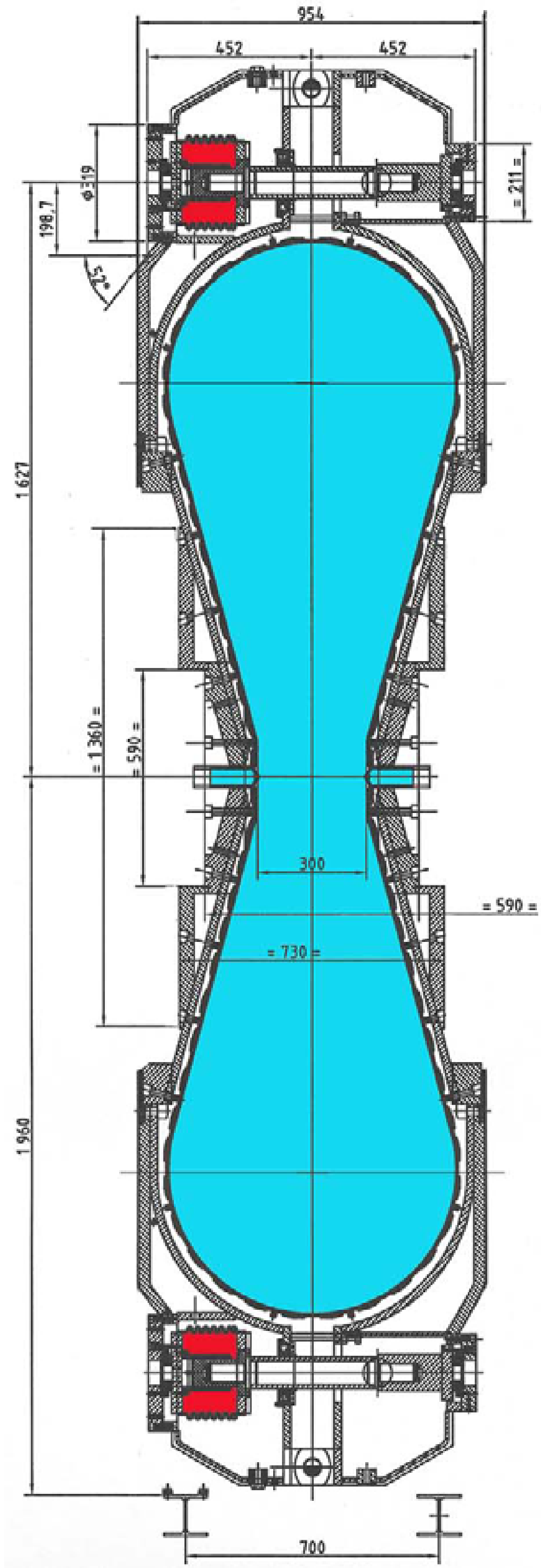


Figure 5: Cavity cross section.

- The shape of the cavity is optimized for a maximum shunt impedance with the constraint that the whole structure has to fit into an existing sector of the ring cyclotron.
- 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. It also provides the necessary vacuum flange connections in the beam plane and a good sealing surface because it is built from stainless steel.
- The tuning system consists of ten hydraulic tuning yokes which work against the atmospheric pressure and keep the cavity tuned at all times.

Fabrication steps

The main steps are:

- Production of the cavity body from copper sheets (8 mm). The welding jig shown in figure 6 is used to fix the sheets during the electron beam welding process.

Figure 6: Copper shell in the welding jig.

- Production of the support structure.
- Joining together the cavity body and the support structure. This procedure irreversibly defines the resonance frequency of the final cavity and is therefore a very delicate step.
- Mounting the tuning yokes and the cooling manifold.

Figure 7: Mounting the yokes.

- Factory acceptance test.

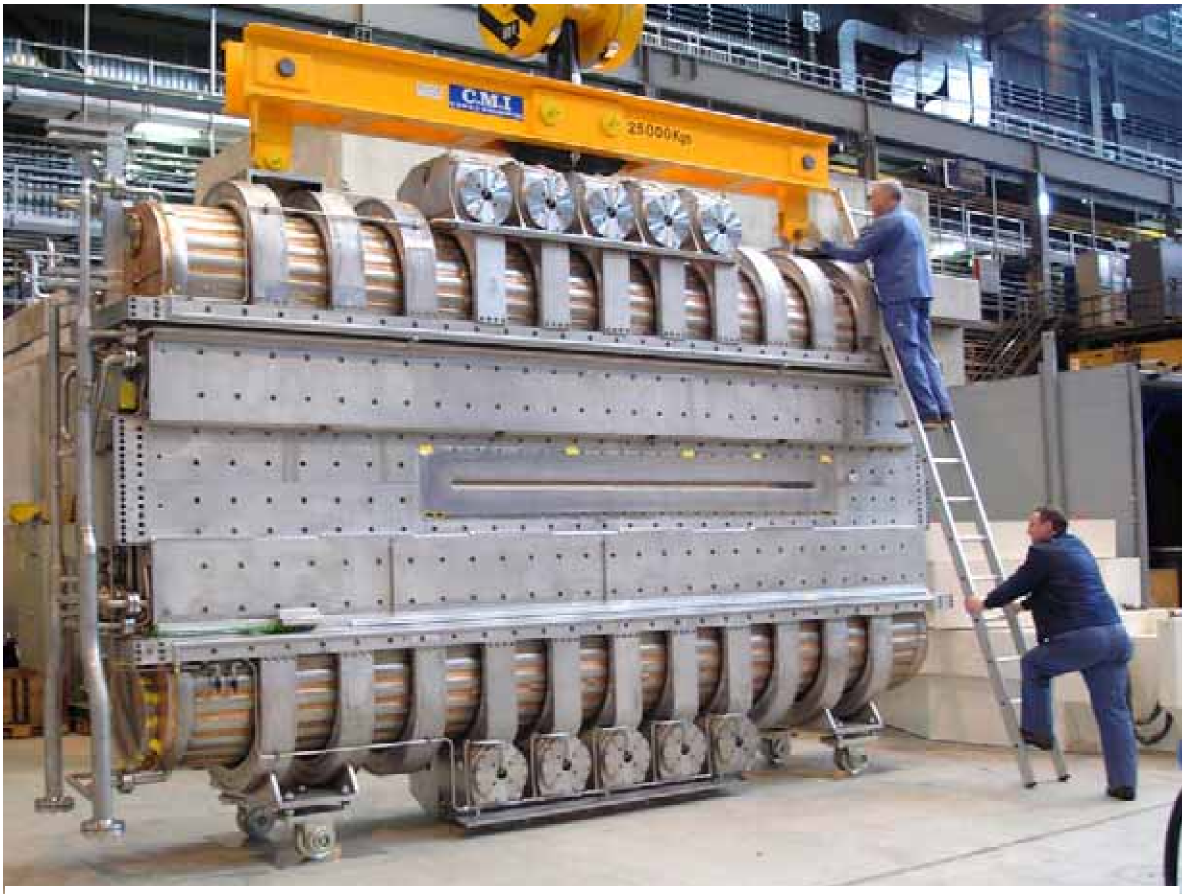


Figure 9: Completed cavity in the experimental hall at PSI.
f_{res}=50.6 MHz, V_{acc}>1 MV, $P_{diss,nom}$=500 kW, $\Delta f_{tun.}$=540 kHz, R_{sh}=1.5MΩ, cooling water flow=34 m^3/h, $p_{vac}=10^{-6}$ mbar, leak rate<10^{-6} mbar l/sec, cavity wall: Cu-OFHC, support structure: 316LN, weight:25000 kg, dimension 5.6x3.9x0.95 m

Simulation/Measurements

A coupled field analysis, thermal/structural/RF, is used to predict the frequency drift of the cavity for the different load cases [7]. The simulation is entirely carried out within the finite element program ANSYS.

The good agreement of the measured Q-value with calculation indicates that the surface condition of the RF wall is satisfactory and that mechanical polishing only is sufficient.

Table 4: Comparison simulation/measurements

Case		Simulation	Measured
Cavity ventilated	f	51.040 MHz T_{amb} 25°C	51.105 MHz T_{amb} 18°C
	Q_o	46050	45130
Cavity pumped	f	50.451 MHz T_{amb} 25°C p_{amb} 1000 mbar	50.472 MHz T_{amb} 18°C p_{amb} 975 mbar
	Q_o	45080	44284
	$\Delta f_{tun.}$	536 kHz	548 kHz
	Δf_{drift}	-96 kHz ΔP_{RF} 500 kW T_{amb} 25°C	-64 kHz ΔP_{RF} 500 kW T_{amb} 31°C

The accuracy of the simulation and the precision of the mechanical fabrication made it possible to hit the target frequency around 50.4 MHz right away.

Test Installation in the cyclotron

During the shutdown 2003, a test installation of the prototype in the ring cyclotron was carried out to see if:

- the deflection of the cavity foundation is OK.
- the cavity would fit into the mounting space.
- the inflatable vacuum seals can compensate the large deflection of the cavity (10 mm) during pump down.
- the RF properties (f,Q) are as expected and the RF-leakage into the beam chamber is sufficiently small.

The test installation did not reveal any problem.

Power Tests

To verify the performance of the cavity, a site acceptance test was carried out in the test bed at PSI. It consisted of a 24 h power run dissipating the nominal 500 kW of RF power. Fig. 10 shows the gap voltage and the dissipated thermal power in the cavity.

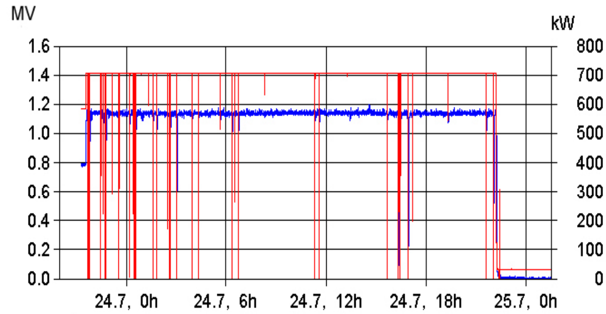


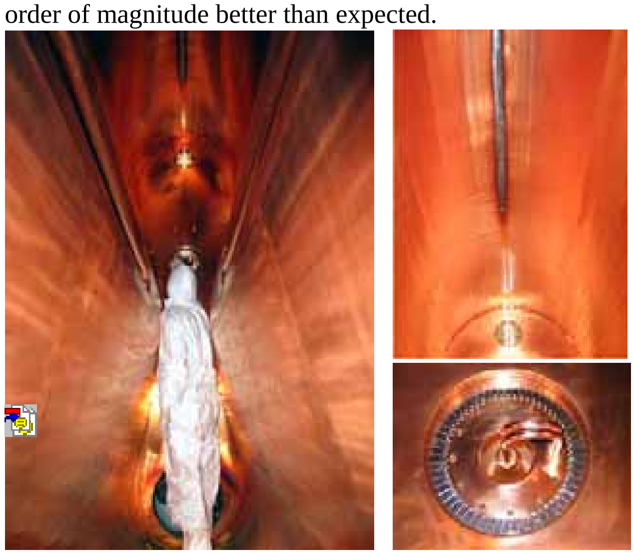
Figure 10: Gap voltage (R_{sh}=1.7MΩ) and dissipated power (570 kW) during the site acceptance test.

The sporadic loss of gap voltage is caused by RF-breakdowns in the cavity. It was possible to run at these voltage levels with virtually no conditioning.

The hydraulic pressure of the cavity tuning system varied between 28.5 bar and 36.5 bar (the maximum is 70 bar) to compensate a drift of the resonance frequency of 64 kHz, which is better than expected. The discrepancy can be explained by the boundary conditions in the simulation, which deviate from the test conditions, such as ambient air temperature and cooling water temperature.

The measured temperatures of the cavity wall were within the expected range and reached a maximum of 65 °C. The highest temperature of 92 °C was found at the stainless steel flange connecting the cavity to the vacuum pumping system. RF shorting bars, installed later, led to a reduced RF leakage and to a lower temperature.

After the 24h test the vacuum in the cavity, with turbo and cryogenic pumps running, reached 10^{-7} mbar, an order of magnitude better than expected.



No major problems occurred during the power tests. Besides some harmless black deposits, an inspection of the cavity interior revealed no faults.

Figure 11: Inspection after the site acceptance test.

Operational Experience

During shutdown 2004 the cavity was installed in the cyclotron definitively. Power tests confirmed that the cavity also works with the presence of the magnetic stray fields of the sector magnets. A harmless multipacting discharge could be observed only at very low RF power levels.

Since April 2004 the cavity runs in beam production mode, with a slightly higher accelerating voltage as compared to the aluminum cavities. Figure 12 shows voltage readings (sampling interval of 60 sec) of all four cavities during July 2004. Superimposed is the beam current (sampling interval of 10 sec). A careful inspection of transient recorder measurements shows that during this period 8 dropouts with duration below 500 μsec and 2 non-recovering trips (not visible in Fig. 12) occurred. The short dropouts are not recognized by the beam interlock system whereas the trips occurring during RF switch-on are not recognized as beam trips. As a conclusion the new cavity runs at least as stable as the old ones.

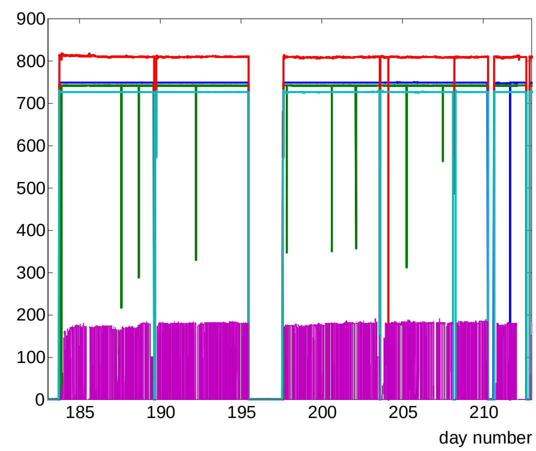


Figure 12: Cavity voltages (in kV) during July 2004. New cavity: 810 kV, old cavities: ~740 kV). Beam current (in μA/10)

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