EXPERIENCE WITH A BROADBAND VITROPERM-FILLED CAVITY AT THE SYNCHROTRON COSY

A. Schnase, U. Bechstedt, J. Dietrich, F.-J. Etzkorn, R. Gebel, K. Henn, A. Lehrach, B. Lorentz, R. Maier, D. Prasuhn, H. Schneider, R. Stassen, H. Stockhorst, R. Toelle, Forschungszentrum Jülich GmbH, Postfach 1913, D-52425 Jülich, Germany

Abstract

At the Cooler Synchrotron COSY, a broadband cavity using the magnetic alloy VitroPerm replaced the existing ferrite cavity in routine operation for more than 8400 hours. The frequency range of the VitroPerm cavity covers 0.4 to 8 MHz without tuning loop. This allows the simultaneous combination of the fundamental together with higher harmonics during the acceleration cycle. Compared to a sine-wave for acceleration, the combination of fundamental and 2nd harmonic improves capture after injection, and the number of particles in flat top of COSY was found to be increased by about 20 percent.

The accelerator COSY allows super-cycles and runs more than 7000 hours per year. Therefore, the control and synthesis of the waveforms and the preparation of the ramping functions needs to support this. To ensure reliable operation, the control of the 7 signal processors is based on a VME system running under the operating system Linux.

1 ROUTINE OPERATION

After installation into the COSY Ring [1], the VitroPerm cavity was driven by 4 combined transistor amplifiers with 500 W each. This was sufficient to demonstrate the possibilities higher harmonics offer at injection, but the power limitation did not allow generating higher harmonic waveforms for acceleration. In 2001 a push-pull tube amplifier was completed with a thyristor controlled anode power supply which can deliver 10 A at 10 kV. Since then the cavity was operated with this tube amplifier [2] and until now more than 8400 hours of operation were obtained. Like COSY [3] the cavity is running almost day and night without much interruption. One problem recently happened: the anode power supply had a failure in the motor driven main switch, because it was not operated for a long time. The electronic circuits were not affected, so repair was straightforward. With the cavity itself we could not observe any difficulties. No service was necessary until now. There was some fear that corrosion of the cores may happen, but it seems the coating of the VitroPerm cores is suitable to protect against such problems. In one element for watching the water flow, we saw some light yellow color, but we are not sure, if it is the plastic of the flow-meter itself, some undetected brass part in the water path of the heat-exchanger, or really some sign of corrosion.

Since one year the cooling water for is circulating in a closed circuit with a heat-exchanger against air and the water itself is clear. It seems the manufacturer of the cores made a good choice with the coating, which consists of thin glass fibres for a good adhesion between the epoxy resin, and the VitroPerm core, and a final painting with a polyurethane paint.

In the early phase of the testing of the cavity, we cooled it with cold water. The temperature was only 10 degrees, so we found that there is some water condensing on the outside of the cavity due to humidity. With the closed loop cooling with a heat exchanger against air, the average temperature is between 25 to 40 degrees, and therefore the condensation problem did not occur anymore.

The cavity is not connected to the main COSY cooling system. The initial reason was the fear of corrosion. Now this issue is less important, but as the cavity operates with 2 bar pressure, the connection to the main cooling system with 10 to 15 bar pressure does not promise advantages.

2 POWER AMPLIFIER SETUP

The tube amplifier uses 2 tubes TH 120 A in class A. The operation mode looks like push-pull, but there is only weak coupling between both cavity sides, due to the gap capacitance, which is less than 30 pF. This results in simple handling of higher harmonics at the expense of increased idling power requirement. The cavity impedance slightly more than 200 Ohm / side is matched to 200 Ohm coaxial transmission lines. The main ripple component of the 10 kV anode power supply is measured to be less than 50 Vpp at 300 Hz. The 50 and 100 Hz noise which results from AC heating of the tubes was reduced by carefully adjusting the symmetry condition of the filaments with respect to ground while observing the sidebands of a 500 kHz sine-wave at 200 Ohm in house made 1 kW RF attenuators with 50 ohm output impedance. Usually the amplitude of a RF system will reduce the amount of noise resulting from 50 Hz and higher, which can cross talk to the synchrotron frequency of the proton beam. So far, we only use a digital amplitude pattern, but no amplitude control loop, because the definition of the amplitude for a combination of harmonics is different from the usual case of a single sine-wave. We found the amplifier can be operated reproducible after a heat up time of 20 minutes after shutdown. There is no gap short relay, because the cavity does not react as a resonator. Machine studies with long flat-tops – either for stochastic cooling or for ultraslow extraction - have shown, that there is some noise from the 500 W transistor driver amplifiers. Therefore in flat-top the RF output of these drivers can be switched to a 50-Ohm load, while the control grid of the tubes is terminated. The RF signal at the gap is measured by permanently installed 1:1000 oscilloscope probes connected to a differential probe amplifier with 50 Ohm output. A quick check of the amplitude is possible by a diode detector. For the precise adjustment of amplitude and phase one needs to analyse the longitudinal beam shape as a function of time.

3 OPERATION EXAMPLES

The RF voltage signal for acceleration up to 3333 MeV/c and the corresponding longitudinal beam signal is shown in figures 1 and 2. For such a measurement, a digital real-time oscilloscope, which can store sequences of data, is indispensable.

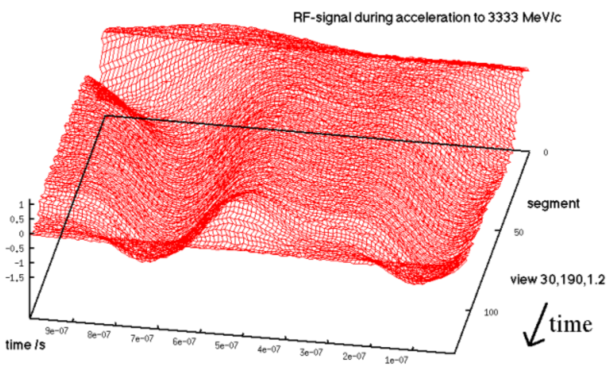

Figure 1: RF signal during acceleration to 3333 MeV/c

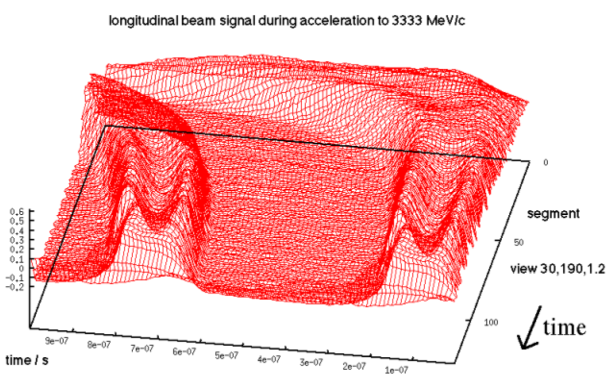

Figure 2: longitudinal beam signal during acceleration to 3333 MeV/c

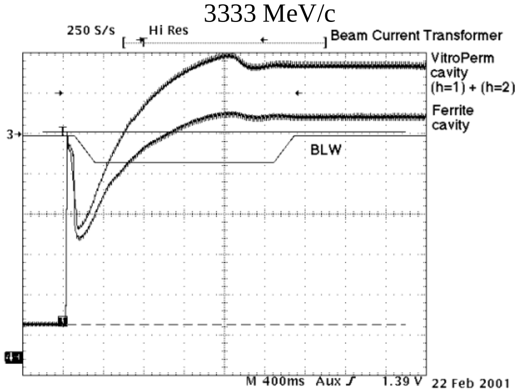

Figure 3: Improved injection with 2nd harmonic

Such data is very helpful to learn how to adjust the amplitude and phase of the 2nd harmonic with respect to the fundamental. Figure 3 compares the beam current for the cases with (h=1) only and (h=1) + (h=2). Figures 4a, b, and c show the bunching process after injection and the start of acceleration.

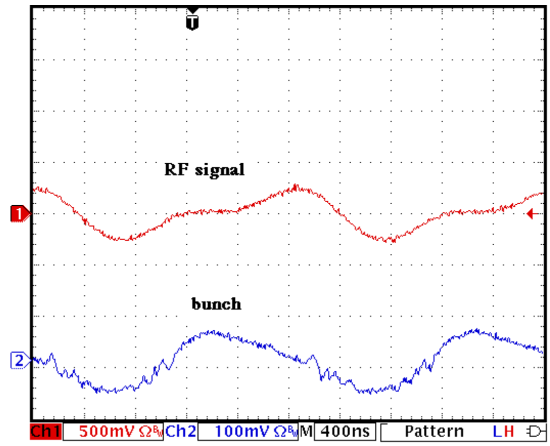

Figure 4a: 100 ms after injection

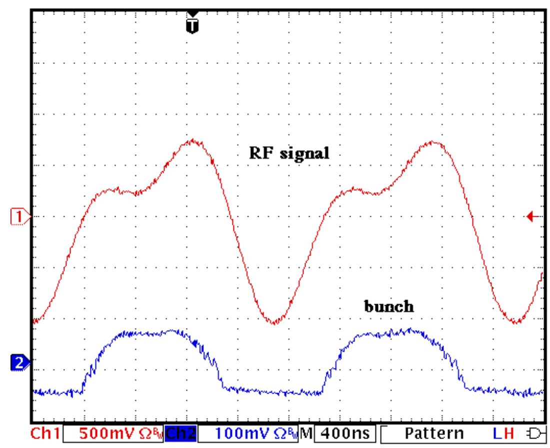

Figure 4b: 200 ms after injection

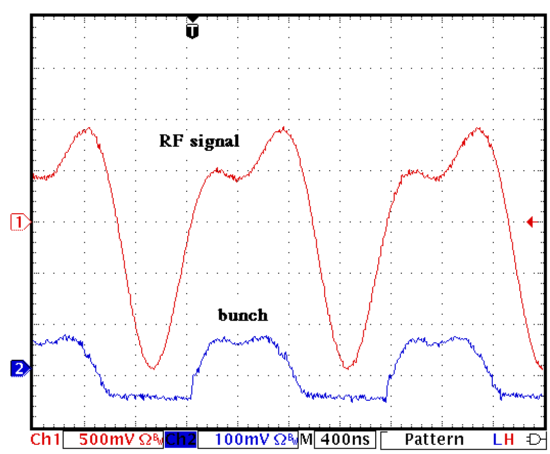

Figure 4c: 300 ms after injection. The blue curve is the longitudinal beam signal; the red one is the RF voltage.

The adjustment of the 2nd plus the 4th harmonic with respect to the fundamental is more difficult. Figure 5 shows that with the 4th harmonic, the longitudinal beam shape is improved.

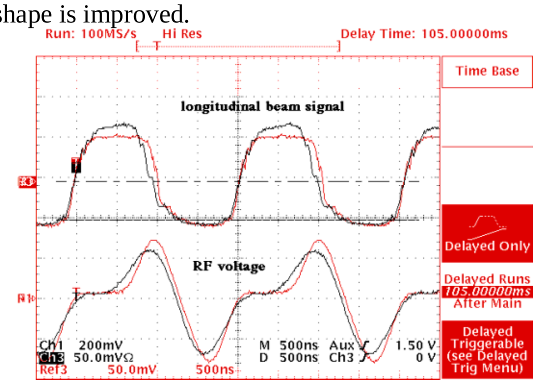

Figure 5: Effect of additional (h=4) component
Black: (h=1) + (h=2) Red: (h=1) + (h=2) + (h=4)
Beam (upper trace) and RF-Signal (lower trace) after bunching (at 100 ms). The longer flat region in the RF Signal generates a wider longitudinal Beam-Signal.

Figure 6a shows an example, where the beam is kept bunched during the flat-top for the internal EDDA experiment. With a sine-wave, synchrotron oscillations are observed. With the higher harmonics signal figure 6b shows that the dipole oscillation does not occur.

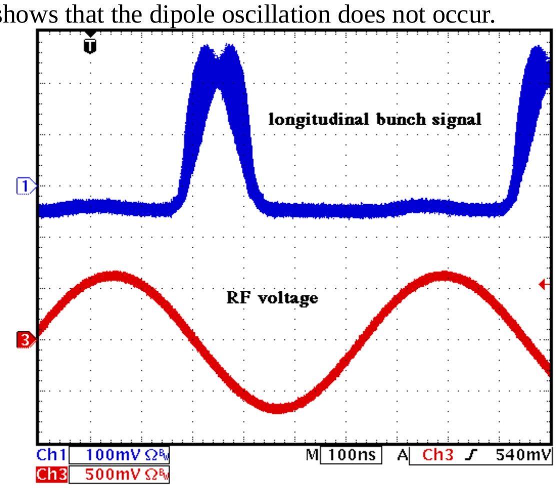

Figure 6a: Dipole oscillations with sine-wave

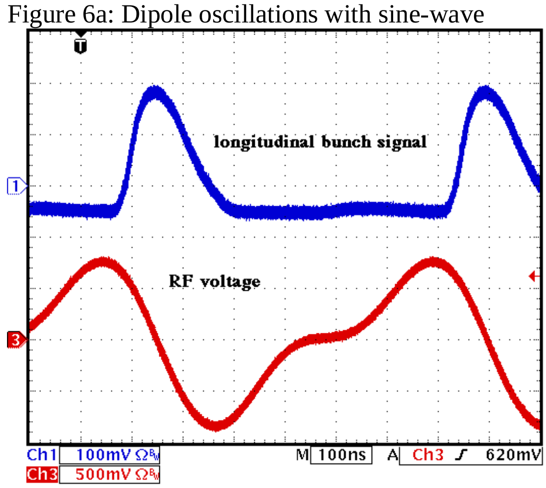

Figure 6b: Stable beam (blue) with harmonics (red)

4 SOFTWARE ISSUES

The cavity is operated without any loops. There is no amplitude loop, and no tuning loop. Therefore it is important to model the behaviour of the cavity in the software, which generates the patterns for the higher harmonics. Pre-programmed amplitude and phase patterns are sufficient to control fundamental and second harmonic amplitude and phase.

The adjustment of the 2nd harmonic with respect to the fundamental done by help of longitudinal beam shape measurements. The definition of amplitude for a sine-wave is simple. For higher harmonics the adjustment is done by looking at the longitudinal beam shape with an oscilloscope. A suitable criterion is the maximum voltage of the sum of harmonics seen by the beam. Therefore, it is an iterative process which needs software support.

First the amplitudes of (h=1) and (h=2) are adjusted to get the desired RF voltage shape. Then the phase of (h=2) is adjusted, so that beam is symmetric and not tilted to the left or right. The amplitudes are adjusted again, so that there a constant peak value during the linear momentum ramp, and that the beam pulse shape shows maximum flatness. We noticed, that the addition of (h=2) allows a lower (h=1) for same peak-peak voltage. Finally one has to adjust the phase again. 0.5-degree resolution is necessary.

Such a process takes some hours, but it was only necessary 3 times for different flat-top energies of COSY. Now this is pre-calculated in software.

With the harmonic (h=4) things become more difficult. 5 parameters need to be adjusted – and the solution will have more than 1 possible result.

Anyway, the choice of Linux for the system controller made it simple to talk to the 7 DSP boards for frequency and amplitude and phase for fundamental and 2 harmonics.

5 CONCLUSION

The VitroPerm cavity is used in daily operating at COSY, which means an up time of more than 7000 hours per year. Full remote operation is possible. In case of problems the ferrite cavity is still available as back up. Now there is a new field for machine studies that will be helpful to prepare for the change of the COSY-injector to a super-conducting LINAC. Also we can compare with future high intensity machines [3].

6 REFERENCES

[1] A. Schnase, et. al, ”Experience with a Broadband Cavity at COSY”, EPAC 2000, Wien.
[2] H. Stockhorst et. al, “Progress and developments at the Cooler Synchrotron COSY”, THPLE081, this conf.
[3] M. Yamamoto et. al, “Longitudinal Beam Dynamics in JKJ 3 GeV Synchrotron” , THPLE005, this conf.