EXPERIENCE WITH THE 208 MHZ AND 52 MHZ RF SYSTEMS FOR THE HERA PROTON ACCELERATOR

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Abstract

The RF system for the HERA Proton Ring consists of four 208MHz systems and two 52 MHz systems. During injection three of the 208MHz system are at 70 kV and one system is at 196kV dephased. The 52 MHz systems are both at 70kV. During ramp the RF voltage and phases of all cavities follow a ramp table. At flat top at 920GeV both 52 MHz systems are at 50kV and three of the 208 MHz systems are at 190kV while the dephased system is reduced to 50kV. The typical beam current is 100mA in 180 bunches with a bunch separation of 96 ns. About one year before shutdown of HERA this presentation gives an review of about 17 years operation of the proton RF system. It is also an overview of the hardware including the beam loading compensation (fast feedback), the tuning system and the other components.

INTRODUCTION

Two different RF systems are installed because of the bucket matching between Petra and HERA during injection and compression of bunches during acceleration to 920 GeV. At the injection energy of 40 GeV the 208 MHz RF is set to a minimum voltage of 16kV (three cavities are set to 70kV and one is set to 196kV (180 degree dephased) and the RF buckets are mainly provided by the 52 MHz systems which are both set to 70 kV.

SYSTEM DESCRIPTION

The 52 MHz System

The HERA 52 MHz system was designed and built at the CRNL (Chalk River Nuclear Laboratories) [1]. It consists of two evacuated aluminum cavities with an independent RF transmitter for each cavity. The cavity resonance frequency is controlled by a coaxial $\lambda/4$ ferrite tuner. The RF drive signal of 52.034 MHz at 40 GeV and 52.048 MHz at 920 GeV is splitted and sent to the tunnel. Here it passes a low level RF crate containing an amplitude and phase module, fast feedback module, resonance controller module and several measurement circuits. The following amplifier chain consists of an exciter (150W solid state amplifier), 10 parallel operating 300W solid state broad-band driver amplifier modules and a final stage with a tetrode power tube (EIMAC 4CW50000). The Fast Feedback open loop gain is about 50. The whole RF system except the power supplies is installed in the tunnel. The whole control and interlock of the system is managed by an industrial computer. The connection to the DESY control system is done by a SEDAC interface and a standard PC with an ethernet card.

Improvements

Because of several water leakages and damages the final tube socket was changed to a better and simpler construction based on an industrial standard tube socket. Also some improvements have been made to the water connections.

The belt driven air blowers have been changed to a direct driven turbine blower.

The anode RF filter capacitors were improved by enlarging the thickness of the dielectrical kapton foil after several damages. By that the capacity was reduced from 8nF to about 3nF without any deterioration.

The higher order mode damping has been improved by optimizing the HOM antennas in the cavity [2].

The 208 MHz System

The 208 MHz system consists of four copper cavities with a RF transmitter for each cavity. The amplifier chain including the fast feedback module is located in the tunnel close to the cavity while the low level RF is in a control room about 200 m away. The main RF input signal (208.137 MHz at 40 GeV to 208.194 MHz at 920 GeV) is distributed to the four systems. The main signal path of each system contains a RF switch, a 180 deg phase module, different regulation modules for amplitude and phase and an optional feed forward module. Additional components are the tuner regulation with the local oscillator, the interlock systems and several measurement devices for cavity phase and amplitude.

The power amplifier chain in the tunnel contains a 600W semiconductor pre-driver, a 10kW driver with a tetrode (RS2026, made by THALES former SIEMENS) and the 60kW final amplifier with a tetrode (RS2058, made by THALES former SIEMENS).

The final stages have common power supplies for the anode (10kV) and the screen grid (1kV) voltages.

The cavity resonance is tuned by plunger tuners with a stepper motor. A signal from a pickup loop in the cavity is compared with the phase of the forward signal delivered from a directional coupler between the final transmitter and the cavity. The output signal of the phase detector acts to the motor and drives the plunger tuner until there is resonance. As long as there is no RF in the cavity or the phase is not locked the tuner is set by the computer to an expected position calculated from the frequency and the cavity temperature. This ensures the system to lock immediately after switching to RF ON. A simplified tuner loop scheme is shown in figure 1.

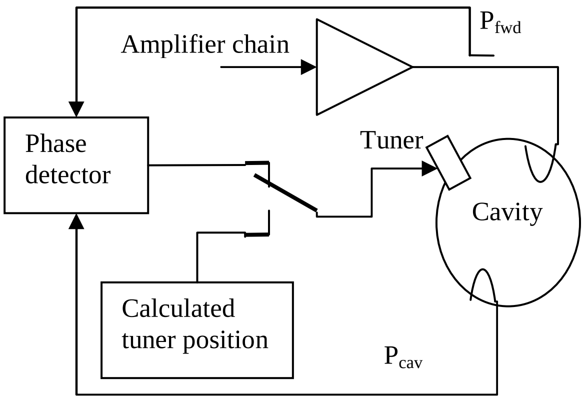

Figure 1: Tuner loop scheme of the 208 MHz system

The cavity voltage and phase is set and kept constant by an amplitude and phase regulation module.

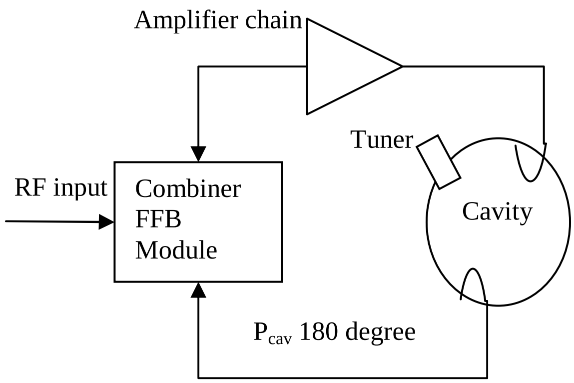

Figure 2: Fast Feedback scheme of the 208 MHz system

A fast feedback module in the tunnel reduces the noise of the cavity voltage and compensates the beam loading [2]. It combines a 180 deg shifted cavity signal with the main RF signal. The output signal of the combiner drives the amplifier chain (see Figure 2). The Fast Feedback open loop gain is about 100.

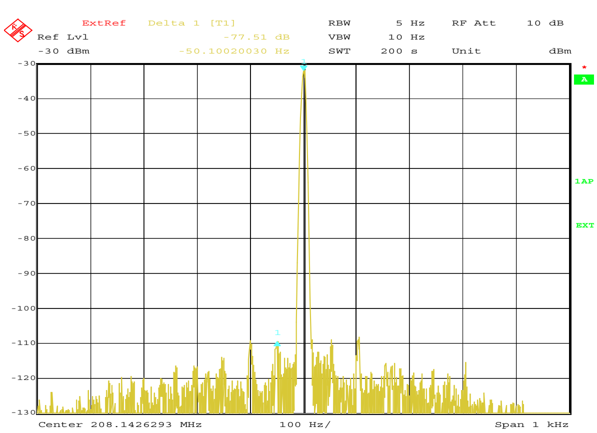

Figure 3: Spectrum of a 208 MHz Cavity with a center Frequency of 208.14 MHz and a span of 1 kHz

A typical spectrum of a 208 MHz cavity signal is shown in Figure 3. The difference between the carrier and 50 Hz modulations is >80 dB.

NORMAL OPERATION

After cycling the magnets of the HERA proton ring some parameters like energy, tunes, chromaticity etc. must be tuned. Therefore 10 bunches are injected into the 52 MHz buckets while the 208 MHz system is in a beam loading compensation mode, this means the amplifier chain including the fast feedback is turned on and the RF drive signal is turned off. For a luminosity run HERA is commonly filled with 180 bunches in three steps (3x60) and ramped up. During ramping the RF voltage of the 208 MHz cavities is increased and consequently the bunch length is reduced. At flat top (920GeV) both 52 MHz systems are set to 90 kV and three of the 208 MHz systems are set to 190 kV while the dephased system is reduced to 50 kV. All cavity voltages follow a ramp table (figure 4).

52 MHz System		208 MHz System		
Energy [GeV]	Sys. A+B [kV]	Energy [GeV]	Sys. A+B+C [kV]	Sys. D [kV]
40	140	40	210	-194
50	170	70	210	-130
60	180	80	210	-90
80	220	100	225	-50
200	220	300	390	-50
300	240	820	570	-50
800	240	920	570	-50
920	180			

Figure 4: Voltage Ramp table for the HERA RF system

The bunch length is changed from typical 2.5ns FWHM (Full Width Half Maximum) at injection to 1.4ns FWHM at flat top.

All cavity phases must be set correct to the beam and kept constant. Phase shifts between the systems according to the frequency change are corrected by a phase ramp table (figure 5).

Frequency [MHz]	52 MHz Sys. A [degree]	52 MHz Sys. B [degree]
52.034	0	0
52.048	13	17

Figure 5: Phase Ramp table:

Because of several trips of the 180 degree dephased 208 MHz system due to an locked off tuner during the ramp tuning had to be improved. In the old configuration the position was set back to the computed value (see figure 1) which did not consider the detuning effect of beam loading when the tuner locked off. A detuning correction factor had to be estimated. The detuning by the beam loading depends on different beam parameter such as current, bunch length, number of bunches etc. A further factor can be determined by the other still locked tuners by comparison of the computed position with the locked position. The difference in position is a value for the effect of beam loading. With this correction the unlocked tuner can be held at the correct position.

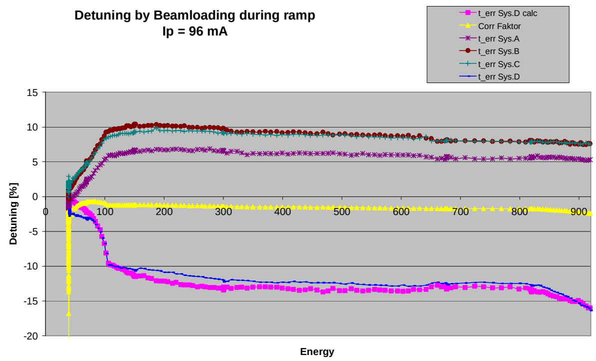

Figure 6: A typical ramp of 96 mA at HERA p. The graph shows the detuning by beam loading (change of tuner position in %). The upper three curves show the detuning of the three cavities which are in phase to the beam. The blue curve shows the detuning of the dephased cavity, while the pink curve represents the calculated position of the dephased cavity.

RELIABILITY

All vacuum tubes are being replaced regularly ca. every 30,000 h. Two EIMAC tubes of the 52 MHz transmitter failed unexpectedly with a short circuit between grid 1 and cathode. The same damage occurred also with two of the SIEMENS\THALES tubes of the 208 MHz final stage after one year runtime. Since the RF systems are now in operation for about 17 years failures of power supplies and other electronic components start to occur, e.g. of electrolyte capacitors, RF power transistors, and mechanical relays. The low level RF is still running with almost no damages. Up to now cavities including feed-through and mechanical tuner components never failed.

Tuning of parameters such as feedback gain and phase, intercavity phases, matching between the different transmitter stages, and calibration of the tuning system etc. had to be done very carefully.

A trip of the 208 MHz transmitter due to a beam loss with higher beam current (>80mA) is difficult to avoid because of transient effects. On the other hand the beam has to be dumped automatically to avoid damages by an unstable beam when the RF system fails. These two cases must to be distinguished. Although a transient recorder was installed for a better and faster diagnostic, sometimes error tracing requires access to the tunnel. Since this is not possible during beam operation, localization of errors is difficult to accomplish.

CONCLUSIONS

Although the RF system is in operation for many years it still fulfills all requirements. The reliability and performance was increased by several improvements of the system.

REFERECES

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