THE RADIO FREQUENCY SYSTEM FOR PROTONS IN HERA

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Abstract

HERA (1) is a large colliding beam facility for electrons and protons which is presently under construction at DESY in Hamburg. In this article the philosophy of the proton acceleration sheme, the associated radio frequency systems and their status are described. The protons are first accelerated to 50 MeV in a linear accelerator (2) and acceleration to 7.5 GeV/c, 40 GeV/c and 820 GeV/c takes place subsequently in the three synchrotrons DESY III, PETRA II and HERA respectively. Finally protons are stored in HERA at the maximum momentum of 820 GeV/c for periods of up to ten hours while they are brought into collision with a 35-40 GeV/c electron beam.

The circumferences of DESY III, PETRA II and HERA are in the ratio of 11 to 80 to 220, i.e. 317, 2304 and 6336 m respectively.

Proton Acceleration in the Rebuilt DESY III Synchrotron

The DESY III RF system operates at the harmonic number h=11. Therefore the frequency changes from 3.27 to 10.33 MHz during the acceleration time of 1.8 s . The DESY III RF cavity consists of an assembly of two quarter wavelength ferrite loaded resonators each with a ceramic gap. The bias current varies between 160 A and 2000 A during each acceleration cycle. The values of cavity Q and R/Q are 80 and 30 Ω. Up to 50 kW of RF power can be delivered to the cavity by a closely coupled RS 2058 CJ Siemens tetrode. Formerly this cavity was installed in the CERN PS, but it has now been made available to DESY. Installation in DESY III was completed in October 87.

During injection of the protons into DESY III, which takes about 33 μs correspon-ding to 10 revolutions, the RF voltage is as low as 500 V. Then, by raising the RF voltage to 6.5 kV, the protons are trapped into bunches of 28.8 m length. This value defines the final bunch spacing in HERA. The bunch phase space area of .072 eVs is determined by the Linac's relative momentum spread $dp/p = \pm 1.2\ 10^{-3}$. The maximum number of protons per bunch is limited to $1.02\ 10^{11}$ by space charge.

The RF voltage is raised adiabatically to 18 kV and the beam accelerated to 7.5 GeV/c. The resultant 2.8 metres long bunches are ejected below transition energy ($\Gamma_t=8.77$).

Proton Acceleration in PETRA II

In the PETRA ring there are two identical RF cavities tuned to the 400th harmonic. This corresponds to a frequency change from 51.64 to 52.03 MHz as the proton's momentum increases from 7.5 to 40 GeV/c. These cavities consist of cylinders of 2 m length with a diameter of one metre, which are loaded by an intermediate cylinder. Since only the beam-tube is evacuated, a cylinder made of low loss ceramic has been inserted into the gap. This RF system has been built at CRNL in Canada and is described in detail in (3). It was commissioned at DESY in May 88.

The maximum number of bunches is 11 in DESY III and 80 in PETRA II, so that with a DESY III cycle time of 3.6 s filling of PETRA will typically last 30 s. Injection occurs above transition ($\Gamma_t=6.55$). During the injection period the circumferential voltage has to be maintained at 50 kV for matching the RF bucket size to the afore mentioned bunch length of 2.8 m.

Beam-loading is most severe during injection when the PETRA ring is filled to 50%. The maximum effective beam current is .3 A. With a loaded cavity shunt impedance of .3 MΩ, beam loading will initially change the cavity gap voltage at a rate of 550 volts per μs and its phase by typically 11 degrees per μs. These deviations may be compensated by a feedbackloop of open loop gain 50, which is incorporated in the RF amplifier chain. A supplementary feedforward system is under consideration.

After filling, acceleration takes place at a constant rate of .3 GeV/c/s which is limited by eddy currents in the aluminum vacuum chamber. With a stable phase of 178° the acceleration time will be 120 s. The cavity voltages are subsequently raised to 93 kV for adiabatic compression of the bunches to the length of 2.16 m. In the meantime the bunch phase space area is assumed to have grown to .14 eVs due to intra-beam scattering and imperfections of synchronization during transfer from one machine to the other one.

Proton Injection, Acceleration and Storage in HERA

Injection of the 40 GeV/c protons in HERA is well above the transition energy since here $\Gamma_t=27.6$. There are two RF systems in the HERA p-ring. One operates at lower frequency because it has to handle the 2.16 m bunches arriving from PETRA. A second system operates at higher frequency to assure a final bunch length of 60 cm. The harmonic number of any RF system in HERA must be a multiple of 220, the maximum number of bunches. For the first RF system h = 1100 was chosen. Therefore the RF frequency is the same as in PETRA, namely 52.03 MHz. The second system operates at h = 4400, i. e. 208.13 MHz at 40 GeV/c and 208.19 MHz at 820 GeV/c.

At least three PETRA fillings are needed to completely fill HERA. During this time, which will typically last 20 minutes, only the 52.03 MHz system will be active. At this frequency, a total RF voltage of 26.4 kV is required to match the bunch's phase space which is assumed to have increased to .175 eVs by now. All the beam loading associated with a partially filled ring has to be handled by this system. As in PETRA, a feedbackloop of gain 50, possibly supported by a feedforward system, is considered adequate for beam loading compensation. This system is presently being built at CRNL in Canada and is described in more detail in (4). There will be two cavities similar to the ones used for PETRA II, but they will be entirely evacuated. Commissioning at DESY should take place in March 89.

During the injection period the Rf voltage of the 208 MHz system ideally should be kept at zero volts. This is supported by the choice of the bunch length of 2.16 m at injection, which is the length of minimum (3%) harmonic content at 208 MHz.

Injection is succeeded by a first compression phase where the total 52 MHz RF voltage is raised to 280 kV which reduces the bunch length to 1.15 m. In the second phase, where the 208 MHz voltage is raised adiabatically to its maximum total value of 2.4 MV, the bunches are adiabatically compressed to 58 cm.

For the four 208 MHz cavities, which have a loaded shunt impedance of about 4 MΩ each (see below) beam loading is only relevant during compression. At the end of the first compression phase, the 208 MHz harmonic content of the beam current is 50 %, whereas, for the final bunch length, it will have increased almost to the maximum possible value of 300 mA for the maximum dc beam current of 150 mA. Amplifier peak current and plate dissipation capabilities necessary to compensate beam-loading until the cavity voltage has reached about 200 kV are well within the specified limits. As the cavity voltages increase above this value, detuning by the mechanical plungers starts. Detuning of about 8 kHz is necessary for the cavity impedance to appear real to the transmitter under worst case conditions.

Acceleration of the protons up to the final momentum of 820 GeV/c at a stable phase of 179° will last 10 minutes. As in PETRA II, the acceleration rate of 1.3 GeV/c/s is limited by eddy currents in the copper plated vacuum chambers.

Description and Status of 208 MHz Hardware

There will be four 208 MHz cavities installed in the HERA ring, and to each cavity a transmitter with a Siemens tetrode RS 2058 CJ is closely coupled by a coaxial line of electrical length $\lambda/2$. These cavities and the transmitters strongly resemble the 200 MHz ones which are being installed in the CERN SPS ring for preacceleration of leptons to be injected into LEP. The dimensions of the basic cavity body are actually exactly the same as of the CERN cavities (5) which have a diameter of one metre and a width of .66 m. In order to achieve the desired frequency shift of 8 MHz, the nose cones have been slightly modified so that the gap width is increased by some 56 mm to 343 mm. The cavities were manufactured by brazing the two copper half shells, premachined to match each other to a precision of 0.05 mm, in a vacuum oven. Simultaneously, the nose cones and several flanges were brazed to the main cavity body. In total, five cavities had been ordered, the fifth one for laboratory use. By January 88 all of them had passed the acceptance tests and had been delivered to DESY. Measured values of R/Q = 170 and Q close to 54000 agree well with calculations.

The five associated transmitters have been built by the proton RF group at DESY. With the exception of the transmitter resonator volume, which has been slightly decreased to raise the resonance frequency by 8 MHz, these transmitters are also copies of the 200 MHz CERN transmitter, which is described in (6). In Feb. 88 the first 208 MHz transmitter cavity system was operational at DESY. By April all five transmitters had delivered the maximum RF power of 60 kW to a water load. By the middle of this year all the cavites will be conditioned to maximum power. Under normal operation only 25 kW are needed.

At present an old TV transmitter is used as a driver amplifier. Delivery of five commercially made driver chains is expected in May 88. Each of these will consist of a solid state 55 dB gain pre-amplifier followed by a Siemens RS 2026 tetrode. For an input power of 1.6 mW the driver will deliver its maximum output power of 10 kW. Only 2 kW are needed to drive the final amplifier to its maximum output of 60 kW. During the compression phase, where high tube current is required for beam loading compensation, up to 3.5 kW of driving power will be necessary.

By the end of this year all four cavities together with their complete amplifier chains should be installed in the HERA tunnel.

Development of slow amplitude and phase regulations, with the aim of reducing the noise in the frequency spectrum in the range of two kHz around the fundamental frequency to about -100 dB/Hz, are in progress. For initial beam loading compensation, a fast feedbackloop of gain 100, possibly in combination with a feedforward system, is being built. A combined electrically and magnetically coupled antenna for damping higher-order-modes is also being developed. So far, for frequencies below one GHz, most of the modes have been damped to shunt impedances less than 7 kΩ.

Summary

The DESY III and PETRA II RF systems have been installed. The 208 MHz cavities and transmitters are operational. Installation in the HERA tunnel will be finished by the end of this year. Development of low power electronics is in progress. The complete HERA 52 MHz system will be delivered to DESY in March 89.

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References

(1) The HERA Project, this conference
(2) Project Study for the 50 MeV HERA Linac, Editor U. Timm, DESY HERA 84-12
(3) W. Funk, this conference
(4) W. Funk, this conference
(5) Study of the Mechanical Design of 200 MHz Single Cell Cavities for Application in the SPS
G. Rogner, CERN/SPS/80-14 (SME)
(6) RF Power Amplifier for the CERN SPS Operating as LEP Injector
W. Herdrich, H. P. Kindermann, CERN SPS/85-32 (ARF)