The Radiofrequency System for the PETRA Storage Ring

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"DIE VERANTWORTUNG FÜR DEN INHALT
DIESES INTERNEN BERICHTES LIEGT
AUSSCHLIESSLICH BEIM VERFASSER."
Introduction

The radiofrequency installation for the 19 GeV electron-positron colliding beam storage ring PETRA (1) is large compared with the accelerating systems of the DESY synchrotron and the DORIS storage ring (2). Therefore it was necessary to work out a design with high efficiency, low cost components. Many of these components were developed and constructed in the DESY laboratories and partly fabricated in the DESY workshops.

In this paper the radiofrequency system and the main components are described and the parameter are presented.

Choice of frequency

When the design work for the PETRA storage ring was started the frequency of the accelerating system had to be fixed. Discussions and calculations to find the optimum frequency took into consideration many different aspects of the problem. The desired long bunch length, low synchrotron frequency, large synchrotrons phase angle, large stored energy per cell and low parasitic mode losses (3) favour a low frequency. The maximum available shunt impedance for a given installation length, low components costs and small dimensions of the ring tunnel favour a high frequency. Also high efficiency radiofrequency amplifiers at economic prices should be available. It was shown, that there is a flat optimum in the frequency range between 300 MHz and 700 MHz. Since the 7 GeV synchrotron and the DORIS storage ring are operated at 500 MHz and many components and test facilities were available at this frequency, it was decided to use 500 MHz also for the PETRA storage ring. In this way it was possible to shorten the time schedule for development, fabrication and installation of the rf-system.

General description of the system

The accelerating system is installed in two of the four long straight sections of the PETRA ring tunnel (fig. 1). In each of these 90 m long sections there is space to install 32 accelerating structures. The rf-power
is produced by klystron amplifiers (4) housed in four transmitter halls, located close to the ring tunnel. Two of these halls also contain the air- and water-cooling equipment and the power supplies of the ion getter pumps for the adjoining rf-sections. The high voltage power supplies for the klystron amplifiers are constructed as outdoor stations. The power of the two klystrons of each transmitter is combined by a matched magic T and fed into the accelerating structures via a WR 1800 wave-guide system (fig. 2). A circulator is installed to decouple the power source and the cavities. In the transmitter halls are also housed the modulators to control the output power of the klystrons and the racks, which contain the equipment needed to control the klystron amplifier, the accelerating cavities and the high voltage power supplies as well as the rf-interlock systems and the Sedac-modules for computer control of the rf-system (5).

In the first installation period only 32 of the total 64 accelerating cavities are installed. By operating the four amplifiers at the full power of 4.4 MW maximum attainable particle energy is 17.5 GeV.

Parameter and components

PETRA is designed to operate in the energy range from 5 GeV to 17 GeV with 32 accelerating structures and up to 19 GeV with 64 cavities installed. The required circumferential peak accelerating voltage and the maximum synchronous phase angle for a quantum lifetime of $10^5$ s is shown in figure 3 as a function of energy. The rf-power dissipated in the accelerating structures with 32 or 64 cavities installed, and the radiated beam power at a circulating beam current of 10 mA is plotted versus energy in figure 4.

The injection of electrons and positrons into PETRA is done via the DESY synchrotron in the energy range between 6 GeV and 7 GeV. After intensity accumulation a ramping up to the operating energy is necessary. Due to the strong increase of the radiation loss the rf-power has to be raised over a range of 20 dB by that time.

When the rf-power is varied, the phase of the klystron output power has to be kept constant. This is done by a control loop comparing the phase of the
drive signal with that of the output signal of the klystron amplifier and tuning the deviation to zero by an electronic phase shifter (fig. 5).

The high power klystron is a special development (6) with fixed frequency and high gain. It is operated in a vertical position with the collector down. Four cavities are tuned to the fundamental frequency, and to increase the efficiency, an additional cavity, operated at the second harmonic, is incorporated. The beam focussing is done by solenoid coils. Collector, body and metal parts of the rf-window are cooled by water, the cathode-area and the output window by forced air. The klystron is driven in saturated operation using an AGC-output controlled transistorized amplifier. The control of output power is done by means of a modulating anode, located between the cathode and the body. The main klystron data are given in fig.6. The output power is varied by one triode-modulator, acting on the modulating anodes of both klystrons. The grid supply of the modulator is placed at high voltage potential. It is driven by a pulse generator via glass fibre optics and a frequency-voltage converter. The control circuit of the klystron amplifier is given in figure 7. It shows the amplitude modulator, a loop which keeps the klystron phase constant and an additional loop used for stabilizing the phase of the accelerator voltage at the corresponding cavities. The output power of the amplifier is controlled by a loop, comparing the amplitude of a precisely adjusted directional coupler in the wave-guide line and a reference signal, related to the power level. The tuning of the reference voltage can be done either locally in the transmitter hall or by computer in the PETRA control room.

The rf-power is distributed to the cavities in the ring tunnel via a WR 1800 wave-guide system (fig. 8). For decoupling of the adjacent cavities due to beam induced signals the power splitting is done by hybrids, matched to coaxial water loads at the differential ports. A power reflection to the klystrons is prevented by a high power circulator (fig. 9).

The accelerating cavities are inductively coupled five cell structures (7), with a shunt impedance of $R_p = \frac{\hat{U}^2}{2P_c} = 12.3 \, \text{M} \Omega/\text{m}$ and an unloaded quality factor of $Q_o = 30.000$ (fig. 10). The resonant frequency is tuned by two
inductively acting plungers and the power is coupled into the centre cell via a coaxial rf-window. The frequency control of the cavity required because of beam loading and thermal effects is done by comparing the phase of a cavity pick up loop signal and the forward signal of the directional coupler, connected to the wave-guide coaxial transition. An additional balance loop ensures a symmetrical energy distribution along the structure (fig. 11). The cavity control equipment (8) is located directly below the cavity in the ring tunnel to avoid long coaxial cables.

A view of one of the four transmitter halls is given in figure 12, showing the two klystrons, the power combining magic T and the tubing for air- and water-cooling. Figure 13 shows the rf-installation in the PETRA tunnel. Aluminium wave-guides feed the rf-power via wave-guide coaxial transitions into the accelerating structures. The frequency control equipment is housed in a lead shielded rack below the corresponding structure.

The parameter of the two periods of cavity installation are given in figure 14.

References

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Fig. 1: Location of the rf-installation in the PETRA ring tunnel
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Principle arrangement of one of the four PETRA rf-sections. Two klystrons, 550 KW\textsubscript{CW} power each, feeding 8 resp. 16 cavities via a WR 1800 wave-guide power distribution system.

Fig. 2: Principle arrangement of one of the four PETRA rf-sections. Two klystrons, 550 KW\textsubscript{CW} power each, feeding 8 resp. 16 cavities via a WR 1800 wave-guide power distribution system.
Fig. 3: Rf-parameter. Circumferential peak accelerating voltage ($\hat{U}_c$), energy loss per turn ($U_0$) and maximum synchronous phase angle ($\phi_s$) for a quantum life time of $10^5$ s, versus particle energy
Fig. 4: Rf-parameter. Power dissipation in the accelerating structures with 32 cavities ($P_{c32}$) and 64 cavities ($P_{c64}$) installed and the radiated beam power at a circulating beam current of 10 mA ($P_b/10$ mA), versus particle energy.
Fig. 5: Principle arrangement of the PETRA klystron amplifier

Fixed frequency, narrow band, 500 MHz
CW-operation
RF-power controlled by means of a modulating anode
Solenoid focusing
4 cavities for fundamental frequency
1 second harmonic cavity
Mounting position vertical, collector down

Frequency \( f = 499.65 \text{ MHz} \)
Bandwidth (1db) \( b = 2 \text{ MHz} \)
Gain \( g = 40 \text{ db} \)
Beam-voltage \( U_K = -58 \text{ kV} \)
Power output (VSWR \( \leq 1:1 \)) \( P_o \geq 500 \text{ kW} \)
with an efficiency of \( \eta \geq 60 \% \)
Power output (VSWR \( \leq 1:1 \)) \( P_o \geq 570 \text{ kW} \)
with an efficiency of \( \eta \geq 52 \% \)

Fig. 6: PETRA klystron data
Basic Circuit Diagram of PETRA 500 MHz Transmitter

Fig. 7: Block diagram of the control equipment of the PETRA klystron amplifier
Fig. 7: Block diagram of the control equipment of the PETRA klystron amplifier
Fig. 8: PETRA wave-guide distribution system
(1/4 of the first installation)

Frequency \[ F = 500 \pm 2 \text{ MHz} \]
Forward power up to \[ P_p = 1.2 \text{ MW} \]
Reserve power up to \[ P_r = 0.3 \text{ MW} \]
Insertion loss \[ \alpha \leq 0.3 \text{ db} \]
Insertion loss at full power \[ \alpha < 0.2 \text{ db} \]
Isolation \[ i \geq 20 \text{ db} \]
Input standing wave ratio WSWR \[ > 1.1 : 1 \]

Fig. 9: Data of the circulator used in the PETRA rf-power distribution system
Fig. 8: PETRA wave-guide distribution system
(1/4 of the first installation)

Frequency \( F = 500 \pm 2 \) MHz
Forward power up to \( P_p = 1.2 \) MW
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Fig. 9: Data of the circulator used in the PETRA rf-power distribution system
Fig. 10: PETRA accelerating structure
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Fig. 11: Scheme of the PETRA cavity control
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Fig. 13: One of the four PETRA rf-sections

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Fig. 14: Parameter of the PETRA rf-system
Fig. 13: One of the four PETRA rf-sections

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