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THE RADIOFREQUENCY-SYSTEMS OF PIA

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Abstract

To decrease the filling-time of positrons into PETRA single bunches of high intensity must be delivered from the DESY-Synchrotron. Therefore the linac injects positrons into an intermediate storage ring PIA, where the particles have to be accumulated and compressed in bunch-length to match the DESY-bucket. A two cavity system, operating on different frequencies was developed and shall be described here. One of these cavities, resonating at the low frequency of 10.4 MHz needs a very strong capacitive load of about 680 pF to keep it at a small volume. This capacity is achieved by coaxial rings, welded to the inner conductor of the resonator. The second cavity resonates at 125 MHz and operates on a pulsed mode for the final bunch compression. It is a reentrant coaxial resonator with a high shunt impedance. During the injection into the PIA-ring the high Q-value must be loaded down by a PIN-switch, to avoid selfbunching into different buckets.

Introduction

For the positron-injection into PETRA an intermediate storage of positrons is necessary, because only one of the 528 buckets of the DESY synchrotron can be used for injection into PETRA after accelerating up to an energy of 7 GeV. Since the intensity of the positron linac is about 2×10^7 particles per 2 ns bucket length, 2×10^5 pulses were required for accumulation of 4×10^{12} positrons in PETRA. With maximum injection repetition of 10 Hz the total positron filling of PETRA would take 6 hours. In 1976 it was proposed to install a small 450 MeV storage ring between the positron linac and the synchrotron as a positron intensity accumulator (PIA) [2]. The final design of PIA was completed in 1977 [3]. Two radiofrequency systems[4, 5] are used in this ring. One of the rf-cavities is operated at 10.4 MHz (first harmonic). At least 150 of the injected 3 GHz linac bunches will be captured and damped down to a bunch length of about 80 cm. After accumulation of about 15 mA circulating current, the second cavity operated at 125 MHz (12th harmonic) is switched on and it compresses the bunch to a length of nearly 22 cm, so that the bunch can be accepted by the synchrotron. The radiofrequency systems for PIA are described in this paper.

Description and Design of the System

A peak voltage of about 25 kV is necessary for the cw-driven 10.4 MHz system. The limited installation space in the ring of 1800 mm length and 500 mm diameter made it necessary to develop a strong capacitively loaded coaxial resonator (fig. 1), with rather low shunt impedance and high power dissipation. For reasons of low cost and easy production it is made out of aluminium. The capacitive load of about 680 pF is achieved by coaxial rings welded to the inner conductors of the resonator. The impedance was calculated to be $R_p/Q_o = 22.4\ \Omega$. A shunt impedance of $R_p=\hat{U}^2/2P_c=$ 59.6 kΩ was assumed with an unloaded quality factor of Q_o=2660, not taking into account the losses of the input coupler, tuning plungers and contact areas. An unloaded Q-value of 1910 and a shunt impedance of 43 kΩ was measured. The tuning of the cavity frequency is done by two inductively acting plungers similar to those used at the PETRA cavity[6]. Also the equipment to control the frequency in the presence of beam loading and thermal effects is similar to the PETRA development[7]. For a peak voltage of 25 kV the rf-power dissipation in the cavity walls is 7.2 kW and much higher than the radiation loss of 57 W for 15 mA circulating current.

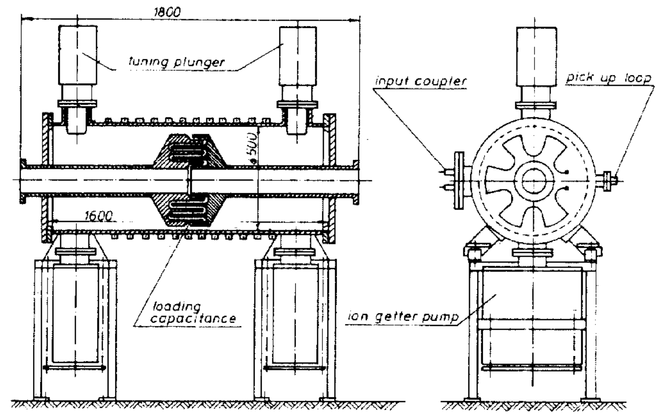

Fig. 1: Principle arrangement of the 10.4 MHz PIA - cavity

The power is supplied by a 10 kW beam power tetrode. The 125 MHz system for compressing the bunch to the final length of 22 cm is pulsed with a duty cycle of about 16 % and produces a voltage of 22 - 25 kV. The admitted space between vacuum flanges to install the cavity is 800 mm. A reentrant coaxial resonator was developed as shown in figure 2.

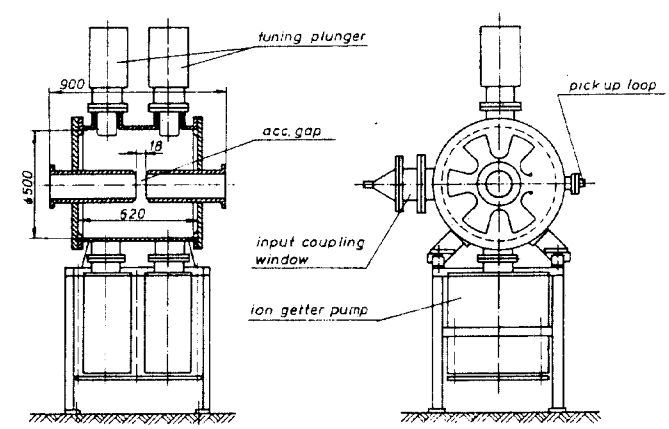

Fig. 2: Principle arrangement of the 125 MHz PIA - cavity

It is fabricated from aluminium, too, using parts constructed for the 10.4 MHz cavity. For frequency control the same inductive acting plungers and a similar electronic equipment is used as for the 10.4 MHz-cavity. The impedance was calculated to be R_p/Q_o=106.6 Ω and the unloaded quality factor should be Q_o= 10 600. So

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the shunt impedance is $R_p = Q^2/2P_c = 1.13$ MΩ. During injection of positrons into the PIA-ring, the high quality of the 125 MHz-cavity must be loaded down to a Q-value of about 500 to prevent selfbunching into different buckets. This is done by a coaxial line which is inductively coupled to the cavity and loaded with a resistor. To unload the line when the amplifier is pulsed, a PIN-switch short-circuits the loading line a quarter-wave length away from the coupling loop (fig. 3). The PIN-switch is driven by the same pulse-device which acts on the amplitude modulator of the amplifier. The rf-power is gained by a 1.5 kW-triode amplifier.

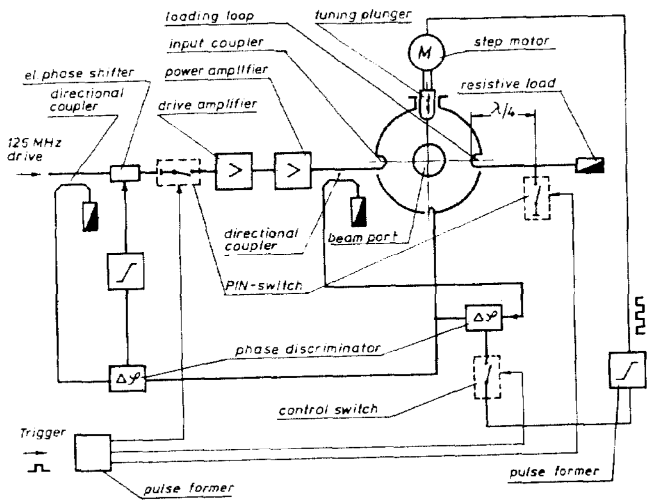

Fig. 3: Principle lay out of the 125 MHz PIA rf-system

Construction and Test of the Components

The frequency tuning and control of the cavities is done with devices, developed for PETRA and modified for this application. DORIS-coaxial windows with modified coupling hooks are installed for power input and Q-damping of the 125 MHz-cavity. Also the pick-up loops for phase- and amplitude-control are similar to those used in PETRA and DORIS. The cavities are fabricated from an aluminium alloy with 3 % magnesium, having a conductivity of 20 x $10^{-4}\Omega^{-1}cm^{-1}$. The parts are joined mainly with electron beam welding. The DEPI welding technique[8], which has been developed at DESY for the PETRA vacuum system, was used to weld stainless steel flanges to the aluminium cavities. The endplates of the cavities, supporting the inner conductors, are screwed to the cylindrical outer conductors by use of a "Helicoflex" metallic vacuum gasket. For water cooling of the cavities rectangular aluminium pipes are welded on the endplates and the outer cylinders. Channels are machined into the inner conductors and the loading capacitor parts for the same purpose. Two ion getter pumps, each with a pumping speed of 400 l/s are used to evacuate the cavity to a pressure of at least 10^{-7} mbar. The loading capacitance of the 10.4 MHz-cavity is a multiring coaxial arrangement with a gap width of 1 cm as shown in figure 4. The input coupler is a coil with four turns to match the impedance of the cavity to the power tetrode. The anode is connected to the input coupler directly via an isolating vacuum capacitor. For a calculated gap-voltage of 25 kV a power of 7.2 kW is required. At a load resistance of 2 kΩ the anode dissipation of about 2.8 kW is rather small compared with the rated value of 10 kW, so that there is no risk of tube damage, even when the cavity is detuned. Two capacitive dividers at the grid and the anode give the 180° out-of-phase information for the frequency control of the cavity. The tube is operated in class-B and needs for the full output of 16 kW a grid driving power of 100 W. With a grid bias resistor of 1 kΩ the input resonance circuit is damped to avoid self oscillations and reduce mismatching. Due to input mismatching as a function of input level and because of cw-operation a drive amplifier with a high gain power tetrode was chosen instead of a transistorized amplifier. It delivers more than 500 W with an input power of 1 W in class-AB mode and is capable to withstand full reflected power without damage, even at full output power. The design features of this tube allows maximum power without driving the grid into the positive region.

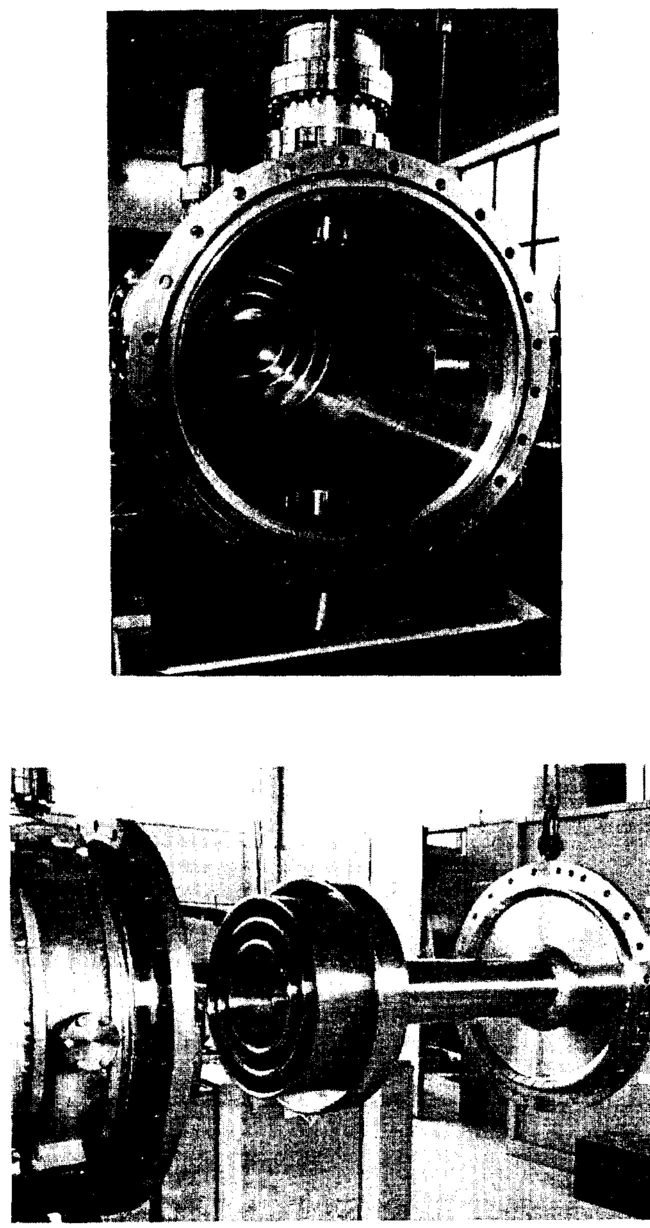

Fig. 4: 10.4 MHz - PIA - cavity with one of the inner conductors dismounted and the inner conductor with one half of the loading capacitance

Therefore it has excellent input matching. The very low grid - plate - capacitance of 0.015 pF offers good stability against self oscillations without additional neutralization. At some operating conditions the reverse screen current of about 25 mA given by the characteristics of this tetrode has to be compensated by an adequate bleeder resistor. The anode load resistance is 1 kΩ and properly adjustable with variable coupling and tuning capacitances. The Q-value of the 125 MHz cavity is loaded down to about 500 during injection of positrons into PIA. At this time the radiofrequency amplifier is turned off, too. The loading of the cavity is done by a rf-water load via a strong coupling loop. A quarter wave length apart from the coupling area of this loop, a PIN-switch is installed, which is opened for loading the cavity. Eigth PIN-diodes of the type Ma 47081 (Microwave ASSOCIATES) each with a series resistance of 0.3 Ω maximum (0.15 Ω nominal) are connected in parallel to the water-cooled inner conductor of the coaxial arrangement. The forward switching time of the diode is 60 ns and reverse 200 ns. The switching time of the switch itself is 2µs, and the max. tolerable power loss at a water temperature of 30° C is 60 W.

rf - Parameters:	1st System	2nd System
frequency	10.4 MHz	125 MHz
harmonic number	1	12
max. peak voltage	25 kV	25 kV
duty cycle	cw	16 %
natural bunch length 2 σ =	2.3 ns	0.76 ns
phase oscillation frequency	17 KHz	60 KHz
mechanical length of cavity	1800 mm	800 mm
shunt impedance of cavity $R_p = \hat{U}_c^2/2P_C$ (kΩ)	43	1100
quality factor (unloaded)	1910	10 000
quality factor (loaded by input coupler and closed by PIN-switch	-	4800
quality factor (loaded by PIN-switch	-	440
input coupling factor β_0	1.06	1.04
tuning range (by plungers) (kHz)	$^{+15}_{-12}\}\hat{=}2.7$ °/oo	$^{+350}_{-214}\}\hat{=}4.5$ °/oo
frequency change by evacuating the cavity (kHz)	-2.6	-60
acceler.peak voltage(kV)	25	25
rf-power dissipation in the cavity at $\hat{U}_c$= 25 kV (kW)	7.2	0.5

The important data measured at the two radiofrequency systems are presented in the table above.

If the switch is closed an impedance of about 10 MΩ is transformed in parallel to the cavity shunt impedance of 1 MΩ. So 10 % of the total rf-power is dissipated into the PIN-diodes. With open switch the maximum beam induced voltage at the diodes is 160 V, which is small compared with the break-down voltage of 500 V. The same pulse forming device which controls the PIN-switch, also controls the modulation of the rf-amplifier and opens the control loop for the frequency tuning of the cavity when it is loaded, so that no detuning may happen by bunch induced signals. For power amplification a modified VHF-transmitter is used as final stage. It is a grid grounded class-B 1.5 kW amplifier and uses a forced air-cooled triode with a rated anode dissipation of 1 kW. A two pole network consisting of a variable inductance and capacitance matches the 50 Ω source impedance down to the impedance of the cathode circuit. The plate tank circuit consists of a capacitive loaded quarter wave coaxial resonator with variable tuning and loading. The anode power supply has a floatable negative output, so the bias of +100 V can be supplied in the cathode return lead. With an output power of 520 W for a calculated gap voltage of 25 kV the anode dissipation is about 200 W, so that for beam stability the cavity can be detuned capacitively without damaging the tube. In grid-grounded amplifiers with strong coupling between anode- and cathode-circuit a detuning of the anode-circuit influences the grid-circuit, too. Therefore the drive amplifier has to be protected. This is done by a three-port circulator, so that both the final and the drive stage can be operated in cw-mode, as it may be necessary to study beam instabilities or in case of pulser malfunction. The solid state drive amplifier is a narrow band design with a maximum output power of 300 W. It contains four 100 W rf-power transistors of type MRF 317. The frequency tuning range of the two plungers installed at the cavities is 2.7 °/oo and 4,5 °/oo for the 10.4 MHz cavity and the 125 MHz cavity respectively.
More details are reported in Ref. 9).

Acknowledgements

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