THE 1 MV 114 MHZ ELECTRON ACCELERATING SYSTEM FOR THE CERN PS

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Summary

In addition to its original function as a proton accelerator, the PS will become part of the LEP injector chain [1] accelerating electrons and positrons from 600 MeV to 3.5 GeV. For this purpose, two 114 MHz cavities with a gap voltage of 500 kV have been installed. This paper describes the cavities together with their related auxiliary systems and the low level electronics. Special features include mechanical short-circuiting of the gaps in order to avoid perturbing the high-intensity proton beams, fast tuners using perpendicularly biased ferrites and higher order mode dampers.

Introduction

The basic operating modes [1] for electron or positron acceleration in the CPS require a new RF system with the following specification:

Harmonic number	: 240	
Frequency	: 114.511	MHz
Nominal DC beam current	: 6.1	mA
Peak RF voltage	: 1000	kV

The RF voltage is obtained using two high Q cavities. They are independently fed via 40 m coaxial cables by amplifiers situated outside the ring and accessible during operation. The amplifiers, rated at 50 kW CW and 200 kW pulsed, are housed in a Faraday cage to avoid interference with the navigation system of the airport nearby [2].

The cavity

The shape of the cavity (Fig. 1) was chosen to give high values of Q and R/Q (evaluated by Superfish [3]) and small deformations under atmospheric pressure (verified using Safeshell [4]).

As the cavity has to be non-magnetic due to its proximity to the PS magnets, it was decided to use a stainless steel shell internally copper-plated (0.1 mm). The nose cones are machined from solid OFHC copper. We measured a Q of 90 % of the value calculated, ignoring any effects of the many holes for tuners, pumps and shorts. A further 10 % drop is due to the penetration of the tuning cylinders and the shorting elements.

Due to the poor thermal conductivity of stainless steel, it was necessary to enclose the whole cavity surface in a water jacket, which is divided into a large number of radial channels in order to maintain a low-temperature gradient. The nose cones are separately cooled by water flowing through holes drilled in the massive copper forgings. The cavity is pumped by two 400 l/sec ion pumps.

Parameters of the cavity

Resonant frequency	114.511	MHz
Tuning range (slow)	0.260	MHz
Tuning range (fast)	0.020	MHz
Gap voltage	500	kV
Q value (Superfish)	70'000	
Q value (measured) fully equipped	56'000	
R/Q	180	Ω
Shunt impedance	10	MΩ
Power for 500 kV	12.5	kW

Cavity tuning

The inital setting of the resonant frequency of the cavities was done by machining the tips of the nose cones with a tolerance of 1/10 mm which corresponds to 15 kHz.

A pair of piston tuners covers the range of 260 kHz within a minute.

For displacing the beam ± 10 mm radially, a fast tuner is being developed with a range of ± 10 kHz. The tuner consists of a coaxial line, partly filled with rings of microwave ferrites (ϕ 160 mm) and coupled to the cavity. A coil is wound around the external conductor producing a bias field perpendicular to the RF flux (Fig. 2). The magnetic circuit is closed by a laminated iron core. The perpendicularly biased microwave ferrite rings (G 810), exhibit a Q of over 1000 at permeabilities below 4 [5,6]. With the nominal gap voltage and the desired tuning range each of the two tuners has power losses below 1 kW. Ordinary ferrites with parallel biasing would generate 10 times these losses.

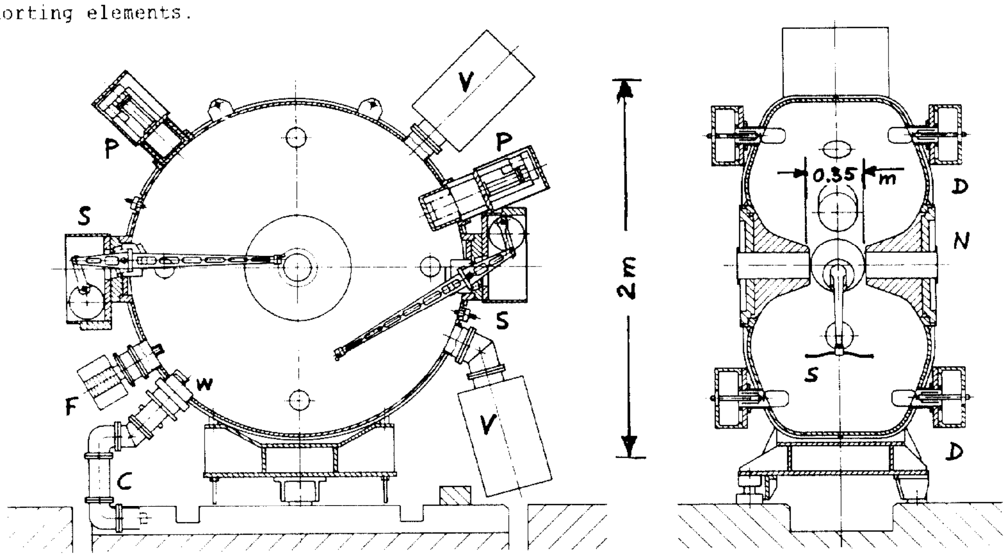

Fig. 1

The 114 MHz cavity

N = nose cone
D = damper
W = RF window
C = cable to amp.
F = ferrite tuner
S = short
P = piston tuner
V = vacuum pump

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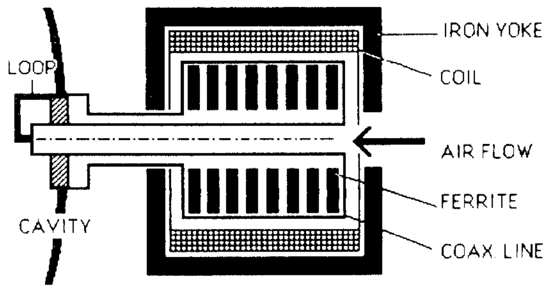

Fig. 2 The ferrite tuner

The short circuits

When accelerating electrons, a high cavity shunt impedance saves RF power. However, when accelerating a high intensity proton beam (using another RF system) the impedance of the idle 114 MHz cavity must be reduced to a few kΩ to avoid instabilities.

Tests having shown that the desired result could not be obtained using coupling loops and loads, we decided to use two shorting bars bridging the gap. The lowest mode is then at 180 MHz and both Q and R/Q are very much reduced. Furthermore, all the resonances of the short-circuited cavity fall within the range of the dampers. Q measurements indicate that in the open position the shorting devices account for 3 % of the total cavity dissipation.

The shorts are actuated by an electrical servo-motor with controlled acceleration.

Problems have arisen with the lifetime of the bellows, and under CW operation at full power the short-circuiting bars overheat. A water-cooled version is being prepared.

The dampers

Higher mode resonances in the cavity are attenuated by dampers consisting of a 50 Ω load coupled through a notch filter tuned to the fundamental frequency of the cavity.

The damper has a triaxial structure. The inner coaxial line connects the loop to the external load. The outer conductor of this line and the surrounding enclosure form a resonator tuned to 114 MHz. The coupling loop is connected between the innermost conductor and the cavity wall (Fig. 3) [7].

With 4 dampers, we attenuate the shunt impedance of the parasitics by 30-40 dB (Figs. 4,5). The R/Q was obtained by perturbation. At 300 MHz the short is rather inefficient, but the spectral density of the proton beam decays strongly above 200 MHz.

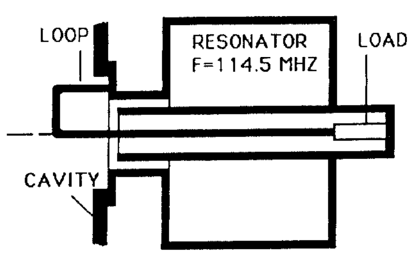

Fig. 3 The higher mode damper

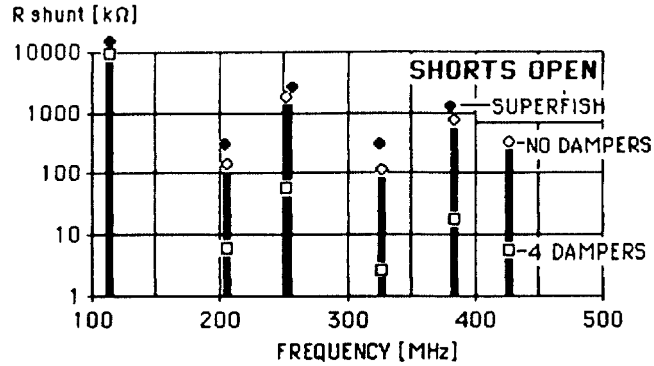

Fig. 4 R shunt with and without damper (for electrons and positrons)

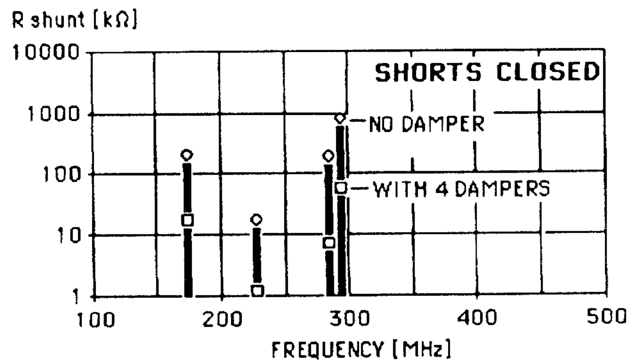

Fig. 5 R shunt with and without damper (for protons)

The RF power amplifier

The two power amplifiers are commercial types, manufactured by Herfurth GmbH., Hamburg. Each consists of a transistor broad-band preamplifier (300 W) followed by a selective driver stage with a tetrode (10 kW dissipation). The final grounded grid stage uses a tetrode of 70 kW maximum dissipation. The anode circuit, a half-wave resonator, is capacitively coupled to the 50 Ω feed line (Flexwell 4 1/8"). A variable length line covering half a wavelength is inserted in series with the 40 m of cable to the cavity.

Low-level RF beam control and cavity servos

Requirements

The CPS is supposed to [1]:
- receive leptons from EPA using a bunch-into-bucket transfer scheme, where the CPS RF system is locked to that of the EPA;
- accelerate them either with the usual ferrite cavities, driven on h = 16, or with the new 114 MHz cavities on h = 240;
- accurately position the bunches at high energy for a correct bunch-into-bucket transfer to the SPS;
- shape the bunches so that they are stable in the SPS making use of any one of the 3 techniques envisaged ("bunch compression" + "bunch expansion" described in [8] or "long bunch expansion" as in [9]).

This means the low-level RF system must be able to:

- drive two groups of cavities with the correct phasing, both the 10 ferrite cavities on h = 16 or h = 8 and the two 114 MHz cavities on h = 240;
- synchronize the RF on EPA at injection and position the bunches for SPS at ejection;
- damp the coherent phase oscillations of the beam.

Block diagram description [10]

The system (Fig. 6) is based on a 114 MHz RF synthesizer which drives the 114 MHz cavities through two phase-locked loops used as phase shifters.

7.6 MHz (h = 16) or 3.8 MHz (h = 8) are derived by division from the same source. Cable delays are used to obtain the correct phases to drive the 10 ferrite cavities.

Signals from electrostatic PU's are bandpass filtered around 114.5 MHz (Q = 1000) and leveled off in a limiting amplifier (60 dB dynamic range) to serve as beam phase reference for the phase discriminator of the beam phase loop.

RF synchronization on EPA, before injection, is obtained by momentarily locking the beam phase loop on an ad hoc signal derived from EPA RF and revolution frequency (switch S1 on "EPA RF*6" in Fig. 6).

Bunch synchronization on the SPS, before ejection, is effected by changing the RF frequency until the phase difference between the bunch position signal and an ad hoc signal derived from SPS reference is at zero (switch S2 "on" in Fig. 6).

Cavity servo system

A medium speed servo system (several 100 Hz bandwidth) insures that the peak gap voltage follows the computer-generated program. Its dynamic range is 36 dB (10 kV to 500 kV). Slow drift of the cavity tune, as well as deliberate detuning are controlled by a sampled tuning loop (several 0.1 Hz bandwidth). Sampling is done once per cycle, before beam injection.

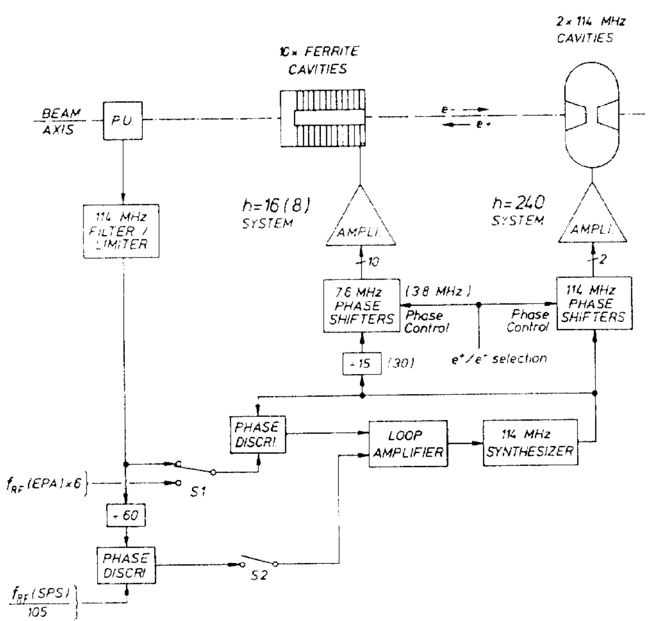

Fig. 6 Beam control system

Conditioning

Conditioning the cavity required some time and care. In particular, it was found essential to limit the pressure to well below 10^{-6} torr while progressively raising the voltage.

At some voltage levels extending from 50 kV to 400 kV an increase of even 0.1 dB of RF input caused an excessive pressure rise. The time required to break through these levels varied from hours to days. The stray fields from the magnets in the ring also contributed to these effects.

Beam experiments

Successful results were obtained with this system in 1986; they are described in detail in another paper in these proceedings [11].

Acknowledgements

The high power part of the project was defined and started by W. Pirkl. The associated electronics were developed by J. Broere, M. Croizat and G. Serras. G. Roux was an essential contributor for the low-level system and for the beam experiments. P. Barthelémy was responsible for the AVC system.

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