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THE PS 40 MHZ BUNCHING CAVITY

R. Garoby, D. Grier, E. Jensen,
CERN - CH 1211 Geneva 23, Switzerland
A. Mitra, R.L. Poirier,
TRIUMF 4004 Wesbrook Mall, Vancouver, B.C., Canada V6T 2A3

Abstract

A 40 MHz cavity has been designed and built at CERN as part of the preparation of the PS as injector for LHC. The cavity will provide the necessary bunch spacing of 25 ns prior to injection into SPS and subsequently LHC. The mechanical design of the copper coated steel cavity was dominated by space constraints in the PS tunnel and by vacuum requirements. The salient design features described are i) tight, multipactor-free, capacitive coupling from the power amplifier, ii) fast RF feedback, iii) inductively coupled tuners, iv) an efficient, pneumatically operated gap short-circuit. The operation cycle consists of an adiabatic capture up to 100 kV gap voltage, a non-adiabatic jump to 300 kV, and subsequent bunch rotation. The multipactor voltage level at the gap lies below the operating voltage range and is easily passed through. A fast RF feedback system with a total group delay of 220 ns copes with heavy beam loading (10^{11} protons/bunch) and prevents unwanted interaction with other beams in the PS. The cavity has recently been installed, the nominal gap voltage of 300 kV has been attained, and bunch lengths below 8 ns have been achieved in first tests at nominal intensity. Experimental results are reported.

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1 INTRODUCTION

For the LHC era, the PS will have to provide a new type of beam [1] compatible with SPS injection, and in particular to cope with a fast growing microwave instability at the SPS injection front porch. The 3.8 ns length bunches, spaced at 25 ns, will have an intensity of up to 1.7 10^{11} particles per bunch and a longitudinal emittance of 0.35 *e*Vs (corresponding to $\Delta p/p = 2.5\ 10^{-3}$). This bunch structure will be impressed on the beam in the PS at the end of the acceleration cycle, at 26.4 G*e*V/*c* momentum, by a new RF system consisting of one cavity producing a gap voltage of 300 kV at 40 MHz as described in this paper and a set of two 80 MHz cavities (under construction) with nominal gap voltage of 300 kV each. The design was strongly influenced by the severe space restrictions in the PS and the requirement not to deteriorate the performance of other beams.

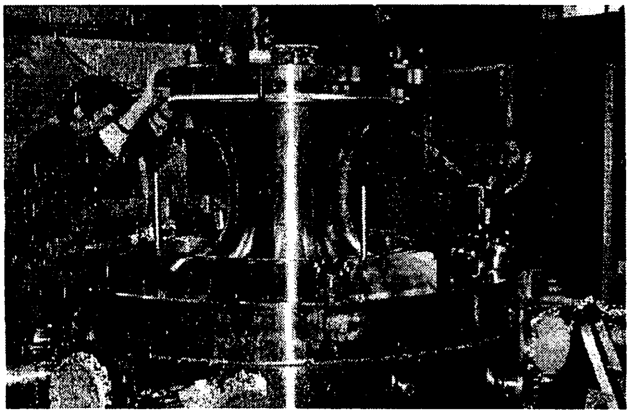


Figure 1: Mounting the center electrode into the cavity.

1.1 *Operation Cycle*

After acceleration on harmonic h=16, the beam is adiabatically debunched. The bunching process at 40.055 MHz starts with a quasi-adiabatic compression from 4 to 100 kV, followed by a non-adiabatic (20 µs) rise to 300 kV. After 180 µs (the synchrotron period is »1 ms), when the bunch is tilted in phase space, the 80 MHz cavities with 600 kV will be switched on. This further increases the bucket height, bunch rotation continues and the final 3.8 ns, 0.35 *e*Vs will be attained 110 µs later.

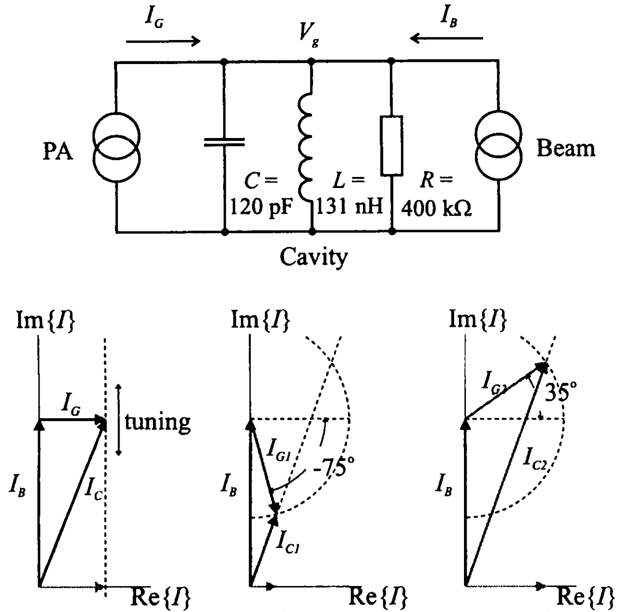
2 CAVITY DESIGN

2.1 *Choice of parameters*

In order to fit into a short section (1 m) of the PS the cavity has strong capacitive loading. As a compromise between power requirements and sensitivity to beam loading a moderate R/Q of 33 Ω was chosen, which, with an unloaded Q of 12000 (measured), corresponds to the equivalent circuit parameters of Fig. 2. Approximately 100 kW are needed to produce a gap voltage of 300 kV, with 5.4 J stored in the cavity. The instantaneous power required to fill the cavity to 300 kV during 25 µs is 300 kW.

2.2 *Cavity behavior under beam loading*

A reactive beam current I_B is equivalent to a detuning of the cavity by $\frac{\Delta\omega}{\omega} = \frac{1}{2}\frac{R}{Q}\frac{|I_B|}{V}$, which cannot be corrected during the very fast non-adiabatic gap-voltage variations. In our case, V changes rapidly by a factor 3 during 20 µs while I_B is virtually constant, leading to a rapidly varying and strongly reactive load on the power amplifier (PA). Fig. 2 b) and c) illustrate, in the complex plane, the conditions before (I_{G1}) and after (I_{G2}) this voltage step respectively. In order to minimize the maximum PA anode current, the cavity has to be pre-tuned such that $|I_{G1}|=|I_{G2}|$. The detuning angle is kept within acceptable limits by the moderate R/Q.



a) reference: I_B compensated by detuning: real I_G

b) detuning at low V_g

c) 20 μs later: detuning at high V_g

Figure 2: Varying tuning angle with non-adiabatic variation of the gap voltage.

2.3 Higher order mode damping

The strong capacitive loading (low *R/Q*) results in a cavity in which the main electric and magnetic field energies are stored at different locations in the cavity. As a result, the first higher order mode (HOM) appears more than 2 octaves above the fundamental which alleviates the problem of HOM damping. The higher order mode dampers are described elsewhere [2].

2.4 Coarse and servo tuners

Although the cavity is designed to operate at a fixed frequency, it is nevertheless equipped with 2 types of tuners. These tuners are described in detail in [3].

2.5 Mechanical and vacuum aspects

For mechanical stability and for good magnetic and vacuum characteristics, the cavity is manufactured from forged 316LN steel with an internal 40 μm copper plating (4 skin-depths). The accelerating gap of 50 mm is located close to the upstream end, which allows enough space for an efficient, pneumatically operated gap short-circuit.

Four ion pumps of 400 l/s each and three sublimation pumps bring the vacuum to a level of below 10^{-9} mbar. The cavity is equipped with heating jackets for in-situ bake-out at 120 °C.

3 GAP SHORT-CIRCUIT

During normal operation, the cavity impedance seen by the beam is kept low by means of the fast RF feedback. The gap is otherwise closed by the pneumatically operated short-circuit (S-C).

The S-C consists of a tube which moves like a piston across the gap (stroke 78 mm). The tube has the diameter of the vacuum chamber and is constrained by a cylindrical ball guide. RF contacts assure well defined current paths and two bellows assure vacuum tightness. The gap is opened or closed in 0.6 s by two pneumatic arms, and end-switches serve as indicators and interlocks. The S-C system has proven reliable.

4 AMPLIFIER AND CAPACITIVE COUPLING

The choice of power amplifier design was influenced by two major constraints :

1. The need for a fast RF feedback loop with about 40 dB loop gain.
2. A reactive amplifier load with a varying impedance and phase angle due to strong beam loading .

In a feedback loop such as shown in Fig. 3, a safe working value for the group delay T_g round the loop is approximately given by $T_g=0.7 \cdot Q/(A\omega_0)$, which yields, for a loaded Q of 10000, about 280 ns. With the high gain 40 kW RF driver amplifier chain occupying 160 ns, the power amplifier could have been conveniently sited beside the PS ring at about 10 m distance and coupled to the cavity with 50 Ω cables. This solution was abandoned because of the difficulty of maintaining loop stability in the presence of intrinsic strong resonances in the plane of the anode at a few MHz from f_0.

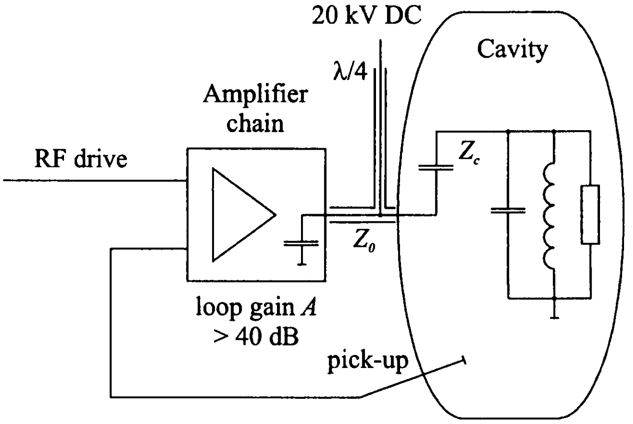


Figure 3: Simplified block diagram of the amplifier/cavity feed-back system.

With the power amplifier coupled to the cavity via a line of appropriate length (≈λ/10) and Z_0, the resonances close to f_0 are avoided. Care must be taken in the choice of the coupling impedance Z_c and of Z_0 under these conditions, such that the transformation, at the anode, of the off-resonance impedance of the cavity in series with Z_c does not cause unacceptable distortion of the anode to gap step-up ratio when operating with beam loading.

Since the form of the cavity gave a strong electric field in the vicinity of a convenient coupling port, capacitive coupling was adopted. The 18 kV peak RF envelope at the anode reduces to a low value at the coupling window where the anode 20 kV DC (via a λ/4-line) and cooling water enter. The tube is a Thomson type TH 681 and delivers up to 400 kVA to the cavity during operation.

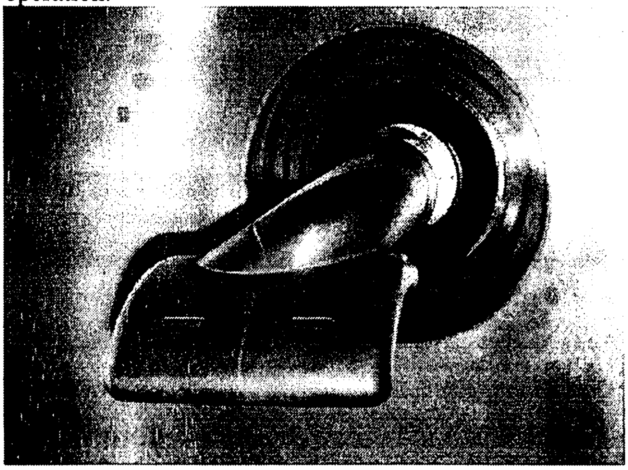


Figure 4: The capacitive power coupler mounted inside the cavity. The form is adapted to the electrode, which is not mounted.

The presence of the DC anode voltage on the coupler inside the cavity suppresses multipactor (MP) at the coupler window [4]. The value of Z_c, which determines the anode/gap step-up ratio, is adjustable by rotation of the coupler around the axis of the window.

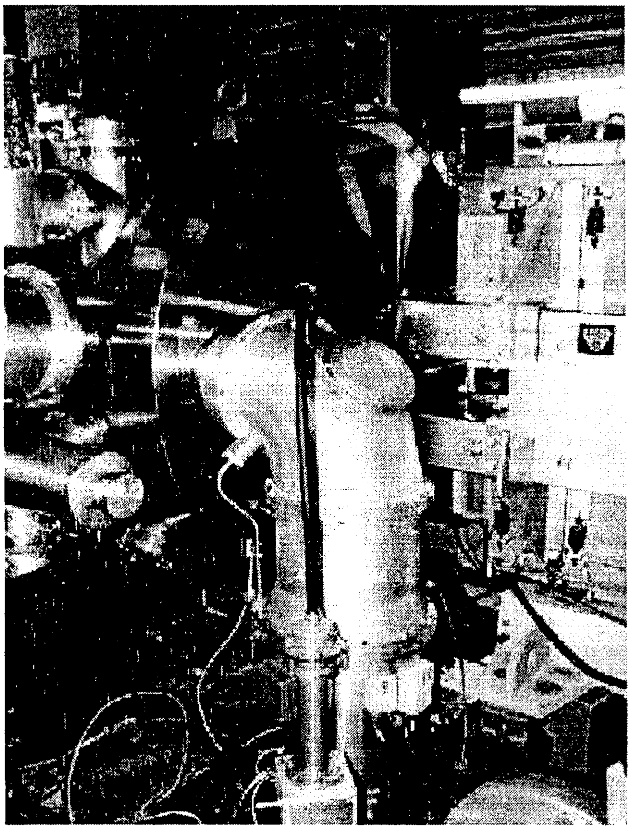


Figure 5: The cavity installed in the PS tunnel. The 400 kW final amplifier and the λ/4-line for the HV supply are visible in the foreground.

5 EXPERIMENTAL RESULTS

The cavity was first installed and commissioned in the PS tunnel in October 1996. The required gap voltage range, rise time and stability were readily obtained. A loop gain of 43 dB was measured yielding an effective cavity *Q* of 72.

A MP level at about 500 V gap voltage was identified as 2-point MP in the gap, but could easily be passed through without conditioning. Above a lower limit of 1 kV no other MP levels were observed. The fringe field of the nearby main magnets (cf. Fig. 5) increases this lower limit to about 4 kV.

It was observed that for beams of low intensity, the MP alone limits the induced gap voltage. For higher intensities this voltage breaks through the MP, but is suppressed by the RF feedback.

With the appropriate RF programme, the PS beam was successfully rebunched on *h*=84 with bunch lengths of ≈10 ns. Rotation of a single bunch [from *h*=20] is shown in Fig. 6.

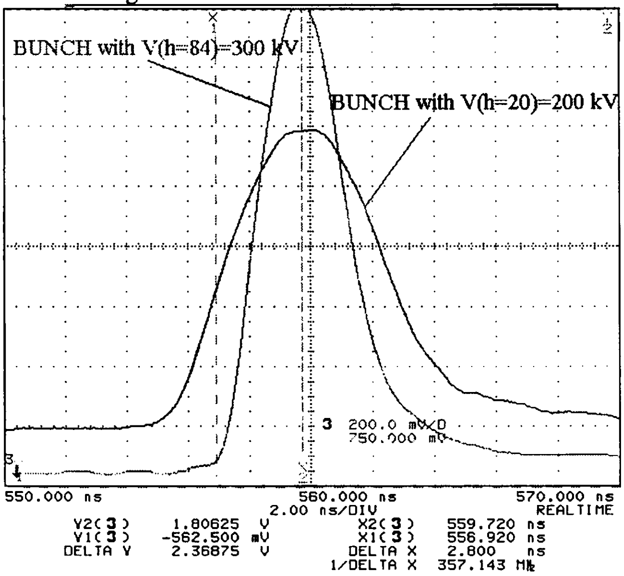


Figure 6: Single bunch rotation: bunch length ≈ 5 ns

6 ACKNOWLEDGEMENTS

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