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THE PS 80 MHZ CAVITIES

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Abstract

As part of the preparation of the PS as injector for LHC, two new 80 MHz cavities have been designed and built at CERN. Bunches spaced by 25 ns and less than 4 ns long are required at injection into the SPS. The bunch spacing is obtained with a 40 MHz system installed in the PS in 1996, but the nominal small bunch length will only be obtained with the 80 MHz systems producing a total of 600 kV. These systems also have the capability to accelerate leptons in the PS, providing a total of 400 kV with high duty cycle (25%). The mechanical design is similar to that of the 40 MHz cavity with many common parts, but cooling water circuits had to be added. The cavity is equipped with an efficient, pneumatically operated, coaxial short-circuit. The power coupling loop has the form of a wide strip to minimize the ratio of self to mutual inductance. It has a DC insulation permitting multipactor suppression by a bias voltage. The final amplifier is mounted directly onto the cavity. A fast RF feedback with a loop gain of 44 dB reduces the Q to about 100. Higher-order-mode dampers designed and built at TRIUMF have been installed.

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1 INTRODUCTION

For the LHC era, the PS will have to provide a new type of beam, compatible with SPS injection and, in particular, be able to cope with a fast growing microwave instability at the SPS injection front porch. The 3.8 ns long bunches, spaced at 25 ns, will have an intensity of about 1 10^{11} particles per bunch and a longitudinal emittance of 0.35 *e*Vs (corresponding to $\Delta p/p$ = 2.5 10^{-3} r.m.s.). This bunch structure will be impressed on the beam in the PS at the end of the acceleration cycle, at 26.4 G*eV*/*c* momentum, by a new RF system consisting of one cavity producing a gap voltage of 300 kV at 40 MHz described elsewhere [1] and a set of two 80 MHz cavities with nominal gap voltage of 300 kV each, described in this report.

2 CAVITY DESIGN

2.1 Cavity Body

The concept of both the 40 MHz and the 80 MHz cavities was studied together. This led to very similar designs with many shared parts. The cavity body is non-magnetic forged steel of type 316 L+N. The main difference between the 2 designs is the electrodes, which represent the "hot" side of the gap. The inside of the cavity was galvanically copper plated at CERN. The gap spans only 50 mm, and is designed to hold off voltages well above nominal, while keeping the 2-point multipactor (MP) band at low enough voltages (< 4 kV) not to disturb the quasi-adiabatic bunching process which requires smooth voltage variations.

In contrast to the 40 MHz cavity, the 80 MHz cavity is designed to enable long pulse operation. The heat distribution in the cavity wall was calculated with the CASTEM code to optimise the distribution of cooling water circuits.

Initially, a simplified full-scale, copper-lined, wooden model of the 80 MHz cavity was built and measured at TRIUMF [2]. The model allowed verification of the design, identification of higher-order-modes (HOM) and permitted the optimization of the power coupling loop and the HOM dampers described below.

2.2 Gap Short-Circuit

At the same time, the narrow gap allowed for an elegant mechanical short-circuit (S-C) which moves axially. The S-C is pneumatically operated and has proven to be very reliable. Identical devices are used in the 40 MHz and the 80 MHz cavities. They are described in detail in [1].

3 AMPLIFIER & POWER COUPLER

The power amplifier design was influenced by two major constraints :

1. The need for a high gain fast RF feedback loop.
2. A reactive amplifier load with a time-varying impedance and phase angle due to strong beam-loading of the cavity.

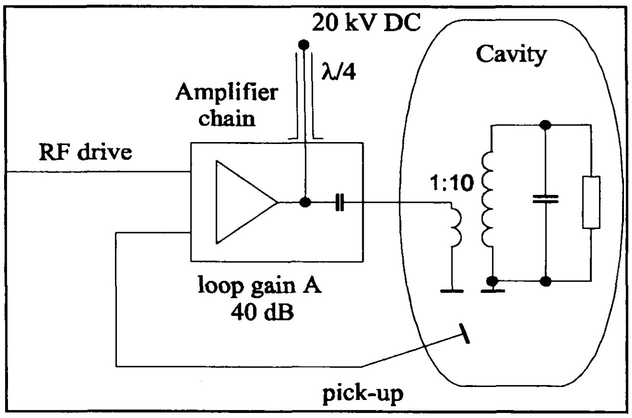

Figure 1: Simplified block diagram of the amplifier/cavity feed-back system.

In a feedback loop such as shown in Figure 1, the maximum group delay for a stable loop is given by $T_g = Q\pi/(A\omega_0)$. This yields, for a measured loaded Q of 9600 and a gain A of 120 (42 dB), about 500 ns. The loop gain margin is T_g/T so that for 6 dB gain margin, the loop delay T should not exceed 250 ns. The high gain 40 kW rf driver amplifier chain occupies 130 ns, leaving 120 ns for the connecting cables to and from the electronics annexe to the final amplifier (PA) mounted directly on the cavity. Figure 2 shows the 80 MHz cavity in the test stand with the amplifier in the foreground.

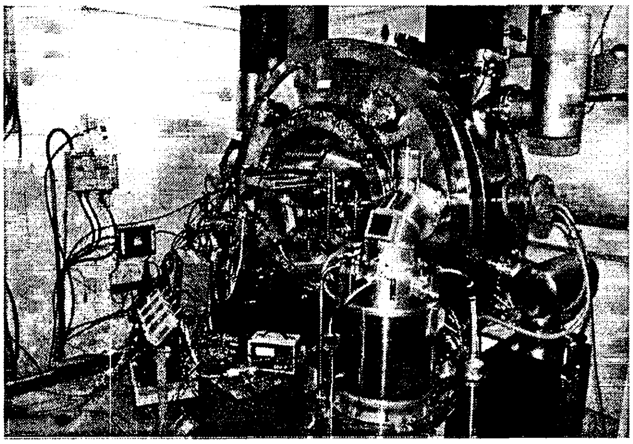

Figure 2: Cavity and amplifier in the test stand.

The characteristics of the short line and the power coupler connecting the PA tube anode to the cavity determine the position of the side resonances, and also the voltage step up ratio from anode to cavity gap. The line and coupler have been designed such that with a voltage step-up ratio of 20, the upper side resonance is at about 90 MHz. An additional damping circuit assures that this resonance is sufficiently attenuated so as to give a 12 dB gain margin with the control loop closed. Approximate symmetry of the cavity impedance, seen at the plane of the anode at frequencies above and below 80 MHz, maintains the step-up ratio of about 20 under de-tuned operation with beam-loading.

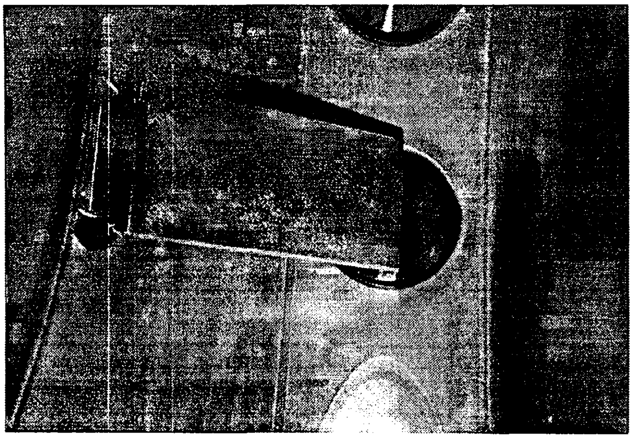

Figure 3: Power coupling loop mounted inside the cavity.

The cavity geometry is such that magnetic coupling is the most convenient. A water-cooled coupling loop in the form of a wide strip is connected between two ceramic windows (cf. Figure 3), the strip being dimensioned so as to obtain the correct mutual to self-inductance ratio. The window on the rf ground side of the coupler is used to feed coupler cooling water and a 1.5 kV DC potential to reduce MP.

With the amplifier coupled directly to the cavity in the manner described above, i.e. with no matched coupling cable, no adjustment mechanisms are necessary in the amplifier, since the tube anode circuit is adjusted by the servo variable capacitor cavity tuning.

Initially, a HOM resonance in the anode line caused a strong 1 GHz instability. This resonance was suppressed by placing a concentric resistor network in the line so as to couple with the longitudinal component of the HOM field [3].

The tube is a Thomson TH 681. Cooling water and the 20 kV anode voltage enter at the rf voltage node just above the water and high voltage connections of the tube. Under beam-loaded conditions the amplifier can deliver up to 400 kVA to maintain 300 kV at the gap.

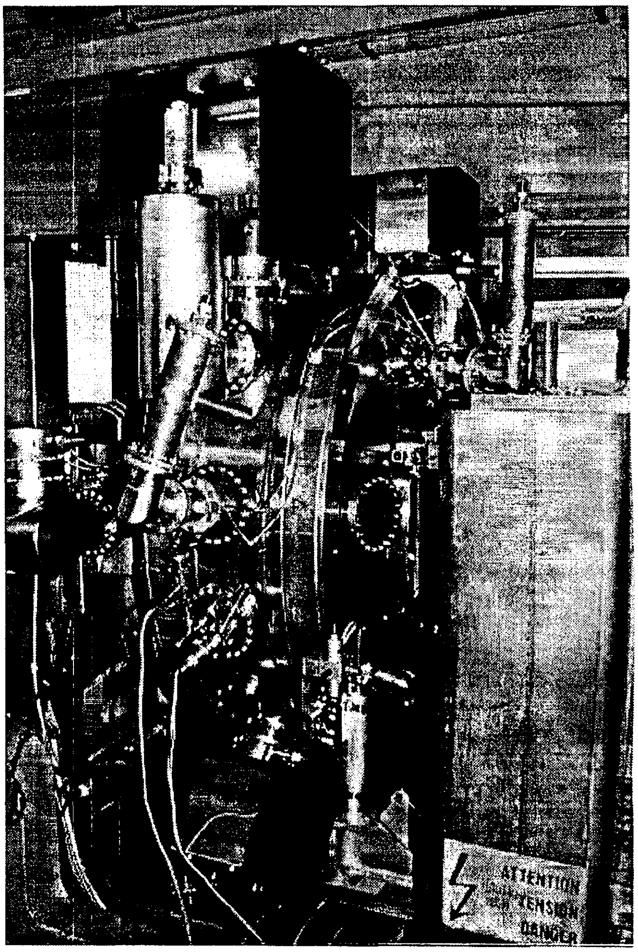

Figure 4: 80 MHz cavity after installation in the PS tunnel.

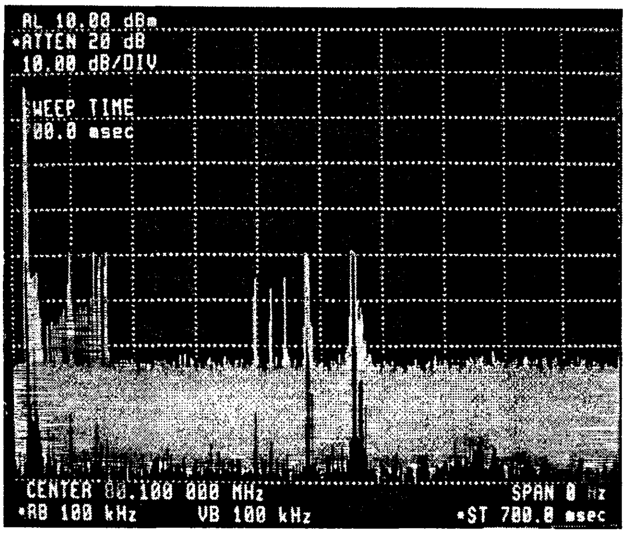

Figure 5: Detected gap voltage vs. time, feedback off. Horizontal: time, 700 ms total, trigger 15 ms before injection. Vertical: gap voltage, 10 dB/div, reference level (top) 290 kV at the gap.

4 HOM DAMPER

The HOM-dampers were designed and built at TRIUMF. To reduce the fundamental power loss, a compact and robust 3-element high-pass filter was designed which connectes between the antenna type coupler and the load. A detailed description of both the HOM dampers and the filter can be found in [4]. Figure 4 shows a 80 MHz cavity after installation in the PS tunnel, two of the four HOM dampers and high pass filters can be seen in the foreground.

5 FIRST RESULTS WITH BEAM

The cavities were installed and commissioned during the winter shut-down '97/98. During first machine developments earlier this year, the new cavities were tested with beam. The desired bunch length could however not yet be attained and requires further work. At the time of writing, the shortest attained bunch length with nominal emittance was 5.5 ns.

Figure 5 shows the gap voltage at the fundamental resonance induced by the beam during the acceleration cycle (700 ms). After an initial peak in the induced voltage up to about 65 kV, the voltage does not exceed 1 kV later during the acceleration cycle, a threshold which is believed to be due to a MP level. The useful reduction of the induced voltage by MP is however insufficient and unreliable since MP cleanup can occur at some levels. The RF feedback loop is required to further reduce the beam-induced gap voltage as shown in Figure 6, which was taken with identical measurement settings, but with the feedback loop closed. The induced voltage is now reduced to noise level, i.e. below 50 V at the gap.

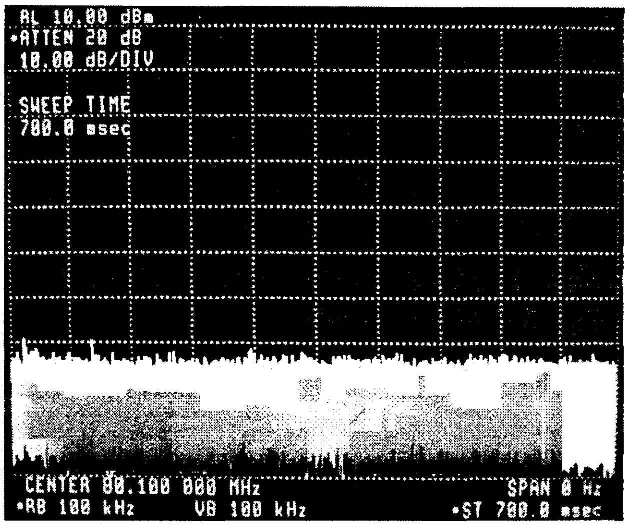

Figure 6: Detected gap voltage vs. time, feedback on. Settings identical to Figure 5. The noise level corresponds to about 50 V at the gap.

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[3] W. Pirkl, private communication.

[4] A. K. Mitra, S. Rose, "Higher-Order-Mode Damping of the CERN 80 MHz Cavity, TRIUMF design note TRI-DN-97-8, April 1997.