THE PS 13.3-20 MHZ RF SYSTEMS FOR LHC

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Abstract

As part of the preparation of the PS as an injector for the LHC, a prototype 20 MHz rf system has been used, to demonstrate that the nominal longitudinal performance of the proton beam for LHC can be obtained using multiple bunch-splittings. Based on these successful results obtained during 2000, the development of the operational rf system began in 2001. To allow the preparation of bunch trains with a bunch spacing of 25 or 75 ns, this system must operate either at 20 or 13.3 MHz respectively. Two new ferrite cavities and their associated amplifiers have been designed and built. Each one can provide a maximum voltage of 20 kV peak during 200 ms with a 10% duty cycle. The cavities are equipped with fast (~20 ms) gap shorting relays, and rf feedback reduces their Q below 10 at both frequencies. A single system is sufficient to generate the nominal beam for LHC. The second one will then be both a "hot spare" and a very valuable performance enhancement providing the possibility of handling a larger than nominal emittance or generating bunch trains with different spacings in the same PS supercycle. The design and the results measured on the final device are described and discussed.

INTRODUCTION

This project is part of the preparation of the PS complex as injector for the LHC. During the year 2000 a new scheme for producing the LHC beam structure was successfully tested, using a prototype 20 MHz rf system installed during the 1999 PS shutdown. Making use of rf systems operating at 10, 20, 40 and 80 MHz, bunches are split in 12 without debunching/rebunching, and a nominal bunch spacing of 25 ns is finally obtained [1, 2]. In 2001, 75 ns bunch spacing was proposed for the early stage of LHC operation, to limit electron cloud induced heating of the vacuum chamber and maximise luminosity for a limited total beam intensity [3]. To make both bunch spacings feasible, the operational rf systems have then been specified to be able to operate either at 13.3 or 20 MHz. A first system was finished in 2002 and installed during the winter shutdown in the PS ring. The second one is under construction and will be installed one year later.

GENERAL SYSTEM SPECIFICATION

Each system is made-up of a power amplifier driving one cavity and occupies a single short straight section in the PS. It is tunable at 13.3 and 20 MHz and it can deliver the full voltage (20 kV) during 200 ms with a 10% duty cycle. When not in use, high voltage relays short-circuit the resonators. When in use, the relays are open and rf feedback reduces the quality factor to 10 and the shunt impedance accordingly. A single system is sufficient to generate the nominal beam for LHC, either with 25 or 75 ns bunch spacing. The presence of two systems will make both types of beam available within the same PS supercycle, without activating excessively the mechanical devices used for tuning.

CAVITY DESIGN

The request for a maximum peak rf voltage of 30 kV, together with the space constraint imposed by the PS short straight section (1.5 m), have led to the decision of installing two identical systems. The cavity mechanical layout is shown in fig. 1. The resonator is made of two sections, each of them with its own ceramic gap. Splitting the rf voltage between two gaps is imposed by the safe voltage holding limit of the gap relays (10 kV).

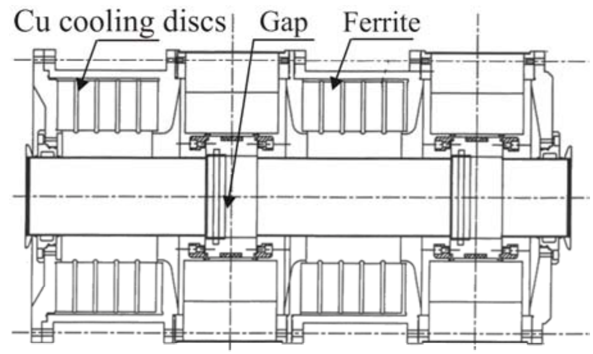

Figure 1: Cavity mechanical layout

Compared to a single resonator solution, more ferrite rings are used and losses are lower. The two sections are driven in parallel by the common tube amplifier with two short transmission lines. The cavity is shown in Fig. 2.

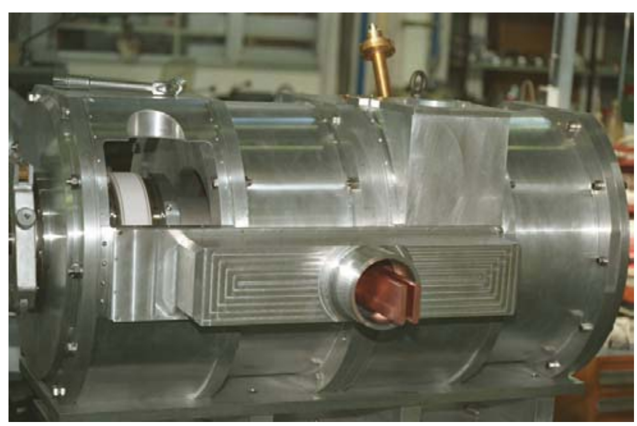

Figure 2: The ferrite cavity. The end part of the transmission lines and the ceramic gap are visible

The ferrite rings are Philips (now Ferroxcube) standard grade 4E1, and heat is removed by water-cooled copper disks. This grade has been chosen for its low permeability

(σ~14) and low loss at 20 MHz. The ferrite ring size is 440x250x33.3 mm. Each cavity has ten rings in total. During the development, the cavity characteristics have been estimated with multiple measurements on small size ring samples. Since only two fixed resonant frequencies are required, magnetic bias has not been selected and, instead, tuning is achieved with two variable vacuum capacitors connected in parallel with the gaps. The cavity being very close to the PS main magnets (see Figure 3), a magnetic shield surround the ferrite rings to avoid unwanted detuning due to the fringe field. Its main characteristics are summarized in Table 1.

Figure 3: The cavity installed in the PS ring. The magnetic shield and the PS magnets are visible.

Table 1: Main characteristics of a 13 – 20 MHz cavity

Parameter \ Frequency [MHz]	**13.3**	**20**
Quality factor at 20 kVp	82	63
Quality factor at 100 Vp	163	100
Nominal V_{RF} [kVp]	15	15
Maximum V_{RF} [kVp]	20	20
Shunt resistance at 20 kVp [kOhm]	1.7	2
Power dissipation at 20 kVp [kW]	25	30
RF magnetic flux density at 20 kV [mT]	9.7	6.7
Peak power density at 20 kVp [mW/cm^3]	860	730

AMPLIFIER CHAIN

A grounded cathode tube power amplifier has been developed, based on a water cooled tetrode RS1084CJ (THALES), driven by a 400 W solid state amplifier. Feedback from the cavity gap provides reduction of the cavity impedance seen by the beam. Both amplifiers are kept as close as possible to the cavity resonator in order to keep the group delay low. A low Q (~2.5) resonator is implemented in the grid of the tetrode. A coaxial rf switch selects between two shorted coaxial cables to tune the grid resonator at the two frequencies. Fine tuning is obtained using a coaxial line stretcher. The anode dissipation of the tetrode is minimised by pulsing to 4 A the DC current only during operation (10 % maximum duty cycle). The CERN-made driver amplifier has a gain of 54 dB, a group delay of only 30 ns, and a 3 dB bandwidth extending from 0.15 to 80 MHz. The presence of the two transmission lines generates high frequency resonances that limit the overall loop gain. At 20 MHz the unwanted resonance is located at 56 MHz while at 13.3 MHz it is at 71 MHz. The 56 MHz resonance is especially dangerous, because the gain is only 24 dB below the value at 20 MHz. Two notch filters, connected directly to the feedback probe, are used to filter out the two resonances. The main characteristics of a complete rf system are summarized in Table 2.

Table 2: Main characteristics of a 13–20 MHz system

Parameter\Frequency [MHz]	**13.3**	**20**
Feedback gain at 100 Vp [dB]	25	21
Feedback gain at 20 kVp [dB]	20	17
Open Loop Bandwidth [kHz]	75	176
Closed Loop Bandwidth [MHz]	2.6	4.5
Forward Path Gain [dB]	94	95

TUNING

Four different components have to be adjusted as a function of the operating frequency: the grid circuit of the power amplifier, the cavity, the rf feedback loop (gain and phase) and the servo control of the rf voltage amplitude (AVC). The cavity tuning is obtained by changing the capacitance in parallel with the two gaps. That method has two disadvantages. First of all, the variation of the resonant frequency with the amplitude (~85 kHz in both cases) cannot be compensated. This affects the closed loop transfer function (modulus and phase) of the system. The phase is amplitude dependent and it changes by 4.5° at 13.3 MHz and 3° at 20 MHz. The amplitude of the frequency response becomes tilted (see next paragraph). The second disadvantage is the slowness: changing the operating frequency requires about two minutes. A single stepping motor monitored by a 12 bit encoder drives the variable capacitors. The other three elements are adjusted by means of four rf coaxial switches. All these operations are performed by a programmable logic controller (PLC). The PLC, together with hard-wired logic, blocks the system during the frequency change and detects and signals any fault in the switching elements. To ensure stability during the process, the open loop gain is kept low by disabling the grid pulser of the tetrode and blanking the driver.

EXPERIMENTAL RESULTS

Measurements of the cavity and of the closed loop frequency responses at 20 kVp are shown in Figures 4 and 5. Low voltage results (100 Vp) are given in Figures 6 and 7.

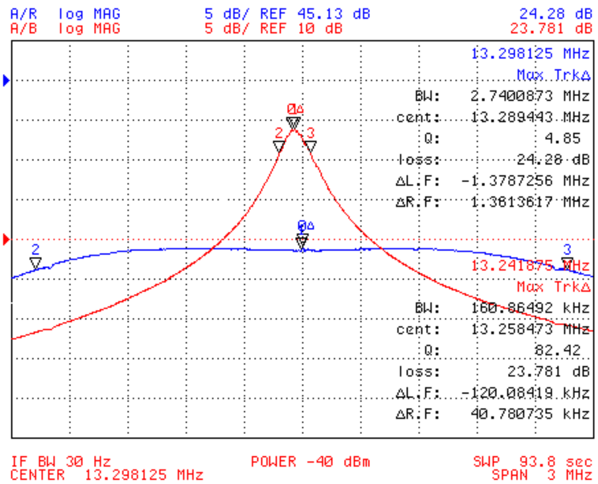

Figure 4: Response of the system at 13 MHz and 20 kVp.

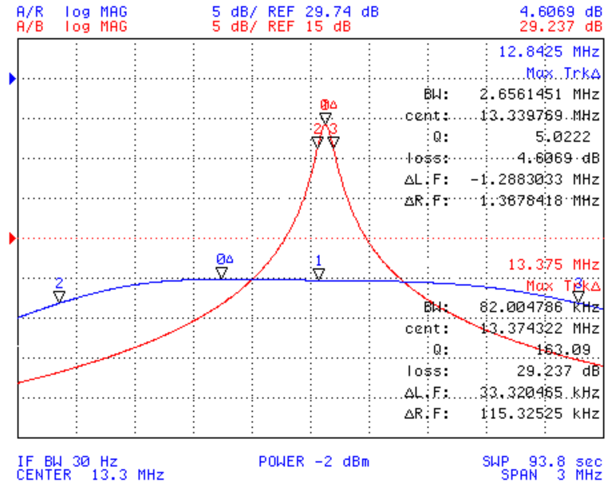

Figure 6: Response of the system at 13 MHz and 100 Vp.

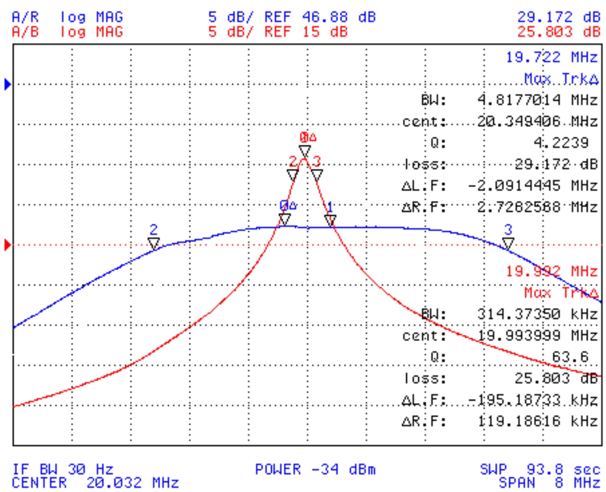

Figure 5: Response of the system at 20 MHz and 20 kVp.

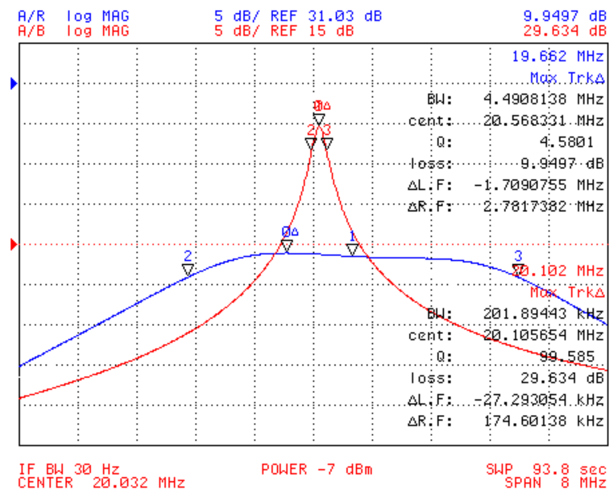

Figure 7: Response of the system at 20 MHz and 100 Vp.

The maximum voltage has been obtained with a duty cycle of 15% and 300 ms rf pulse length. The limiting factor is the gap heating. The feedback is adjusted at maximum and the measured bandwidths exceed the specifications by a factor two. At such high feedback gains, the frequency response is deformed and the ratio of closed loop over open loop bandwidth is greater than the amount of feedback introduced. Because of the change of the tune of the resonators with amplitude, the frequency responses are different at low and high voltages, and feedback adjustment is a compromise.

The system now installed in the PS will start being used with beam in June 2003. The first goal will be to check the performance of the gymnastics leading to 75 ns bunch spacing. The second system, presently in construction, will benefit from this experience and it will be installed during the next winter shut-down.

ACKNOWLEDGEMENTS

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