# INSTALLATION AND OPERATION OF THE NEW RF SYSTEM FOR LEPTON ACCELERATION IN THE CERN SPS

P.E. Faugeras, H.P. Kindermann, T.P.R. Linnecar, V. Rödel, A. Warman

European Organization for Nuclear Research (CERN), CH - 1211 Geneva 23, Switzerland

## Summary

32 accelerating modules, each made of a single-cell copper cavity, fed by its own tetrode amplifier, have now been installed in the SPS tunnel. These modules are arranged in groups of 8, each sharing the same HV power supplies and with a common RF driver chain, installed on the ground surface. Each module has its own controls crate, and 4 independent beam control circuits have been built, one for each group of modules. Three groups have already been put into operation and have allowed acceleration of leptons in the SPS up to 18 GeV for the LEP injection tests of July 1988, and up to the design energy of 20 GeV at reduced intensity. First operational experience of this system in the interleaved mode of operation of the SPS is also reported.

## Introduction

In order to adapt the SPS accelerator as an injector for LEP, a new radio-frequency accelerating system has been built and installed in the machine, which can provide a peak RF voltage of up to 32 MV at 200 MHz. As already reported,[1], this system makes use of 32 identical accelerating modules, each one being made of a single-cell copper cavity fed by its own tetrode amplifier which is mounted on top of it. In this paper, we will describe the overall installation, the power part and RF driving chain of the system, the associated beam control electronics and the computer control equipment and will also give the results of the lepton acceleration tests performed in July 1988.

## General layout

As a general rule, a minimum of equipment has been installed in the SPS tunnel, which is not accessible during beam operation, whereas a maximum has been left at surface level to ease operation and maintenance of the system. Therefore, only the 32 accelerating cavities, each with its tuner and damping devices,

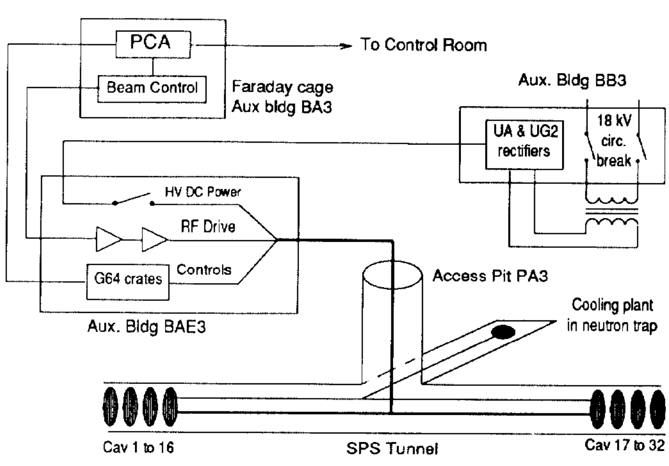


Fig.1 : Overall layout of the system

together with the RF power part of the final power amplifiers, [2], are installed in the SPS tunnel, 60 m underground, in the two missing magnet straight sections on either side of the long straight section 3. All the other equipments, such as DC power supplies for the tetrodes, RF driving chains, computer controls and low level circuitry are housed in existing surface buildings.

The overall layout of the system is sketched in Fig. 1. The Faraday cage contains the low level beam control electronics and the computers which are linked to the main control room. In the auxiliary building BB3 are housed the HV mains circuit breakers which feed the rectifier transformers (outside the building) and the HV anode and screen grid supplies. The DC voltages from these supplies are transported about 80 m to building BA3 where HV isolating and grounding switches provide the distribution to the individual power amplifiers. RF drive equipment and controls racks for all cavities and amplifiers are also installed there, as well as auxiliaries for the final amplifiers, (400 Hz generators for powering the blowers, regulated supplies for the filament transformers, ...). An impressive number of cables, which carry the HV DC power, the RF drive power, the controls and various measurements, leave this building, run down the 60 m access pit, to reach the individual modules in the SPS tunnel, some 280 m away from BA3.

The 60 kW RF final power amplifiers had to be mounted on top of each accelerating cavity: there is not enough space available in the SPS tunnel and access pit to install 32 high power transmission lines, not to mention the cost. Some of the water-cooled elements like the power tetrodes and the cavity damping devices, do not withstand high water pressure. To eliminate the 6 bars pressure due to the 60 m high access pit, a water cooling plant with pumps and heat exchanger, has been placed in a small cavern at the bottom of the pit ("neutron trap"), together with a clean air compressor for cooling the cavity damping loops and RF power windows. The final amplifiers are also air-cooled, but because of the required air flow, with individual small size 400Hz blowers mounted on the tunnel wall, beside the filament transformers, near each amplifier.

## The power plant and RF driver

The 32 cavities have been arranged into 4 identical groups: a common RF driver (identical to a final amplifier) feeds the 8 final amplifiers and one common anode power supply, (10 kV, 1.1 MVA), feeds this driver and its group of 8 final amplifiers. Since the screen grids of the power tetrodes are physically grounded, the use of a common anode supply requires also a common screen grid supply for these 9 tubes. However, each tetrode has its own regulated control grid bias supply, equipped with an active bleeder, using transistors. Anode and screen grid power supplies are equipped with thyristor crowbar circuits, which diverts the stored energy in case of a tube arc.

Motor-driven isolating and grounding switches are included in the anode and cathode lines to the 9 tubes to allow operation of the plant with any amplifier off line. All HV switches of one group

CH2669-0/89/0000-0106$01.00©1989 IEEE

are mounted on a common shaft and magnetic clutches control the switching of the individual tubes. DC current transformers are also installed in the cubicles of the HV switches to monitor the anode current $I_a$ and screen grid current $I_{g2}$ of each tetrode, the latter requiring a differential transformer.

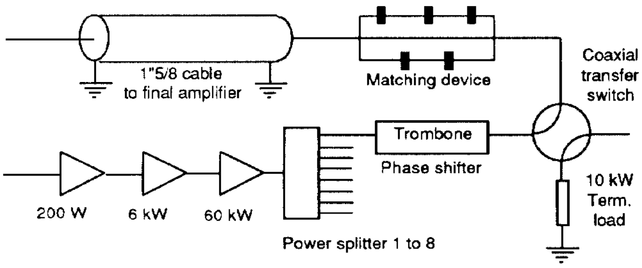


Fig.2 : RF driver chain for a group of 8 cavities

The RF driver chain for one group of 8 cavities is shown in Fig. 2. The predriver consists of a 200 W transistorized amplifier and of a 6 kW TV amplifier. The output power of the 60 kW driver is split into 8, two $\lambda/4$ coaxial transformers matching the 8 50Ω outputs to the driver output impedance. Each of the 8 outputs feeds one final amplifier via a coaxial transfer switch, a phase shifter, a matching device and a 1 5/8" Flexwell cable. The motor-driven transfer switch is connected to a water-cooled 10 kW 50Ω load, which absorbs the corresponding drive power whenever the final amplifier is switched off line. The phase shifter is a coaxial trombone and permits the precise adjustment of the 180 degree phase shift between two successive cavities. The matching device uses a line section with 5 adjusting screws, and allows elimination of any amplifier and cable mismatch, which is important for equal power distribution at the output of the power divider.

## The low-level electronics

The design of the beam control circuitry is influenced by the need for compatibility with the existing SPS accelerating systems as well as by features defined by the power hardware, as described above, and by specific requirements for lepton acceleration in the SPS. As shown on Fig. 3, the low-level system divides naturally into the cavity control electronics concerned with each group of cavities and the beam control electronics related to the interaction of the beams with the RF wave.

The majority of the cavity control electronics is designed at an intermediate frequency of 10.7 MHz, and input and output mixers to the SPS frequency of 200 MHz, are used with a local oscillator, LO, which is controlled by the beam control electronics. Cavity control is done globally on all eight cavities of a group, which have the same driver amplifier. Nonetheless individual cavities must be monitored to prevent, e.g., overdrive of the final amplifiers. A linear detector working at 200 MHz with a linearity of 1 % over more than 40 dB dynamic range is employed to monitor the forward power to each individual cavity. The result is used for limiting, by hardware, the RF power to 1 kW at switch on and subsequently , as soon as the tuner of each cavity of a group is locked to its correct position, to a maximum power level of 60 kW, defined by the capabilities of the hardware.

The tuner position of each cavity is servoed with a loop which uses the phase error detected between the forward power and the cavity signal. Also, an amplitude loop holds the sum of the eight cavities to the level required within the single cavity hard limitation values. Note that each cavity has a high quality cable calibrated in amplitude and phase from the monitoring loop to the electronics, whereas each group of cavities has its own local oscillator at 10.7 MHz, used in a phase loop to keep the relative phases of the different groups to the required values.

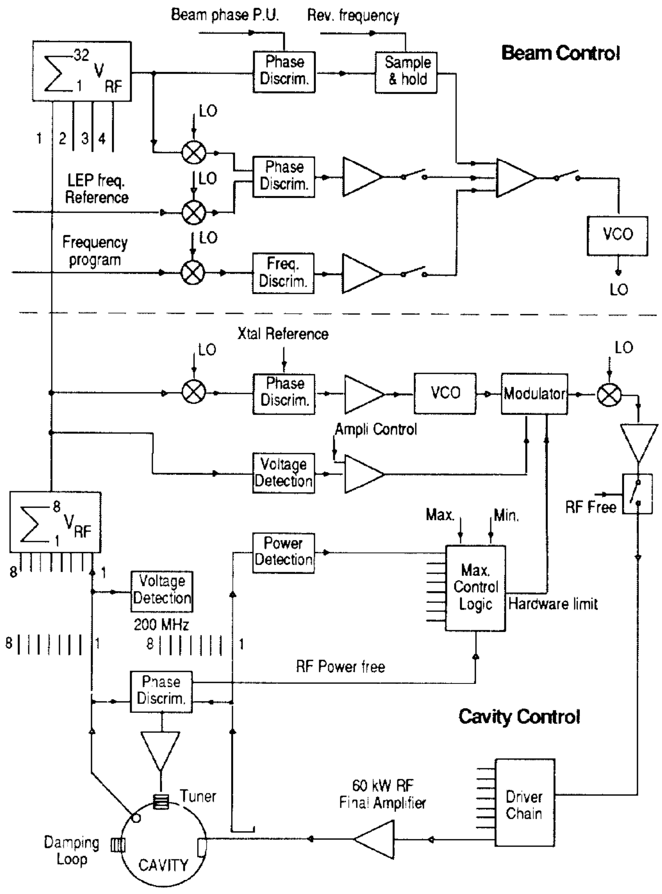


Fig. 3: Low level beam and cavity control

At injection into the SPS, the synchrotron radiation damping time is 5 s. The beam control system has therefore a phase loop, RF-beam, to damp injection oscillations and maintain longitudinal stability on the first dipole mode. Up to eight bunches are injected and the 200 MHz fast phase detector of Fig. 3 is followed by a sample-and-hold circuit, triggered at the revolution frequency. The signal thus obtained from the first injected bunch is used to control the local oscillator at 189.3 MHz via the loop amplifier. The complete loop response time is approximately 150 μs.

The match voltage for the injected beam is 500 kV, while the peak accelerating voltage with 32 modules goes up to 30 MV. The amplitude loop provides this range, but lower voltages values imply counterphasing between groups via the 10.7 MHz reference. The frequency which is constant in lepton operation is maintained by locking the local oscillator to the LEP reference in both frequency and phase using a synchronisation loop. A frequency loop is also provided for diagnostic purposes like chromaticity measurements.

## The microprocessor controls

The controls of this new acceleration system have been built according to the design principles for the LEP controls, [3], and their architecture, sketched on fig. 4, reflects the hardware construction and is based on two main pieces:

- G64 control crates connected to the equipments,
- a Process Control Assembly, PCA, for communication and synchronisation.

For each group of 8 cavities, there are 11 control crates in total, one for each accelerating module, one for the anode and the screen grid power supplies, one for the driver chain, and one for all common services of the group. These crates are fully independent, are built in the G64 standard and make use of two types of cards:

- system cards, which comprises the CPU card, the timing card and the interface with the multidrop bus,
- cards directly connected to the hardware, for digital inputs and outputs, analog I/O and interlocks.

The hardware cards, 6U high, have been specially developed for our needs with a view of minimizing the wiring, junction boxes and electronic interfaces with each equipment, while being fully interchangeable in between different types of crates. For instance, the interlock card can have up to 54 interlock signals on its input and can deliver up to 8 stop signals. The matrix link between interlocks and stops is made by PAL's, which combine easy programing and changing of the matrix if needed while keeping reliability of hardware interlocks. Any stop coming out of this card can either be directly connected to a digital I/O card or be input on another interlock card, such that crates can be linked by hardware from the interlock point of view.

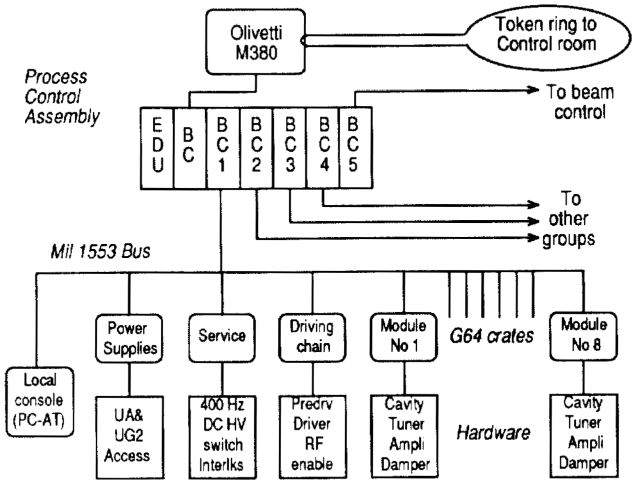


Fig. 4: Principles of the computer controls

The digital I/O card can drive up to 24 different equipments, through floating and insulating Darlington transistors, and makes use of Erasable Programmable Logic Devices which allow any sophisticated equation. The analog I/O card can input up to seven differential signals and 2 times 4 temperature measurements on 2 12-bits ADC's and can give 2 outputs with 12-bits DAC's. Each analog signal may be compared with min and max values set by 8-bits DAC's to provide interlocks.

All G64 crates run programs written in PASCAL under AMX, a small multitask operating system. The microprocessor is actually a 6809 but will be changed for 68000 type with OS9 as operating system. The 11 crates of a group are linked together by a Mil 1553 multidrop bus, driven by a bus controller which resides in the Process Control Assembly. This PCA is a VME crate associated with a PC and houses the five bus controllers together with the Equipment Directory Unit, which allows synchronisation of the action of the G64 crates on a link as well as of the full system. By connecting the PC, (actually an Olivetti M380C), to a token ring, one can access the equipment from the control room and from any place via the CERN local network. The PCA software is written in "C" and runs under XENIX.

## Commissioning and operation

The first eight cavities were installed in the SPS ring in 1987, the next sixteen during the winter shut-down of 1988, and the last group of eight just now in 1989. Part of the SPS shut-downs had to be reserved for commissioning and RF conditioning of the instal-led modules, before restarting the machine. Because of the large distances between the different components, parasitic oscillations of the whole amplifier chains were observed at frequencies between 10 and 500 kHz during commissioning, but could be suppressed by adequate filtering in the anode and control grid leads.

Although the cavities were conditioned in the lab, they had to be reconditioned after their installation. RF conditioning started at a base pressure of lower than $10^{-8}$ Torr. With a small amount of RF at the nominal frequency applied to a cavity, the position of the piston tuner is adjusted for the minimum of reflected power at the cavity input before closing the servo-loop which keeps the cavity in tune. The level of the RF power which is then applied to the cavity is controlled by a fast reacting loop from the pressure which must not exceed $10^{-7}$ Torr. It takes about 8 hours before 10 kW of RF power can be applied on each individual cavity. All eight cavities of the same group are then conditioned together to the full nominal power of 60 kW, which requires typically a further 16 hours.

Three groups have been commissioned so far with beam. This was done by using lepton cycles interleaved with the normal SPS cycles for high intensity proton operation. Note that during the proton part of the supercycle, all the damping loops had to be inserted into the cavities, and then retracted before lepton injection. The lepton cycles were tuned first up to 14 GeV/c with the existing travelling waves structures, then the SWC groups were commissioned one after another with little trouble. For the LEP injection tests of July 1988, the 3 groups provided reliably 18 GeV positrons. Although the four groups are needed for accelerating high intensity lepton bunches to 20 GeV, 3 groups allowed to reach this energy at a somewhat reduced intensity. To verify the voltage calibration of the cavities, one or more groups were switched on and off and the beam loss point during the cycle was recorded for each condition. Knowing the energy loss per turn from the B-field and dB/dt, the total voltage at the beam loss time can be found. This agreed to within 5% with the RF voltage calculated when knowing the R/Q, the RF power and the various cable calibration factors.

## Acknowledgements


This work has benefited from the support of D. Boussard, B. de Raad and E. Picasso. It is a pleasure to also acknowledge the contribution to this project of many members of the SPS division, and in particular G. Bérard, L. Dumas, J.M. Giguet, M. Goujon, J. Grieger, P. Griessen, R. Gueissaz, W. Herdrich, G. Lambert, F. Oude Moleman, G. Patti, G. Pistolato, W. Sinclair, D. Stellfeld, B. Sutton, U. Wehrle and F. Weierud.


## References


[1] P.E. Faugeras et al., "The new RF system for lepton acceleration in the CERN SPS", Proc. of the 1987 Part. Accel. Conf., Washington, 1987, pp 1719.

[2] W. Herdrich and H.P. Kindermann, " RF power amplifier for the CERN SPS operating as a LEP injector", Proc. of the 1985 Part. Accel. Conf., Vancouver, 1985.

[3] The LEP Design Report, Vol.II, CERN-LEP/84-01, CERN, 1984. see also: G. Beetham et al, " Development of the LEP/SPS control system", Proc. of the 1987 Part. Accel. Conf., Washington, 1987.