THE NEW RF SYSTEM FOR LEPTON ACCELERATION IN THE CERN SPS

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Summary

The use of the SPS accelerator as an injector for LEP requires a new radio-frequency system which is being built and installed in the machine. This system is made of 32 single-cell copper cavities, each one being fed by its own 60 kW RF power amplifier, mounted on top of the cavity, thus providing a peak RF voltage of 1 MV per cavity at 200 MHz. The interleaved acceleration of leptons and of intense proton beams in the SPS, as well as collider operation have required the design of special damping and tuning devices, mounted on each cavity. Performances of the first accelerating modules are described, with some emphasis on the effects of the very high surface electric field in the cavity.

Introduction

For the acceleration of electrons and positrons in the SPS to an energy of 20 Gev, a peak RF voltage of about 30 MV is needed at 200 MHz to compensate for the energy lost by synchrotron radiation and for parasitic mode losses and to adapt the bunch shape to the LEP buckets. The existing travelling wave structures of the SPS, which were designed for accelerating intense proton beams, can provide 9 MV at most and cannot be extended for practical and economical reasons.

As the lepton intensity will be low in the SPS and the beam loading not severe, the new RF system which has to be built for lepton acceleration can make use of high Q cavities. 32 single-cell copper cavities, each fed by its own power amplifier, will then provide a much higher energy gain per meter, thus permitting the installation of the new accelerating system in the two medium straight sections on either side of LSS3. The standard SPS frequency of 200 MHz was chosen for this system which can then also be used for collider operation to increase the available RF voltage during acceleration and beam storage.This frequency leads to accelerating modules whose dimensions are compatible with the SPS tunnel cross section: see fig. 1 , which shows the main components of a module.

The single-cell cavity

Fig. 2 is a cross section of a single-cell cavity, whose shape has been optimized with standard computer codes[1],for an outer diameter limited to 1.0 m and a beam hole diameter of 144 mm : the calculated unloaded Q reaches 53,000 and the shunt impedance 11.5 MΩ, but this implies a fairly high peak surface electric field of ≈ 12 MV/m on the radius of the drift tubes, for a total integrated gradient of 1 MV on the cavity axis. The distance between the centres of adjacent cavities is half a wavelength, i.e. 748 mm.

High-conductivity, oxygen free copper is used for the fabrication of the cavities: two half shells are cold-formed first from thick copper sheets. Holes are also cold-drawn on the cylindrical part of the longer half shell. The two shells are assembled by electron-beam welding to form the cavity body. Two nose-cone inserts and six output flanges are then brazed onto the cavity body in a vacuum oven at 800 °C . Finally, the cooling channels are soft-soldered on the outer wall of the cavity.

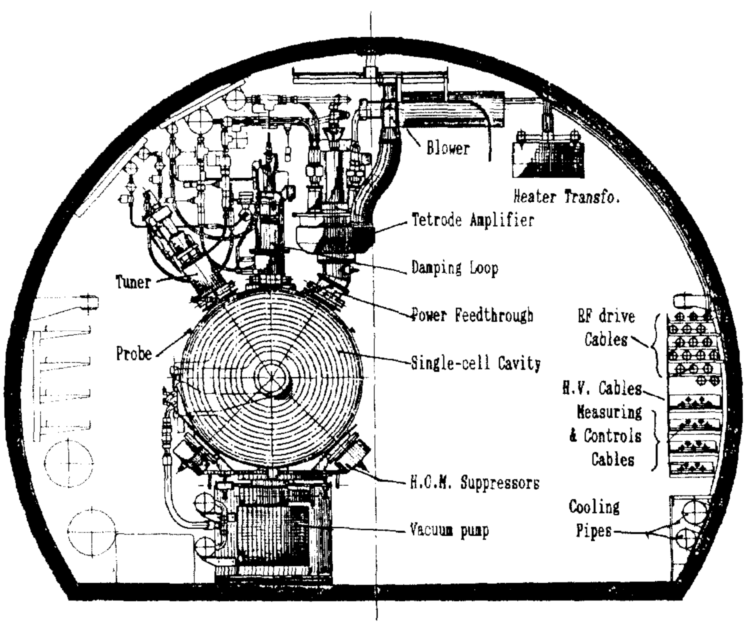

Fig. 1: Cross-section of the SPS tunnel with a new acceleration module

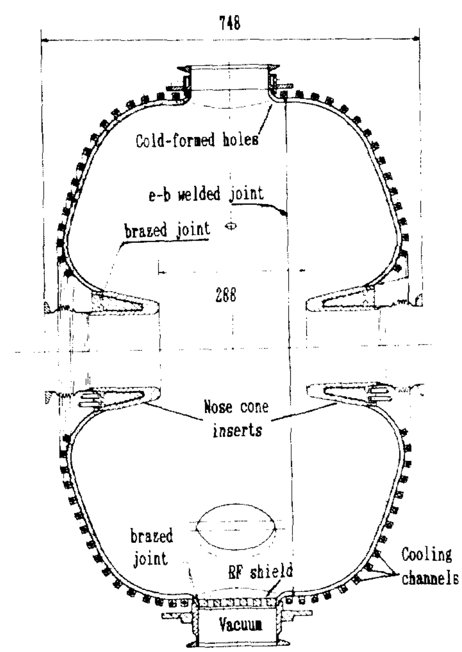

Fig. 2: Cross-section of a single-cell cavity

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This manufacturing procedure was successfully tested at CERN on prototypes, but led to difficulties during the series-production: cracks developed in the main circumferential weld during the high temperature vacuum-brazing. However, the finished cavities were still vacuum-tight and could then be repaired by rewelding them with a small rotating electron gun mounted inside the cavity.

When a cavity is finished, its resonant frequency is adjusted by small axial deformations which change the gap length. Then the cavity is cleaned by complete immersion in a bath with a special detergent at 50 °C, agitated with ultrasound, rinsed in demineralized water, dried out and pumped down. After two days of bake-out at 135 °C, the base pressure in the cavity is better than 10^{-8} Torr.

All cavities have a measured Q_0 higher than 49,000 and a shunt impedance around 8.5 MΩ. 60 kW of RF power are then necessary to reach the design voltage of 1 MV per cavity.

Tuning and damping devices

Piston tuner

Each cavity has a servo-controlled piston tuner which corrects for mechanical tolerances, thermal expansion and varying beam conditions : the available stroke allows a tuning range of 400 kHz which is large enough to also cover the frequency swing required for collider operation.

Damping loop

These new cavities cannot be used when the SPS is accelerating intense proton beams and must be damped sufficiently in order to insure beam stability, [2]. The principle of a resonant damping loop,[3], is shown in fig.3. A rectangular loop of 120*60 mm² strongly couples to the magnetic field of the cavity and is connected to the outside with a coaxial feedthrough. The reactance of the circuit is compensated with a short-circuited line (stub). The resulting real low impedance is then transformed via a $\lambda/4$ line to a 50Ω load resistor which is water-cooled, to cope with the beam induced power(≈3kW for $3{*}10^{13}$ protons in the SPS).

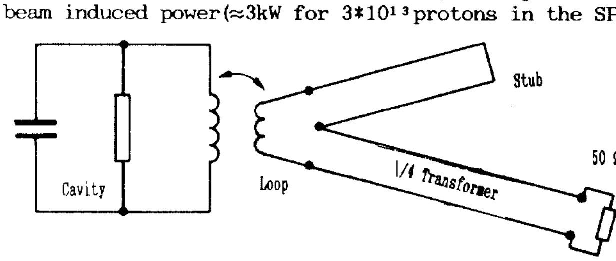

Fig. 3: Schematic of the damping loop.

Before proton acceleration starts, the loop is moved into the cavity, with a pneumatic actuator, thus providing a damping factor greater than 500 at 200 MHz whereas the loop is retracted for lepton operation. This 100 mm movement takes 0.5 sec and is made under vacuum, thanks to thin-wall bellows, which have been specially developed for this application and which are one of the most critical components of the whole system: the operation of the SPS as an injector for LEP, interleaved with its usual running for fixed target physics implies for each damping loop more than one million cycles per year. This damping device is mounted on the vertical top port of each cavity, so as to minimize the effects of shocks induced by the loop movement.

H.O.M. suppressors

Each cavity has an infinite number of resonating modes, some of them being harmful for the stability of the beams, in particular those at 306,396 and 600 MHz. Two types of higher order modes suppressors have been studied and are described elsewhere, [4]. After tests, we have chosen the resonant type as sketched in fig.4

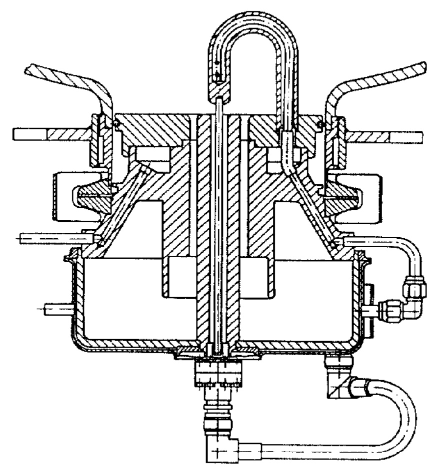

Fig. 4 : Section of the H.O.M. suppressor

This type of suppressor has the advantage of lower losses on the fundamental than the waveguide type . It is also more compact , cheaper to manufacture and easier to adjust, as it is made of machined copper pieces brazed together. Note that this device requires water-cooling, in particular for the coupling loop, because of the ohmic losses induced by eddy currents on the loop surface . Two such suppressors are mounted on each cavity, to take care of the two polarizations. Measurements on a fully equipped cavity, as in Fig.1, have shown that all modes up to 1 GHz and which may be of concern for the beam stability are sufficiently damped.

RF power amplifier and feedthrough

The 60 kW of RF power, which are necessary at the cavity input to reach the design voltage of 1 MV per cavity, are obtained with a tetrode amplifier, which has already been described, [5]. As shown on fig. 5, the amplifier is mounted on a skew port of the cavity, through a coaxial elbow, which is terminated by the power feedthrough and coupling loop,(see also fig. 1). This arrangement allows a quick exchange of the whole amplifier in case of problems and keeps the tetrode in the upright working position.

A coaxial design is used for the power feedthrough because of the short length available: a ceramic disc is brazed onto two thin and hollow copper conductors. The ceramic disc and the inner conductor are air-cooled, and the outer conductor water-cooled. All copper parts of the window in contact with the cavity vacuum are covered by a layer of ≈ 0.5 μm thickness of titanium deposited by sputtering, for lowering the secondary electron emission coefficient.The insulation resistance of the ceramic disc is also lowered down to 10 MΩ with a similar titanium deposit, which allows electrostatic charges to flow away during operation. The orientation of the coupling loop is adjusted to match the cavity impedance to that of the amplifier output (16 Ω for CW operation at 60 kW).

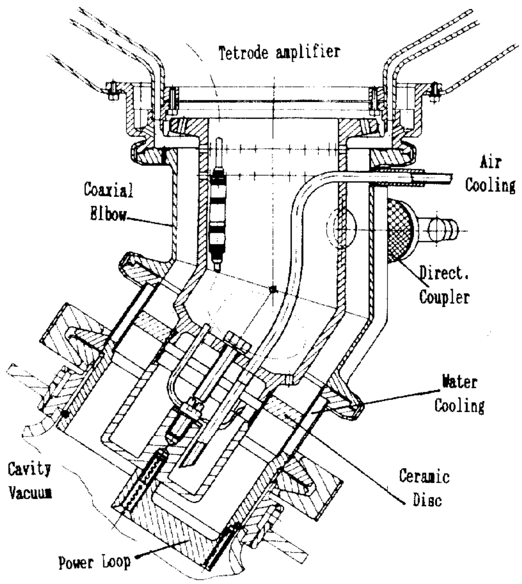

Fig. 5: The coaxial elbow and power window

Cavity conditioning

RF conditioning is done in the lab for each cavity individally and can be started when the base pressure is better than 10^{-8} Torr : RF power is then gradually applied and increased as long as the pressure does not exceed $3*10^{-8}$ Torr. Between this value and 10^{-7} Torr the RF power is kept constant but is reduced above, and stopped, if the pressure rises above $5*10^{-7}$ Torr, to avoid any damage of the power window.This process is done manually up to 3 kW of RF power and then under computer control.

At low power, the conditioning speed is limited by multipactoring on the ceramic window, which occurs at 300 W, 800 W and 2 to 3 kW. Once these limitations are overcome, the RF power can be relatively easily raised up to a level ≈ 20 kW, where horizontal light strips start to appear on the ceramic disc of the window. At the same time, electrons are detected (with a Faraday cup on the cavity axis) and are accompanied by X-rays and short small bursts on the vacuum pressure. One has to wait until the vacuum pressure is quiescent before being able to increase slightly the RF power. It may then take two to three days to reach 40 kW, but above this level the pressure stabilizes around $10*^{-8}$ Torr. The radiations increase with the RF power and reach an average of ≈ 50 rad/h at 1 m distance on the cavity axis for 60 kW in the cavity. Fig. 6 shows the light strips on the window at that power level.

Electrons produced by field emission are likely at the origin of these phenomena. One has then tried to suppress the emitting spots by RF processing: 60 kW of RF power are fed into the cavity filled with Helium or Argon at a pressure of $2*10^{-5}$ Torr. After a few hours the radiation level decreases by a factor 5 and the light on the window is strongly attenuated. However, this beneficial effect disappears after 24 hours of running with the cavity at the normal pressure.

Copper coating of the brazed joints which are in contact with the cavity vacuum looks more promising: the brazing alloy has indeed a high content of silver, which is known to be electron emitter under vacuum. 15 μm of copper have been electro-deposited locally on the two brazed joints between the cavity body and the nose-cones of a cavity.The X-rays and the light on the window are much lowered, but further investigations are necessary to confirm these results.

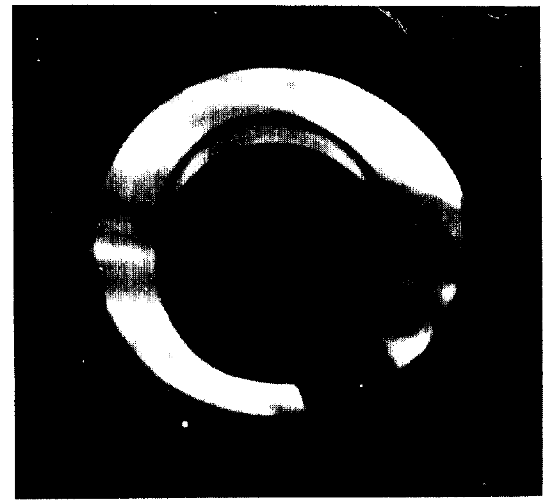

Fig. 6: TV picture of a ceramic window at 60 kW RF

Each module is filled with dry nitrogen after its conditioning and goes in the SPS tunnel fully equipped but without its amplifier and damping loop. In this way, its exposure to air during its installation is kept to a minimum. Eight modules are going to be put into operation this year to gain some experience. The other 24 modules will be installed during the next two SPS winter shutdowns, to be ready for LEP in 1989.

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