# Status of the LEP Accelerating Structure

P. Brown, G. Geschonke, H. Henke and I. Wilson
CERN, Geneva, Switzerland

**Abstract**. LEP uses a dual frequency acceleration system consisting of coupled accelerating and storage cavities. Basic design features of this system with its accessories and tuning system are described. One hundred and thirty cavities have been built by industry; the assembly and conditioning with RF power were done at CERN. All cavities are now installed in the LEP tunnel. The procedures used and first experiences will be presented.

## 1 Introduction

The LEP Phase I RF system has been designed for a circumferential voltage of 400 MV per turn. Since there are only four bunches of electrons and positrons over the circumference of 26.7 km, the time between bunch passages through the cavities is relatively long (22$\mu$s) . This has led to the development of an RF system where acceleration takes place in a five-cell cavity but between bunch passages the RF energy is stored in a low loss resonator which is coupled to the centre cell of the accelerating structure[1] . This system allows a reduction in the RF power requirements of 35%; its main parameters are shown in Table 1. The RF energy oscillations between storage and accelerating cavities are induced by simultaneously exciting the zero and $\pi$ mode resonances of the coupled cavity system. The five-cell accelerating structure is considered as a single resonator. Figure 1 shows a schematic view of the coupled cavity system.

| | |
|---|---|
| RF frequencies $f_1$: | 352.209 MHz |
| $f_2$: | 352.299 MHz |
| Total circumferential voltage | 400 MV |
| No. of cavities | 128 |
| Total RF generator power | 16 MW |
| Coupling between accelerating and storage cavity | $2.55\times10^{-4}$ |
| Effective shunt impedance of coupled cavity system ($V^2/P$) | 40 M$\Omega$/m |
| Active length of accelerating structure | 272.6 m |
| Maximum dissipated power per cavity unit | 116 kW |
| Dissipated power in storage/ accelerating cavity | 23/93 kW |

Table 1: Basic LEP Phase 1 RF Parameters

## 2 Cavities

### Accelerating Cavity

For the accelerating structure a copper five-cell slot coupled reentrant cavity was chosen; the optimized cellshape is shown in Fig. 2. The basic building blocks are disks with nose cones and seamless cylinders, which are machined from solid forged pieces, assembled and then electron beam welded together. All transitions to stainless steel components are made by vacuum brazing with a copper-silver eutectic. Water cooling of the cavities is provided by rectangular copper tubes brazed onto the cylinders and by a star shaped circuit of deep drillings into the disks.

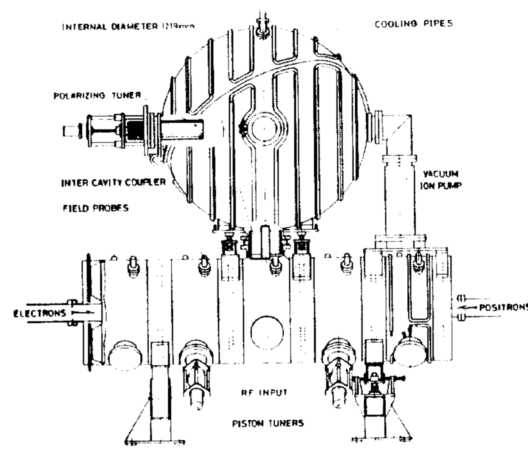


Figure 1: Coupled cavity system

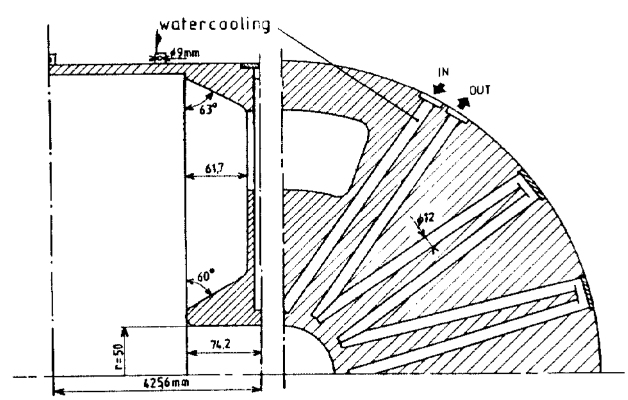


Figure 2: Accelerating cavity cell shape

A thermal analysis of this arrangement shows that with 125 kW of RF power dissipated in the accelerating cavity and a water flow of 114 $\ell$/min the maximum temperature increase will be 24.4°C on the cylinder walls and 20.2°C on the nose cones. This increase in temperature leads to a reduction in shunt impedance of 4.2% compared to the value at 20°C[2].

The main measured parameters of the accelerating cavity are:

| | |
|---|---|
| Shunt impedance | 26 M$\Omega$/m |
| Cell to cell coupling | $1.29\times10^{-2}$ |
| Surface electric field /average accelerating field | 5.1 |
| Q value | 40 000 |

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### Storage Cavity

The spherical storage cavity is operated in the low loss $H_{011}$ mode. The cavity together with its tuner has a measured Q value of 160 000. This mode has three-fold degeneracy, but the action of the tuner-polarizer defines the orientation of the desired polarization and moves the other two $\approx$ 3 MHz down in frequency. The cavity is made from oxygen free high purity copper with 0.1% Ag to improve the creep properties during bakeout at 150° C. The 1.22 m diameter spherical cavity is formed from two hemispheres spun from 8 mm sheet which are electron-beam welded together on an inclined equator. Due to the large tolerances of this technique each cavity pair of hemispheres is individually trimmed. This is done by mechanically clamping together two oversized hemispheres, measuring and then correcting the resonant frequency by machining the faces. Water cooling is provided by copper cooling pipes brazed to the outer surface.

## 3 Couplers

### Power Coupler

A drawing of the power coupler is shown in Fig 3. The RF power is coupled inductively into the cavity by a short circuit loop terminating a short coaxial line which is an integral part of the coax-waveguide transition. This design allows easy access for water cooling of the inner and outer conductors. The vacuum seal is made with a cylindrical ceramic window (97% $Al_2O_3$) between the outer coaxial conductor and the doorknob transformer. A metal ring is vacuum brazed to the ceramic on the outside of each end, these rings are TIG welded to stainless steel rings which are themselves brazed to the copper. The ceramic has a sputtered Ti coating on the inside with a surface resistance of $10^8\Omega$. These couplers have been tested at a maximum CW power of 180 kW, the nominal maximum operating power being 116 kW.

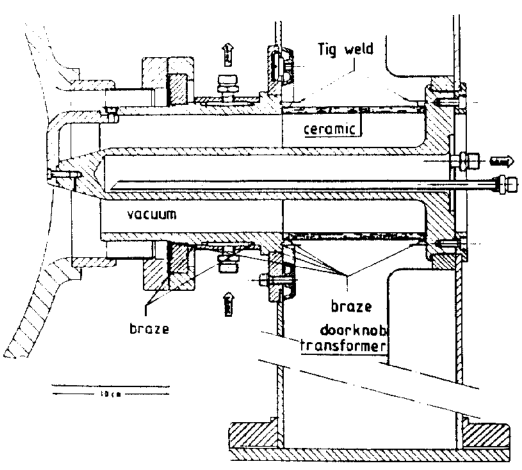


Figure 3: Power coupler

### Intercavity Coupler

The intercavity coupler is shown in Fig. 4. It couples to the magnetic fields of both cavities via a short coaxial line with a short circuit loop at each end. The loops are oriented at 90° to each other so that the coupling strength can be adjusted by rotation of the coupler. Both inner and outer conductors are water cooled.

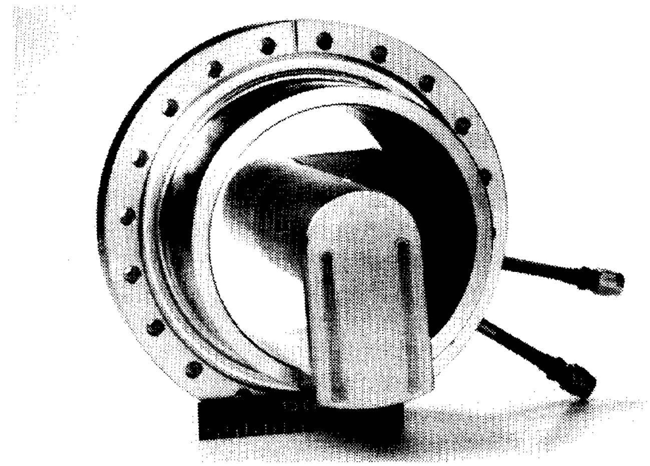

Figure 4: Intercavity coupler

## 4 Tuning System

The resonant frequency of each coupled cavity system is tuned by a set of three piston tuners, an identical pair of short tuners in cells 2 and 4 of the accelerating cavity and a longer but otherwise identical combined tuner/mode-polarizer in the storage cavity (Fig. 5). The tuners are moved by 5-phase stepping motor driven trapezoidal screw drives. The tuners in the accelerating cavity have 100 mm diameter copper pistons with a stroke from -20 mm to +50 mm of penetration from the position flush with the inner wall of the cavity, giving a tuning range of 450 kHz. In the storage cavity the longer 120 mm stroke allows tuning over an 800 kHz range. At maximum penetration of the tuner the Q value of the storage cavity is reduced by 5%. The mechanical resolution of the tuners is 1$\mu$m/step which corresponds to 7 Hz/step. The bellows of the accelerating cavity tuners are protected from RF currents by berylium bronze finger contacts. Cells 1 and 5 are equipped with fixed tuners, which are simple water cooled copper pistons of 100 mm diameter , individually adjusted by machining to compensate for fabrication tolerances of the cavity. A block diagram of the cavity tuning control system is shown in Fig. 6. The tuning control is complicated by the fact that the storage-accelerating coupled cavity system is simultaneously excited at both its zero and $\pi$ mode resonant frequencies $f_1$ and $f_2$ respectively.

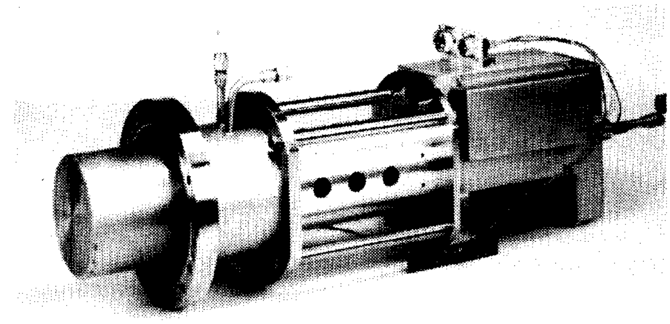

Figure 5: Tuner

Samples of the RF fields in the storage cavity and each cell of the accelerating cavity are taken via inductively coupled field probes whilst the forward and reflected drive signals are sampled by directional couplers mounted in the waveguide just upstream of the doorknob transition of the power coupler.

Since synchrotron radiation levels in LEP prohibit installation

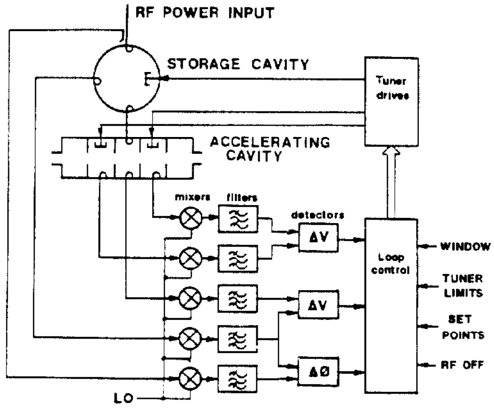


Figure 6: Tuning Control System

of electronic devices in the tunnel, all of these signals are transmitted from the accelerator tunnel to the equipment racks in the parallel klystron tunnel via low loss coaxial cables. These signals are then distributed for power measurements, general monitoring and tuning control. In the tuning control system double balanced mixers and filters convert these 352 MHz RF signals down to an IF of 20 KHz still retaining the original phase and amplitude ratios but where the increased fractional separation allows simple filtering of the IF corresponding to $f_1$ or $f_2$. For the tuning control system only the IF signal corresponding to $f_1$ is used.

For closed loop tuning control a phase detector senses phase changes between the forward signal and the fed cavity whilst an amplitude ratio detector senses the relative changes in amplitude between the two cavities. An additional amplitude ratio detector compares the fields in cells 2 and 4 of the accelerating cavity. After processing, these error signals are used to tune the cavities by moving the appropriate tuners. The accelerating cavity is tuned by parallel movement of its tuners and balanced by moving them differentially.

The tuning algorithm uses the following equalities:

$$\Delta\text{phase(Forward-fed cavity)} = K_1(\Delta\omega_{02} + \Delta\omega_{01})$$

$$\Delta\left(\frac{\text{Voltage-fed cavity}}{\text{Voltage-idling cavity}}\right) = K_2\Delta\omega_{02}$$

where

$$\Delta\omega_{01} = \text{tuning error fed cavity}$$

$$\Delta\omega_{02} = \text{tuning error idling cavity}$$

and at resonance

$$K_1 = 5^\circ/\text{kHz and } K_2 = 2\%/\text{kHz}$$

To avoid undue wear of the tuners' RF contacts a window detector inhibits tuning until the error exceeds a preset threshold. Operation is also inhibited in the absence of RF drive. The phase detector and amplitude ratio detectors have resolutions of better than 0.1° and 0.1 dB respectively over a dynamic range of $> 30$ dB. The loop set points are controlled by applying dc offset voltages to the detectors. The tuning system is interfaced to the LEP control system through the cavity EQUIPMENT CONTROLLER (EC). All error signals, setpoints, window thresholds, tuner positions etc. can be individually read or set by the EC which can also override the automatic tuning system and directly move the tuners to any desired position e.g. cold start, detuned etc.

## 5 Fabrication, Assembly and Conditioning

A total of 128 cavity units is needed for LEP. The cavities and all components were produced by industry and the final assembly was done at CERN[4]. During the assembly the fixed tuners were individually adjusted by machining to obtain an even distribution of the electric field in the five cells of the accelerating cavity. The field flatness before coupling to the storage cavity is ±5%. The coupling between the two cavities is adjusted very accurately by rotating the intercavity coupler. The precision for the spacing of the zero and $\pi$ mode frequencies was better than 100 Hz. Matching of the power coupler was adjusted by rotating the loop to a value of $\beta = 1.12$. The inductively coupled field probes were adjusted for a coupling of -50 dB with respect to the power fed into the cavity. After assembly the cavity units were baked out at 150° for 24 hours and then conditioned with RF for about two weeks in an automatic conditioning stand[5]. The pressure in the cavities after bakeout was usually better than $3 \times 10^{-10}$ mbar. During RF conditioning a computer-controlled system maintained the RF power at the maximum level compatible with a pressure below $6\times10^{-7}$ mbar. A separate hard-wired interlock switched off the RF if the pressure exceeded $2 \times 10^{-6}$ mbar. Conditioning a new cavity up to 140 kW usually took 10-15 hours; after two weeks the pressure was $\approx 10^{-9}$ mbar for any level of RF power. The evolution of partial pressure of several masses is given in reference [6] and Fig. 7 shows the result of conditioning.

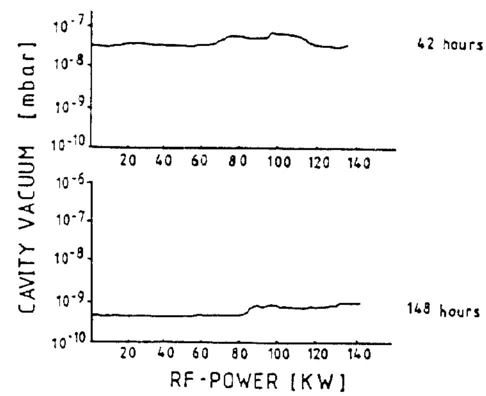


Figure 7: Cavity vacuum as a function of RF power after different conditioning times

## 6 Present Status

All 128 cavity units are finished and installed in the LEP tunnel. Operationally the RF system is organized into eight RF UNITS where each RF UNIT of 16 cavities and two klystrons is an autonomous RF system. At the present time six RF UNITS have been commissioned and operated to maximum nominal power; the remaining two RF UNITS will be commissioned in April 89.

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