The 433 MHz accelerator for the ELSA high-peak power FEL

S.Joly, P. Balleyguier, R. Dei-Cas*, H. Leboutet
Commissariat à l'Energie Atomique
Service de Physique et Techniques Nucléaires
91680 Bruyères-le-Châtel - FRANCE

Abstract

The 433 MHz linac is constituted by one two-cell and two three-cell cavities equipped with HOM absorbers and designed to reduce wake-field effects when intense beams will be accelerated. The linac is powered by a unique 6 MW peak power klystron protected by a three-way circulator. After RF conditioning of the cavities, the linac has accelerated low-intensity electron beams up to 17 MeV.

I - INTRODUCTION

For a high-peak power free-electron laser, the electron beam brightness should be as large as possible while the relative energy spread of electron bunches is to be reduced below 5.10^{-3}, typically. The injector, the accelerator as well as the beam transport line have to be designed to fulfil these requirements.

High-brightness electron beams can be generated with a photo-injector. Our RF gun cavity frequency is very low (144 MHz) compared to usual injectors ; RF effects are minimized and fairly long electron bunches (up to 200 ps) with high charge (10-20 nC) can be handled [1]. It was expected, however, that attainable electric fields would be limited resulting in emittance growth. Recently, up to 1 MW RF power has been injected in this cavity ; the maximum electric fields are about 33 MV/m on the cavity noses and 28 MV/m on the photocathode. The electron kinetic energy reaches then 2.0 MeV. This injector has been tested for two years now and is delivering 5 nC electron bunches at 1.6 MeV at a repetition rate of 14.4 MHz during the 120 µs macropulse.

A minimum energy spread within the bunch and a large peak current can be obtained using a low-frequency accelerator ; 433 MHz was chosen as a good compromise between low (favouring reduced energy spread) and high (higher accelerating fields) frequencies.

II - THE ACCELERATING CAVITIES

For the design, as well as the fabrication techniques, we benefitted from CERN experience with the LEP accelerating cavities [2].

The standing-wave RF cavities consist of three coupled cells operating at 433 MHz in the π-mode ; however, to reduce the emittance growth at low energy, the first 433 MHz cavity has two cells only resulting in a largest accelerating gradient.The cell shape was first optimized by means of computer codes and then with a full size mock-up to reduce the wake field effects and to minimize the emittance growth while keeping the accelerating gradient as high as possible, of the order of 7-10 MV/m [3].

The mock-up was built to measure the E-field distribution in the three cells as a function of the coupling slot area and to measure the higher order mode distribution related to the design of efficient HOM dampers. Two orthogonally located dampers could damp most of the parasitic modes ; a damper includes a stop-band filter at 433 MHz constituted by the outer coaxial structure which is $\lambda/4$ long for the accelerating frequency and terminated by a short-circuit.

The power injection loop was designed to allow high power input resulting in large dimensions. The RF power is coupled inductively into the cavity by a short-circuit loop between the two conductors at the end of a coaxial structure. Consequently, the coupling factor β tends to be large and the short-circuit has to be pushed inside the injection part at 50 mm from the cavity sleeve to lower the β-value down to 2 which is the required value without beam. This short-circuit can be adapted as a function of beam loading.

To minimize emittance growth in the cavities, each port has a symmetric one relative to the cavity axis. In a three-cell cavity, the central cell contains the injection loop and the pumping port in the horizontal plane, the frequency movable piston tuner and a fixed tuner in the vertical plane.The fixed tuners were individually adjusted by machining to compensate for fabrication tolerances of the cavity and to obtain an even distribution of the electric

---

* Present address
DRECAM
CEA - Centre d'Etudes Nucléaires de Saclay
91191 GIF SUR YVETTE - FRANCE

field in the cells. The extreme cells contain two fixed tuners (top and bottom) and two orthogonally located HOM absorbers.

III - THE ACCELERATOR CHAIN

The accelerating 433 MHz cavities are fed by a unique high-peak power klystron delivering 6 MW peak power and 200 kW average power during the 200 µs macropulse. The full power has been tested first on a water load. As the RF amplitude stability during the macropulse is very important for an oscillator-type FEL, a hard-tube modulator has been developed. The modulator uses a feedforward feedback loop compensating the voltage droop caused by the partial discharge of the capacitor bank by controlling the grid voltage of the modulator tetrode tube. The HV pulse applied to the klystron is corrected from macropulse to macropulse using a recurrent algorithm by means of a microcomputer ; the applied 170 kV pulse is constant over 100 µs with a precision level as high as 5.10^{-4} [4-5].

To protect the klystron, especially the RF window, from reflected power, a three-port circulator using ferrite disks has also been developed and tested at full power ; the reflected power was then feeding a water-cooled dummy load. After the circulator, the RF power is transmitted to the accelerating cavities through couplers and WR1800 wave guides, each coupler having its own water load. Two of the three legs are equipped with a phase shifter to allow the fields in each cavity to be set at the desired phase relative to the others. For power measurements as well as interlocks, pairs of directional couplers for forward and reflected waves are mounted : i) between the klystron and the circulator, ii) on the waveguides before the power couplers.

IV - ACCELERATOR TESTS

Up to now, only the first two-cell cavity has been heated up to 110°C with superheated water circulating in the cooling channels and addition to external resistive heaters. The temperature was limited as a result of leaks observed in the RF gun cavity as both are sharing the same cooling section. The residual pressure in the accelerating 433 MHz cavities is usually in the 5.10^{-9} mbar range ; each cavity is pumped with a 400 l/s ion pump.

Because of the unique RF generator, the three cavities have been conditioned simultaneously. The RF power has been increased gradually, with a limited residual pressure below 10^{-6} mbar. Few breakdowns were observed during the process and after about 12 hours, the nominal RF power of 1.5 MW has been injected in each cavity. The macropulse repetition rate was varied between 2 and 10 Hz with a fixed pulse length of 200 µs, i.e. a maximum duty cycle of 2.10^{-3}.

The first time an electron beam has been accelerated, the dispenser cathode was used. Under illumination with a laser at 532 nm, this type of cathode has a fairly low quantum efficiency

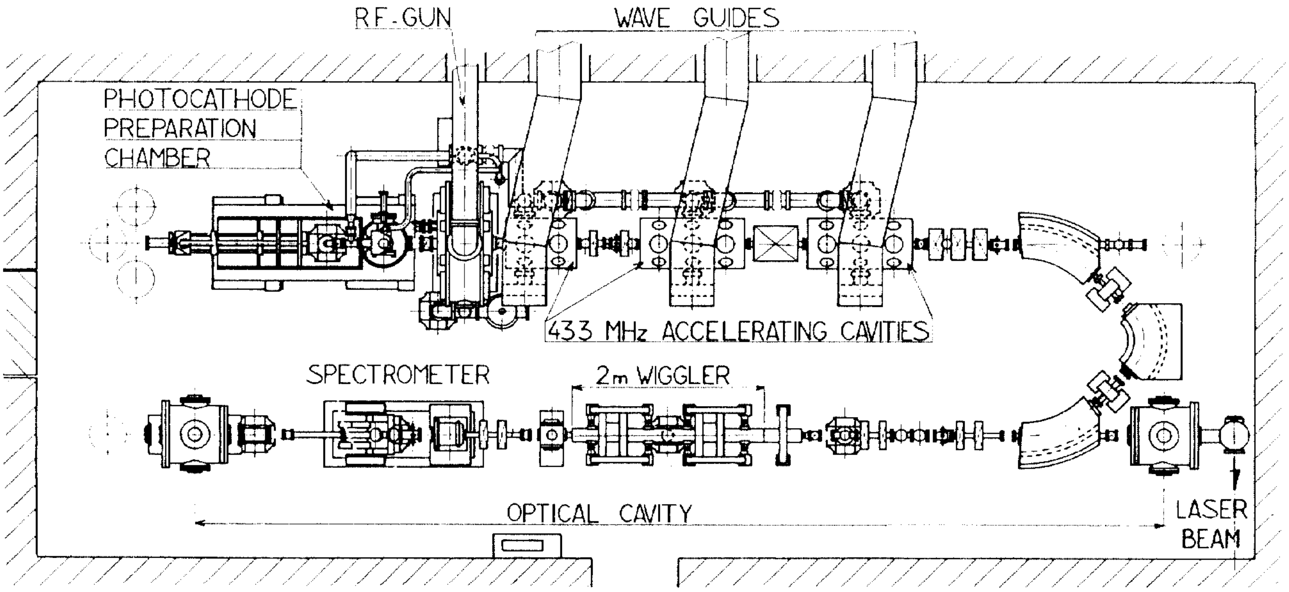

Fig.1. Layout of the ELSA free-electron laser.

(~ 1.10^{-5}) but with 20 to 50 µJ laser pulses, electron bunches with charge up to 100 pC can be produced. This intensity is large enough to tune the accelerating cavities and the beam transport elements like focussing solenoids, quadrupoles, steerers. Later on, bialcaline CsK_2Sb photocathodes have been used to produce electron bunches but the charge with limited to 1 nC ; in the near future 5 nC bunches should be accelerated at 15-16 MeV. The beam position and radius are measured by means of scintillators on actuators ; the position is also determined with strip-lines and the beam current intensity with Rogowski coil as well.

The beam energy is measured in the middle of the U-turn where the beam is first bent by 45° and then by 90° and finally by 45° [6]. A scintillator is introduced in the 90° dipole magnet centre defining the central trajectory location ; the beam energy is then readily deduced.

Figure 1 shows the layout of the ELSA free-electron laser ; the 144 MHz RF gun is followed by the two-cell cavity and then by the two three-cell cavities.

V - REFERENCES

[1] S. Joly et al., "Progress report on the BRC photo-injector", Proc. of EPAC-90, Nice, 1990, p. 140.

[2] P. Brown, G. Geschonke, H. Henke and J. Wilson, "Status of the LEP accelerating Structure", Proc. of the IEEE Particle Accelerator Conference, Chicago, 1990, p. 1128.

[3] P. Balleyguier, R. Dei-Cas, S. Joly and H. Leboutet, "Experimental study of a 433 MHz 3-cell cavity for FEL application", Proc. of the 2nd European Particle Accelerator Conference, Nice, 1990, Ed. Frontières, Gif sur Yvette, p. 910.

[4] R. Dei-Cas et al., "The 433 MHz RF generator for the ELSA-FEL experiment", Nucl. Instr. and Methods A304 (1991) 212.

[5] R. Dei-Cas et al., "Photo-emission studies and commissioning the ELSA-FEL experiment", FEL-91 Conference, Santa Fe, to be published in Nucl. Instr. and Methods.

[6] J. Aucouturier, J.P. De Brion and H. Leboutet, "Layout of the ELSA U-Turn", Nucl. Instr. and Methods A 304 (1991) 305.