PROGRESS REPORT ON THE BRC PHOTO-INJECTOR

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Abstract

The high brightness photo-injector developed for the high-peak power FEL under construction at Bruyères-le-Châtel is under test now. Up to 22 nC bunches have been produced by CsK_2Sb photocathodes and accelerated to 1 MeV ; experiments are under way to measure electron bunch characteristics as a function of charge.

Introduction

Free-electron lasers impose severe requirements for the production of high-current high brightness electron beams ; these are expected to be fulfilled with a photo-injector. Compared to other designs [1], our RF gun cavity (figure 1) has a much lower frequency (144 MHz) ; RF effects are expected to be minimized and longer bunches (up to 100 - 200 ps) can be handled. On the other hand, at low frequency, lower accelerating voltages are attainable and this may induce emittance growth. However, fairly large surface fields have been reached (~ 25 MV/m) in a first conditioning period. The quantum efficiency of CsK_2Sb photocathodes reaches 0.5 % but the preparation technique has still to be improved as only about twenty photocathodes have been prepared up to now. The recent developments on the photo-injector components as well as preliminary experimental results are presented.

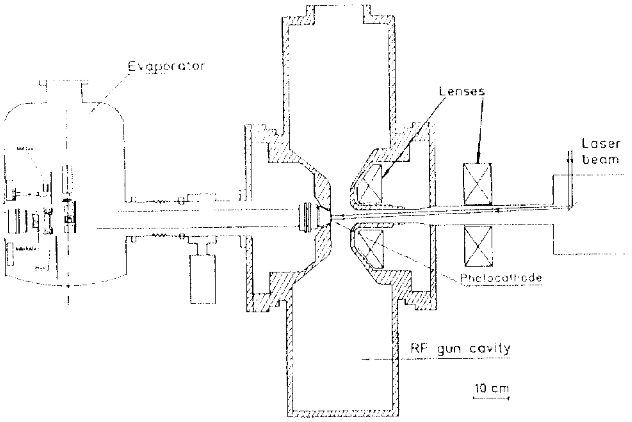

Fig. 1 - Schematic view of the photo-injector and the photocathode preparation system.

RF gun cavity conditioning

The geometry of the 144 MHz RF gun cavity has been described previously [2,3]. To get a good vacuum, the cavity is baked at a maximum temperature of 160°C to make sure the weldings made by the electron beam technique do not suffer.

The cavity is equipped with a turbomolecular pump, a 400 l/s ion pump and a Ti-sublimation pump ; the minimum pressure we obtained was 2.10^{-9} mbar without RF power.

The RF power is supplied by a TH-526 tetrode delivering an average macropulse power of 2 MW and transmitted to the cavity through a 9" coaxial line. For power measurements as well as interlocks, directional couplers are mounted for forward and backward waves ; transmitted power into the cavity is measured as well. The cavity is kept at resonance by means of a piston tuner. The tetrode output power is stabilized via a feedback control loop acting on the RF drive signal at the mV level. The power reflected back to the tetrode is monitored by a fast detector with interlock.

A microcomputer, using parts of the general control system under development, is used as a process controller for the following parameters : cavity vacuum, RF powers, temperature of the anode and cathode noses, some of these are graphically displayed as a function of time whereas RF powers transmitted into the cavity and reflected back to the tetrode are displayed during the macropulse duration. During conditioning the RF power is changed according to the cavity vacuum : starting from about 5.10^{-9} mbar, the pressure increases with power. The power increase is stopped when the cavity pressure is 5.10^{-6} mbar and then changed to maintain the pressure around this limit. The macropulse signal has a trapezoidal shape with a flattop 200 µs long ; for low powers, each side was about 50 µs long. However, as the RF power was increased (P > 250 kW), it was then necessary to have a slower increase, and decrease as well, to reach the flattop, resulting in a total macropulse length of 600 µs for 700 kW transmitted into the RF gun cavity.

Efforts had been devoted for machining the cavity, especially the anode and the cathode surfaces which are about 10 cm apart and have large area ; this geometry could have been a serious limitation for high surface electric fields. Moreover, the RF pulse is fairly large increasing the probability for breakdowns. Up to 900 kW have been injected in the cavity without major problems, the corresponding maximum electric field on the surface is estimated to be 26 MV/m, i.e. twice the Kilpatrick limit at 144 MHz. Apart from the aforementioned controls, a CCD camera was used to observe the light emitted between the insulator and the central line of the feeding loop.

Experiments are presently done around 500 kW giving rise to an accelerating voltage of about 1 MV ; the ultimate electric field limit of the RF gun cavity will be investigated later on. The emittance growth would be minimized if the beam is accelerated as rapidly as possible implying the largest electric field.

Photocathode preparation

After use, the photocathode substrate (molybdenum) is cleaned by heating at 450°C for about 6 hours and then cooled down to 160°C for the alternating deposition of K, Sb and Cs. Before evaporation, the vacuum in the large dimension evaporator is about 10^{-10} mbar. As the photocathode retractable holder is insulated from ground, the evaporation process is controlled through photo-emission measurements. The photocurrent is monitored by means of a low-power HeNe laser (λ = 543 nm) and a white light source with different calibrated filters for wavelength selection in the 455 - 620 nm range.

Several photocathode preparation procedures are being tested to increase the quantum efficiency by changing crucial parameters : substrate temperature, relative layer thicknesses, temperature for the final cesium layer. Up to now, the largest quantum efficiency for λ = 543 nm and for good vacuum conditions ($< 2.10^{-10}$ mbar) has been 0.5 % ; no change in the quantum efficiency was observed after one week in the evaporator.

Photocathode laser

The Nd:YAG laser delivers micropulses about 100 ps wide at 72.2 MHz ; an acousto-optic modulator reduces then the pulse train repetition rate at 14.4 MHz. Pockels cells gate the pulse train producing a macropulse about 200 µs long at a repetition rate of 10 or 20 Hz. After a three-stage amplification, the macropulse average power is 4 W. The frequency is then doubled in a BBO crystal, resulting in a peak power of 140 kW and a pulse energy around 15 µJ. Experiments are usually done with a standard pulse of 100 ps but an optical compressor, using a long optical fiber and two gratings has been installed for reduction down to 20 ps. Because of the long transport line down to the photocathode (~ 15 m), the average laser power on the cathode is estimated to be about 0.5 W.

Electron diagnostics and experimental results

When CsK$_2$Sb photocathodes with quantum efficiency in the 0.2 - 0.5 % range have been prepared and cooled down to 50-60°C, they are inserted in the RF gun cavity where the vacuum is rather poor (in the 10^{-8} mbar range). RF power at the desired level (~ 500 kW) is then injected in the cavity whereas laser macropulses are illuminating the cathode at a repetition rate of 10 Hz, resulting in an average laser energy of 50 mJ per macropulse. Given the pulse train frequency of 14.4 MHz, the number of micropulses per macropulse is around 2500.

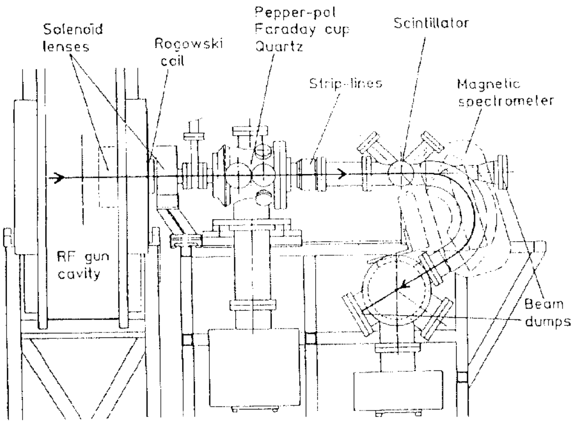

Fig. 2 - Electron diagnostics.

After leaving the RF gun cavity, the electron bunches pass through two iron shielded solenoid lenses as shown in figure 2 and then focused on a pepper-pot used first as a Faraday cup ; the cup is connected to an oscilloscope through a RC = 100 ms constant integration circuit. A maximum charge of 22 nC per bunch has been measured at the beginning of the experiment, usually 3 to 4 minutes after the photocathode has been inserted in the cavity ; assuming a gaussian profile of 100 ps, this gives a peak current of 220 A. Figure 3 shows the bunch charge decrease as a function of time in preliminary operating conditions (0.5 W average laser power and 400 kW macropulse average RF power). We observed a very similar behaviour when the photocathode is just inserted in the cavity without laser and RF fields. The short photocathode lifetime ($T_{1/e} \simeq$ 15 min.) is attributed to the oxygen compounds, observed in the RGA spectrum, which are known to poison the cesiated surface very quickly and, consequently, to reduce the quantum efficiency dramatically.

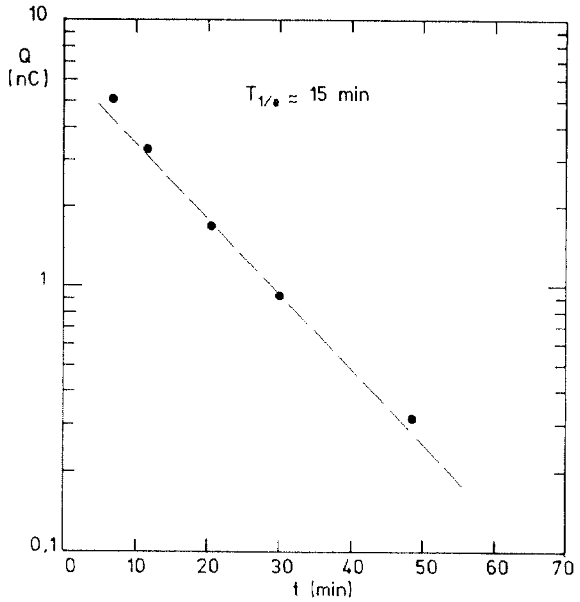

Fig. 3 - Time evolution of the electron bunch charge.

When the extracted bunch charge is important, beam loading effects are immediately observed on the transmitted RF power macropulse as seen in figure 4.a ; then, the feedback loop compensates for this beam power absorption to deliver an almost constant RF power during the RF pulse plateau (figure 4.b).

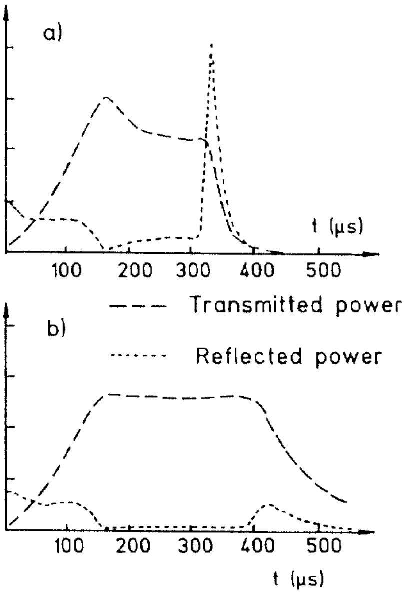

Fig. 4 - Beam loading effect on the RF macropulse (a) and feedback loop correction (b).

The transverse emittance of the beam is measured by the pepper-pot technique ; the pepper-pot is made of a 1 mm thick tantalum plate with 400 µm in diameter holes drilled on lines parallel to the Ox and Oy axes, 3 mm apart. The whole beam radius is measured on a Al$_2$O$_3$: Cr scintillator at a downstream distance of 50 cm by means of a CCD TV camera. A normalized emittance of 90 π.mm.mrad has been measured for 10 nC bunches.

Four strip-lines (figure 2) are used for beam position and beam current measurements ; one of these can be connected to a 7 GHz oscilloscope to provide the temporal profile of the bunches as shown in figure 5. Due to the bandwidth of the oscilloscope and the cable connection effects, the actual electron bunch duration (FWHM) is estimated to be less than 100 ps.

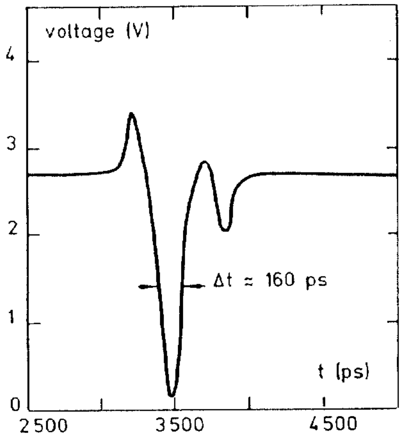

Fig. 5 - Bunch temporal profile as given by a 7 GHz oscilloscope.

The aforementioned electron diagnostics are routinely operated now ; some other will be added in the near future. A pure quartz plate could be inserted in the beam to generate Cerenkov radiation to be observed with a streak camera for bunch temporal profile determination. The beam energy and the energy spread will be measured with the magnetic spectrometer installed on the beam line.

Conclusion

Results obtained with the photo-injector prototype have proved to be very promising. Modifications of the RF gun cavity structure are planned to lower significantly the actual pressure and to increase the photocathode lifetime. Apart from presently used alcaline photocathodes, other types of cathodes are also investigated ; for example, an underheated dispenser cathode will be tested fairly soon. In the next experiments, diagnostics for fine temporal and spatial bunch profiles will be used before the whole diagnostics line is removed, as scheduled for the end of the present year, to install the 433 MHz three-cavity linac just at the 144 MHz cavity exit.

The electron bunch characteristics have been estimated by means of different codes [4] for the present geometry of the RF cavity and the associated diagnostics line.

References

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[2] R. Dei-Cas, S. Joly, F. Coçu, J. Fréhaut and H. Leboutet, "Requirements of High-surface electric fields for high-brightness FEL injectors", XIIIth International Symposium on Discharges and Electrical Insulation in Vacuum, Paris, 1988, pp. 513-515.

[3] S. Joly et al., "A high-brightness photo-injector for a free electron laser proposal", presented at the EPA Conference, Rome, June 7-11, 1988, pp. 257-259.

[4] J. Fréhaut et al., this Conference.