LELIA : AN INDUCTION LINAC DEVELOPED FOR FEL APPLICATION

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Abstract

An induction linac is being studied and built at CESTA for FEL application. At first we studied the induction technology and namely the high voltage (HV) generators and the induction cells.

A HV generator designed to feed the cells with calibrated pulses (150 kV, 50 ns, $\Delta V/V$ <1 %) has been built using a charging resonant system and magnetic switches. This generator is planned for kHz repetition rate operation. A prototype induction cell has also been built and tested with a cable generator. An electron injector (1.5 MeV, 1.5 kA) has been designed and is now under completion : it uses ten induction cells and a thermoionic dispenser cathode. Numerical codes have been developed and simulations have been compared with experimental results for HV generators, induction cells and injector.

An induction accelerating module is now being studied and we plan to have the accelerator working next year at a 3 MeV energy level.

I. INTRODUCTION

The LELIA program is under development at the "Centre d'Etudes Scientifiques et Techniques d'Aquitaine" (C.E.S.T.A) since 1988. Its objective is to produce a high brightness and high average power electron beam for FEL application [1].

Such a beam will be obtained using an 1.5 MeV induction injector able to generate peak current of 1 - 2 kA.

In order to increase the beam average power, limited by the pulse time duration (~ 80 ns), we need to have it working at high repetition rate (> 1 kHz).

Moreover for FEL operation the high voltage (150 kV) pulse used to drive induction cells must be regulated to within 1 % to ensure acceptable variation in beam energy.

All these requirements led us to study and realize a HV pulse generator based on magnetic compression.

On the other hand it was an important task for us to test the induction cell technology before constructing the accelerator itself. In that way a prototype induction cell has been built and a series of experiments has been conducted in order to verify our choices in mechanical, electrical and vacuum engineering.

II. LELIA DESIGN AND EXPERIMENTS

A. *High voltage Pulse Generators*

The LELIA induction cells are designed to be driven by rectangular voltage pulse with 150 kV amplitude and 80 ns duration. Following these parameters a pulse generator has been developed at CESTA [2]. It consits of two parts :

- a Command Resonant Charging System (CRCS)
- a Pulse forming and compression device (MAG)

A cross section for this HV generator is shown in figure 1.

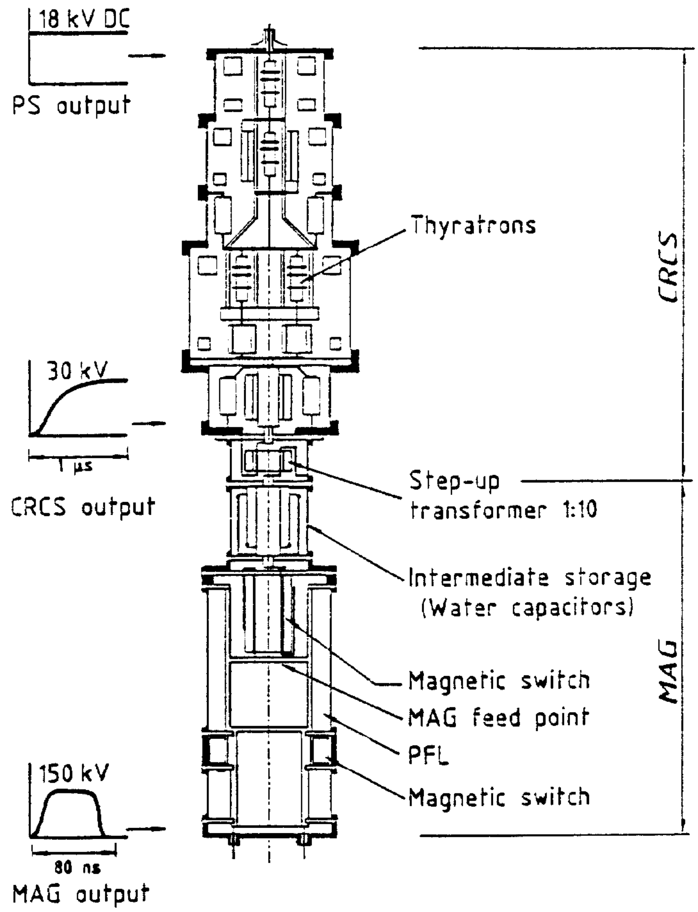

Figure 1 : Cross section of HV pulse generator.

The CRCS transforms the 25 kV DC supply into a low power sinusoidal pulse generator. It is mainly composed of thyratrons (EEV CX 1536), self-inductances and capacitors.

The output signal (30 kV/1 µs sinusoidal pulse) is amplified in a step-up transformer and used to charge the 20 nF intermediate energy storage. Then the MAG compresses this charge pulse to 80 ns and transforms it into a 150 kV rectangular pulse.

This drive pulse is delivered to the induction cells through 100 Ω coaxial cables. Each HV generator can drive 25 cells.

The MAG module is built using a coaxial water filled pulse-forming line (PFL) and magnetic switches operating as magnetic pulse compressors. PFL impedance is 2 Ω.

In a first time the HV generator has been tested with resistive load producing a 150 kV/50 ns flat top pulse. Moreover, as predicted by our numerical simulation, an improvement in the flat top quality was experimentally observed by charging the pulse forming line at the middle (**figure 2**).

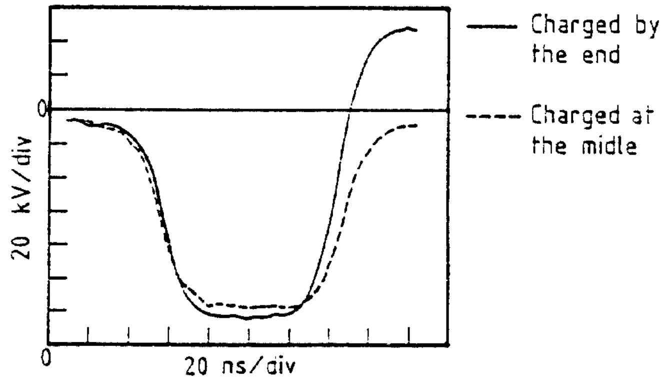

Figure 2 : MAG output voltage

Presently tests are conducted on this HV generator to verify its high repetition rate (~ 1 kHz) working ability.

B. *Prototype induction cell*

Design : LELIA prototype induction cell consists of a ferrite torroid stack housed in a non-magnetic stainless steel body connected to a vacuum pump (**figure 3**).

The value of the inner diameter of torroids is a compromise between a large diameter to minimize the Beam Break Up (BBU) instability and a small diameter to minimize the cost of the accelerator.

Cross sectional area of torroids depends upon the pulse characteristics and the ferrite magnetic properties.
It has been calculated using the relation : $V. \Delta t = S. \Delta B$ where V is the pulse voltage, Δt the pulse duration, S the cross sectional and ΔB the available flux swing of the magnetic cores.

The length of the ferrite stack has been determined from pulse width and electrical characteristics of the ferrite with the formula :

$$l \simeq \Delta t / \sqrt{\mu \epsilon}$$

where μ is the permeability and ε the dielectric constant of ferrite.

According to the above constraints the prototype cell has been constructed around seven PE 11 B ferrite torroids 25 mm thick, 250 mm I.D., 500 mm O.D. manufactured in Japan by T.D.K.

Oil is used as the dielectric and cooling fluid surrounding the ferrites.

Between the beam pipe and the ferrite core internal diameter is a 2 layers, 68 turns solenoid capable of producing a 2 kG axial magnetic field.

The accelerator gap is 8 mm wide and a pure alumina insulator brazed on the cell provides the vacuum-oil interface. This technology allows us to ensure a high vacuum in the beam pipe : measurements exhibit a pressure less than 5 x 10^{-9} torr and no presence of hydrocarbons or halogens was detected by mass spectrometer.

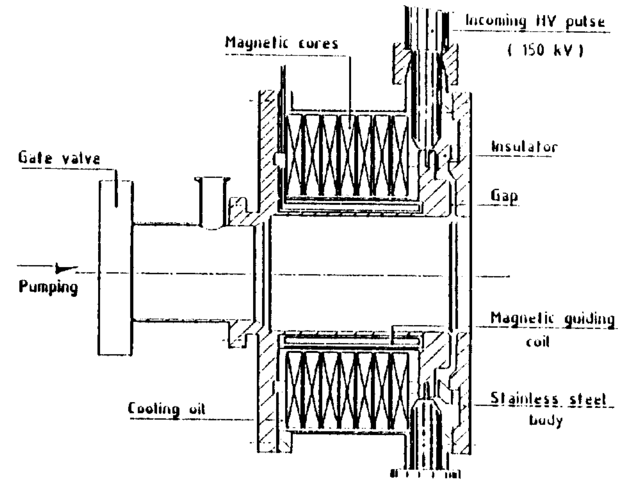

Figure 3 : Prototype induction cell

The gap profile has been designed with PALAS and AMOS numerical codes in order to minimize the BBU instability [4].

AMOS calculations have shown a dominant transverse impedance of 1250 Ω/m at 250 MHz. For utilization in an acceleration module, modifications have been made to decrease this value.

Testing : A cable generator specially developed for this application has been used to test the induction cell with applied gap voltages ranging from 10 kV to 200 kV.

The HV pulse was introduced on two opposite sides from two 100 Ω coaxial cables. No breakdown occured during these experiments.

Using an electro-optic jauge [5] we have also measured the accelerating electric field on the axis of the cell. Results have shown a good agreement between experiments and calculations obtained with FLUX 2D electrostatic numerical code (**figure 4**).

As a consequence it is important to note that the field distribution in the beam pipe is an electrostaticlike distribution.

An induction cell can be represented by the equivalent circuit model shown in **figure 5**.

The HV generator is represented by the voltage source and the transmission line to the cell by the resistor Z_0.

C_g represents the capacitance of the cell, Z_F the ferrite impedance and I_B the beam current.

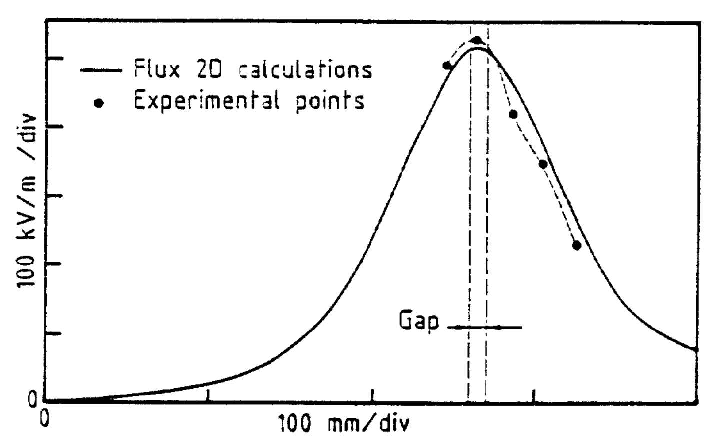

Figure 4 : Electric field profile in beam pipe

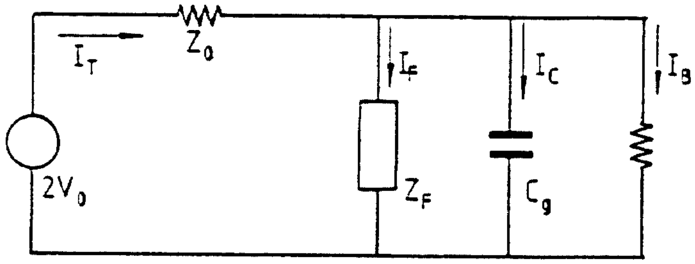

Figure 5 : Induction cell equivalent circuit

To evaluate the electrical characteristics of the prototype cell we have conducted a series of experiments with a resistive load placed on the axis of the cell to simulate the beam. A pulse voltage of 130 kV was applied to the gap ; the total cell current and resistive load current were measured. Results are shown in **figure 6.**

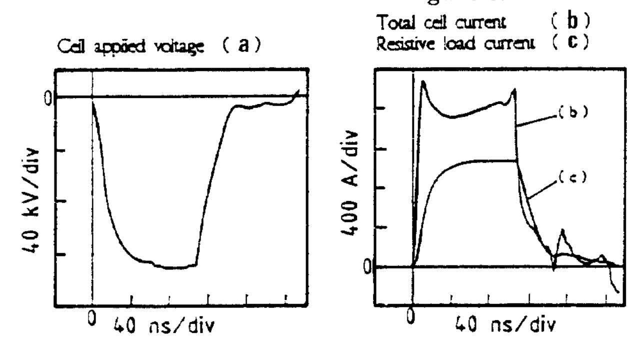

Figure 6

The displacement current I_C due to the gap capacitance can be expressed by

$$C_g \frac{dV}{dt}$$

In a first time using geometrical considerations we have calculated the gap capacitance Cg of the cell.

A value of 180 pF has been obtained.

Then it was easy to deduce I_C from **figure 6a**.

By subtracting I_C and I_B from the total cell current we have also determined the ferrite leakage current I_F.

Results of these calculations are shown in **figure 7**.

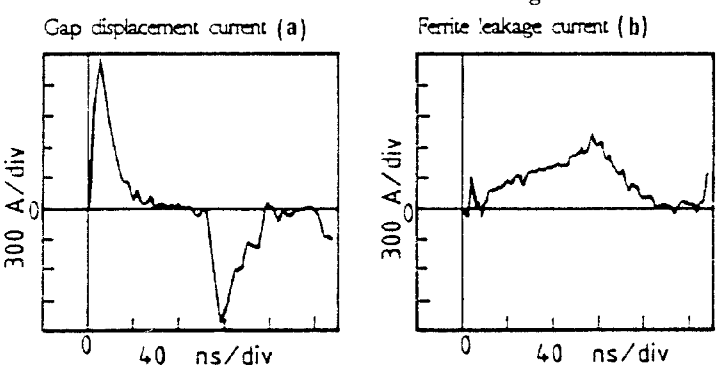

Figure 7

Examining **figure 7-a** it is obvious that the initial surge of current is essenticly due to the gap capacitance.

On the other hand it is apparent in **figure 7-b** that the ferrite reacts like a transmission line with $I_F = V\,t / L$

The slope of this trace gives an inductance L of 15µH which is in concordance with the design value.

The ferrite impedance Z_F is equal to the applied voltage divided by the ferrite current. This impedance has a constant value of 300 Ω during 40 ns.

Experimental work on the prototype cell has also permitted to verify the available flux swing ΔB in the ferrite.

Using the relation $\Delta B = \frac{1}{S}\int V dt$ we have obtained a value of 0.63 Tesla which is in concordance with the value given by the manufacturer.

C. *Injector*

An injector (1.5 MeV, 1.5 kA) has been designed and constructed at CESTA. It comprises ten induction cells similar to the prototype cell and uses a 85 mm diam. osmium dispenser cathode to produce the electron beam. The electrongun is a triode configuration (cathode surrounded by a focusing electrode, intermediate electrode and anode) optimized with SLAC and FLUX 2D numerical codes. The vacuum inside the injector is ensured by two 4500 l/s cryogenic pumps. Measurements indicate a residual pressure of 1.2 x 10^{-9} torr (essentially water and nitrogen).

Now the cells have been electrically tested and we plan to obtain the first beam very soonly after magnetic alignement of the guiding coils has been realized.

III. CONCLUSION

Design and construction of a HV generator and a prototype cell have permitted us to acquire, at CESTA, magnetic pulse compressors and induction technology.

From this experience we have been able to construct an injector of 1,5 MeV for FEL application (for next year construction of a 3 MeV accelerator is planned).

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