DEUTERONS ACCELERATION WITH THE SATURNE LINAC

by

P. A. Chamouard, J. M. Lefebvre,
M. Olivier and M. Promé

C.E.N. Saclay (France)

I. POSSIBILITIES OF DEUTERON BEAMS

Deuterons open fields of wide interest for physics experiments:

a) The study of the $d + d \rightarrow He^4 + X°$ reaction and the elastic diffusion $d + d \rightarrow d + d$ implies the use of incident deuterons. The first reaction is of particular interest since the missing mass X° is produced in a pure state of isospin.

b) The study of the reactions $d + p \rightarrow He^3 + X°$ and $d + p \rightarrow H^3 + X^+$ in the region of 0° in the system of the laboratory and 180° in the system of the center of mass is very difficult if not impossible with incident protons for two reasons: the momentum of the primary proton beam lies in the range of the momentum of the analyzed secondary particles; and the resolution in mass is not as good as in the case of a primary deuteron beam.

c) Deuteron acceleration enables creation of a high energy neutron beam with a small angular opening. This is essential for the study of new reactions implying neutrons.

d) More generally speaking, the acceleration of heavy ions (deuterons, helions, ...) opens new fields in astrophysics and medicine.

At the 1970 Proton Linear Accelerator Conference we reported the obtaining of a 2.10^{11} deuteron beam at 3.8 BeV/C. Since then an effort has been put on the preinjector, the Linac, and the injection system to increase the number of accelerated particles, which is now up to 8.10^{11} per pulse.

II. IMPROVEMENTS OF THE PREINJECTOR AND LINAC

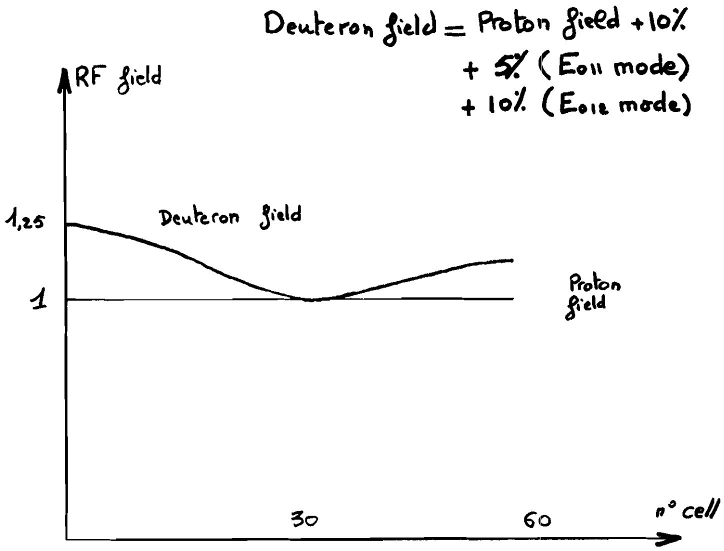
A. Preinjector

Our preinjector and its transport system were calculated for a 100-mA Proton beam at 750 keV, which, transposed to a deuteron beam, is equivalent to 25 mA at 375 keV, from space charge restrictions, the voltages on the focusing electrodes being halves of the proton operation values. Figure 7 shows the voltage repartition along the axis. The theoretical law is linear between E1 and E2, but both the measurements and the calculations indicate that it is desirable to approximate the $V^{4/3}$ law by increasing of the E2 voltage. This voltage increase is particularly easy to realize with deuterons since one does not need to fear sparking limitations. Under these conditions it is possible to obtain a 40-mA deuteron beam at the output of the preinjector with a normalized emittance of 10^{-6} rad·m for 95% of the beam. The pulse length is 600 μs. The corresponding accepted intensity in the Linac is 28 mA.

B. Linac

The lowering of the transit time factor in the first gaps must be compensated by an increase of the rf field level in this same region. Accordingly, the longitudinal acceptance is only limited by the maximum rf field that can be sustained in the first gaps. The examination of the variation of sin ϕ in function of the number of cell (see Fig. 1) represents the rf defocusing effect. The defocusing effect is very strong in the middle of the cavity and cannot be entirely compensated by the quadrupoles that are limited by the power supply possibilities. It is therefore necessary to decrease the rf field in this same region.

Figure 2 shows the stability diagram for protons and deuterons with the rf field distribution indicated below:



The longitudinal acceptance area is 80 keV; 135° for 95% of the beam (Figs. 3 and 4). This value is in good agreement with the theoretical value. (Internal report by Michel Promé.) With this field configuration the intensity at the output of the Linac is 7 mA (with 28 mA at the input) in an emittance of $5.2.10^{-6}$ rad·m normalized (see Fig. 5). The Linac transmission is hence 25% with a first harmonic buncher. The energy spread before debunching is ±30 keV.

The increase of the rf field level in the first gaps led to sparkings until we proceeded in August 1971 to a careful conditioning of the cavity. Since then the sparking problems have disappeared.

III. RAMPED ENERGY INJECTION

In November 1970 the ramping of the proton beam energy across the 600 μs pulse was put into operation. This implies the phase shifting of both the ramping cavity and the debuncher. The first tests of energy ramping with deuterons were started in July 1971. The necessary energy variation law is 300 keV in 600 μs corresponding to a ±45° phase shift with a peak rf voltage in the ramping cavity of 215 kV. (This voltage takes into account the lower transit time factor which, for deuterons, is only half of the proton value.) Because the phase spread is, for deuterons, twice larger than for protons, the debuncher will have to be phase shifted twice faster, which means 300° in 600 μs with a peak rf voltage of 60 kV (including the correction for the transit time factor). The shifting of the phase is obtained from the modulation of the biasing current of a ferrite phase shifter. The transmitted power in the phase shifter is 100 KW; to avoid sparking troubles it is housed in a pressurized tank ($SF6 + N_2$ at 3 atm). The original biasing current generator of the phase shifter was only capable of a 20-A maximum current over a 600-μs period; a new 50-A generator has been specially designed for the deuteron operation. It consists of a D class amplifier delivering modulated 150-V square waves. (Internal report by J. P. Auclair.)

IV. CONCLUSIONS

The recent improvements on the Linac deuteron beam allow the acceleration in the synchrotron of 9.10^{11} deuterons at 4 ms after rf capture and 8.10^{11} deuterons of maximum energy (see Fig. 6). Another conditioning should authorize to tolerate higher a rf field, hence increasing the Linac transmission. Besides, new optics well adapted to deuteron beams are under study for the preinjector and the transport system. They should also lead to an increase of the intensity at the entrance of the Linac. It is also worth mentioning that, as far as Saturne is concerned, measurements made at injection show that the space charge limitation is not reached, therefore the number of accelerated particles will be directly proportional to the current delivered by the Linac.

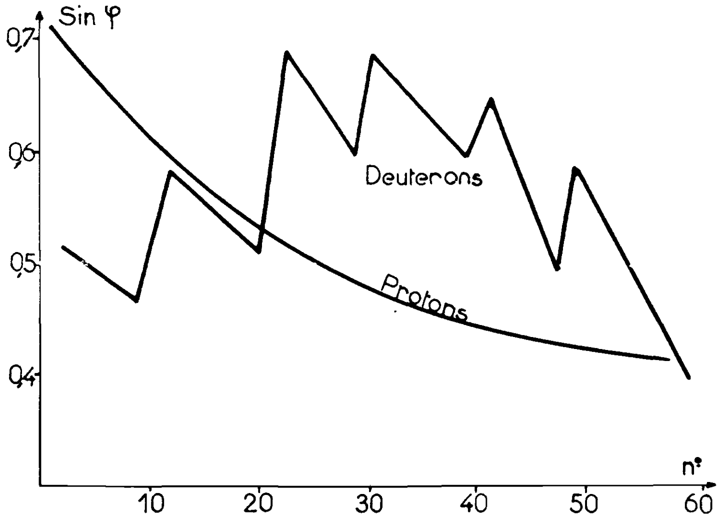


Figure 1

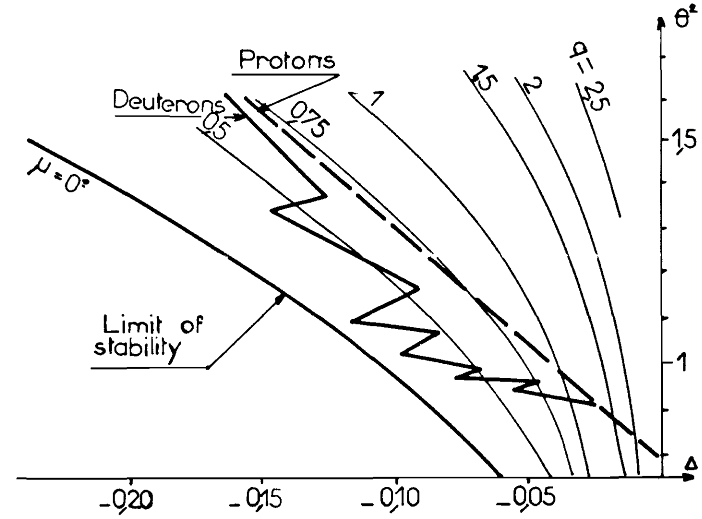


Figure 2

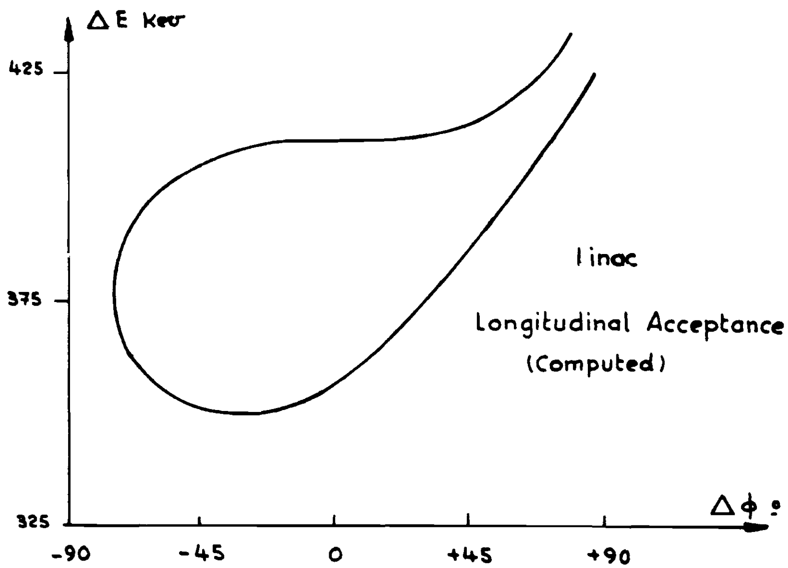


Figure 3

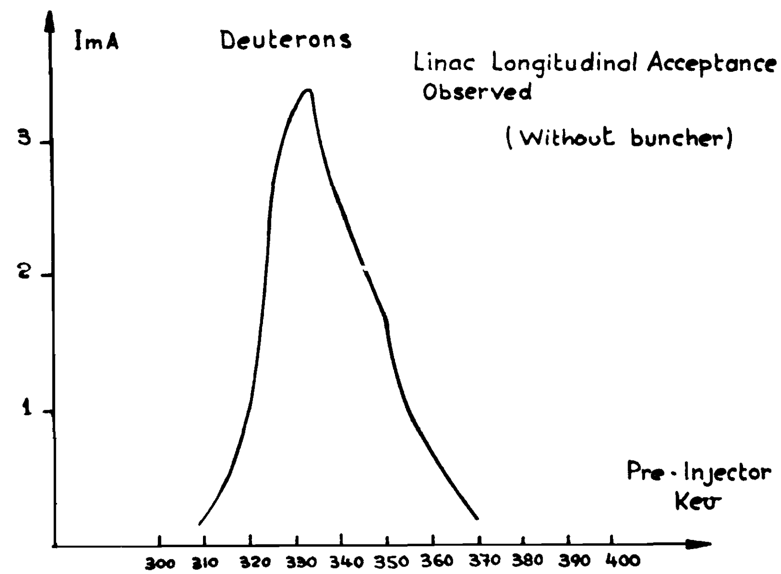


Figure 4

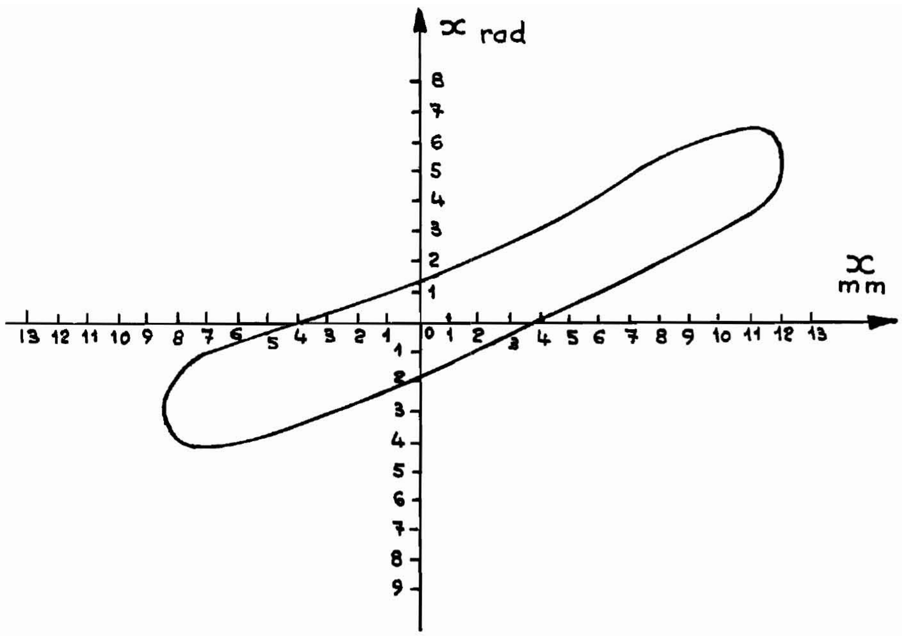
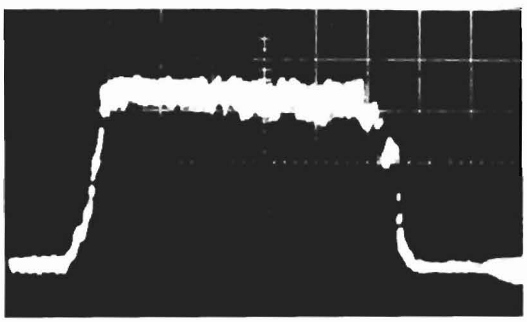
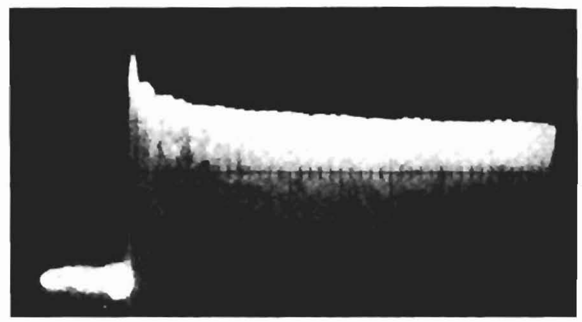


Figure 5



Deuteron beam (10 MeV) 100 μsec/cm, 2 mA/cm



Deuteron beam capture, 3.10^{11}/cm, 1 msec/cm

Figure 6

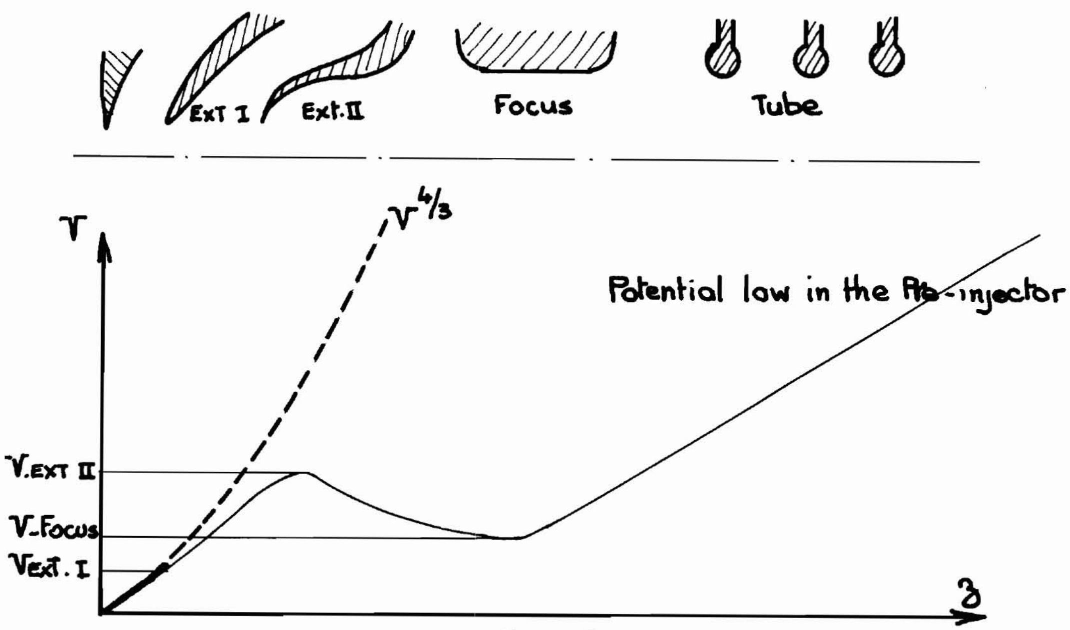


Figure 7