OPERATION REPORT of the SATURNE LINAC INJECTOR

SPACE CHARGE COMPUTATION RESULTS

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It is intended to report here on the results of a one year activity in two fields :

A - Operation of the 20 MeV linac injector of the Saturne proton synchrotron

B - Calculations of space charge effects on linac beam qualities

A - OPERATION of the 20 MeV INJECTOR

After a 6 months test period the 750 keV pressurized preinjector and the 20 MeV linac have been connected to the synchrotron in July 1969. Since then they have been delivering beam to the synchrotron for 4 000 hours.

I - Preinjector operation report

I.1. Normal operation condition

No failure has been recorded during the test period. However, in the 3 months following the installation in the Saturne hall sparkings occured which required slight modifications.

The reasons for sparking were :

- Humidity contamination of the components in the pressurized vessel during the long installation period, the vessel being opened to humid atmospheric air. Exagerated cooling of the column leading to important water condensation any time the vessel was opened. Failures in dew point controls.

- Presence of hygroscopic material :

Mylar wrapped around the potential controlling liquid resistor.

Polycarbonates utilized for the insulating supporting columns that slowly absorb water if an adsorbed water layer is permitted to remain at the surface of the material for several weeks (storage in wet places).

Curings were the suppression of the mylar material and control of the components temperature before openings of the vessel. No sparking has been detected since January 1970.

The preinjector has been running satisfactorily with proton currents of 30 to 100 mA at the entrance of the linac and deuteron currents (at 375 keV) of 20 mA.

Emittances are measured from the angular opening recording of a pencil beam defined by a movable hole.

A xx' emittance is consequently obtained, for a given y and integrated y'.

Typical normalized emittances are 2.10^{-6} m.rd for 90 % of 30 and 80 mA beams.*

The duoplasmatron ion source utilizes BNL type cathodes. After 6 000 hours of operation the original cathode is still suitably working.

I.2. Maximum voltage tests

During August 1970 the voltage was raised to test the preinjector possibilities.

A 1.1 MV voltage was maintained for 1 hour. A 1 MV voltage was maintained for 10 hours.

In both cases a 120 mA beam was delivered within a normalized emittance of $2.3.10^{-6}$ m.rd.

The maximum voltage is limited by the Cockroft-Walton power supply.

From this test it is reasonable to hope for a 1.2 MV normal operation voltage after modification of the power supply. A 1.2 MeV proton injection into the linac would permit to suppress the five first linac drift tubes.

I.3. Space charge calculations for the preinjector beam

They have shown that space charge aberrations occur if the density distribution at the Pierce exit region is not uniform. These theoretical studies have confirmed the experimental results : a hollow on the axis in the density distribution is detected at the exit of the acceleration tube if the tuning of the Pierce parameters is incorrect.

II - Linac operation report

II.1. Mechanical behaviour

The main cavity is made of 4 separate sections assembled by bolted flanges. The drifts tubes are single stem supported.

Each section was moved to its final location with the drift tubes mounted in.

After connection of the sections together, alignment of the drift tubes was checked and found good within the admitted tolerances. In August 1970 the alignment was checked again and found unchanged. Three leaks have developped from the body of 3 drift tubes, rough pumping through the stems of the concerned drift tubes have permitted to maintain a 10^{-7} torr pressure in operation.

Over a 9 months operation period 13 hours of failure time have been attributed to the mechanical components of the linac : 90 % of that time is due to troubles with the refrigeration equipment of the D.C. current quadrupoles of the linac.

II.2. R.F. behaviour

The main cavity was opened to atmospheric air for 3 weeks during implantation. 7 days of conditionning were necessary to reach the nominal field value.

Under nominal acceleration conditions (maximum field on all drift tubes about 14 $MV.m^{-1}$) sparkings have seldom occur, they always happened in the very first drift tu-

* The given figures are areas.

bes.

Deuterons operation requires a higher field in the low energy end of the linac. The rate of sparking began to be disturbing for field increase of 20 %, corresponding to a maximum field in the first gaps of 16 $MV.m^{-1}$.

The failure rate of the R.F. generator equipment has been 15 hours over the 4 000 hours operation period. Most of the failure time concerns the two last amplifier stages (TH 515 and TH 470) crowbar detection system (8 hours).

A field stabilization servo system has been put into operation for beam loading compensation ; but the optimum power to be delivered to the load being close to the maximum available power, the final amplifier is working almost at saturation and the servo system does not achieve the desired stability ; efforts are being made in order to increase the maximum available power.

II.3. Beam behaviour

The normal accelerated current is 15 mA at the output of the linac, for a 30 mA injected current, with a 300 µs long beam.

With correct adjustment of the R.F. field level the energy dispersion is 200 keV, constant through the pulse length.

Emittances are recorded in the same fashion as for the preinjector, their normalized values are $3.4.10^{-6}$ m.rd in the xx' plane, and $3.6.10^{-6}$ m.rd in the yy' plane, for 80 % of 15 mA beams.

The stabilization of R.F. field level during beam pulse has been found critical as far as beam position, and energy dispersion stabilities are concerned.

The use of the double harmonic bunching cavity has brought little improvement to the linac intensity transparence.

II.4. Deuterons acceleration

The preinjector is capable of delivering a 20 mA D^+ beam within a $1.4.10^{-6}$ m.rd normalized emittance.

Acceleration through the linac was made possible by shaping properly the field on the axis. Firstly, the net power supplied to the cavity was raised to compensate for the general deterioration of linac efficiency. Secondly, the field had to be increased at the low energy end of the linac to compensate for the specially poor transit time factor in the first few gaps ; 10 % of E_{011} mode was introduced for this purpose by adjusting ball tuners. Doing so, the field became too large in the middle of the linac ; the working phase in this section was so large that radial defocusing effects required more quadrupole currents than possible to supply ; consequently 5 % of E_{012} mode was introduced to produce a hollow in the middle of the linac.

With these adjustments 4.5 mA of 10 MeV deuterons were obtained at the linac output. The energy spread of the beam was only 60 keV which is significant of the poor longitudinal acceptance of the linac. Better adjustements might be found, if it were not for the sparking problems in the first few gaps.

B - COMPUTATIONS on SPACE CHARGE EFFECTS

I - As was earlier reported at the Yerevan Conference [1], two beam dynamics programs resulted from a joint effort of CERN and Saclay. Both include space charge ;

the first one, MAPRO I, is based on a particle to particle interaction, while the second one, MAPRO 2, takes benefit of a continuous distribution equivalent to the bunch. Numerous runs have been made at Saclay with MAPRO 2 which is much faster, together with a few comparisons with MAPRO I to check the results. The major goal these runs aimed at was to answer some of the questions raised by Dr R. CHASMAN's results [2] [3].

The linac through which trajectories were computed was the 0.52-10 MeV first tank of the CERN PS injector. Here are briefly reported some of the findings.

II - The first question is related to the influence of the input longitudinal emittance on the transverse emittance growth. All emittances are understood to be normalized emittances, and the longitudinal emittance is defined as being an integral in

$$\frac{d\ (\Delta W) dz}{m_o c^2\ \beta}$$

For all emittances a root mean square expression as introduced by Dr R. CHASMAN (réf. [2] and [3]) is used.

Examining the longitudinal as well as the transverse emittances, two stages appear in their evolution; during the first one which lasts for ten cells approximately, both emittances generally grow rapidly ; along the remaining of the tank, emittances either remain nearly constant, or one grows slightly while the other decreases, according to the focusing law chosen for quadrupoles. So that neither longitudinal nor transverse emittance is fully representative of space charge damage ; but it seems that the sum H of the two transverse emittances plus the longitudinal one, which remains almost constant during the second stage, is more representative of space charge effects.

III - Trying to understand more precisely the mechanism of transverse-longitudinal coupling, root mean square transverse and longitudinal velocities have been looked at. (By longitudinal velocity one means with respect to the longitudinal velocity of the bunch). Although statistical noise on velocities is large with 500 computed particles, it can be seen that velocities definitely tend to equalize as the beam travels along the linac ; the higher the current, the quicker the equalization ; at 0 current there is no equalization at all, and velocities remain unchanged. This can be considered as a semi-empirical justification of Dr P. LAPOSTOLLE's "statistical model" [4], to whom was borrowed the idea of comparing the velocities.

IV - Coming back to the sum H of the transverse and longitudinal emittances, one can look for a relationship between this sort of hyperemittance at linac input and output ; beam intensity i is obviously involved in such a law :

$$H_o = f\ (H_i,\ i)$$

where the subscripts o and i stand for output and input. What has been found after some 100 runs is that surprisingly enough the linac does not behave as an emittance multiplier but rather as an emittance adder. Several hours of CDC 6600 are summed up in the very simple following law :

$$H_o = H_i + K\ i$$

with $K = 6.10^{-5}$ m.rd/A for the particular linac tuning (with ++-- focusing) adopted during the computations. One can hope that this law is too simple for not applying to other linacs.

R E F E R E N C E S

[1] M. MARTINI, M. PROME

"Beam dynamics in a proton linac with space charge"

VIIth International conference on high energy accelerators

[2] R. CHASMAN

"Numerical calculations of the effects of space charge on six dimensional beam dynamics in protons linear accelerators"

1968 - Proton linear accelerator conference - Brookhaven

[3] R. CHASMAN

"Numerical calculations on transverse emittance growth in bright linac beams"

1969 - Particle accelerator conference - Washington

[4] P. LAPOSTOLLE, C. TAYLOR, P. TETU, L. THORNDAHL

"Intensity dependant effects and space charge limit investigations on CERN linear injector and synchrotron"

CERN 68-35 12 oct. 1968

DISCUSSION

R. W. Chasman (BNL): What kind of emittance growth do you get in your linac?

J. M. Lefebvre for M. Promé (Saclay): About a factor 2 growth in normalized emittance.

P. Grand (BNL): What gas and what pressure do you use in the 1 MV preinjector?

M. Promé (Saclay): The gas is a mixture of nitrogen and carbon dioxide at a pressure of 10 kG/cm^2.