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TRANSVERSE INSTABILITIES IN THE LIL

M. Boussoukaya, R. Chehab, J. Le Duff, G. Bienvenu, J.C. Bourdon

Laboratoire de l'Accélérateur Linéaire (IN2P3)
Université de Paris-Sud, 91405-ORSAY-France

SUMMARY

In view of a Beam Break Up (BBU) study, we have calculated and identified series of transverse deflecting modes in the S band sections of the LEP Injector Linacs (LIL). In these TW quasi-constant gradient structures with various iris diameters from 18 to 26 mm, only π-modes of the C band of the HEM_{11}, having negative group velocities and phase velocities around c will lead to cumulative BBU. These deflecting π-modes occur at frequencies in the range from 4558 to 4290 MHz for diameters from 18 to 26 mm. Frequency variation with iris diameter is -15 MHz for each added mm for calculated and measured 0-modes and about twice that value for π-modes. Levels for starting transverse instabilities have been determined for various accelerated Beam Currents with different pulse widthes.

I. INTRODUCTION

This study concerns the transverse RF modes occuring in the 200 MeV high-intensity linac (linac V) of the LEP injector[1]. Such a linac is made with iris sections presenting variable shunt impedance. Our concern is with the transverse instabilities created by the electron beam in these structures.

A theoretical approach and an experimental study led to the microwave characteristics determination of a set of high order modes between 3 and 7.2 GHz. A particular attention has been paid for two deflecting hybrid modes -HEM_{11} and HEM_{21}- which can lead to Beam Break Up (BBU) instabilities. Their study allowed the identification of the associated BBU types. A first estimation of the threshold current for the HEM instability is given.

II. THEORETICAL APPROACH AND EXPERIMENTAL RESULTS

It has been shown[2,3] that :

- resonant frequencies of TM_{mno} high order modes in cylindric circular cavity are linked with the fundamental mode TM_{010} frequency by the relation :

$$f_{mn} = \frac{U_{mn}}{U_{01}} \cdot f_{01} \tag{1}$$

where U_{mn} is the nth root of Bessel function $J'_m(U_{mn})$

- quality factors of high order modes can be obtained using the expression :

$$Q_{mn} = \frac{f_{mn}}{f_{01}} \cdot \frac{R_{S01}}{R_{Smn}} Q_{01} \tag{2}$$

where R_{Smn} is the surface resistance of the (m,n) mode.

In the iris structure of the linac, the first deflecting modes appear with hybrid configuration ; the most important of them are the HEM_{11} and HEM_{12} modes.

On the Fig. 1 series of curves representing the dispersion characteristics of the HEM_{11} mode have been drawn. These curves are related to different diameters D varying from 18 to 26 mm with step variation of 2 mm. These results were obtained on different sets of linac cells, one for each iris diameter.

We can observe that the frequency associated with the 0-mode of the HEM_{11} is of 4520 MHz for an iris diameter D of 26 mm and increases with a rate of 30 MHz for a 2 mm D diminution. We thus obtain a frequency of 4640 MHz for a 18 mm diameter. Formula (1) gives a value of 4800 MHz for D = 0 whereas extrapolation form measurements leads to 4880 MHz.

Phase velocity of c value occurs for π-mode. We then assume that no regenerative BBU could be dangerous in such structures. This is the consequence of the multiplicity of iris diameter values leading to a multiplicity of frequencies associated with phase velocities about c. Therefore no synchronism between the beam and the HEM_{11} instabilities will occur on significative lengths in the structure.

However the knowledge of the starting current of these instabilities is important because they can lead to cumulative BBU.

For that, many microwave parameters of these modes must be determined, especially transverse shunt impedances, quality factors, transverse electric field variation with radial distance from the axis and longitudinal abscissa. Such parameters are necessary to know the transverse movement behaviour of the beam particles and hence to determine the emittance evolution along the linac. Therefore we made serial of tests with a model of 3-cell structure to obtain informations about that parameters. We then idientified all the $\frac{n\pi}{3}$ (n = 0, 1,2,3) modes and measured the quality factors of the HEM_{11} and the HEM_{21}. Measured variations of the HEM_{21} transverse electric field are represented on Fig. 3 : that curves corresponding to the 2π/3 mode are related to a variation of r from 0 to 10 mm.

The transverse shunt impedance was determined by perturbating the transverse component of the electric field with a dielectric rod. The shunt impedance expression for an HEM_{mn} mode :

$$\left(\frac{r_\perp}{Q}\right)_{eff} \overset{=}{\Delta} \frac{L\left\{\frac{1}{L}\int_0^L \left|grad_\perp E_z\right| dz\right\}^2}{\omega W_{mn}} \tag{3}$$

could be simplified[4] giving :

$$\left(\frac{r_\perp}{Q}\right)_{eff} = \left(\frac{\lambda_{mn}}{2\pi xo}\right) \cdot \frac{2}{\pi f_{mn}} \left|\frac{\Delta f_{mn}}{f_{mn}}\right| \frac{C.T^2}{\varepsilon_o(\varepsilon_r - 1)A} \tag{4}$$

where xo, A and ε_r represent respectively the radius, cross section and dielectric coefficient of the rod and T is defined as :

$$T = \frac{\left|\frac{1}{L}\int_0^L Ez.dz\right|}{\frac{1}{L}\int_0^L |Ez|dz} \tag{5}$$

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we remain that :

$$\left(\frac{r_\perp}{Q}\right)_{eff} = \frac{r_\perp}{Q} T^2 \quad (6)$$

where

$$T_{mn} = \frac{1}{J_o(U_{mn})} \frac{\sin\left(\frac{\omega_{mn}}{2} \frac{L}{c}\right)}{\frac{\omega_{mn}}{2} \frac{L}{c}} \quad (7)$$

For instance $T_{11} \simeq 0.53$ and $T_{21} \simeq 0.4$.

Experimental results as theoretical evaluations are summarized on table 1.

TABLE 1

Characteristics	HEM_{11}		HEM_{21}	
	Measured	Calculated	Measured	Calculated
Q	6 500	7 500	5 200	5 600
$\left(\frac{r_\perp}{Q}\right)$ [Ω/cm]	24.3	26.4	32	35
$\left(\frac{r_\perp}{Q}\right)_{eff}$ [Ω/cm]	6.7	7.3	4.5	5

III. STARTING OF THE INSTABILITIES

In the last twenty years, many authors studied the starting conditions of the BBU instabilities for different accelerators with normal or superconducting structures working in L or S bands[5,6,7,8]. Evaluation of threshold currents were given for SW and TW linacs.

The starting of the HEM_{11} instability may lead to the cumulative BBU when the energy given by the beam to that mode reaches a critical level[3].

An evaluation of the starting current of that instability has been done using the results which we obtained with the 3-cell model. The following formula[7],

$$I = \frac{v_g}{c} \frac{(c\omega)^2}{L^3} \cdot \frac{1}{\left(\frac{r_\perp}{Q}\right)_{eff}} \times \frac{V_o}{g_1 g_2} \quad (8)$$

gives with the measured quantities a threshold current of 20 Amps peak current in the V linac : the time structure of the beam is of 12 ns pulses with a repetition rate of 100 Hz.

Such a determination has to be more precised with other values of $(r_\perp/Q)_{eff}$ corresponding to different geometries of the linac V.

Before reaching that threshold current the electron beam trajectories spread out from the longitudinal axis leading to emittance growth. For an intense electron beam which will be used to produce positron beam on a target, such growth in the emittance leads to positron beam production limitation due to the limited geometrical acceptance of the positron linac[9]. Therefore the trajectories will be calculated with the real model to determine the optics parameters to maintain the beam into appropriate dimensions as in ref. 9.

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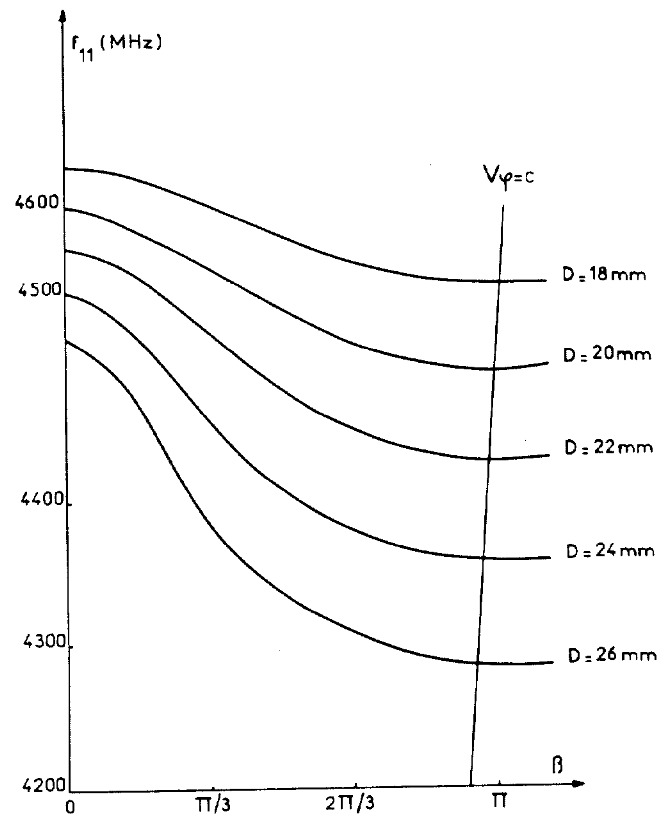

Fig. 1 - Dispersion curves of the HEM_{11} in the linac V

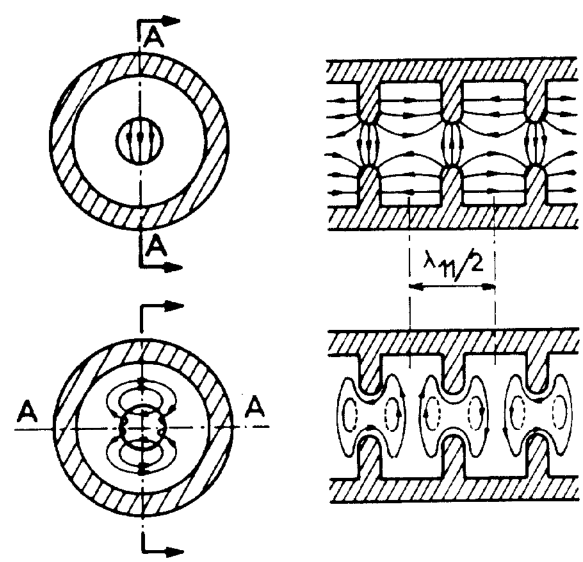

Fig. 2 - Electric and magnetic field configuration of SW π deflecting mode

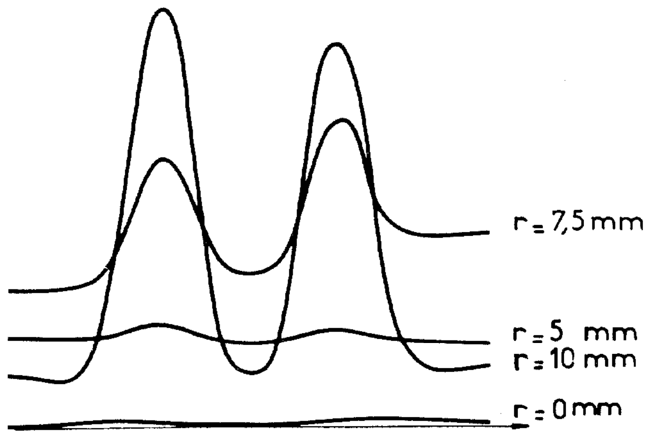

Fig. 3 - $E_1(r)$ in the structure for $2\pi/3(HEM_{21})$

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