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ACCELERATING STRUCTURE DEVELOPMENTS FOR THE LEP INJECTOR LINACS (LIL)

G. Bienvenu, JC Bourdon, P. Brunet, J. Rodier
Laboratoire de l'Accélérateur Linéaire
Université Paris-Sud - 91405 ORSAY Cedex France

Summary

The LIL accelerating structures will operate at 3 GHz in the 2 π/3 mode. The inner shape of the unit cells has been optimized, with the help of superfish, in order to get a good compromise between high Q and high shunt impedance values and a reasonable ratio between the accelerating field and the wall field. A special technology of the outer shape has been developped which permits final tuning of the cavities up to 1 MHz, and even more, by simple wall deformation. The tuning jig and the tuning method will be presented as well as the experimental results obtained on a 1.5 meter long prototype structure.

Introduction

The LEP Injector Linacs (LIL) consist of two linacs[1], a 200 MeV high current electron linac followed by a 600 MeV positron linac. Apart from the bunching sections, the two linacs use nearly identical travelling wave S-band accelerating sections, 4.5 meters long each.

The high intensity linac consists of 4 such sections fed by a single 35 MW peak power klystron through a couple of storage cavities (LIPS system almost identical to the SLED one).

The positron linac consists of 12 sections, 2 groups of 4 sections being fed with LIPS, and 2 groups of 2 sections being fed directly, without LIPS.

For the LIL project, LIPS (LEP Injector Power Saver) permits to reduce the total number of modulator-klystrons from 9 to 6 for the same overall average accelerating gradient (∿ 17 MV/m).

The disc-loaded accelerating sections are made of 135 elementary cells and operate at f = 2998.55 MHz (30° C in vacuum) in the 2π/3 mode. Each cell consists of an iris between two half resonant cavities. To reduce the number of different cell types the section consists of nine constant impedance landings with eleven identical cells per landing, except the input and output landings which consist of thirteen cells (quasi constant gradient structure). From one landing to the next the iris diameter varies by 875 µm (in range 25 mm to 18 mm) and this causes the required change in group velocity. The step in iris diameter between consecutive landings in made smoother by inserting 4 transition cells which reduce the elementary step to 175 µm.

In the LIPS mode, due to the peculiar shape of the compressed high peak power pulse, the effective accelerating field as seen by the particle does not remain "quasi-constant" but increases by roughly a factor 2 from the input to the output (the average gradient being ≳ 17 MV/m if the direct input rectangular pulse is ≳ 3.5 µs with P = 7.5 MW).

In addition to the 135 accelerating cells are two couplers, an input coupler and an output coupler, the latter being matched to a terminating water cooled resistive load, which absorbs about 22 % of the input power. The two couplers contribute to the acceleration with nearly the same efficiency as individual cells.

After being assembled and brazed by silver diffusion at 350° C the accelerating section is placed into a vacuum envelope.

The basic accelerating cell

Starting from conventional accelerating cells, as used in the LAL and SLAC linacs, it was possible to improve the RF characteristics, Q, r/Q, E_z/Emax by a suitable shaping of the inner walls. Such an optimization of the geometrical parameters made use of both the efficiency of new computer codes, like SUPERFISH, and considerable improvements in high precision machining.

Systematic studies with SUPERFISH led to the followings :

- A round inner shape for the resonant cavities gives higher Q values. The corresponding radius ρ has been optimized (as large as possible) while the height of the cell was kept constant and equal to λ/3. (Fig. 1).

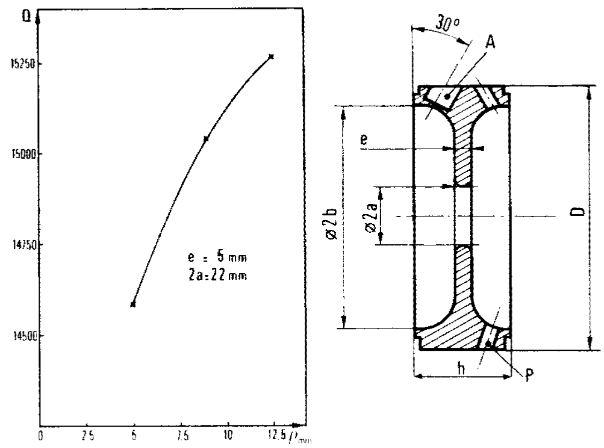

Fig. 1. Quality factor versus radius ρ

- The iris thickness e has been optimized in order to get an acceptable compromise between a high Q and a large ratio E_z/E_{MAX} for the useful range $40 < c/V_g < 140$ and for a minimum iris diameter $(2a)_{min}$ = 18 mm (Fig. 2).

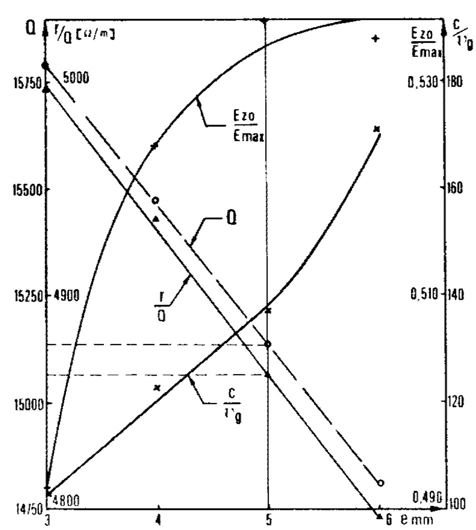

Fig. 2. Cell characteristics versus iris thickness e

The final choice for the geometrical parameters has been ρ = 12.5 mm and e = 5 mm. The corresponding theoretical RF characteristics as function of the iris aperture are shown on Fig. 3.

The outer cell geometry has been designed to meet some contraints :

- Four thin holes will help pumping the inner volume through an outer vacuum envelope. The required vacuum is 10^{-7} Torr.

- At four places around the cell the wall thickness has been reduced to 1 mm to permit an easy tuning deformation using a special tool. A frequency shift of at least 1.5 MH_z can be made without critical damage in surface roughness and joint area.

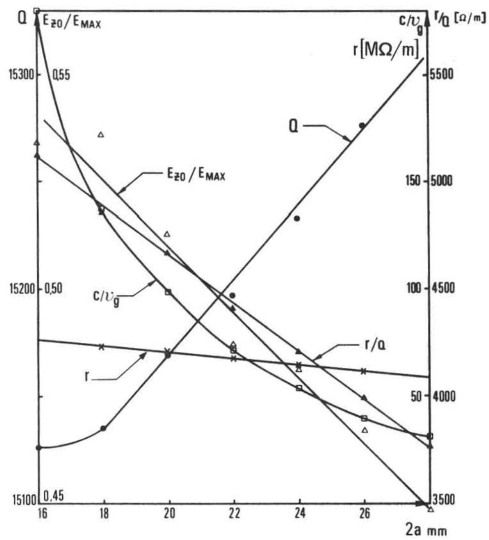

Fig. 3. Cell characteristics versus iris diameter 2a

The cells are made of oxygene free copper of high purity and small grain size.

The tuning methods

There is concern with the tuning of individual cells, the tuning and matching of the couplers and the fine tuning of the structure after being assembled and brazed.

The tuning of individual cells. The tuning by wall deformation over a relatively large frequency range permits to avoid final machining operations. In the present case the cells are machined to obtain a much lower frequency than the operating frequency f_o :

$$f = f_o - .8\ MH_z \qquad (2\pi/3 \text{ mode})$$

and the tolerable random geometrical defects are such as to keep the error frequency within ± .7 MH_z.

The tuning apparatus works with three normal cells in order to measure the right mode frequency. At each extremity a $\lambda/4$ cell ($\pi/2$ mode) is placed to give the right boundary conditions. The fact that the electric field is zero in volumes 2 and 5 (Fig. 4) gives the opportunity of tuning the landing cells ; for instance by inserting a new cell a' instead of a, which is already tuned, it is possible to tune volume 3, which has a finite field, between a' and b by acting on cell a'. By cell translation in the bench it is then possible to tune all the landing cells.

Such a "five cell bench" which has been already used elsewhere[2] is placed in a screw press which also includes the deformation system acting on the four tuning volumes of the normal cell (Fig. 5).

The frequency of the five cell bench is adjusted by comparison with a standard resonant cavity, first adjusted to the right frequency.

Considering the need of two cells to make a single resonant cavity, the cells will be systematically tuned one after the other, in the bench, following their assembly order in the section[3]. This requires firstly to adjust a set of three reference cells, taken from a landing, and make all half resonant cavities as identical as possible by permutation. The other cells including the transition cells will be then tuned by insertion in the

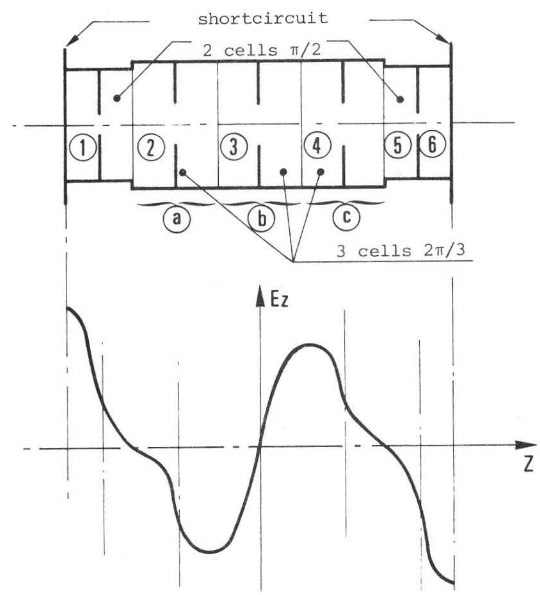

Fig. 4. Five cell bench

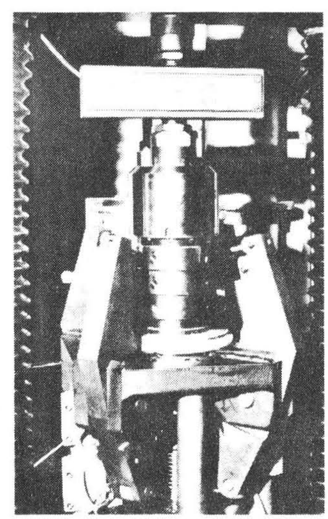

Fig. 5. The tuning apparatus and the screw press

5 cells bench. In fact, to avoid adding errors, there will be nine sets of three reference cells, corresponding to the nine landings of the section, being prepared in a first stage, which later on will serve for all the linac sections. Finally one set of three reference cells is used to tune one landing plus two half transitions for each section. Moreover, due to the large variation of iris diameter between the two opposite landings, three sets of two $\lambda/4$ cells will be used in the bench.

Tuning and matching of the couplers. Each coupler consists of a resonant cavity, which height is equal to the small size of the rectangular waveguide (and hence differs slightly from $\lambda/3$), and half a normal cavity. The coupler is fed from the waveguide through an input iris.

Both input and output couplers of a section are tuned and matched to the section after assembly and before brazing. The method which is used has been developed by R.L. KYHL[4]. Due to its peculiar shape and larger height (39 mm) the coupling volume has RF phase shifts of 109° and 105° respectively for the input and output couplers, as compared to 120° for the normal cells, after matching. These phase measurements are done by moving a short circuit, from cell to cell, along the accelerating section.

The fine matching assumes that all the normal cells have been already perfectly tuned.

Fine tuning of the section. After assembly and before brazing a check of the couplers adjustement can be done with a matched load connected to the output coupler. The amplitude and phase of a travelling wave is measured using a perturbation method.

After brazing, if the resonant frequency of the structure, as obtained by phase shift measurement between cells, has moved, the cells can be slightly retuned by using special tools. If the frequency is too low a two screw jack device will press the cell walls. If the frequency is too high a special stem will be introduce into the pumping hole to erase the previous deformation (pumping holes are opposite to the tuning holes).

Careful amplitude and phase measurements of a travelling wave permit to locate the cells which need retuning.

Experimental results on the prototype section

A prototype section, 1.5 meters long, has been built (Fig. 6). It is made up of the three first landings

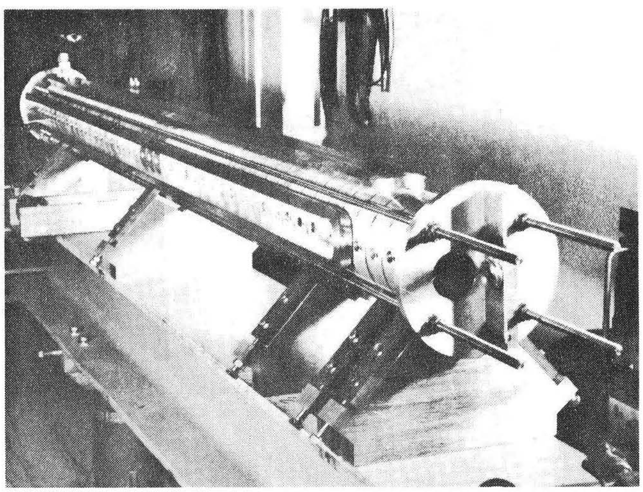

Fig. 6. Prototype section

and the two corresponding transitions, and it has been used to test the whole fabrication procedure :

- Tuning of individual cells by a wall deformation.
- Tuning and matching of the couplers.
- Measurement of the RF characteristics.
- Assembling and brazing technologies.
- Influence of brazing on RF characteristics.
- Fine tuning of the accelerating section.

The RF measurements in the travelling wave mode have been done with the final version of input coupler, while the output coupler has been especially designed to match the third landing to a resistive load[5]. In order to approach the final version of the output coupler, a second prototype section, 0.5 meter, has been also built corresponding to the last landing but has not been brazed.

Phase shift between cells has been measured by displacing a short circuit along the section, at the resonant frequency. Fig. 7 shows a phase dispersion which remains in the range ± 2 degrees. Small tuning corrections were necessary for the transition cells. The resonant frequency of the prototype section was 120 KH_z above the individual tuning frequency.

The RF characteristics as measured on the prototype section[6] are compared to the theoretical values in table 1.

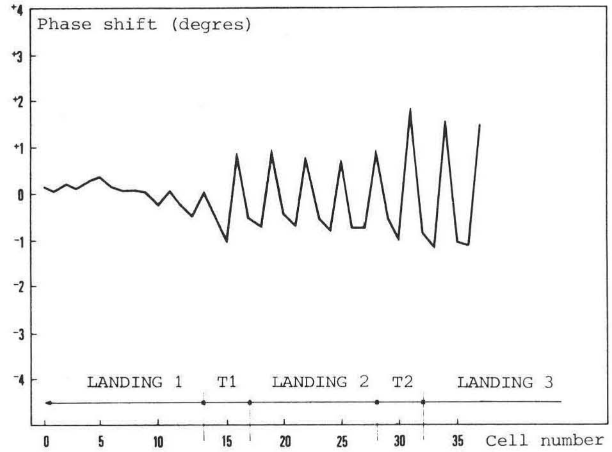

Fig. 7. Phase shift along the prototype section

	Theory	Measurement
Attenuation α	.168 N_p	.184 N_p
Filling time τ_f	.272 µs	.278 µs
Quality factor $Q = \frac{\tau_f \omega_o}{2\alpha}$	15200	14200
Average shunt impedance (TW mode) ; r	64 MΩ/m	64 MΩ/m

Table 1 : RF characteristics of the 1.5 meter prototype section

The group velocity has also been measured on a few landings and well agrees with the theoretical values ($46 < c/v_g < 133$).

Measurements before and after brazing do not show any technical fault. In particular the variation of the resonant frequency does not exceed 20 KH_z and the change in Q is about + 2 %.

The amplitude and phase asymmetries of the couplers[7] have been measured by using a perturbation method. The amplitude asymmetry has been minimized by shifting the coupler axis away from the input iris by 1.9 mm and 1.15 mm respectively for the input and the output couplers. This brought the amplitude asymmetry from 12 % down to .5 %. The remaining phase asymmetry is less than 1.5 degree.

References

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