4PI/5 BACKWARD TW STRUCTURE TESTED FOR ELECTRON LINACS OPTIMIZATION

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Summary

Electron linac wider uses requires to improve accelerating units. For this purpose, a large shunt impedance 4pi/5 H-coupled backward TW structure has been measured and brazed and is presently under power tests. Design of the structure and evaluations of peak field and energy gain (compared with conventional forward TW geometry) are presented, based on simulations, cold tests measurements and power tests with beam.

Introduction

Electron linac development for new applications as injectors for light sources requires acceleration to energies well over 100 MeV (but usually under 1 GeV). Cost increases with klystron output power as modulator voltages becomes very high; SLED RF compression introduces severe parameters constraints if one wants to keep a narrow energy spectrum. The direct approach of improving accelerating structure shunt impedance has been made these last decades for SW structures. Similar progress has not occured on forward E-coupled TW structure.
It is why new proposals to use H-coupled backward TW geometry has been recently made at the 4pi/5 mode [1] and at the 7pi/8 mode [2]. The idea is to dissociate the RF matching region from the beam-field interaction region (as it is the case in SW), to leave room for optimization. All modes between 2pi/3 and pi can be chosen but a compromise must be found between high Q values and sufficient coupling for moderate slot apertures. One must not forget the difficulty to adjust the frequency of each cell. This is one of the reasons why we choose the lower fractional value of 4pi/5.

4pi/5 backward TW structure design

General design

Figure 1 shows the structure which consists of 29 cells plus input and output couplers. These couplers are magnetically coupled to the structure but also to the external RF wawe guides. Working frequency is 2998 Mhz. The total length is 1.27 meter. One notes that input coupler corresponds to the beam exit to insure proper synchronism between electrons and the travelling wave.

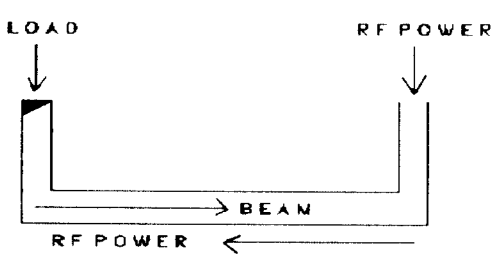

Figure 1: 4pi/5 backward TW unit

Cell design

Figure 2 shows cell geometry where beam clearance is 12.8 mm and coupling slots corresponds to c/vg=46 for a bandwith of 92 Mhz. Cells are all identical and are rotated by 90 degrees to avoid having coupling slots face to face. Distance between noses has been optimized by calculations with SUPERFISH for a half-cell geometry. An optimum effective shunt impedance corresponds to 27.5 mm.

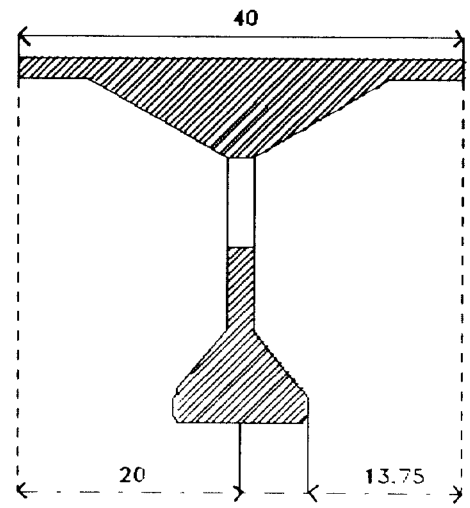

Figure 2: 4pi/5 H-coupled cell design

Tuning method

Figure 3 shows the 29 cells line numbered from 1 to 29 and distinguished from each side by H and L. Cells being identical, a good method would be to tune each electrical volume [(1L,2H);(2L,3H);...] under press at frequencies Fpi/2=F and Fpi=F'chosen such that one would be at the operating frequency at 4pi/5 mode. But problems with courts-circuits on coupling slots prevented us from tuning at pi mode. Finally, we adopted the following method:
One tunes volume (1L,2H) by the half-volume 2H at Fpi/2=F (figure 4a) and volume (1H,2L) by the half-volume 2L at Fpi/2=F (figure 4b). One replaces cell numbered 1 by the 3 and one begins again until cell numbered 29. One notes that we were obliged not only to tune real electrical volumes but also fictitious volumes like (1H,2L) to insure good tuning. The half-volumes 1H and 29L are tuned with input and output couplers.

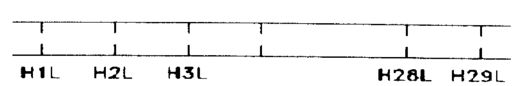

Figure 3: 29 cells line

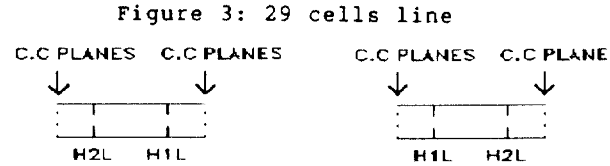

Figure 4a Figure 4b
Tuning at pi/2 mode under press

Cold measurements of the structure

Figure 5 shows measurement of electrical field on-axis where triangles represent Ez in the cell mid-planes. The deviation in phase from cell to cell with respect to theoretical value which is 144°, is shown on figure 6. The total dephasing misadjustment from cell 1 to cell 29 with respect to a theoretical value of 4176° could not be detected. The total deviation on the whole structure (cells plus input and output couplers) is 4464.8°. Ones gives below the results of attenuation and filling time measurements after brazing, which take into account input and output couplers:

attenuation factor: A = 0.172 Np
filling time: Tf = 0.203 Microseconds

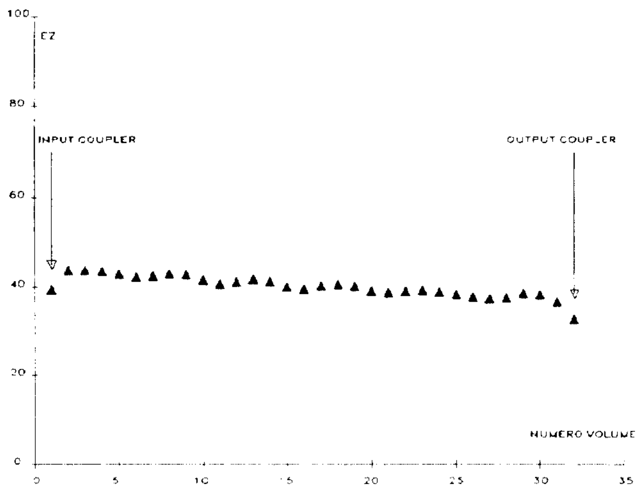

Figure 5: Electrical field on-axis in the cell mid-planes

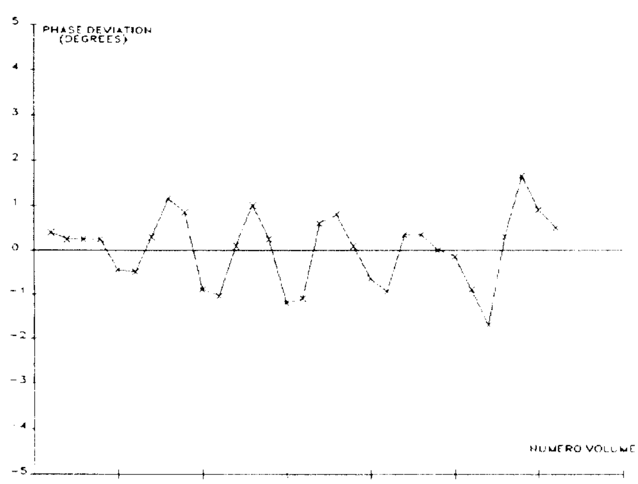

Figure 6: Phase deviation from cell to cell

Energy gain of 4pi/5 TW structure based on cold tests measurements of H-coupled cells

Cold tests measurements

It is necessary to measure RF parameters of H-coupled cells to know their shunt impedance as it is not possible by now, with help of 2D computer codes, to calculate them because of the coupling slots. We measured in SW at 4pi/5 mode, the Q and R/Q factors for several values of the coupling slots angle S. This angle is defined on figure 7. Experimental results are shown on figure 8. The Q absolute value has been adjusted for S=0° by calculating at 4pi/5 mode Q parameters of the same cells for several values of central aperture. One observes that Q values converge for a central aperture of 12 mm toward Q value calculated for a half-cell geometry at pi mode or 2pi mode. So, Q factor of H-coupled cell must also converge toward the same value since the H-coupled cell when S=0° is identical to the E-coupled one. By the same way, it is possible to verify the gauging for R/Q measurements.

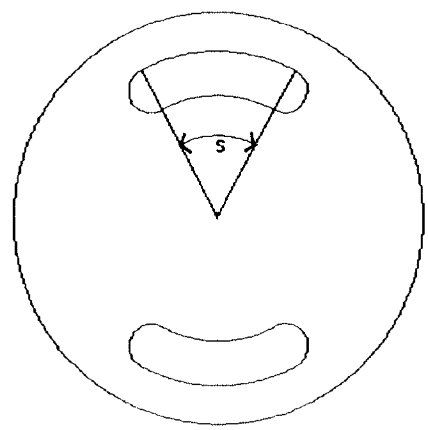

Figure 7: Coupling slots of 4pi/5 cell

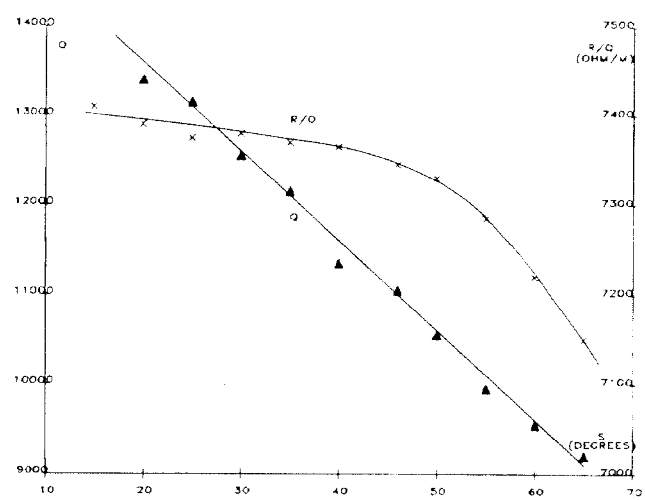

Figure 8: Variations of Q and R/Q with the coupling slots angle S

From these measurements, one can obtain the effective TW shunt impedance by the classic relation:

$$Z_{eff} = 2 \times R \times T^2$$

where T is the transit time factor in SW equal to 0.69; one gives on table 1 a comparison of TW Zeff values between 4pi/5 H-coupled and 2pi/3 E-coupled cells which are used for the LEP Injector Linac.

Table 1: Zeff values for 2pi/3 E-coupled and 4pi/5 H-coupled cells

2pi/3 E-coupled		4pi/5 H-coupled	
c/vg	Zeff (Mohm/m)	Zeff (Mohm/m)	c/vg
154	72.3	95.6	141
104	69.1	92	94
74	66	88.6	67
54	62.8	85	48
48	61.2	81.4	36
42	59.5	76.9	27
		73.9	22
		69.9	18
		65.7	14
		61.5	12

One sees on figure 9 that difference for any same c/vg is around 24 Mohm/m. It means a gain of 39% on Zeff for c/vg=48.

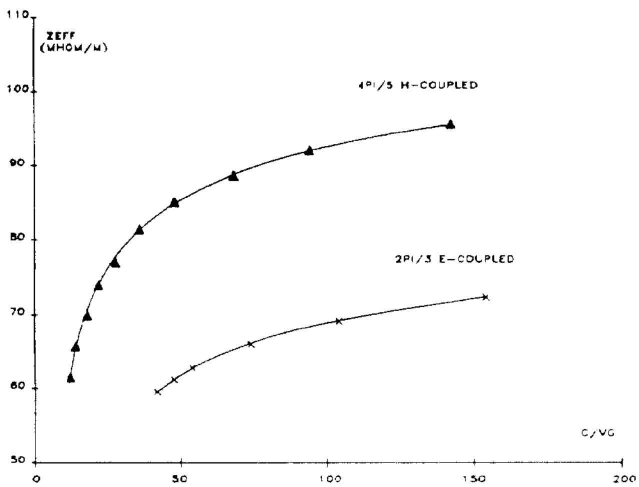

Figure 9: Zeff comparison between 4pi/5 H-coupled and 2pi/3 E-coupled cells

Energy gain of 4pi/5 TW structure

From cold tests measurements and calculations comparison for a half-cell geometry, one obtains the following cell RF parameters for the c/vg value of 46 used on the power tested structure: Q=12300, R/Q=7200 Ohm/m, Zeff=84.3 Mohm/m.

Energy gain W is given for an incident RF power P and attenuation factor A, by:

$$W = (PLZeff)^{1/2} \times (2/A)^{1/2} \times (1-E^{-A})$$

If P=20 MW, the MeV energy gain W is:

$$W = (20 \times 1.27 \times 84.3)^{1/2} \times (2/0.172)^{1/2} \times (1-E^{-0.172})$$

$$W = 25 \text{ MeV}$$

Maximum on-axis Ez value is related to input RF power P by:

$$Ez = 2pi/\lambda \times (R/Q)_{TW} \times c/vg \times P$$

with $(R/Q)_{TW} = 1.23 \times R/Q$[4]. For P=20 MW:

$$Ez = (2pi/0.1 \times 8850 \times 46 \times 20)$$

$$Ez = 22.6 \text{ MeV/m}$$

The peak field on noses calculated by SUPERFISH is 2.6Ez on-axis. The maximum peak field on copper reachs 59 MeV/m.

Power tests measurements

The structure has been installed in the test station of LAL Universite PARIS XI ORSAY. The maximum RF power available up to now is around 20 MW. The input beam in the structure has an energy of several MeV.

The structure is presently in formative process but we have already made preliminary energy measurements at weak power. For P=12.8 MW, one has an energy gain of 19.1 MeV. Knowing the energy gain, the input power and the attenuation factor, one obtains an effective shunt impedance of 77 Mohm/m. This result is pessimistic as the RF power value is well below the operating nominal point of the buncher, so electrons at the input of the structure are not optimized with respect of energy and the microbunch has a large phase extension. The true Zeff must be higher than 77 Mohm/m. We hope to ascertain the extrapolated value from cold tests of 84.3 Mohm/m.

Conclusion

Cold measurements data are now available for the design and the RF adjustement of 4pi/5 H-coupled backward TW structure. Preliminary power tests have just validated the expected energy gain in reference [1]. We know that higher power levels will give more precise figures. It is important also to ascertain the upper limit without too high field emission or spark ing, eventually with SLED. Present day experience leads us to the following figures:

A +20% $\pm$ 5% energy gain (or a -40% $\mp$ 10% power requirement). It is also interesting to note that the impedance Zeff remains large even for very low c/vg (i.e 60 Mohm/m for c/vg=12).

Our goal is an economical accelerating unit made of a 6.8 m single backward 4pi/5 structure with a filling time under 1 microsecond powered by a 45 MW-4.5 microsec. RF pulse leading to 140 MeV without SLED or 230 MeV with SLED. It would replace the unit described in reference [3].

References

[1] D.Tronc, "Electron linac optimization for short RF and beam pulse lengths", 1985 Part. Acc. Conf., IEEE Trans., NS-32, 3243.
[2] R.H. Miller, "Comparison of standing-wave and travelling-wave structures", 1986 Linear Acc. Conf., Stanford, Slac-pub-3935.
[3] D.Tronc, D.T. Tran, G. Meyrand, A. Setty "Electron injector design for light source", this conference.
[4] The 1.23 figure is deduced from SW to TW conversion calculations, see for ex. G.Dôme, Review and Survey of acc. struct. in Linear Accelerators, ed. by Lapostolle and Septier, 1970.