# The $3\pi/4$ Backward TW Structure for the ELETTRA 1.5 GeV Electron Injector

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## Summary

The $3\pi/4$ backward traveling wave (BTW) structures used for the ELETTRA 1.5 GeV Electron Injector [1] have been designed and are now under realization. These accelerating units will be fed by a TH 2132 45 MW-4.5 $\mu s$ klystron coupled to a Thomson CIDR (Compresseur d'impulsion à Double Résonateur) similar to the CERN design of the SLED. The expected energy gain is equal to 33 MeV/m. This paper justifies the use of the $3\pi/4$ accelerating mode. After a description of the structure design, the choice of RF parameters leading to optimization with RF pulse compressor, evaluations of energy gain and peak field on copper based on simulations and cold tests measurements are presented. RF cold test measurements of the first unit are analysed.

## Introduction

Electron linac development as injectors for light sources and the availability of several RF pulse compressor systems (SLED, LIPS etc...) renewed the interest for traveling wave accelerating structures optimized for the pulse compression mode of operation. To improve acceleration efficiency of classical forward TW units usually composed by $2\pi/3$ E-coupled cells, proposals have been made to accelerate electrons with a larger shunt impedance H-coupled backward TW structure at the $4\pi/5$ mode [2] or at the $7\pi/8$ [3] mode. Energy gain measurements of the 1.27 m $4\pi/5$ BTW section installed at $LAL$ [4,5], associated to previous cold tests measurements on reference cells and simulations, have validated the improvement in energy expected in reference [2], i.e +23% within a 5% margin error. The high power levels reached with RF pulse compressor have also permitted to expect a good peak field behaviour of a longer unit. Finally, this new kind of BTW accelerating structure has been chosen for the ELETTRA Electron Injector [1]. In this paper, justification and characteristics of the $3\pi/4$ BTW structure are presented.

## Choice of $3\pi/4$ mode

For a given cell geometry synchronous at 3 Ghz and several modes between $2\pi/3$ and $\pi$, we study variations of effective shunt impedance $Z_{eff}$ according to the length of accelerating gap. Obviously, cell length changes for each mode to respect synchronism between wave and particule. Figure 1 shows the geometries for $3\pi/4$ and $4\pi/5$ modes. There is a value of the accelerating length gap which maximises $Z_{eff}$ for each mode. The following table gives these maximum figures of $Z_{eff}$ calculated with SUPERFISH for a half-cell geometry (boundary conditions corresponding to $\pi$ mode).

Table 1: Optimum $Z_{eff}$ values

| mode | $2\pi/3$ | $3\pi/4$ | $4\pi/5$ | $5\pi/6$ | $\pi$ |
|---|---|---|---|---|---|
| $Z_{eff}$ Mohms/m | 91.7 | 94.5 | 94.6 | 94.2 | 86.2 |

Optimum mode for H-coupled cells lies between $3\pi/4$ and $4\pi/5$ without the effect of magnetical coupling. Higher modes will have larger coupling slots for a same $c/v_g$ value, and so, a larger decrease of Q factor or $Z_{eff}$ since the ratio $Z_{eff}/Q$ remains constant [6]. The $3\pi/4$ mode has been chosen for this reason and also because it is very simple to adjust in frequency.

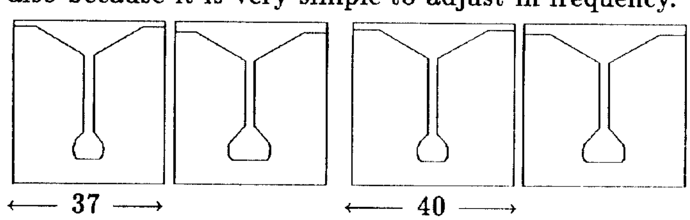


Figure 1: Variations of accelerating gap length for $3\pi/4$ and $4\pi/5$ cells

## Characteristics of $3\pi/4$ BTW structure

### General design

Figure 2 shows the structure which consists of 162

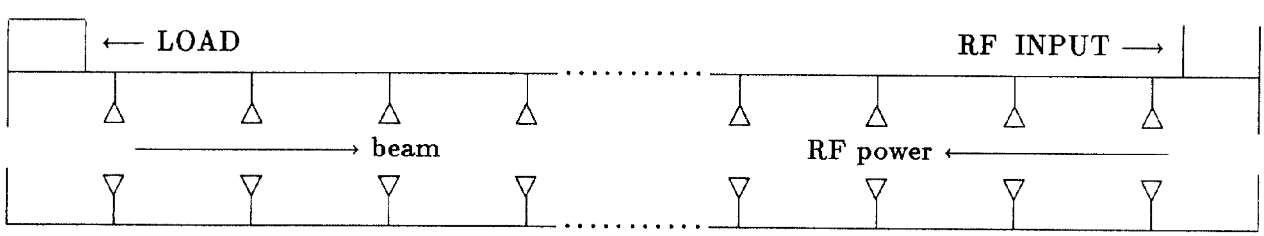


Figure 2: $3\pi/4$ BTW unit

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cells plus input and ouput coupler cells. These coupler cells are magnetically coupled to the RF rectangular waveguides. Operating frequency is 2998 Mhz. The total length is 6.15 m. The input coupler corresponds to beam exit to insure proper synchronism between electrons and traveling wave.

<u>Choice of filling time structure</u>

For ELETTRA linac, beam pulses from 10 *ns* to 150 *ns* will be accelerated at 1500 MeV. The use of RF pulse compressor gives large no-load energy variations around optimum time injection, leading to poor energy spectrum. But by advancing the phase-reversal time on one or two klystrons and by using transient beam-loading properties, energy spectrum remains inferior to ± 0.5% for jitters lower than ± 10 *ns* [7] (beam energies at the beginning and end of the pulse are equal). Figure 3 shows energy variations versus unit filling time for several beam pulse lengths, klystron power of 45 MW, klystron pulse length of 4.5 $\mu s$, transmission losses of 7% and CIDR cavities Q factor of 150000. Optimum for no-load energy corresponds to 0.65 $\mu s$. These variations shows that the filling time value finally adopted and equal to 0.76 $\mu s$ is better for longer beam pulses.

For a compressed pulse duration of 0.76 $\mu s$, i.e a phase reversal-time occuring at 3.74 $\mu s$, the compressed power pulse amplitude varies from 259 MW (at 3.74 $\mu s$) to 88 MW (at 4.5 $\mu s$), as shown on figure 4.

<u>The peak field</u>

After a formation process duration of about 200 hours, high power tests of the $4\pi/5$ BTW test structure reached a peak field value on copper of 146 MV/m in good operating conditions [5]. It is important to note that it was achieved for a similar mode of operation as the $3\pi/4$ BTW unit, i.e a similar phase-reversal time (3.7 $\mu s$) and a same klystron pulse length (4.5 $\mu s$). Then, $3\pi/4$ cell geometry near axis has been chosen to limit peak field value on copper to 140 MV/m.

<u>Cell design</u>

Figure 5 shows the two kinds of cell composing the structure: 54 cells of type I and 108 cells of type II. Main RF parameters of each cell type is given in table 2. $\widehat{E}_s$ and $\overline{E}_a$ are respectively the peak field on copper and the average field on-axis. The ratio $\widehat{R}_{eff,tw}$ between $\widehat{E}_s$ and the effective accelerator field on-axis is related to $\widehat{R}_{tw}$ by $\widehat{R}_{eff,tw} = \widehat{R}_{tw}/T_{tw}$.

Cells of type I are placed at input coupler side to limit peak field on copper to 140 MV/m when peak power (259 MW) enters into the structure. They are replaced by cells of type II when section attenuation

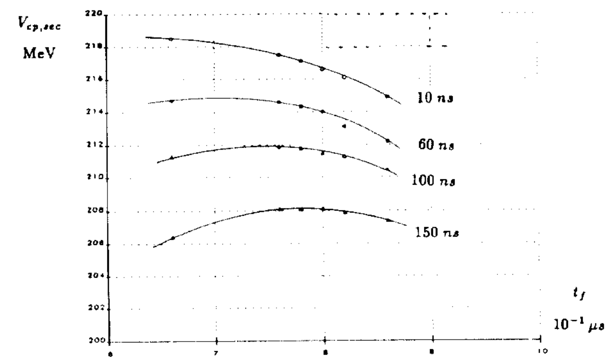


Figure 3: Variations of energy gain per section with filling time

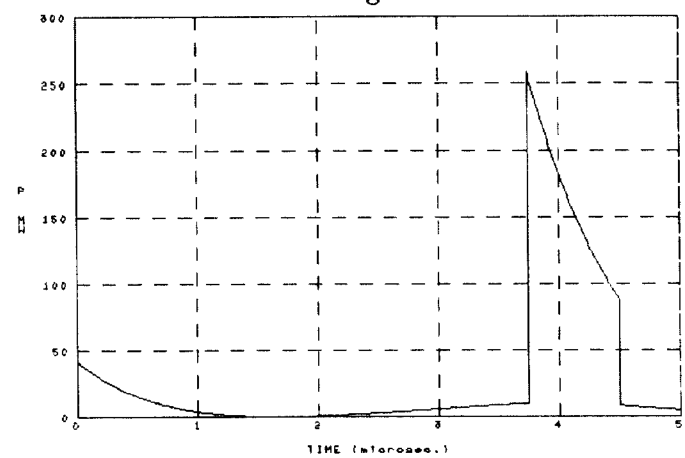


Figure 4: Power pulse amplitude after compression

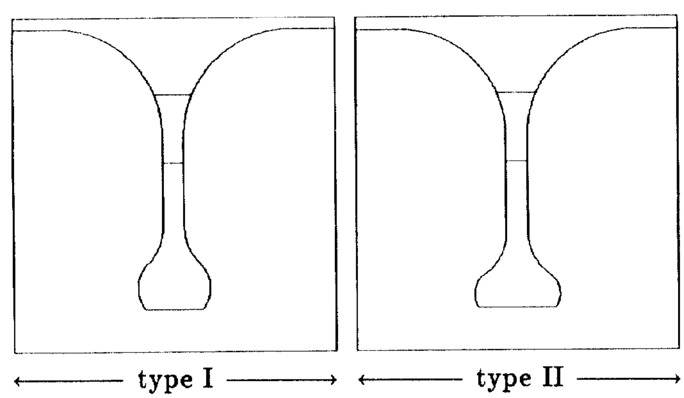


Figure 5: $3\pi/4$ H-coupled cells design

Table 2: Characteristics of $3\pi/4$ TW cells

| | type I | type II |
|---|---|---|
| Beam clearance | 10 mm | 10 mm |
| $Q$ | 12500 | 12500 |
| $Z_{eff,tw}/Q$ | 6195 | 6485 |
| Transit time factor $T_{tw}$ | 0.856 | 0.860 |
| $\widehat{R}_{tw} = \widehat{E}_s/\overline{E}_a$ | 1.96 | 2.30 |
| $c/v_g$ | 37.1 | 37.1 |

compensates the increase of $Z_{eff,tw}/Q$ and $\widehat{R}_{tw}$ so that peak field on copper is again limited to 140 MV/m. The change of cell type increases energy gain of 2%.

Coupling slots dimension has been defined by cold measurements on test cells. Without cell cleaning, experimental $Q$ value measured in SW has been found equal to 11500 [8]. After cleaning and brazing, one expects a final $Q$ value higher than 11500.

## Evaluations of energy gain and peak field

The following table summarises expected energy gains per section and peak fields for short and long beam pulses.

Table 3: Energy gains per section and peak field

| Beam pulse ns | Energy gain per section MeV | peak field MV/m | peak field at beam time MV/m |
|---|---|---|---|
| 10 | 217 | 140 | 88 |
| 150 | 207 | 140 | 91 |

These results give an energy gain margin of 3.5% to 8.5% with respect to the required value equal to 200 MeV. The critical point for peak field corresponds obviously to peak power injection time and not to beam injection time. It is interesting to note that for $Q$ value equal to 11500 cited before as a preliminary pessimistic result, it decreases energy gains given in table 3 only by 2.5%.

## RF cold tests measurements of the first unit

Figure 6 shows measurement of the electrical field on-axis $E_z$ in cell mid-planes. The amplitude increase around $z = 200$ cm corresponds to the substitution of cells of type I by cells of type II. The phase-shift deviation from cell to cell with respect to the theoretical value equal to $135^o$ is shown on figure 7. The maximum phase-shift deviation is lower than $2^o$. Before cleaning and brazing, the measured filling time has been found equal to 0.76 $\mu s$.

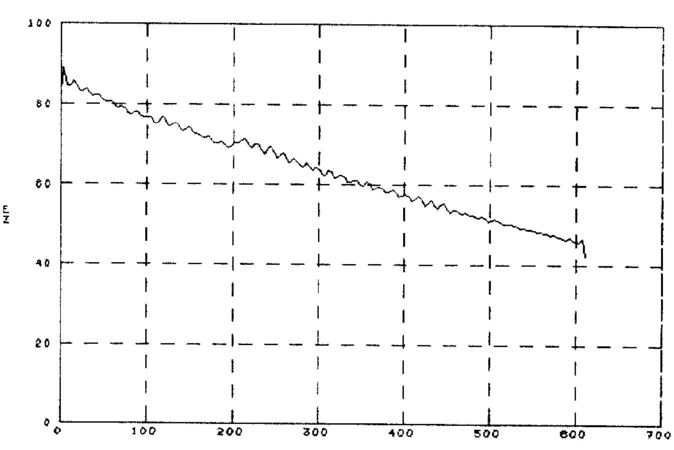

Figure 6: Electrical field on-axis in cell mid-planes

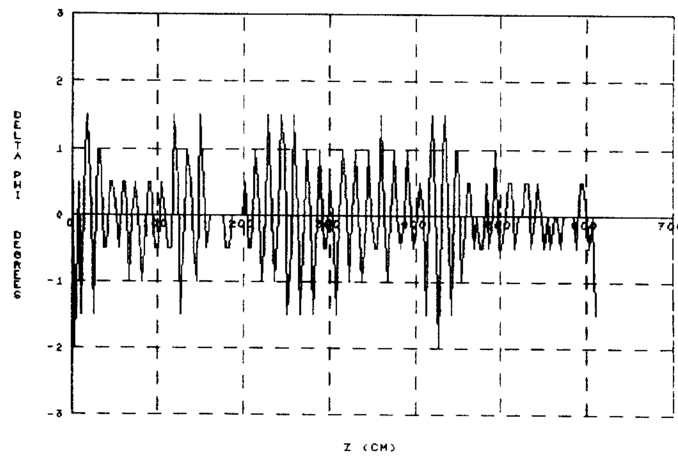

Figure 7: Phase-shift deviation from cell to cell /t $135^o$

## Conclusion

Preliminary RF cold tests measurements of the first $3\pi/4$ BTW structure have permitted to ascertain the tuning method validity and the filling time value with respect to optimization with RF pulse compressor. After cleaning and brazing, attenuation measurements will precise experimental $Q$ value found in SW with no-cleaned test cells. Next power tests with RF pulse compressor will also permit to confirm the good expected peak field behaviour of the $3\pi/4$ unit.

## References


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