POWER TESTS RESULTS OF $4\pi/5$ BACKWARD TW STRUCTURE WITHOUT AND WITH SLED RF PULSE COMPRESSOR

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Summary

Futur electron linacs require high gradient acceleration. For this purpose, a high shunt impedance backward TW structure, installed at *LAL*, has been tested without and with RF pulse compressor. After a description of the experimental set-up, this paper justifies the values of 22 MeV/m energy gain, 73 MV/m peak field on copper without pulse compression and 48 MeV/m energy gain, 170 MV/m peak field on copper with pulse compression. It compares them to conventional E-coupled ones and gives RF dark current measurements. It presents also the geometries which will be used for 6 meter 200 Mev accelerating units.

Introduction

Electron linac development as injectors for light sources and the availability of several RF pulse compressor systems (SLED, LIPS etc...) renews the interest for high shunt impedance accelerating structures optimized for the pulse compression mode of operation. Instead of using classical E-coupled TW units, proposals have been made to accelerate electrons with a larger shunt impedance H-coupled backward TW structure (BTW) at the $4\pi/5$ mode [1] or at the $7\pi/8$ mode [2], where the dissociation between the RF coupling region and the beam-field interaction region, leaves room for optimization. Cold tests measurements on reference cells and preliminary warm results on the test structure installed at *LAL* [3] have validated the improvement in energy expected in reference [1], i.e +23 % within a 5 % margin error.

In this paper, we discuss again the energy gain, and we analyse the results obtained on the test structure with pulse compression at higher power levels.

Experimental set-up

$4\pi/5$ TW structure

Figure 1 shows the geometry of the critical input part of the 1.27 m section which is described in detail in reference [3].

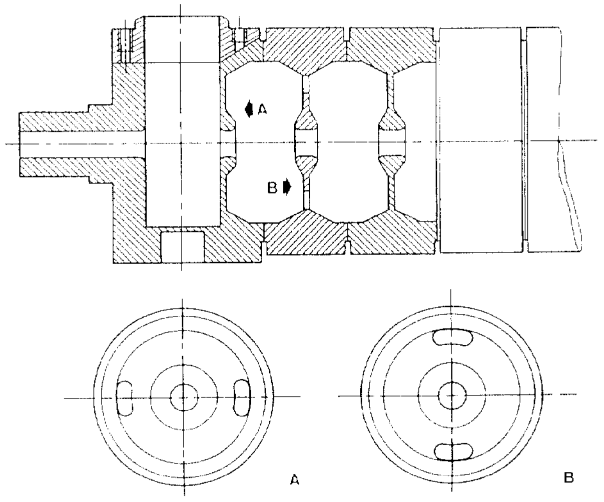

Figure 1: $4\pi/5$ TW structure

The following table reminds the main parameters of the cell and structure. Cell figures are obtained from cold tests measurements on reference cavities and SUPERFISH simulations. Section figures are obtained from cold measurements after brazing, including input and output couplers.

Table 1 : Characteristics of $4\pi/5$ TW structure

Cells	
Beam clearance	12.8 mm
Q	12300
$Z_{eff,tw}/Q$	6100 Ω/m
"Transit time factor T_{tw}"	0.854
$\widehat{R}_{tw} = \widehat{E}_s/\overline{E}_a$	2.6
c/v_g	46
Section	
Operating frequency	2998 Mhz
Filling time	0.203 μs
Phase shift	$4\pi/5$
Attenuation	0.172 Np

$\widehat{E}_s$ and $\overline{E}_a$ are respectively the peak field on copper and the average field on-axis. The average effective accelerator field $\overline{E}_{a,eff}$ is related to $\overline{E}_a$ by $\overline{E}_{a,eff} = T_{tw}\,\overline{E}_a$.

The experimental Q values, deduced from transmission and reflexion attenuation measurements, are respectively equal to 11120 and 12050. In the worst case corresponding to the retained attenuation value, the difference between the experimental figure and the expected one equal to 12300 corresponds to a difference of 0.15 db on power attenuation measurement, value which lies within the measurement uncertainty margin.

Test station

Figure 2 shows the test station used for high gradient accelerator studies at *LAL*.

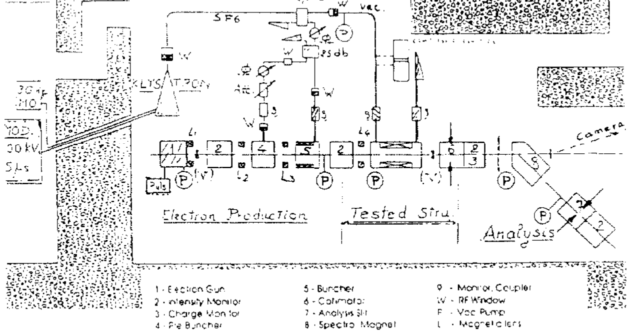

Figure 2: Test station

The whole accelerating unit is presently composed by:

- a 35 MW klystron providing 0.5 μs to 4.5 μs pulse duration with a frequency rate of 100 Hz or submultiples, with or without RF pulse compressor.
- an electron source including a triode gun of the SLAC type, a pre-buncher cavity and a buncher.
- a free space to insert accelerating test structures until lengths equal to 1.8 m.
- an instrumentation system for the beam measurements.

Kwowing the gauged power P_k at the klystron output and taking into account the RF waveguide loss and the amount of power transfered to the electron source, the power P_{inc} injected in the section is related to P_k, when there is no pulse compressor, by $P_{inc} = 0.88\ P_k$. With the RF pulse compressor, the electron source is not supplied and then $P_{inc} = 0.93\ P_k$.

The energy measurement is made by a spectrometer usable until 75 MeV/c. The dark current produced by field emission is measured in term of electric charge with a Faraday cup followed by an integrator located at the end of the section.

Experimental results without pulse compression

Two klystrons were used with maximum power values equal to 25 MW and 35 MW. The energy gain V of the structure is deduced from the measured value to which is substracted the energy gain due to the electron source. The $Z_{eff,tw}$ experimental value is determined by the relation:

$$Z_{eff,tw} = \frac{V^2}{P_{inc}} \times \frac{\tau}{[2\,L\,(1-e^{-\tau})^2]} \tag{1}$$

where τ is the attenuation factor, L the length of the structure. With $\tau = 0.172$ Np and $L = 1.27$ m, one has:

$$Z_{eff,tw} = 2.71 \times \frac{V^2}{P_{inc}} \tag{2}$$

One gives below the values obtained:

- 25 MW klystron

$$\begin{aligned} Z_{eff,tw} &= 83 \pm 5\,\%\ \mathrm{M\Omega/m} \\ Z_{eff,tw}/Q &= 7460 \pm 5\,\%\ \Omega/\mathrm{m} \end{aligned} \tag{3}$$

- 35 MW klystron

$$\begin{aligned} Z_{eff,tw} &= 69 \pm 5\,\%\ \mathrm{M\Omega/m} \\ Z_{eff,tw}/Q &= 6200 \pm 5\,\%\ \Omega/\mathrm{m} \end{aligned} \tag{4}$$

One has some doubt about the value found in (3). Indeed, the 25 MW klystron began to have some trouble and we suspect that the original gauging was no more correct. The $Z_{eff,tw}/Q$ value found in (4) is in good agreement with the figure given in table 1. The difference between the $Z_{eff,tw}$ value found in (4) and the expected one of table 1 corresponds only to the difference between theoretical and experimental τ figures which defines the constant in the expression (2).

The energy gain is related to P_{inc} by:

$$V = \overline{E}_{a,eff}\ L\ \frac{(1-e^{-\tau})}{\tau} \tag{5}$$

With the values given in (4), one has:

$$V = 5.04\ \sqrt{P_{inc}} \tag{6}$$

where V is in MeV, P_{inc} in MW.

The peak field on copper $\widehat{E}_s$ in the first cell is related to the average energy gain $\overline{V} = V/L$ by:

$$\widehat{E}_s = \frac{\widehat{R}_{tw}}{T_{tw}}\ \overline{V}\ \frac{\tau}{(1-e^{-\tau})} \tag{7}$$

Thus:

$$\widehat{E}_s = 3.30\ \overline{V} = 13.1\ \sqrt{P_{inc}} \tag{8}$$

The maximum klystron power (35 MW-4.5 μs) has been used to supply the test structure. For these conditions, $P_{inc} = 31$ MW. It corresponds to 22 MeV/m energy gain and 73 MV/m peak field on copper.

Experimental results with pulse compression

With pulse compression, experimental conditions are not yet optimized. The SW buncher cannot be supplied because of the RF phase reversal and the power is not injected in the BTW structure at the end (seen from the electron source). This means that emitted electrons are accelerated in the opposite direction with respect to the spectrometer. So, it is not yet possible to measure energy gain and field emitted electrons energy.

The RF pulse compressor is used with the 35 MW klystron. The Q value of the compressor cavities is equal to 170000 and the coupling coefficient β to 9. The phase-reversal time occurs at 3.7 μs and the klystron pulse duration is equal to 4.5 μs. The shape of the pulse after the compression is shown on figure 3.

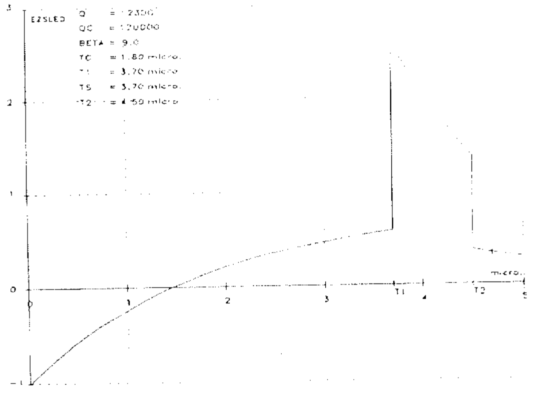

Figure 3: Pulse shape after compression

Calculation gives an energy gain factor due to pulse compression equal to 2.38. The theoretical ratio value between the peak power $\widehat{P}_{pc}$ et P_{inc} is 6.60. The experimental figure is found equal to 6.50 ± 3 %. This excellent figure has been carefully checked. Thus, the energy gain V_{pc} and the peak field on copper $\widehat{E}_s$ in the first cell are given by:

$$V_{pc} = 12\ \sqrt{P_{inc}} \tag{9}$$

and

$$\widehat{E}_s = 3.53\ \overline{V}_{pc} = 13.1\ \sqrt{\widehat{P}_{pc}} \tag{10}$$

For a long period without breakdown (less than $3\,10^{-4}/s$), the maximum power P_{inc} injected in the test structure is equal to 19 MW. It corresponds to 124 MW peak power, 41 MeV/m energy gain and 146 MV/m peak field on copper.

For a short period with a breakdown rate around $3\,10^{-2}/s$, the maximum P_{inc} value is 26 MW. It corresponds to 169 MW peak power, 48 MeV/m energy gain and 170 MV/m peak field on copper.

These results, obtained after a conditioning time of about 200 hours, are not upper limits. The formation process will be continued to use the maximum available klystron power and to improve the operating duration without breadown.

Points of comparison are today as follows:
At LAL, with the 0.6 m $2\pi/3$ E-coupled TW structure, the maximum P_{inc} value is also 26 MW which leads to 80 MeV/m energy gain and 167 MW peak field on copper [4].
At SLAC ,with the positron section [5], 50 MeV/m energy gain and 130 MV/m peak field on copper have been reached for an incident power value of about 40 MW [6].

Dark current values evolve toward asymptotic figures with respect to formation time. We give in table 2 dark current measurements in term of electric charge where aymptotic values are reached for peak power inferior to 140 MW.

Table 2 : Dark current evolution with respect to peak power

$\widehat{P}_{pc}$ (MW)	90	103	115	127	139	154
q (10^{-9} C)	0.9	1.8	2.9	4.1	4.9	6.6

Cell design of BTW 200 MeV accelerating units

Figure 4 shows the geometries of $2\pi/3$ FTW, $4\pi/5$ BTW and $3\pi/4$ BTW cavities, these last ones being used for 200 MeV units. Cell of type (I), at the section input, are replaced by cell of type (II) when power attenuation compensate the increase of $\widehat{R}_{tw}$. Cell parameters are obtained by SUPERFISH simulations and BTW Q values take into account the coupling slots influence. One notes that the ratio $\widehat{R}_{tw}$ of the $3\pi/4$ BTW geometry of type (I) is slightly lower than the $2\pi/3$ E-coupled one.

We give in table 3 simulation results for $2\pi/3$ FTW and $3\pi/4$ BTW units without or with pulse compression. The length of the structure is equal to 6 m and c/v_g to 38. The klystron length pulse, the incident power at the section input and the Q of the compressor cavities are respectively equal to 4.5 μs, 42 MW and 150000.

Table 3 : Comparison between $2\pi/3$ FTW and $3\pi/4$ BTW

	FTW $2\pi/3$	BTW $3\pi/4$
V (MeV)	94.3	115.5
$\widehat{E}_s$ (MV/m)	43	57
V_{pc} (MeV)	178.9	218.3
$\widehat{E}_s$ (MV/m)	107	142

We find that $V_{btw} = 1.22\ V_{ftw}$ and, for a same energy gain, $\widehat{E}_{s,btw} = 1.09\ \widehat{E}_{s,ftw}$. The expected field on copper value for the 200 MeV unit is similar to the peak field obtained with the $4\pi/5$ BTW structure for a long period with pulse compression. This comparison is realistic because in the two cases, cells "see" a very high field during a same period, i.e about 0.8 μs.

Conclusion

Present day experience leads us to the following results:

- Energy gain measurements, associated to previous cold tests measurements and simulations, confirm the expected energy gain of +23 % within a 5 % marge error. This is illustrated by a +9 % marge for the 200 MeV unit.
- Power tests have exceeded the peak field value of the 200 MeV unit with a similar pulse compression mode of operation, i.e a similar phase-reversal time and a same klystron pulse length. This means we can expect a good peak field behaviour of the 6 m structure.

The formation process of the $4\pi/5$ BTW structure is going to be continued to improve the section behaviour under very high power levels. The maximum available power must allow to reach 230 MW peak power in the RF waveguide, 215 MW peak power in the structure, 54 MeV/m energy gain and 190 MV/m peak field on copper.

References

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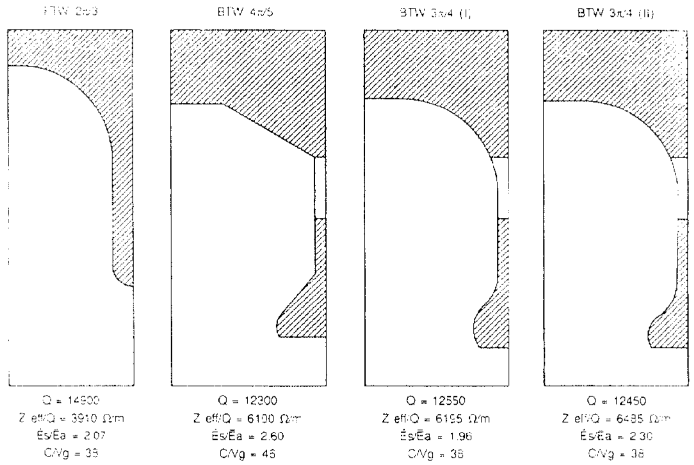

Figure 4: Cell geometry comparison between FTW and BTW