IEEE Transactions on Nuclear Science, Vol. NS-32, No. 5, October 1985

ELECTRON LINAC OPTIMISATION FOR SHORT RF AND BEAM PULSE LENGTHS

D. TRONC, THOMSON CGR MeV,
551 rue de la Minière, BP 34, 78530 BUC, FRANCE

Summary

New applications of electron linacs require better use of the space available and the success of the SLED RF compression method renews the interest for the conventionnal E-coupled TW accelerating structure which has the required short filling time. We propose to use the less conventionnal backward-wave H-coupled TW accelerating structure which allows an higher shunt impedance. A unit of acceleration could include a 37 MW TH 2094 klystron, with SLED feeding through a 3 db hybrid coupler including a load in the fourth arm, two 6 meter long backward TW structures with thickened irises near the acceleration axis. Output loads could be avoided. The choice of the H-coupled 4 π/5 mode and the cell shapes and properties are analyzed. Conclusion stresses the advantages as simplicity and also the limits of this optimization.

Introduction and present status

The development of dedicated synchrotron radiation sources for research and sub-micron technology as the fabrication of microelectronic devices call for the injection in storage rings of high energy electrons from several hundreds MeV to more than one GeV (1, 2). There are two ways to produce economically these electrons : either by circular machines well suited for the highest energy range or by linacs well suited for the lower energy range. The frontier between the two approaches is not clearly defined today.

The electron linac designers try to increase the energy communicated to electrons per unit of acceleration length keeping at the same time the level of the primary RF source power at a reasonably low value. They take advantage of the rather special requirements for the electron accelerated beam : short pulses (typically ≤ 0.1 microsecond) with low repetition rate and moderate peak intensity (typically ≤ 30 milli-ampères). The possibility of increasing the RF peak level at the expense of its length appears very interesting and recent developments proves the workability of the SLAC Energy Doubler or SLED approach (3, 4).

From the accelerating structure point of view a similar breakthrough has not occured. One needs to use a travelling-wave type of structure as the RF filling time is a critical parameter in connection with the use of very short RF pulses. This is due to the fact that in S-band, taken as example, TW structure can have a propagation filling time at the nominal field level of less than one microsecond, value which is very favourably compared to SW filling times of several microseconds (to reach 95 per cent of the field level asymptotic value).

The choice of the c/vg law along the TW structure axis is not critical and the total energy gain do not depend too much on its average value linked to the structure length as a careful analysis has recently shown (5). One can summarize this saying that short structures allow a good RF compression factor but a poor transfer from the RF power to the beam in contrast with longer structures which make a better use of the available power at the expense of the compression. However short structures appear somewhat more interesting.

The poor intrinsic geometrical quality or low shunt impedance of the TW structure are not improved. It is due to the two conflicting requirements of large RF coupling and best beam-field interaction which occurs simultaneously near the on-axis E-iris coupling. In contrast SW structures separate the RF coupling made by a magnetic peripheral coupling and the on-axis beam field interaction.

TW backward-wave accelerating unit description

We propose an approach which combines the filling-time advantage of the standard travelling-wave geometry with the better geometrical quality or higher shunt-impedance value of the standing-wave geometry (6). It optimizes the use of a backward travelling-wave geometry in the case of short RF pulses of very high peak values.

Figure 1 shows an S-band optimized acceleration unit design giving 300 MeV to an electron beam at low intensity. The total length is 13 meters including two 6 meter long accelerating structures at 25 MeV/ meter mean energy gain value. The two structures are fed by 37 MW peak power 5 microseconds RF pulses, from a Thomson CSF TH 2094 klystron (7). The peak power is increased by a SLED system of the LAL-CERN type (3, 8), which ensures a power increase by a factor of three (value averaged on the length of the 0.9 μs RF compressed pulse) or a peak energy increase by a 1.7 factor. Note that the input couplers to the structures correspond to the beam exits, to insure opposite

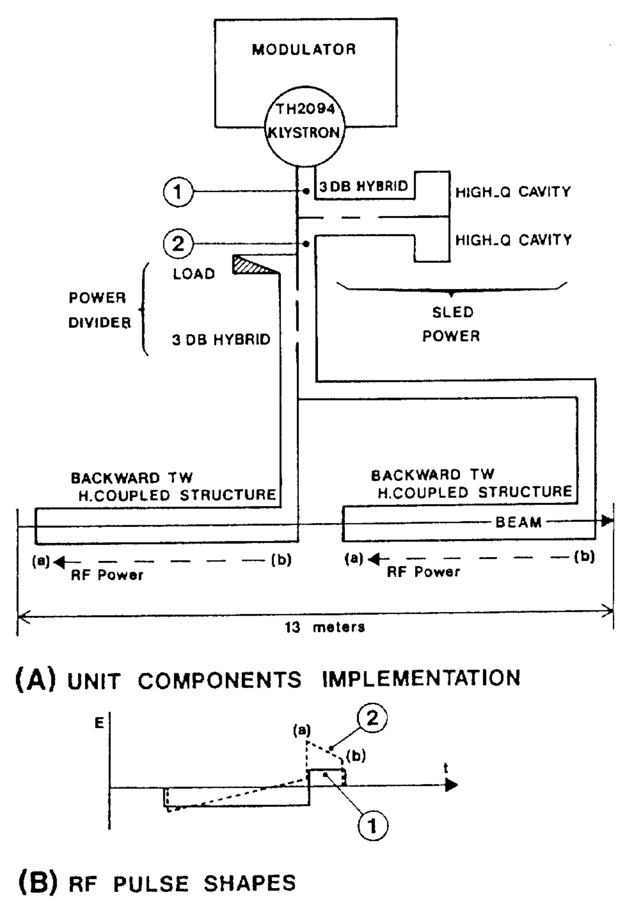


Fig. 1: S-Band optimized acceleration unit.

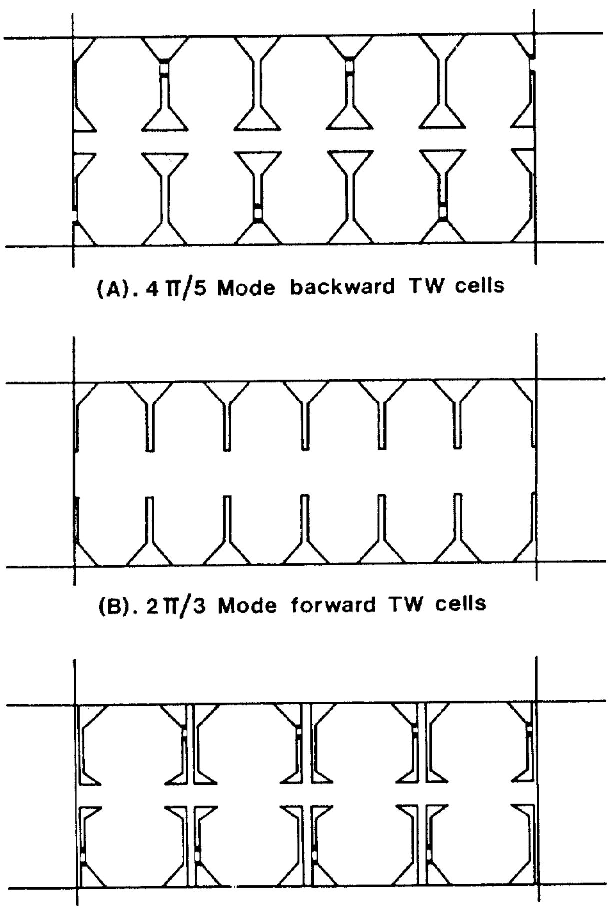
directions of the RF power and of the beam as it is required for proper synchronism and acceleration. The figure gives also the RF power pulse shapes before (1) and after (2) SLED transformation together with the corresponding wave edge positions (a) and (b) along the structures at the time when the beam crosses (quasi-instantaneously) the structures.

Optimization could include the absence of power loads at the exit of the structures. This is possible as the beam length of less than 0.1 microsecond is much shorter than the propagation filling time of 0.8 microsecond so that reflection does not influence the beam energy gain.

The SLED system and the klystron are protected by the power divider made of a 3 db hybrid coupler with a load on its fourth arm. This requires proper phasing of the parallel RF lines and of the beam at the entrance of each structure. It means that the waveguide lengths and the on-axis position of the structures must be set properly. Note that this improvement would become an absolute necessity in case of SW structures (13).

TW backward-wave H-coupled cells design

The cells of the H-coupled backward wave structure are all indentical as for conventionnal E-coupled forward structure. Otherwise they are rather similar in shape



(A). 4 π/5 Mode backward TW cells

(B). 2π/3 Mode forward TW cells

(C). π/2 Mode biperiodic SW cells

Fig. 2: Backward and forward TW cells, SW cells.

to the optimized geometry typical of conventionnal SW H-coupled cells.

Figure 2 shows two wavelengths of the new geometry (a) compared with the same lengths of the conventionnal 2 π/3 SW structure (b) and the biperiodic SW structure (c). The resonance mode is 4 π/5. All modes nπ/m such that n/m $\geq$ 2/3 could be used but a compromise must be found between high Q values for a closed cell (meaning n/m value near unity) and sufficient coupling for moderate slot apertures (meaning lower n/m value).

If one takes some simple approximation of the dispersion curve $\omega(k)$ such as (9) :

$$\omega^2(k) = \omega_0^2 + \omega_1^2 \sin^2 \frac{ka}{2}$$

where k varies between 0 and π/a value, then :

$$v_g = \frac{d\omega}{dk} = a\omega_1^2 \sin\frac{ka}{2}\cos\frac{ka}{2}$$

giving a 0.68 ratio for vg (mode 4 π/5) divided by vg (mode 2 π/3).

A bandwith of 2 percent (for which $c/v_g \simeq 37$ at 2 π/3 mode) has a negligible effect on the shunt impedance but a bandwith of 3 percent (for which $c/v_g \simeq 36$ at 4 π/5 mode) can be set as a limit where the shunt impedance begins to decrease of several percent for SW similar cell shapes (10). Our TW backward-wave 4 π/5 mode accelerating unit choice corresponds to a c/vg value $\simeq$ 40.

Figure 3 gives an example of possible design at 2998 MHz for three mechanical units. The dimensions of the central one are detailed. The cell total length of 40 mm gives a good volume/surface ratio leading to a high Q value. The distance between the noses of 26 mm corresponds to an effective equivalent rectangular field length of $\simeq$ 28 mm for beam holes of 10 mm diameter.

A simulation with the help of the SUPERFISH code gives shunt impedance values Z = 145 MΩ/m and with transit factor included ZT^2 = 104.5 MΩ (obtained with a half cell geometry). They must be compared to the TW 2π/3 geometry values Z = 99.6 MΩ/m and ZT^2 = 68.7 MΩ/m (obtained with a one and a half cell geometry for which irises have 22 mm diameter). The measured averaged equivalent value on TW 2π/3 Saclay Linear Accelerator or ALS structures was ZT^2 = 61 MΩ/m (47 MΩ/m with end loss of power taken into account). These simulations correspond to an increase of 52 percent on ZT^2 (or 23 percent on the energy) from the 2π/3 mode standard E-coupled geometry to the 4π/5 H-coupled one.

Note that with a realistic shunt impedance value ZT^2 = 93 MΩ/m (to be compared to the ALS 61 MΩ/m value) the unit of acceleration of fig. 1 making use of three-quarter of the circulating power gives approximately $V_o = (0.75\ P\ ZT^2\ L)^{1/2} = (0.75 \times 37 \times 3 \times 93 \times 12)^{1/2}$ = 305 MeV at zero current.

The price to be paid is the peak field level on copper. For the 4 π/5 H-coupled geometry an acceleration of 25 MeV/m corresponds to a rectangular on-axis peak field of 25 (1/T)x(40/28) = 42 MV/m and to a peak field on noses calculated by SUPERFISH of 42 x 2.60 = 110 MV/m. It is more than twice the iris peak field value for the TW 2 π/3 geometry. However measurements for longer RF pulses of 4 microseconds made on THOMSON-CGR MeV structures indicate a safe limit of 150 MV/m (11) and higher values can be reached in laboratory conditions (12).

Conclusion

There are some possibilities of progress from the classical forward TW central iris E-coupling structure, by combining the advantages of short propagation time with a better geometry, usually linked to the SW approach.

Our proposal is to give a new life in the linac field to the backward-wave approach applied until now in the RF tube amplifiers field and to eliminate the terminal loads for each linac structure thanks to the proper feeding of two similar structures from the same power source. Standard RF laboratory work remains to be done to ascertain precisely the parameter values.

Our proposal is valid in a restricted area of the electron linacs field : injection of moderate currents, short RF pulses and even shorter beam pulses, moderate total accelerator length to avoid the possible effect of the induced wake fields. The sensible but rather modest gain in energy is worth while if one considers that the realization is very simple : all the mechanical cells are of the same indentical type for a constant impedance structure to be used with SLED and easily shaped with numerically-controlled milling machines. With the advent of higher RF levels in the future this alternative could become a necessity as the shunt impedance of the forward TW conventionnal approach decreases much with c/vg.

References

1. A. Van STEENBERGEN, Optimization of a synchrotron radiation source, NIM 177 (1980) 53.

2. V.N. KORCHUGANOV and al., Optimization of parameters of a dedicated synchrotron radiation source for technology, NIM 208 (1983) 11.

3. A. FIEBIG and R. HOHBACH, Sucessful high power test of Lep Injector Power Saver, CERN PS/LPI/RF/Note 82-16, 1982.

4. H.A. HOGG, G.A. LOEW and V.G. PRICE, Experiments with very high power RF pulses at SLAC, 1983 Particle Acc. Conf., IEEE NS 30, 1983, 3457.

5. J. Le DUFF, Optimization of TW accelerating sections for SLED type modes of operation, Proc. of the 1984 Linear Acc. Conf., Darmstadt, 171.

6. D. TRONC, French patent n° 85 00743, 1985.

7. G. FAILLON and P. KERN, A high-efficiency 37 MW/3 GHz/5 µs multicavity klystron, Proc. of the 1984 Linear Acc. Conf., Darmstadt, 405.

8. A. FIEBIG and R. HOHBACH, Study of peak power doublers with spherical resonators, 1983 Particle Acc. Conf., IEEE NS 30, 1983, 3563.

9. F.S. CRAWFORD, Ondes (Berkeley : cours de physique), Colin, 87.

10. A. BENSUSSAN, D.T. TRAN and D. TRONC, Standing-wave triperiodic structure for a 10 MeV medical accelerator, NIM 140 (1977) 231.

11. C. PERRAUDIN, 1984 RF power measurements, private communication.

12. E. TANABE, Breakdown in high-gradient accelerator cavities, Proc. of the 1984 Linear Acc. Conf., Darmstadt, 403.

13. H. LEBOUTET, private communication.

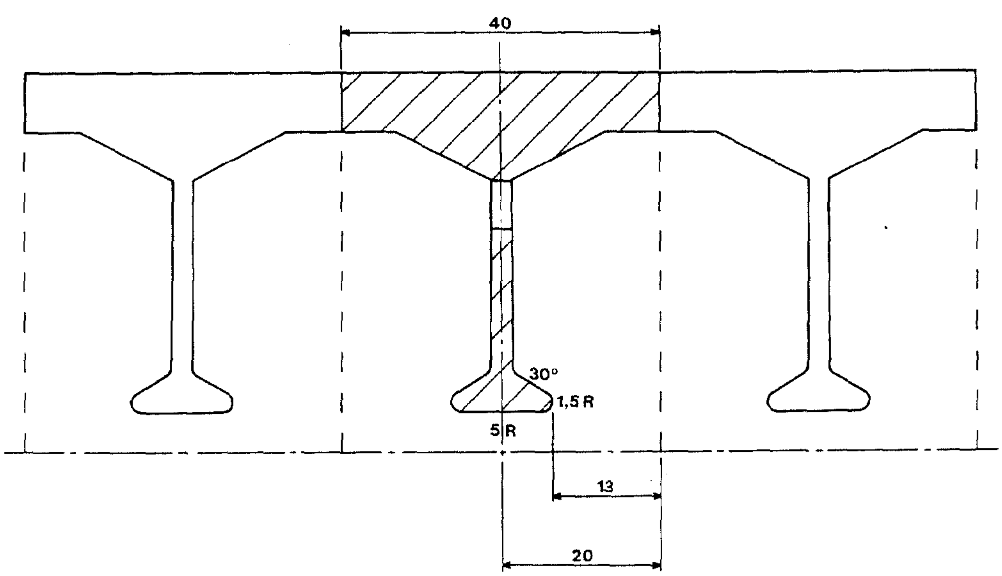


Fig. 3 : Backward TW cells design