DESIGN AND CONSTRUCTION OF TURNKEY LINACS AS INJECTORS FOR LIGHT SOURCES

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Abstract

Turnkey linacs were manufactured by Thales Communications & Security in order to inject electrons into boosters of SOLEIL [1], ALBA and BESSY II synchrotrons. This paper will describe the beam dynamics tools and methods for the design and construction of those linacs. Cavities tuning and prebunching characterization methods will be given. Beam loading compensation and simulations will be explained. Specified and measured beam parameters will be compared.

INTRODUCTION

The electron dynamics are complicated. Their energies varies from zero to more than one MeV in a length comparable to the prebucket dimension. Velocities are different at the same abscissa. On-axis oscillations occur. Space-charge effect can locally be large. RF field phase and amplitude laws must be shaped precisely. Such non-linear bunching and acceleration process requires a step-by-step simulation made in time domain.

BEAM DYNAMICS TOOLS AND METHODS

For the design of a linac we use 5 principal codes:

- Our in house code PRODYN [2], for the beam dynamics simulations.
- Our in house code SECTION, for the design of the travelling wave accelerating structures and the beam loading compensation.
- The well-known EGUN [3] code written by Dr. Hermannsfeldt from SLAC, for the gun design.
- The also well-known SUPERFISH code written by Ron. F. Holsinger and Klaus Halbach from LOS ALAMOS for the design of cavities and electric field in accelerating structures.
- The also well-known POISSON code written by the same authors from LOS ALAMOS, for the shielded lenses and solenoids.

PRODYN Code

PRODYN code tackles particle dynamics, electrons in our case, according to time and in the presence of an electromagnetic field. The code includes backward as well as forward movements and relativistic space-charge effects. The space to be simulated is divided into several elementary cells. Each cell changes the input beam into an output beam that can then be injected into the next cell. If the simulation covers a large number of cells, one can test a change by taking the beam at the output of the cell that precedes the change, and injecting it into the sequence of new cells.

The particle beam is either generated by the code using the entered settings, or read from the particle file supplied by the user.

An elementary particle is represented by its position, its energy, and its phase. To solve differential equations, one uses the Runge-Kutta method with x, y, z, Vx, Vy and Vz as variables, and time as the integration variable.

The provided elements are: RF accelerating cell, drift, magnetic lens, quadripole, dipole and bending magnet. The accelerating cell may include a magnetic lens and a dipole. Subharmonic frequencies can be used.

SECTION Code

SECTION code provides along a travelling wave structure the filling time, the group velocity, the circulating power, the shunt impedance, the electric field and the energy gain.

This code uses the beam loading theory, based upon diffusion equation (Beam loading and transient behavior in travelling wave electron linear accelerators", J.E Leiss page 151, linear accelerators edited by P. Lapostolle and A. Septier, 1970 North-Holland publishing company-Amsterdam) and the S band measurements mainly the ALS structures ("Les sections accélératrices" page 1194 D. Tronc et Al, L'onde électrique Vol 49, Fasc 11-n°: 513 Dec 1969).

This code was used recently for the design of the ALBA and BESSY accelerating structures, in particular the beam loading effects.

The accelerating structures met the calculated values at ALBA, 53 MeV for 18.8 MW in the first accelerating structure (16 MeV in the buncher) July 2008 Spain.

Methods

We separate the longitudinal behavior from the paraxial behavior. The introduction of radial force is more realistic but complex. More clarity is obtained by treating longitudinal dynamics as a first-order effect and radial dynamics as a second-order one.

The first step deals only with the longitudinal simulation, without space charge and without radial focussing. It allows us to optimize the different drift spaces between the two pre-bunching cavities, at 0.5 GHz and 3 GHz, and the buncher.

The second step deals with the complete simulation with space charge and radial focussing. In particularly, we adjust the modulation voltage of the sub harmonic pre-bunching cavity with respect to the different beam modes.

Validation on Operating Machines

The PRODYN dynamics code enabled us to simulate the beam line of the following accelerators:

- Helios I injection at 200 MeV (IBM - USA).
- ESRF synchrotron accelerator at 200 MeV.
- ELETTRA synchrotron accelerator at 1200 MeV.
- SOLEIL synchrotron at 100 MeV.
- ALBA synchrotron at 100 MeV.
- BESSY II synchrotron at 50 MeV.

This code also enabled us, using adjustment settings only, to improve the ARTEMIS accelerator (Moronvilliers AEC) by reconstructing the computer model of the accelerator, conducting a setting optimization survey, and recovering the corresponding performance results at the experimental level.

CAVITIES TUNING

To build a constant gradient travelling wave structure, one must perform cold tests under a press in order to tune the different cells individually. For the tests to be valid, the test cells must be terminated by shorting planes located in planes of symmetry in which the electric field vector is normal in such a way that the standing wave "trapped" between them is an exact representation of the instantaneous travelling wave one wishes to study [4].

Under the press, we have metallic shorting planes at both ends and the frequency control of TW cavities is performed in a standing wave mode. Fig. 1 shows the measurement setting for the cavities' frequency controls under the press together with the equipments needed.

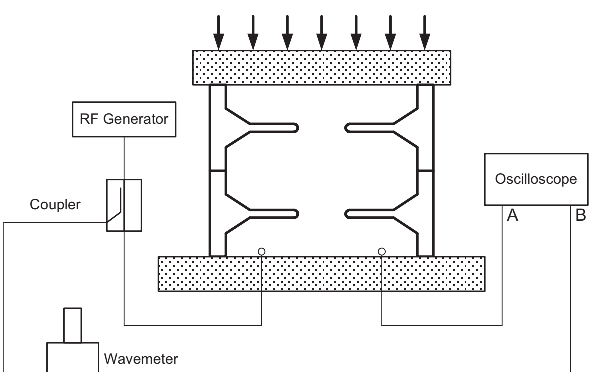

Figure 1: Measurement setting under the press.

The frequency controls are made during the process of building TW as well as SW structures. Frequency adjustments on individual cells are of great help as they limit the tuning on the assembled structure to slight localised adjustments. Fig. 1 shows the simplest case of the $\pi/2$ mode, for the TW cavities of our structures, where the resonant end cells are made of the two mechanical parts unified as a unique cell in the final assembly. The propagating modes for these three volumes can only be 0, $\pi/2$ and π.

For the $\pi/2$ mode, the central volume has no field and does not contribute to the frequency determination. The final structure assembly, obtained by reversal of the mechanical parts corresponds to the sequence in the natural order. Fig. 2 shows the first ALBA accelerating structure after brazing at PMB plant. Fig. 3 shows the ALBA linac in its bunker.

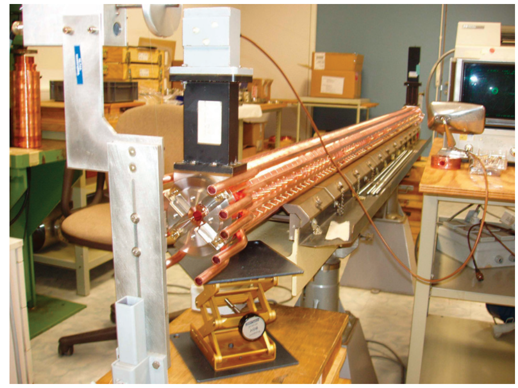

Figure 2: ALBA accelerating structure after brazing.

Figure 3: ALBA linac.

BEAM LOADING COMPENSATION

Generally, the first electrons of a long pulse have the greatest energy gain while crossing an accelerating section as the stored energy left for the last electrons is reduced. This is what we call the beam loading effect.

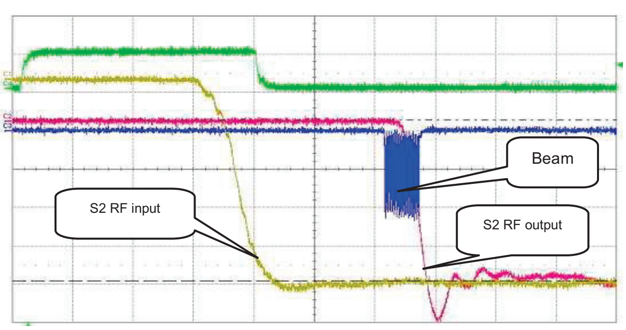

Figure 4: Beam loading compensation.

The beam loading compensation is achieved by sending the beam during the filling time of the second accelerating structure. In fact, the first electrons cross the last part of the section without the nominal stored energy in it. The last electrons cross a full stored energy section. In certain conditions of power, charge and pulse length, the beam loading effect can be considerably reduced [1].

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Fig. 4 shows the RF input and output signals of the second section of SOLEIL together with the beam pulse.

For the simulations, we take into account the energy gain curve without beam versus the filling time. The beam loading compensation can be then evaluated precisely as the fitted curve provides the energy slope versus the filling time. For an 18 MW power with our accelerating structure and between 700 and 900 ns, the slope is around 3.7 MeV per 100 ns. For a desired charge, we can then adapt the beam current together with the pulse length for a total beam loading compensation.

Fig. 5 represents, for a 200 MeV linac, the energy gain without beam versus the injection time together with the beam loading energy spread without compensation. The total beam loading energy spread is equal to 7.2 MeV.

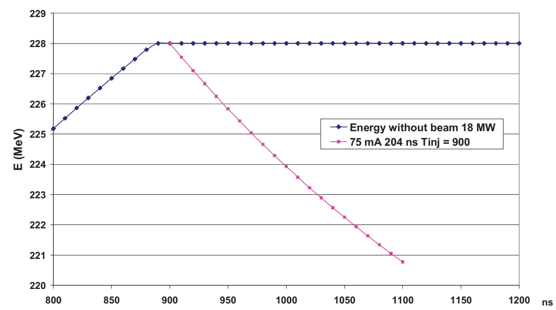

Figure 5: Energy spread for 15 nC.

Fig. 6 represents, the energy gain without beam together with the beam loading energy spread with compensation. The energy spread is reduced to 0.24 MeV.

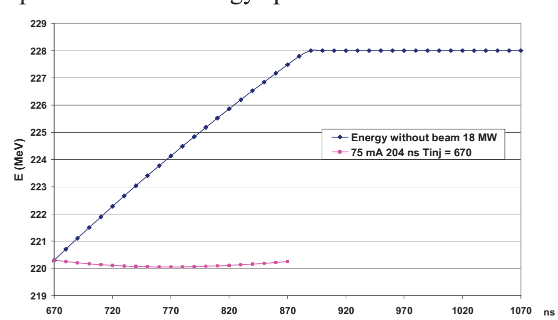

Figure 6: Energy spread with compensation for 15 nC.

Fig. 7 shows, for SOLEIL, the 2 measured curves without and with beam loading compensation. The FWHM energy spread has been reduced from 3.75 MeV to 0.77 MeV for the 9.3 nC behind the slit.

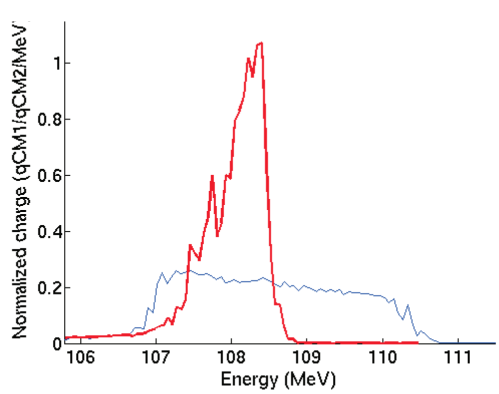

Figure 7: Energy spread for both cases.

PREBUNCHING CAVITIES

For ALBA, measurements of the beam at 70 MeV were done with and without the prebunching cavities for the Multi Bunch Mode [5]. The measured values met the simulated ones. The results are summarized in Table 1.

Table 1: Simulations and Measurements (%)

	Buncher exit		AS1 exit	
Beam mode	Simul.	Meas.	Simul.	Meas.
0.5 & 3 GHz	98	96	68	66
3 GHz	84	83	67	58*
0.5 GHz	77-87**	80	47	47
No cavities	59***	64	-	37

* Measurement was done without the phase adjustment of the 3 GHZ prebuncher.
** Simulations show oscillations of some electrons being apart from the main bunch. The main bunch and the first satellite contain 77% and 5% of the gun current.
*** Simulation has been done without space charge and without magnetic field.

The 500 MHz prebunching cavity allows for only one pulse at 3 GHz, instead of three, from the 1 ns pulse. The energy spread is then reduced. Table 2 gives the summarized results at 70 MeV.

Table 2: Charge and Energy Spread Measurements

	BCM1(nC)	ΔE/E%
Without cavities	0.25	0.6
500 MHz	0.30	0.6
3 GHz	0.45	**0.9**
500 MHz & 3 GHz	0.55	0.6

CONCLUSION

In the last decade, turnkey linacs were manufactured by Thales Communications & Security in order to inject electrons into boosters of SOLEIL, ALBA and BESSY II [6] synchrotrons. The measured linacs parameters fitted well with the beam dynamic simulations.

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