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 vary 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.

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.

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 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.

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 $\pi$.

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.

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.

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].

Figure 2: ALBA accelerating structure after brazing.

Figure 3: ALBA linac.

Figure 4: Beam loading compensation.
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.

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.

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.

**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>
<thead>
<tr>
<th>Beam mode</th>
<th>Buncher exit</th>
<th>ASI exit</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5 &amp; 3 GHz</td>
<td>98</td>
<td>96</td>
</tr>
<tr>
<td>3 GHz</td>
<td>84</td>
<td>83</td>
</tr>
<tr>
<td>0.5 GHz</td>
<td>77-87**</td>
<td>80</td>
</tr>
<tr>
<td>No cavities</td>
<td>59***</td>
<td>64</td>
</tr>
</tbody>
</table>

* 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>
<thead>
<tr>
<th>BCM1(nC)</th>
<th>∆E/E%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Without cavities</td>
<td>0.25</td>
</tr>
<tr>
<td>500 MHz</td>
<td>0.30</td>
</tr>
<tr>
<td>3 GHz</td>
<td>0.45</td>
</tr>
<tr>
<td>500 MHz &amp; 3 GHz</td>
<td>0.55</td>
</tr>
</tbody>
</table>

**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.

**REFERENCES**