

USE OF THE LANA CODE FOR THE DESIGN OF A HEAVY ION LINAC

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Abstract

The LANA computer code (Linear Accelerators Numerical Analysis) has been developed in INR, Moscow during the last several years and still is in further development. This code is designated for the design and simulation of various kinds of linear accelerators. Recently the code has been extensively used for the design and study of the *separated function* heavy ion DTL for the ISAC project at TRIUMF. The paper describes the mathematical models used in the LANA code including *space charge* effects and three-dimensional *realistic* accelerating field representation. In particular the procedure for drift tube geometry generation based on three-dimensional electromagnetic field distributions extracted from MAFIA is described in detail. The LANA code is also used to determine the influence of the *asymmetry* in the fields of the H-type structure on the beam dynamics.

1 INTRODUCTION

The LANA code has been developed at INR, Moscow during the last several years [1] as a powerful tool for the design and study of the beam dynamics in various linear accelerators [2, 3, 4].

The LANA code is especially useful for the simulation of complicated beam dynamics problems in linacs [5]. The completeness and flexibility of the graphics output and convenience of the operator's intervention during simulation allows research into new linac concepts. Recently the code has been applied successfully in the design of the Separated Function DTL for the ISAC project at TRIUMF [6].

2 MATHEMATICAL MODELS

The main simulation mode used in LANA assumes the so called *square wave* approximation of the accelerating field in the gaps of the DTL. This mode allows quick calculations with an accuracy sufficient for establishing gross specifications (ie. number and length of tanks, effective voltage, phase, stability requirements etc.) Therefore this regime is preferable for simulations of such procedures as phase scanning [3], Δt - procedure [3, 4], *variable energy* scans [6, 7], etc.

However this code permits detailed calculations with a *realistic field* distribution in the accelerating structure (a particular iterative procedure is described in section 2.4). Actually the mathematical background in both cases is identical, but in the case of *realistic fields* the accelerating cell is split longitudinally into a number of steps and

the formulas for the *square wave* are applied for each step sequentially.

The *realistic fields* have to be calculated using some available electromagnetic codes like SUPERFISH for 2-D, MAFIA for 3-D [8] or other similar codes. The calculated field distributions inside the aperture of the accelerating channel can be imported to LANA. The data are interpolated linearly on all three coordinates where needed during the simulation. A more detailed description of the interpolation algorithm is given in [1, 9].

2.1 Linac Structure Representation

In the code the linac is considered as a number of independently fed cavities. This means that the accelerating field amplitude and phase can be different in sequential cavities. The linac to be simulated can be a combination of different available structure types such as DTL, IH, CCL, etc.

Each cavity can consist of several separate sections (modules). Focusing and/or bending magnet systems (in the horizontal plane) may be included in front of the first and after every section. The focusing system can include quadrupoles, solenoids and drifts. In addition to dipoles the bending magnet system can include a stripping foil. The stripping foil is simulated as a thin element with a pre-defined equilibrium charge state as well as parameters to account for transverse scattering and energy straggling.

2.2 Beam Representation

The LANA code uses a 3-dimensional multi-particle Monte Carlo model of the beam. All particles are traced separately, sequentially and independently, through the elements of the focusing and bending magnet systems, the drift spaces and the accelerating cells.

The interaction between the charged particles is estimated only at certain points along the accelerating cell, magnetic element or drift and is used as a constant up to the next point of the estimation. The space charge effects can be ignored in order to speed up the computations in the case of low current beams. The 3-D space charge calculation is valid for bunched beams only. The method [10] is based on analytic relations between charge density and electric field for the distribution with 3-D ellipsoidal symmetry in real space.

2.3 Formalism

Dipoles, quadrupoles, solenoids and drifts are simulated using standard matrix formalism [11]. The simulation of the accelerating gap is done using formulas of the *iteration*

procedure [12]. This procedure has been redeveloped for the 3-D particle dynamics and space charge consideration.

The initial equation of the particle's motion in the accelerating gap is:

$$\frac{d}{dt} (\gamma \cdot \dot{\vec{x}}(t)) = \frac{e}{m_0} \cdot \vec{E}(\vec{x}(t)) \cdot \cos(\varphi_0 + \omega t) + \frac{e}{m_0} \cdot \vec{E}_c(\vec{x}(t))$$

where: $\gamma = \frac{1}{\sqrt{1-\beta^2}}$ – the Lorentz factor, β – longitudinal relative particle velocity, c – speed of light, e – particle's charge, m_0 – particle's rest mass, $\varphi_0 + \omega t$ – phase of the accelerating field at the corresponding moment of time, $\vec{E}(\vec{x}(t))$ – amplitude of the accelerating field at the corresponding space coordinates, $\vec{E}_c(\vec{x}(t))$ – static electric field equivalent of the space charge force (with the magnetic field impact included).

This equation is solved numerically in LANA for both the transverse and longitudinal motion. The equivalent space charge electric field could be presented in the approximation of the elliptically symmetric charge distribution in configuration space:

$$\begin{cases} E_{cz} = Q_z \cdot \zeta \\ E_{cx} = Q_x \cdot x \\ E_{cy} = Q_y \cdot y \end{cases}$$

where: $\zeta = \zeta_0 + z - z_c$, x and y are the particle displacements in the corresponding space coordinates relative to the center of the rms ellipsoid, $z_c(t)$ – current longitudinal coordinate of the center of the rms ellipsoid, ζ_0 is the initial longitudinal displacement of the particle from the center of the rms ellipsoid, and $Q_{z,x,y}$ – the functions of the parameters of the rms ellipsoid (constant for the current step of the integration of the particle motion).

All details about the the final formulas used in LANA can be found in [9].

2.4 Procedure for DTL Design with Realistic 3-D Fields

In order to perform the DTL geometry correction and beam dynamics simulation in the linac with a *realistic field* distribution several sequential stages of the calculations should be made:

1. Conceptual design of the accelerator in the *square wave* approximation.
2. General optimization of the physical tank geometry in order to satisfy the requirements of the rf power consumption distribution, the electric gradient distribution in the structure, the peak surface field distribution along the structure, etc. An example of such a study is described in detail in reference[8] for MAFIA simulation procedures.
3. The additional LANA geometry generation run should be performed using the correct values for the average accelerating gradients and the desired g/ℓ ratios in the sequential cells.

4. The electromagnetic field recalculation (with MAFIA or SUPERFISH codes for instance) should be done in order to provide self-consistent data for the next LANA geometry correction procedure.
5. The main geometry correction stage is performed at this point. This stage involves special algorithms of the longitudinal DTL geometry correction with the tracing of the reference particle through the *realistic fields*.
6. For the final check of this procedure and in order to have self consistent data an additional electromagnetic field recalculation should be done.
7. The last stage is to run LANA on this consistent set of field data.

This procedure actually converges at stage 5, so the final two stages provide an extra verification of the overall procedure.

3 EXAMPLE OF BEAM DYNAMICS SIMULATION

The most recent studies of the beam dynamics using LANA were done in application to the Separated Function DTL for the ISAC project at TRIUMF [6, 9]. A typical LANA graphic screen from these studies is shown in Fig. 1. This screen provides the beam phase space portraits and also transverse and longitudinal envelopes in the intermediate cell of the second IH tank of the DTL.

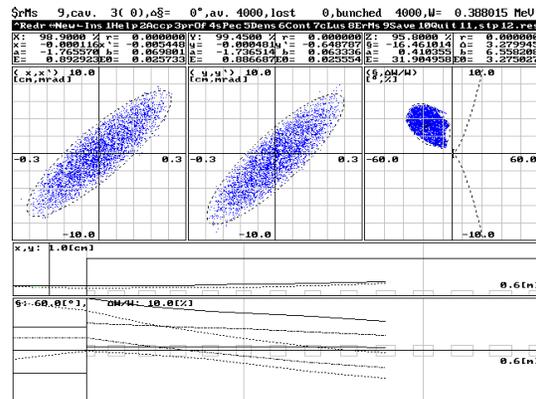


Figure 1: A typical PC screen of the LANA simulation session.

The simulation shown in Fig. 1 has been performed with *realistic fields* calculated from MAFIA. An example of the longitudinal electric field component, E_z , in the vertical plane of symmetry of the IH structure for the second cell of tank 2 is given in Fig. 2. This picture is typical for all other cells of the IH structure. A detailed study of the first IH tank field components and properties is done in reference[8].

One of the most interesting features of the beam dynamics study of the IH structure is the vertical asymmetry of the

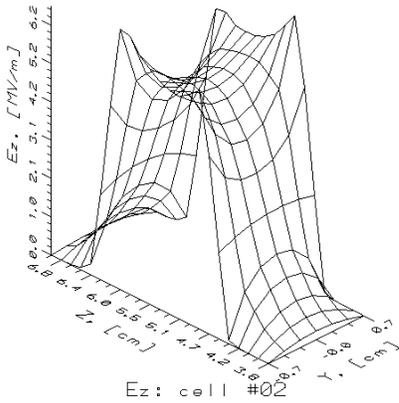


Figure 2: A typical MAFIA calculated 3-D field distribution in the accelerating gap.

stems geometry. This asymmetry produces a *dipole component* in the on axis vertical electric field. The overall effect, however, is negligible because of the alternating nature of the deflections. Fig. 3 provides the scaled integral of the effective E_y electric field component along the second IH tank. The corresponding markers represent the vertical divergence of the beam bunch center in the middle of each drift tube as calculated with LANA. Fig. 3 illustrates the self-compensation of the *dipole component* effect at the exit of the cavity. This result was proved by the actual beam dynamics simulation in the 3-D fields by LANA.

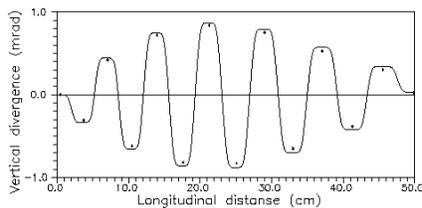


Figure 3: The overall accumulated dipole component effect in the IH structure.

The thin lens model of the rf defocusing is used in LANA in the *square wave* approximation, which coincides completely with the results of the simulation with 3-D *realistic fields* [9]. The relative difference between the transverse envelopes in these two approximations is always less than 3%.

The longitudinal dynamics is insignificantly changed as a result of the small change of the final optimized drift tube geometry for the *realistic field* case compared to the "generic" *square wave* case. These changes are concerned only with the position of the bunch in longitudinal phase space and its shape. While the energy spread increased by $\sim 3\%$, the phase spread decreased by about the same relative amount.

4 CONCLUSION

The LANA code is a user friendly tool for the design and study of multi-cavity linacs. LANA offers the convenience of the PC platform, a graphical representation of the beam

during the simulation process, the possibility of intervention during simulation and flexibility of several simulation models.

At the present time LANA is successfully used for the design of a high intensity H^- linac.

The LANA code is in continuous development and improvement in order to cover the widest possible range of different studies applied to various kinds of linear accelerators.

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6 REFERENCES

- [1] D.V. Gorelov and P.N. Ostroumov, 'The LANA Computer Code for the Beam Dynamics Simulation in Multi-Cavity Linacs', INR Internal Report, 1993-1994.
- [2] S.K. Esin *et al.*, 'Linear Accelerator for Production of Radioactive Beams', proc. of Linear Accelerators Conf. 1992, Ottawa, 1992.
- [3] S.K. Esin *et al.*, 'Commissioning/Operating of the Moscow Meson Factory Linac', proc. of International Linac Conf. 1994, Tsucuba, Japan, Vol. 1, p. 31, 1994.
- [4] M. Popovic *et al.*, 'Measurements of the Longitudinal Beam Parameters in the Fermilab Linac', proc. of International Linac Conf. 1994, Tsucuba, Japan, Vol. 2, p. 896, 1994.
- [5] D.V. Gorelov and P.N. Ostroumov, 'Application of LANA Code for Design of Ion Linac', proc. of European Particle Accelerators Conf. 1996, Barcelona, Spain, Vol. 2, p. 1271, 1996.
- [6] R.E. Laxdal, 'A Separated Function Drift Tube Linac for the ISAC Project at TRIUMF', these proceedings.
- [7] R.E. Laxdal and D.V. Gorelov, 'Optimization and Design Specifications for Tank1 of the ISAC Drift Tube Linac', TRIUMF Design Note TRI-DN-ISAC-97-4, 1997.
- [8] D.V. Gorelov, 'MAFIA Studies of the ISAC DTL Tank1', TRIUMF Design Note TRI-DN-ISAC-97-5, 1997.
- [9] D.V. Gorelov, 'Beam Dynamic Simulation with 3-D Realistic Fields Using LANA Code', TRIUMF Design Note TRI-DN-ISAC-97-6, 1997.
- [10] A.D. Vlasov, 'Theory of the Linear Accelerators', Atomizdat, Moscow, 1978. (in russian).
- [11] K.L. Brown *et al.*, 'TRANSPORT. A Computer Program for Designing Charged Particle Beam Transport Systems', CERN, Geneva, 1980.
- [12] B.P. Murin *et al.*, 'Ion Linear Accelerators. V.1. Problem and Theory'. Edited by B.P. Murin, Atomizdat, Moscow, 1978. (in Russian).