COMPUTATIONAL TOOLS FOR ACCELERATOR DESIGN

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Abstract
Based on the method generally followed for an accelerator design, this contribution describes some of the computational tools which can be used. A brief review is given for simulation codes related to the design of accelerator components and those related to the beam dynamics with emphasis on electron linacs.

1. INTRODUCTION

The title of this contribution is rather ambiguous. Indeed it could imply that all computational tools available for accelerator design are described. Although the purpose is to describe the codes running on various computers, and probably not the machines themselves, it would be hard to cover all the codes currently available, even if we restrict ourselves to the field of linacs and cyclotrons.

Therefore we will focus on the *method* which can be applied in the design of any accelerator and after that on the *codes* which have been found to be particularly useful in the analysis and design of accelerators. If some readers do not find mention of their favorite codes, this is possibly due to limitations of knowledge or of room to describe them.

A deliberate choice is also made to avoid detailed description of the physics of the codes. In the references and bibliography given at the end, the reader will find more information about existing and known codes and the related physics.

2. METHOD AND TOOLS

During the design phase of a whole accelerator project or a small test facility, or even improvements to an existing accelerator, many discussions and calculations are involved. Once the guide lines (physics) and the goals (beam performance) of the project are defined, the exercise starts. The different steps, with many interchanges between them, are:

i) submit the project to discussion by presenting the basic ideas

ii) check the orders of magnitude for the main parameters and see if the beam performance is achievable

iii) elaborate a first model, generally based on analytical calculations

iv) realise the next model either from existing simulation codes or from a new one to be written in order to model the real machine as well as possible

v) improve the model by including new factors and new effects if necessary.

These general rules have to be taken as advice and will avoid disappointment to the accelerator designer tempted to jump directly to calculations with a 3-D code!

To illustrate the different phases, the following tool list is proposed:

i) pencil + paper

ii) pocket calculator

iii) desktop computer

iv) large computer.

Emphasis will be made on some existing simulation codes for linacs. Among the proposals for the future linear accelerators, there is the CLIC (CERN Linear Collider) which is foreseen beyond the year 2000. A small linear accelerator CTF (CLIC Test Facility) has been installed at CERN and has been running for several years. *It will be used, as an example, to illustrate this contribution.*

3. DESIGN ACCORDING TO THE MACHINE

For a given type of particle (leptons, ions,...), two main topics should be considered:

1) the accelerator structure

2) the beam dynamics.

Three main families of accelerators and a particular case are presented.

3.1 Linear accelerators

A linear accelerator is a machine in which particles are accelerated on a linear path, a charged particle q crossing an electric field $\boldsymbol{E}$ being submitted to a force $\boldsymbol{F} = q\,\boldsymbol{E}$. An electrostatic field can be used to accelerate such particles. The dc accelerators (type Van de Graaff) are still used for low energy ion acceleration. Due to the limitations to high continuous voltage, the acceleration in linear accelerators is produced by time-varying electric fields. The two methods used are:

i) the RF (Radio Frequency) linac

ii) the induction linac.

The RF linacs are composed of resonant cavities (standing-wave structures) or waveguides (travelling-wave structures) with sinusoidally varying electromagnetic fields in the range of some MHz up to 30 GHz [1,2,3]. Induction linacs [4] are composed of an array of modules where a pulsed current passing through a toroid produces a rapidly changing magnetic flux and according to Faraday's law a voltage is induced across an accelerating gap. The beam dynamics concern the longitudinal and the transverse planes. They will normally differ according to the type of particles. Electrons are light particles and they are quickly relativistic. In a path length less than 1 m, they can approach the velocity of light and they travel inside the linac at this essentially constant velocity. The consequence in the longitudinal phase plane is that the classical stability diagram of non-relativistic particles opens up and no phase oscillations can occur. As the beam charge increases some additional beam-dynamics effects begin to degrade the beam performance (space charge, beam loading, wake fields,...). Solutions for reducing or cancelling these effects can significantly influence the parameter choice for the accelerator design.

3.2 Circular accelerators

If linacs can be considered as RF-oriented machines, circular ring accelerators are rather magnet-oriented machines. The accelerator structure consists basically of a pattern of successive dipoles, quadrupoles and drift spaces. For the acceleration process or for particular RF requirements, one or more RF cavities are installed. Again, the beam dynamics handle both transverse and longitudinal planes. For the latter the behaviour is similar to the linac for non-relativistic particles. For leptons, synchrotron radiation cannot be neglected and should be taken into account from the beginning even for the first model. In order to get a correct closed orbit, limitations on periodicity are preponderant in designing the lattice. Since a particle passes the same place several times, there is a repetitive exposure to the errors and perturbations existing in the machine. This can lead to destructive resonances.

An uncommon use for a circular machine is to decelerate particles. An example is given by the CERN Proton Synchrotron (PS) which receives antiprotons at 3.5 GeV/c and after deceleration down to 0.6 GeV/c ejects the particles towards LEAR (Low Energy Antiproton Ring). A storage ring represents also a special design and application.

Some particular beam-dynamics effects related to circular machines (closed-orbit distortion, intra-beam scattering, instabilities due to resonances, transition energy,...) and the computational tools related to them, will not be described in this contribution.

3.3 Cyclotrons

As in the other accelerators the two main topics, the accelerator structure and the beam dynamics should be considered. However for such machines, the magnet system and the RF system are extremely interdependent. The cyclotron magnet design and the RF design require a complete view of the cyclotron [5]. The two main issues are:

i) the isochronous aspect where the particles and the accelerating RF remain in phase and where the magnetic field follows the relativistic mass increase during the acceleration process.

ii) the resonances: during the acceleration it is unavoidable to cross resonances, as in synchrotron machines. The time that the charged particles remain on the resonance and the amplitude of the driving term determine the beam behaviour.

The analytical equations are given in Ref. [5, 6] and can be treated with a pocket calculator or desktop computer. The available simulation codes will be mentioned in section 9.

3.4 Transfer lines

Although they are not accelerators, great care still needs to be taken in order to preserve the beam quality. Here the transfer structure is composed of drift spaces, dipoles and quadrupoles. For linacs the structures are open at each end and therefore they do not require specific techniques to inject and extract beams. Only at the injection should the beam be bunched. For circular machines, the beam characteristics at the end of the transfer line will determine the injection process, while the beam characteristics at the end of the acceleration will determine the optics of the transfer line. Devices like septa and kickers should be included in the design. The goal is to get 100% transmission in the transfer line and no degradation of the beam performance at the entrance of the next machine or in the detector. Many computational tools used for beam transport in transfer lines are those used for linear or circular accelerators. Therefore, no specific development is required and the names of the programs dealing with such issues are mentioned later on in the text.

4. AN EXAMPLE: THE CLIC TEST FACILITY (CTF)

In 1985, a first proposal [7] for the CLIC project was made. For this new accelerator project, where an electron beam collides with a positron beam, the choice for the RF frequency is 30 GHz. At this frequency, there is no device available which is able to deliver enough power to accelerate the beams. For the collision energy (500 GeV), an electric field of 80 MV/m is required in order to keep the length of the linear accelerators reasonable (in the range of 4 km).

Therefore, the guide lines are: " invent a device (type klystron) which is able to deliver several tens of MW at 30 GHz and prove that is possible to accelerate an electron beam with such a device". The goals are:

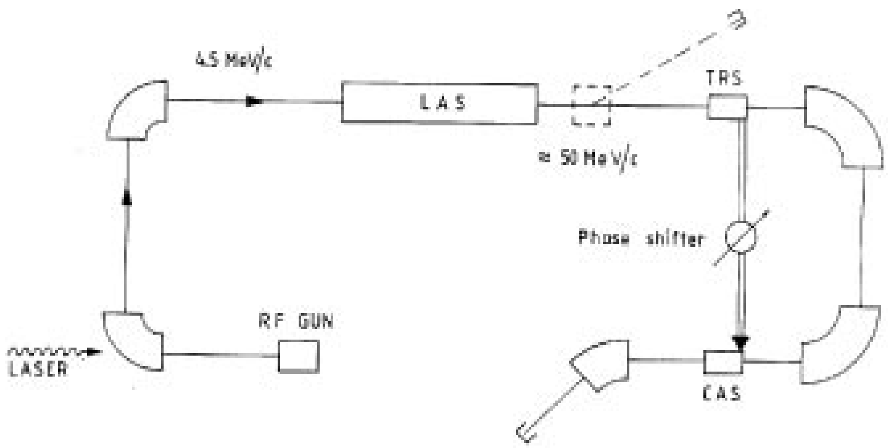
i) production of an accelerating gradient of 80 MV/m

ii) prove that the RF structure is able to sustain such a high electric field.

We will see how the proposed steps for an accelerator design, with the corresponding computational tools, can be applied.

5. BASIC IDEAS USING A PENCIL AND PAPER

When it was decided to produce a 30 GHz RF power source from an electron beam, a rough investigation showed that a short pulse (10 ps) and high charge (20 nC) were required. After having analyzed almost all classical machines, it became clear that both parameters were not achievable simultaneously. Therefore it was necessary to find a new source producing such electron pulses. The choice was made in the direction of photo-electrons: a photo-cathode illuminated by a laser pulse would be able to produce such a beam. Figure 1 shows the first layout of the CTF.



LAS: LIL Accelerating Structure: it is a 4.5 m long travelling-wave structure (3 GHz)

TRS: TRansfer Structure: it is a CLIC decelerating structure (30 GHz)

CAS: CLIC Accelerating Structure (30 GHz)

Fig. 1 First layout of CTF

6. ANALYTICAL CALCULATIONS USING A POCKET CALCULATOR

A pocket calculator is a common computational tool but very useful in the accelerator design. Based on the CTF example, an exercise of rough estimations, for the order of magnitude, is proposed below.

The electric field generated by a single bunch crossing a RF structure is given by the following formula:

$$E_1 = -\frac{\omega_0 r_0'}{2} q F(\Delta) \quad (1)$$

where ω_0 is the RF angular frequency, r_0' the normalised shunt impedance, q the charge and $F(\Delta)$ the form factor of the bunch.

The peak power at the exit coupler of the structure is given by:

$$P_{10} = \frac{\omega_0 r_0'}{4} v_g q^2 F^2(\Delta) \quad (2)$$

where v_g is the group velocity.

Now (see Fig. 1) if the exit of this first structure (TRS) is connected to a second structure (CAS), then the accelerating field, E_2, in the second structure, is given by:

$$E_2 = \eta \frac{\omega_0 r_0'}{2} q F(\Delta) \, exp\,(-\frac{\omega_0 T_f}{2Q}) \quad (3)$$

where η is the transfer efficiency between the two structures, T_f is the filling time and Q is the quality factor. The input data necessary for the calculations are the following:

$$\begin{aligned}
\omega_0 &= 2\pi \times 30 \text{ GHz} \\
r_0' &= R'/Q = 26.2 \text{ k}\Omega/\text{m} \\
v_g/c &= 0.082 \\
Q &= 4\,224 \\
\ell &= 0.287 \text{ m} \\
T_f &= \ell / v_g \\
\eta &= 0.92
\end{aligned}$$

By virtue of (3):

$$E_2 = 1.755 \times 10^{15} \, q F(\Delta).$$

The goal being E_2 = 80 MV/m, one finds:

$$q F(\Delta) \approx 46 \text{ nC}.$$

Table 1 gives the results of the rough estimations if the form factor is equal to 1.

Table 1

Electric fields and power for CTF

Parameters	Values	Unit
Charge q	46	nC
Power P_{10}	63	MW
Peak decelerating field E_1 on axis	113	MV/m

From these rough estimations, one can imagine that a single bunch of 46 nC with a form factor close to 1 (i.e. bunch length [FWHH] of 5 ps) will not be easy to produce and transport. Also a peak electric field of more than 100 MV/m on axis is not a current value for an RF structure and will require a careful design. A pocket calculator is sufficient to estimate the main parameters at this step of the accelerator design.

7. COMPUTATIONAL FACILITIES FROM A DESKTOP COMPUTER

7.1 First model of accelerator design from analytical calculations

It is often possible to give analytical expressions to calculate the beam dynamics in a given accelerator as a first model. For example the paraxial equation is used as a first approximation in many designs. References [1,2,3] provide basic equations for linacs and References [5,6] for cyclotrons.

Coming back to the CTF, it was found after experiments that the space-charge effects combined with large dispersion of the first optics had an effect too significant to reach the expected beam performance. Therefore it was decided to simplify the optics for the electron beam (i.e. no bends between the gun and the subsequent acceleration) and shorten the path length of the beam at low energy. But as a consequence the optics for the laser became more complicated to correctly illuminate the photo-cathode. A new RF structure (Booster) was added to decrease the space charge-effects at low energy. Figure 2 shows the layout of the new design.

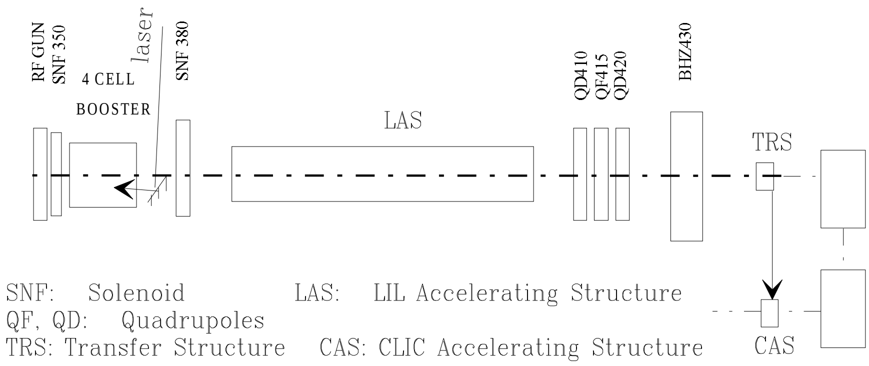


Fig. 2 Layout of the present CTF

An analytical model was developed on a desktop computer for this new layout. Figure 3 gives the beam envelope between the photo-cathode and the RF transfer structure (TRS) at 30 GHz.

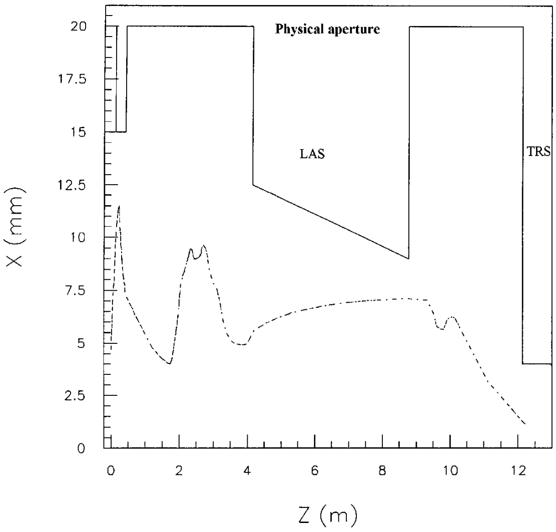


Fig. 3 Horizontal beam envelopes

It is worthwhile to mention another problem for this facility. Although the different steps were respected in the design of such a linear accelerator, it was found experimentally that it is still not straightforward to reach the goals. Several effects were not taken into account in the various simulation codes (high current density on the photo-cathode, beam loading, wake fields, misalignments, ...). Therefore, a new idea was proposed, to produce long pulses at the source with high charges, accelerate them, and compress afterwards in a bunch compressor. After some studies of existing devices (three dipoles, α magnet, wiggler) and after rough calculations, the conclusion for the best solution seems to be the magnetic bunch compressor with three dipoles. An analytical model was developed. Figure 4 gives the trajectory of the reference particle inside the bunch compressor.

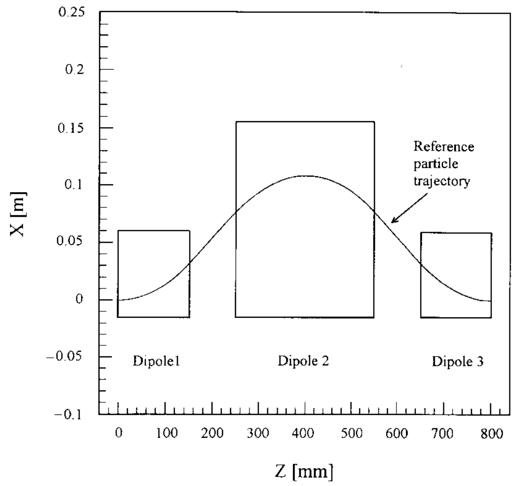


Fig. 4 Central trajectory for an electron at 10 MeV/c in the bunch compressor

The main characteristics are derived from a matrix product of three dipoles and two drift spaces. The beam parameters at the output of the bunch compressor are given as a function of the beam parameters at the input by the following expression:

$$\begin{bmatrix} x \\ x' \\ \ell \\ \frac{\Delta p}{p} \end{bmatrix} = \begin{bmatrix} 1 & 4\rho\tan\alpha + 2d/\cos^2\alpha & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 4\rho(\tan\alpha - \alpha) + 2d\tan^2\alpha \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x \\ x' \\ \ell \\ \frac{\Delta p}{p} \end{bmatrix}$$

output input

The final equation which gives the compression factor is:

$$\Delta\,\ell = \left(4\,\rho\,(\tan\alpha - \alpha) + 2\,d\tan^2\alpha\right)\frac{\Delta p}{p}$$

where $\Delta\,\ell$ is the path length difference from the reference particle at the exit of the bunch compressor,

$\frac{\Delta\,p}{p}$ is the relative energy spread,

ρ is the curvature radius of the dipoles,
α is the deflection angle of the dipole,
d is the drift space between each dipole.

For this sub-system, after having developed the analytical model, one can use a tracking program to optimise it (see 8.1.3).

7.2 Exchange of software sources and data

One of the advantages of working on a desktop computer is the possibility to develop one's own software. It is also helpful to receive or to send data files without having to recreate them. An input file which already worked correctly for a given accelerator (linac, cyclotron) is very beneficial if one only has to change some input data in order to adapt it to another specific design. The possibility to receive files containing a magnetic or electric field map from the person who made the measurements is a big advantage. The accelerator design will be improved if the measured fields are used rather than an ideal or a simplified distribution.

Last but not least the program written on a desktop computer will always be available in the form preferred by the user and will not be modified by the Computer Central Facilities.

7.3 Graphic plots and schematic drawings

Although millimetric paper is still useful, the possibility to plot various graphics from a desktop computer represents an enormous advantage. It is almost impossible to mention all existing software with facilities to plot graphics (EXCEL, Cricket graph, Canvas,...). A tool like MathCad allows interactive calculations from mathematical formulae and enables simultaneous plotting of any corresponding graphics related to the formulae.

7.4 Desktop computer versus large computer

For the purpose of this contribution, both computers have been mentioned separately. However, with the increase of the computational power of the desktop computers, the limits between them tend to nullify each other. Several computational tools can be run with almost the same facilities in both types of computers, at least those concerned by the accelerator design.

8. SIMULATION CODES FROM LARGE COMPUTERS

One can split into two main families the sophisticated simulation codes running on large computers; those related to the beam dynamics and those related to the design of particle accelerator devices. Often they contain more than 15000 lines of standard FORTRAN-77. The minimum time of execution is an important feature for the big codes.

8.1 Beam dynamics simulation codes

8.1.1 Example of an electron linac

An electron linac can be modelled with the three following codes: EGUN for the thermionic gun, PARMELA for the bunching system and TRANSPORT for the accelerating sections.

EGUN [8] computes trajectories of ions and electrons in electrostatic and magnetostatic fields. It includes space-charge effects and self magnetic fields. It assumes either a rectangular or a cylindrical symmetry. Magnetic fields may be used from POISSON output or from an externally calculated array of the axial fields. New versions of EGUN have been implemented and are also available for desktop computers. EGUN is distributed by W.B. Herrmannfeldt (SLAC) for a fee. Figure 5 gives an example of EGUN output for electron trajectories coming from a thermionic cathode capable of delivering up to 15 A with pulses of 30 ns. An external magnetic field of 0.2 T is applied at the exit of the anode.

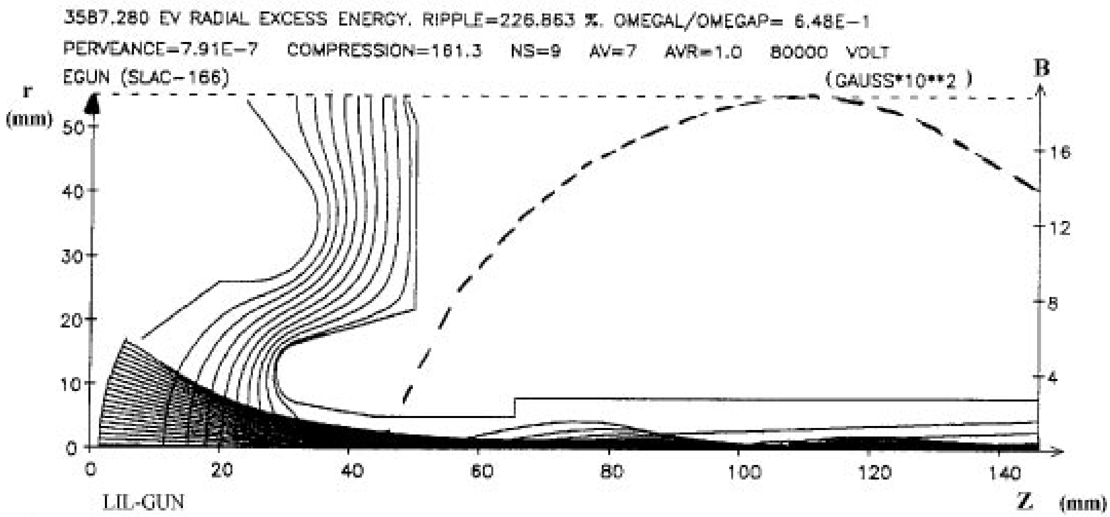


Fig. 5 Beam trajectories from a thermionic cathode calculated using EGUN

PARMELA (Phase And Radial Motion in Electron Linear Accelerator) is a multiparticle tracking program with space-charge forces. It computes the particle distribution in six-dimensional phase space at the exit of each RF cell for any bunching system, the independent variable being time. The code generates several types of initial electron distributions but the contour of the chosen distribution should be as close as possible to the beam dimensions derived from EGUN. The electric and magnetic fields in the RF structure can be provided by Fourier coefficients for ideal sine waves or from a table calculated by a code such as SUPERFISH. External magnetic fields can be superimposed on any element (RF structure or magnet) in the model. Although the main uses of PARMELA are for bunching systems, such codes can be used to simulate the beam dynamics in a whole linac composed of RF structures but also of magnets (dipoles, quadrupoles, solenoids, ...). From the output data it is possible to plot the transverse and the longitudinal phase spaces at any place of the bunching system. In addition, the beam envelopes and the energy gain can be plotted all along the line. PARMELA is distributed by Lloyd Young (Los Alamos) free of charge. This code has proven to be a user-friendly tool and rather powerful in predicting the real behaviour of the beam. However it is poorly documented and some laboratories have written specific user guides [9]. Figure 6 gives the transverse phase space at the output of the bunching system. From such a distribution, it will be possible to fit an ellipse from which parameters can be used as input data for TRANSPORT. These ellipses provide a good estimation of the transverse beam emittances.

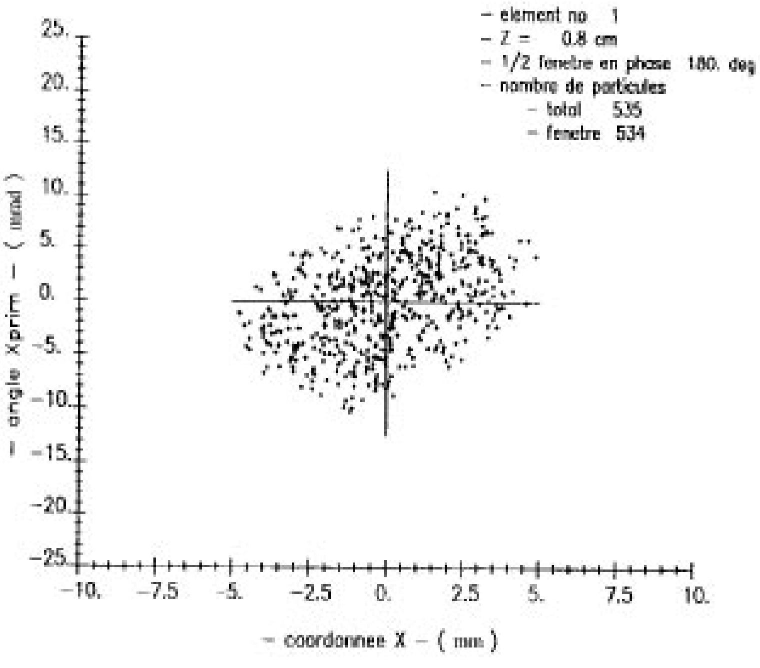


Fig. 6 Transverse phase space at the bunching system output calculated with PARMELA

TRANSPORT [10] computes the transfer matrix of a beam line (first order up to the third order). Elements of the line could be dipoles, quadrupoles, sextupoles, octupoles, solenoids and accelerating cavities. Starting from an ellipse in the transverse planes, one can perform the calculations all along the line for a given energy. As soon as particles are ultra-relativistic one can forget the space-charge effects. This is the case, in general, at the bunching system exit. However if the charge is high in the accelerating structures, another phenomenon appears: beam loading. By simulation of the extreme energies, TRANSPORT can simulate the beam loading effects in the electron linacs. From the output data one can plot the beam envelopes, the energy gain, the beta functions, the dispersion function. Figure 7 shows an example of half-beam envelopes. The initial conditions are taken from PARMELA output and an ellipse of emittance is defined for 90% and 50% of particles and for a given distribution. Then the optimisation of the optics is made in such a way to obtain 100% transmission. TRANSPORT includes fitting conditions which, for example, allow either to obtain a given beam radius (in the RF structure) or a minimum spot size (on the positron target). It is also possible to obtain an ellipse of emittance for the following transfer line or the following accelerator.

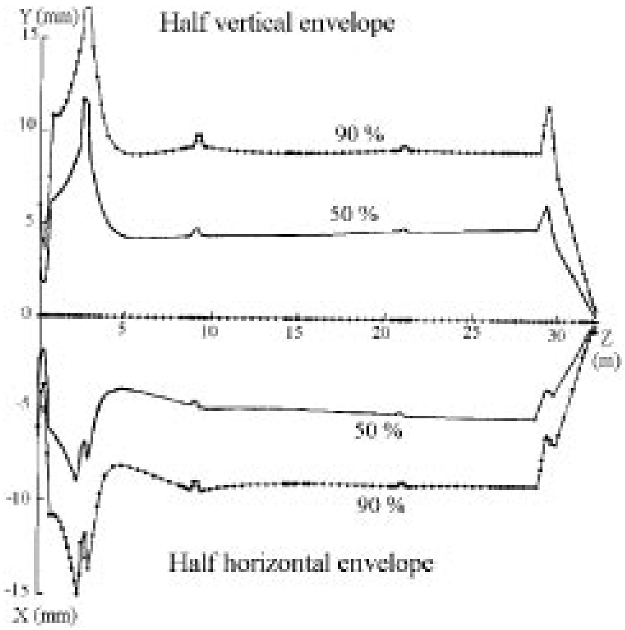


Fig. 7 Beam envelopes along the linac calculated with TRANSPORT

8.1.2 Example of a cyclotron

As already mentioned for an electron linac, the design starts with a crude and simple model. The design process will then be carried on by iterative steps. The big computers are necessary to perform detailed and time-consuming calculations for a final optimization. Although the cyclotron is a circular machine, the beam dynamics differs from that on synchrotrons because the particle trajectory is not a closed orbit. It is a spiral starting from the center of the magnet and ending up outside the magnetic field. The design of the magnet is the most important point. After the simple and analytical calculations, detailed magnet calculations, using a finite elements method, are performed. First, a 2-D code solves x - y problems where the third dimension is long enough to be “seen” as infinite. Axisymetric 3-D problems can be solved by a 2-D code.

Secondly, a 3-D code is used to be as close as possible to the real device.

Finally magnetic maps, from 2-D and 3-D codes are elaborated in the cyclotron median plane. Then, they are used as input data to specific programs which calculate the particle trajectories. The main output parameters are the frequency error, the integrated phase shift and the betatron frequencies.

8.1.3 Example of a sub-system

When it is necessary to handle high charges where the space-charge effects are not negligible, a sophisticated code like PARMELA becomes indispensable. The example of the longitudinal phase space for the bunch compressor in the CTF is given below.

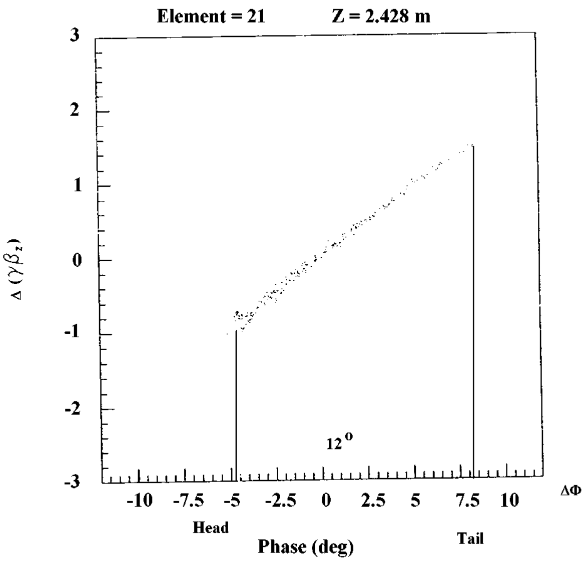


Fig. 8 Longitudinal phase space at the buncher input for low charge

Figure 8 gives the distribution of 100 particles before the bunch compressor (Fig. 4). One can derive the phase extension (12°) and the energy spread (± 1 %) of the bunch. Figure 9 shows the same distribution after the bunch compressor. The bunch length becomes (2°) and the energy spread remains the same as predicted by the analytical calculations. Both figures are plotted from PARMELA output for a very low charge. With high charge, the lower energy particles in the head of the bunch are accelerated by the space-charge forces and therefore gain energy while the higher energy particles in the tail of the bunch are decelerated and lose energy. The global result is a decrease in energy spread and can be evaluated only with a sophisticated code.

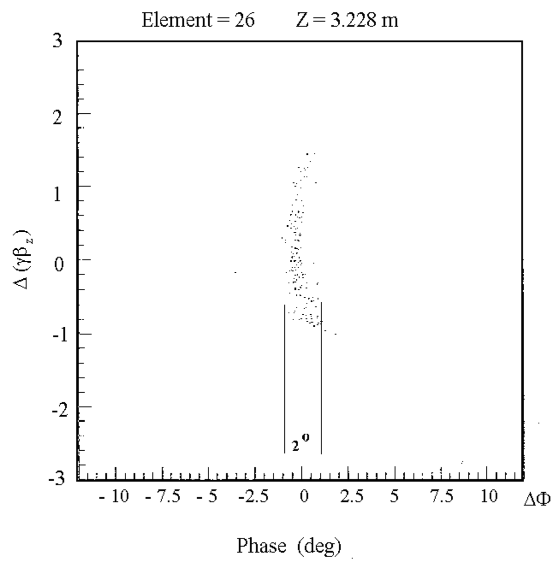


Fig. 9 Longitudinal phase space at the buncher output for low charge

8.2 Component design simulation codes

In all accelerators, there are several types of components and devices which perform various functions: acceleration, bunching, focussing, injection, extraction, monitoring. As for the beam dynamics one can divide the components into two main families; one deals with the longitudinal plane and the other with the transverse planes. To illustrate such simulation codes, one example of each family will be considered.

8.2.1 RF cavity design: SUPERFISH code [11]

This simulation code evaluates the eigenfrequencies and the fields for arbitrarily-shaped two-dimensional waveguides in Cartesian coordinates, and three-dimensional axially-symmetric RF cavities in cylindrical coordinates. SUPERFISH calculates time varying fields and spatial RF fields. It can also calculate quantities which are relevant for the design of drift-tube linacs (transit-time factor, power losses, ...). It contains subroutines to generate the mesh, to define the lattice, to solve the equations and to plot the fields. Figure 10 shows the electric field calculated by SUPERFISH for the RF gun of the CTF. It is a standing-wave structure with cylindrical symmetry. The density of the field lines can be changed according to the needs.

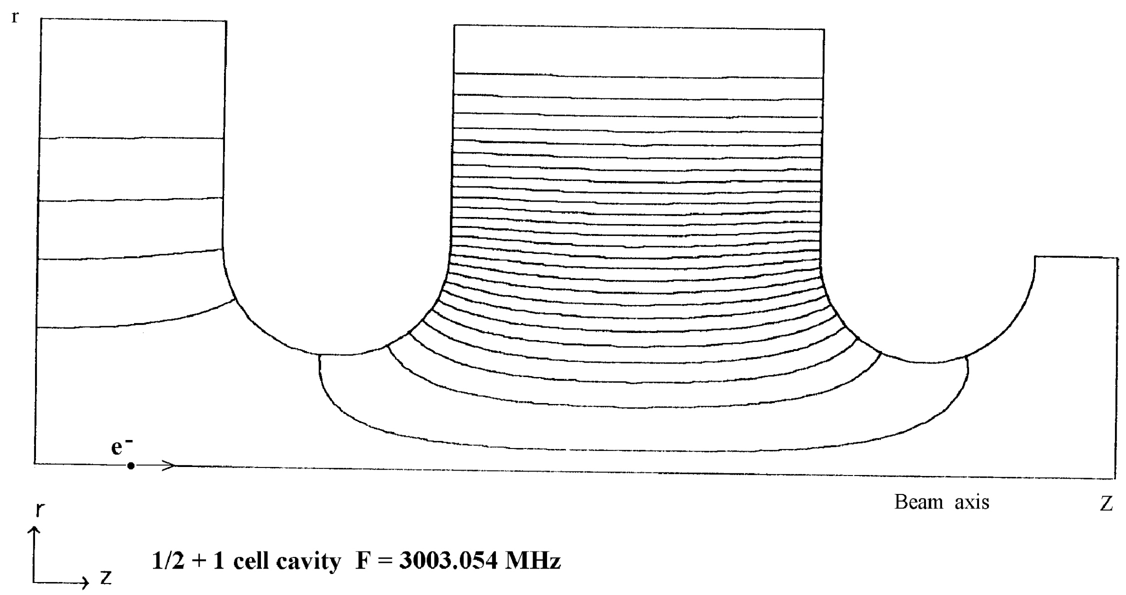


Fig. 10 Electric field in the RF gun from SUPERFISH calculations

From the output of SUPERFISH, the following parameters are deduced: the quality factor *Q*, the shunt impedance *Rs*, the power *P*, corresponding to the requested electric field *Ez*, and the stored energy. Also the ratio of the peak electric field to the accelerating electric field is given. For example, the RF gun shown in the Figure 10, has a shunt impedance of 1.6 MΩ. For the nominal peak electric field on the photo-cathode of 100 MV/m, the requested RF power is 5.5 MW. From this data, one can calculate the necessary power that a klystron should deliver according to the loss along the RF line.

8.2.2 Magnet design: POISSON code [12]

This simulation code is a finite-element triangular-mesh which performs two-dimensional calculations for electrostatic, magnetostatic and temperature distribution problems. The code solves Poisson's or Laplace's equations in 2-D regions and handles problems with finite permeability iron but not with permanent magnets. Several laboratories have made improvements (LANL, BNL, LBL, Texas Accelerator Center, CERN, ...). The code contains sub-routines like AUTOMESH, LATTICE, which give to the user more control over the type of mesh to be generated. Different mesh sizes can be used at any number of places. Figure 11 gives an example of a mesh for a solenoid. The mesh is finer where the beam passes. Figure 12 shows a plot of the magnetic flux lines.

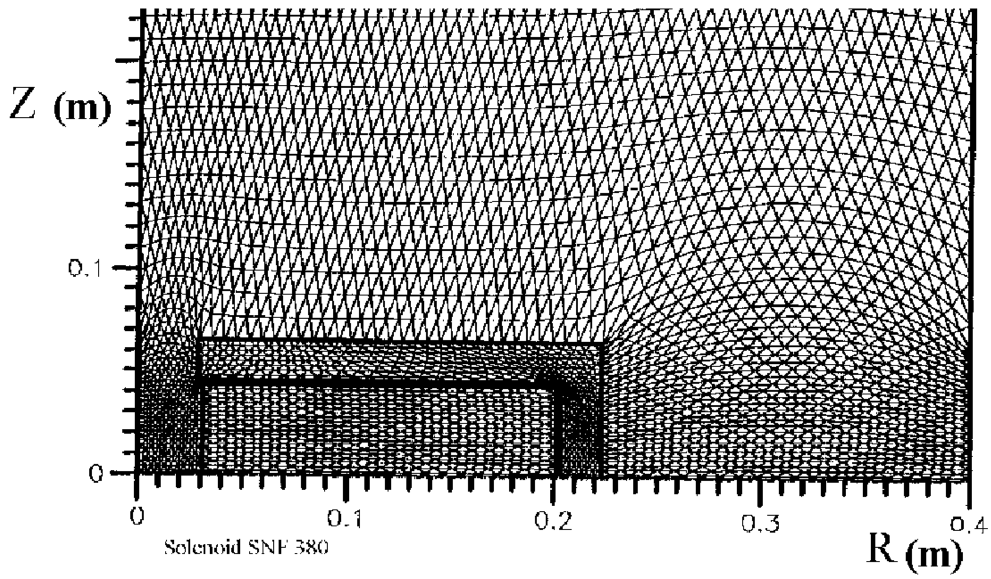


Fig. 11 Mesh line for a solenoid from POISSON

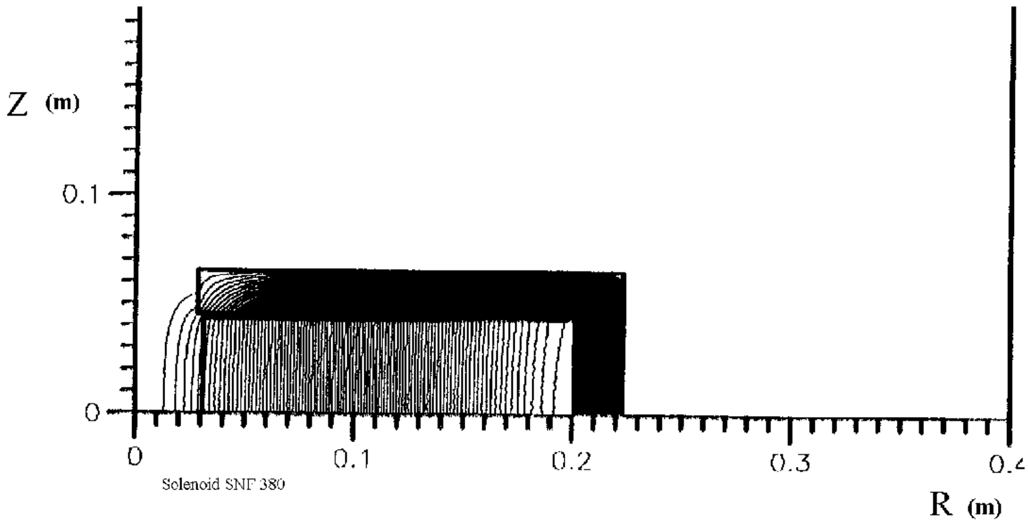


Fig. 12 Magnetic flux lines inside the solenoid of Fig. 11

9. COMPUTER CODES FOR PARTICLE ACCELERATOR DESIGN

Many useful codes are widely distributed but several users make their own improvements and the original author loses control. With each new generation of high energy accelerators, limitations in the existing codes are found and therefore it is necessary either to improve an existing code or to write a new one. The consequence is often a duplication of the effort and a proliferation of different codes. When a simulation code provides an output which is inconsistent with the experimental results or when the data are suspicious, one should make comparisons with another similar code. But then arises the problem of different types of input and output and the different theoretical approaches. Table 2 lists some of the simulation codes presently available (alphabetic order).

Table 2
Some current simulation codes

Use	Codes
Beam Dynamics:	
- Linacs	DYNAC, FLUX 2D, ITACA, MAPRO, PARMILA, PARMELA, ...
- Cyclotrons	NAJO, RELAX 3D, ...
- Circular machines	ABCI, MAD, PATRAC, PATRICIA, SAD, ...
- Transfer lines	TRANSPORT, TURTLE, ...
Component design	
- RF cavities	MAFIA, SUPERFISH, ...
- Magnets	PE2D, POISSON, TOSCA, ...
- Ions and e^- sources	AXCEL, EGUN, ...
- Klystrons	RMKT, ...

For the design of the next generation of high energy accelerators, there is a strong wish to establish an international collaboration and even an international center for accelerator codes. However it is not obvious how such collaborations can deal with the various types of machines and with the different types of particles. For the time being, each laboratory involved in the design of accelerators uses the widely distributed codes like TRANSPORT, SUPERFISH, POISSON, and develops its own codes for the specific applications. A compendium has been published by the Los Alamos Accelerator Code group [13] which gives a description of 203 codes used in 10 laboratories around the world. Though it is not an exhaustive list, it represents a useful document for those who are looking for existing simulation codes which could cover the specific problem they have to deal with. Some new improvements are not reported in [13]. For example, starting with the same approach as MAPRO and PARMILA (protons and ions), the code DYNAC [1] provides a better accuracy and can also be applied to electrons.

10. CONCLUSION

Whatever accelerator design one has to elaborate, it will always be necessary to use a pencil and paper to express the basic ideas to be submitted to discussion and critics.

It is fundamental to develop analytical models in order to understand the simple physics principles and for that a pocket calculator will always be useful and sufficient.

Finally when the physics is sufficiently understood, it is time to move to a desktop computer or a large computer to run sophisticated codes which, when they are correctly used, allow a rather good description of the new accelerator design and save time since it is not necessary to build a prototype (magnet for example).

The door is still open to develop new simulation codes to take into account the very high charges with their related effects, the superconductivity in linacs, cyclotrons and other circular machines, and the high energies of the future accelerators.

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