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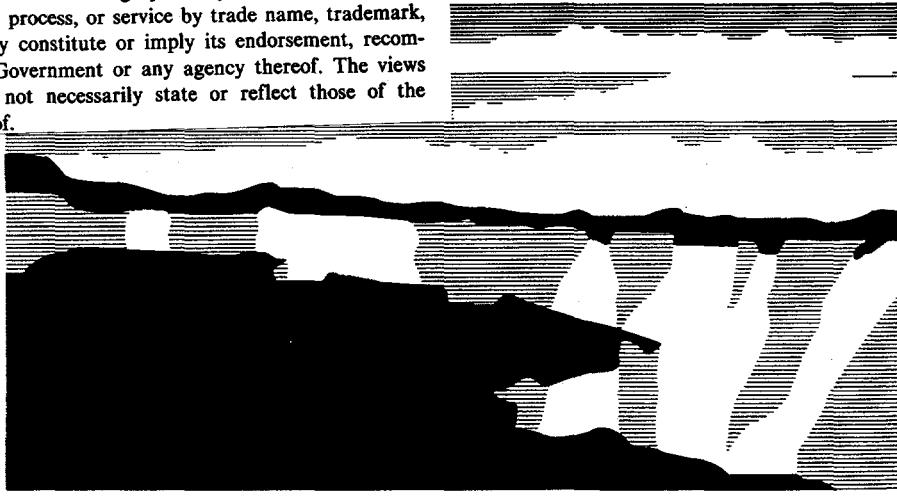
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MODIFIED PARMILA CODE FOR NEW ACCELERATING STRUCTURES*

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The PARMILA code was originally developed as a numerical tool to design and simulate the beam performance of the drift-tube linac (DTL). We have extended PARMILA to the design of both the coupled-cavity linac (CCL) and the coupled-cavity drift-tube linac (CCDTL). We describe the new design and simulation features associated with these linac structures and improvements to the code that facilitate a seamless linac design process.

PARMILA and New Accelerator Architectures

PARMILA stands for Phase And Radial Motion in Ion Linear Accelerators. This computer code originated in the 1960's to study DTL structures¹ and it has been widely used in the accelerator community. This popular code has benefited from years of use and improvements. It has been the basis of many successful linac designs and has been rigorously studied and tested. In recent years, we have seen the development of high-energy RFQ linacs and the CCDTL, a new rf structure² that extends the operating range of the CCL down to the output energy of the RFQ. These developments have motivated work to generalize the PARMILA code for various accelerator architectures.

A CCDTL cavity contains one or more drift tubes. Unlike the conventional DTL, the CCDTL drift tubes usually contain no focusing elements. Quadrupole lenses between cavities or between multi-cavity tanks provide the transverse focusing just like the arrangement in CCL structures. The section of PARMILA that generates the linac now also calculates the lengths of the inter-cavity drift spaces containing the quadrupole lenses. The input stream has several new options that describe the new cavity geometries and their associated focusing requirements. The cavity periodicity and the type of focusing lattice (e.g. FODO) are among the new input-stream entries. To make room for beam-line diagnostic equipment, quadrupole lenses can be either upstream, downstream, or centered in the inter-cavity drift space.

Cavity Configuration Options

PARMILA treats each accelerating gap and the adjacent drift distances as a "cell." A cavity can contain one or more cells. For example, DTL cells have length $\beta\lambda$, where β is the synchronous particle velocity and λ is the rf wavelength. The accelerating gap is in the middle of this cell. In the CCDTL, a cell extends from the center of one drift tube to the center of the next one or to the start of a drift space. Individual cell lengths in a CCDTL cavity differ depending on whether the cell abuts a cavity outside wall or another drift tube. Figure 1 shows short sections of CCDTL and CCL structures. The

length of a CCDTL end cell is $3\beta\lambda/4$, while the length of an internal cell is $\beta\lambda$. The gap is not centered in this cell. Each CCL cell has length $\beta\lambda/2$.

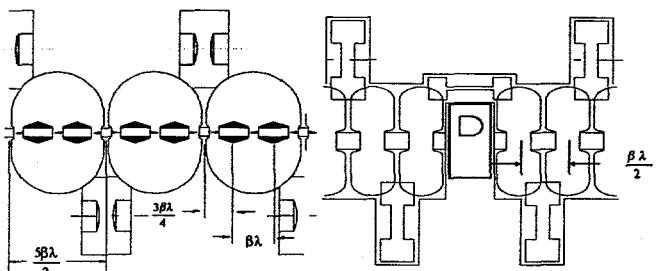


Figure 1. Short sections of CCDTL (left) and CCL (right). The coupling cells above and below the accelerating cells are nominally unexcited in the $\pi/2$ structure mode. The CCL shows a dead space between accelerating sections containing a quadrupole magnet.

The code stores a unique length for each cell in a cavity. For the CCDTL, this generality allows asymmetric cavities, though we expect most designs to use symmetric cavities. The cell geometry as well as the electric fields are treated differently in cavities containing single and multiple drift tubes. To calculate the individual cell geometry the cell generator uses multiple transit-time factor and shunt impedance tables for each type of cell tabulated as a function of β . The code interpolates intermediate values as required. The user supplies these tables as part of the input stream. PARMILA designs each cell so that the beam maintains synchronism with the time-varying rf fields. The algorithm³ used to derive the cell lengths is the same for all types of linac. The code divides each gap at its midpoint and calculates the length of each side separately using the synchronous particle velocity before and after applying an energy kick. In CCL and CCDTL structures, the electric fields in adjacent cavities are out of phase. The electric field for all cells within a CCDTL cavity are in phase. If a quadrupole lens is inserted between two cavities, additional multiples of $\beta\lambda$ may be needed to maintain synchronism with the drifting beam. It is often desirable to maintain a transverse focusing period which is constant in $n\beta\lambda$, especially across changes in the accelerating structure.

In our recent linac designs, we start with two-drift-tube CCDTL structures at low β and later switch to single-drift-tube CCDTL. This procedure uses each cavity type where it has high shunt impedance. In these $\pi/2$ -mode structures, conventional TM₀₁₀-mode coupling cells provide a phase shift of π radians between accelerating cavities. Adjacent gaps in such a structure must be $\beta\lambda/2$ apart. Longer coupling cells can add odd-integer multiples of $\beta\lambda/2$ between active structures to create additional space for focusing lenses and diagnostics.

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while still maintaining synchronism. By reorienting the coupling cavity (see Fig. 1 for the CCL), the designer can provide a 2π phase shift between cavities. This technique allows integer multiples of $\beta\lambda$ between cavities. Long spaces between active structures may require a bridge coupler when the length of a coupling cell approaches a full wavelength. Bridge couplers contain excited and unexcited cells placed off the beam axis to allow space for longer focusing elements or diagnostic devices. Using these techniques, the drift length between tanks can be tailored to practically any value of $n\beta\lambda/2$, where n is an integer. In PARMILA, these adjustments can be specified globally or for individual tank junctions. These options are controllable from the input stream. The code divides the space charge calculation in the connecting drifts into steps corresponding to a distance of about $\beta\lambda$. PARMILA accepts input data for either FODO or FOFODODO focusing lattices. It assumes, as a default, a constant magnetic field gradient for all focusing lenses. The designer can specify each quadrupole gradient individually or automatically ramp the gradient linearly with accelerator length, or as $1/\beta$. If part of the accelerator is turned off (for example, to produce a beam of lower energy than the nominal design), the code can compensate for the over focusing using the automatic ramping feature.

Tables of Transit-Time Factors

We have extended the linac-design and beam-dynamics simulation parts of PARMILA to accommodate the new cavity structures and external quadrupole specifications. PARMILA defines a DTL as a collection of resonant tanks containing cells delimited by drift tubes. This definition has been extended to accommodate CCLs and CCDTLs which may be comprised of tanks containing one or more cavities each of which may contain one or more cells. Cells may be delimited by either cavity end walls or drift-tubes. Because of the possibility of having differing cell characteristics within a CCL or CCDTL cavity, two or three transit time factor tables, corresponding to the same range of β are required. One table is used for "mid-cells" where the geometry is symmetric about the center of the gap. One table is used for CCDTL "end-cells" which are bounded by a half drift-tube and a cavity end wall. A third "quad-cell" is one in which there is no immediately adjacent accelerating cavity. In the third case the fields penetrate into the inter-tank drift because there is no resonator to define their termination point. For a single drift-tube CCDTL cavity only the "end-cell" and "quad-cell" tables are needed. For a CCL cavity only the "mid-cell" and "quad-cell" are needed. If the "quad-cell" table is omitted, the program defaults to using the "end-cell" table for both cases.

Because of the asymmetries possible in both CCL and CCDTL cavities, the actual field strength in the individual gaps, for a nominal cavity excitation, may not all be the same. Additional table entries describe relative electric field strength factors for each type of gap (end-cell, center-cell and quad-cell) as a

function of β . Each cell length is iteratively calculated using transit time factor, shunt impedance, electric field factors, etc. which are interpolated from the SFDATA tables as a function of β . The present version of GENLIN2 generates only graded β linacs, so unlike some present CCL linacs, every cell has a different length. Tanks containing constant length cells will be implemented in the future.

During the linac design phase, GENLIN2 stores each cell geometry as well as the interpolated transit time factors and electric field factors. In addition the cavity wall losses are calculated, summed and saved in a separate file for each run. During the particle simulation phase, each cell is treated as drift + gap + drift sequence for both CCLs and CCDTLs. For DTLs each cell is simulated by a half-quad + drift + gap + drift + half-quad sequence.

Longitudinal Adjustment

To adjust the longitudinal acceptance, the user can manipulate both the synchronous phase ϕ_s and the spatially averaged electric field E_0 . Two types of ramping schemes are provided. A static ramp varies either ϕ_s or E_0 linearly with real-estate length. A dynamic ramp varies these parameters as a function of β . Another feature allows the designer to maintain a constant synchrotron oscillation frequency or constant longitudinal phase advance per cell. Additional ramping options based on cell number and active cavity length will be added to give the designer more flexibility.

The input stream includes the distribution of E_0 for designing the linac. For DTLs, E_0 can be only be ramped linearly with tank length because we assume limited control over the detailed field distribution in the cavity. When an accelerator design varies E_0 in a CCDTL, the ramp applies only cavity to cavity. The cells within each cavity will have the relative field strength determined by a cavity design code such as SUPERFISH. For example, the center gap of a two-drift-tube cavity may in general have a different voltage gain from the end gaps. Designers will usually avoid longitudinal ramps within a cavity, because of the way it would complicate the cavity-to-cavity coupling.

The actual phase of the field in the cavities, of course, is fixed by the resonant rf mode. But, as seen by the beam, arbitrary phase shifts between cavities are possible by adjusting drift lengths between cavities. Using this feature we can create flexible longitudinal bunching and matching sections between different linac structures, for example between a RFQ and a CCDTL.

Simulation Studies

Like previous versions of PARMILA, the new code designs the linac and simulates its performance with beam in the same run. The design process involves generating cells of the appropriate length for the particles' increasing velocity. To facilitate the beam matching between two linacs (e.g. of different types), half quads may be included before or after the

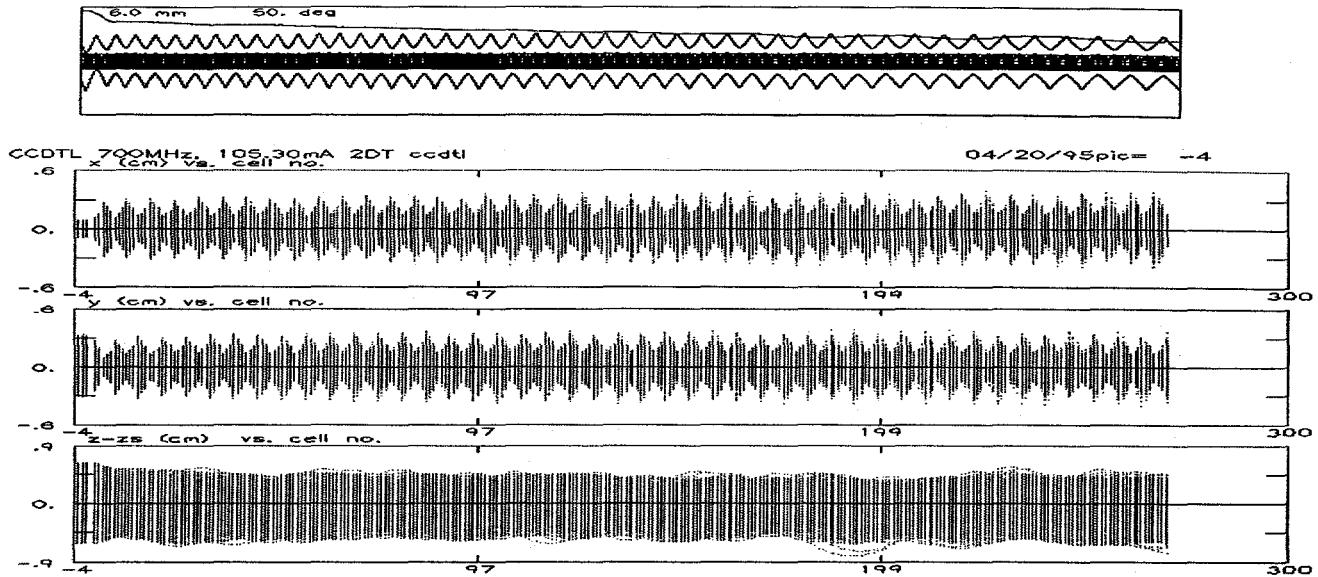


Figure 2.

linac to create complete lattice periods. At the conclusion of the design and simulation calculation for a linac a trailing half-quad may be inserted and the beam distribution written to a file for another run on a subsequent accelerator section. The next run would start with the another half quadrupole lense. This facilitates the design of a linac comprised of several different types of accelerating structures and provides a true end-to-end simulation capability.

PARMILA can read the particle distribution produced by PARMTEQ at the RFQ exit and use it as the input distribution for a dynamics simulation. For a seamless design process a TRACE 3-D⁴ [4] input file containing the beam line elements that comprise the linac can be produced. TRACE 3-D calculates a variety of useful matching conditions.

During the simulation phase the bunching can be characterized by two bucket filling factors which measure the beam distance from the separatrix. Also calculated after each cell is the synchrotron wavelength. These three parameters are used as the tools for manipulating the longitudinal match. The beam behavior is diagnosed by plots of envelope or particle distributions displayed as VGA graphics. These plots are produced by a post-processor that fetches the beam particle distributions that have been saved at the end of each cell, and at the center of external quads.

In addition to the standard geometrical quantities that PARMILA saves, additional parameters associated with the new structures are saved and can be listed at the completion of the design phase. These include CCDTL and CCL cell lengths, cavity spacing and the external quadrupole magnet characteristics.

Figure 2 shows sample profiles for a proton beam in the CCDTL from 7 MeV to 20 MeV. The beam goes through a matching section made of three CCDTL cavities and four quadrupole lenses. This is followed by ramped accelerating gradient and synchronous phase along the linac. Then the beam is accelerated to 20 MeV.

Summary

PARMILA can now design DTL, CCL, and CCDTL linacs and simulate their beam dynamics performance. The code designs a single structure per run. Several runs comprised of more than one type of linac structure can be linked to facilitate the design and simulate accelerators. At the time of this conference (May, 1995), documentation for the new code is still in preparation. We plan to announce the release of the code and its on-line documentation on the World Wide Web. Interested users can consult the home page of the Los Alamos Accelerator Code Group⁵ for the latest information on PARMILA.

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