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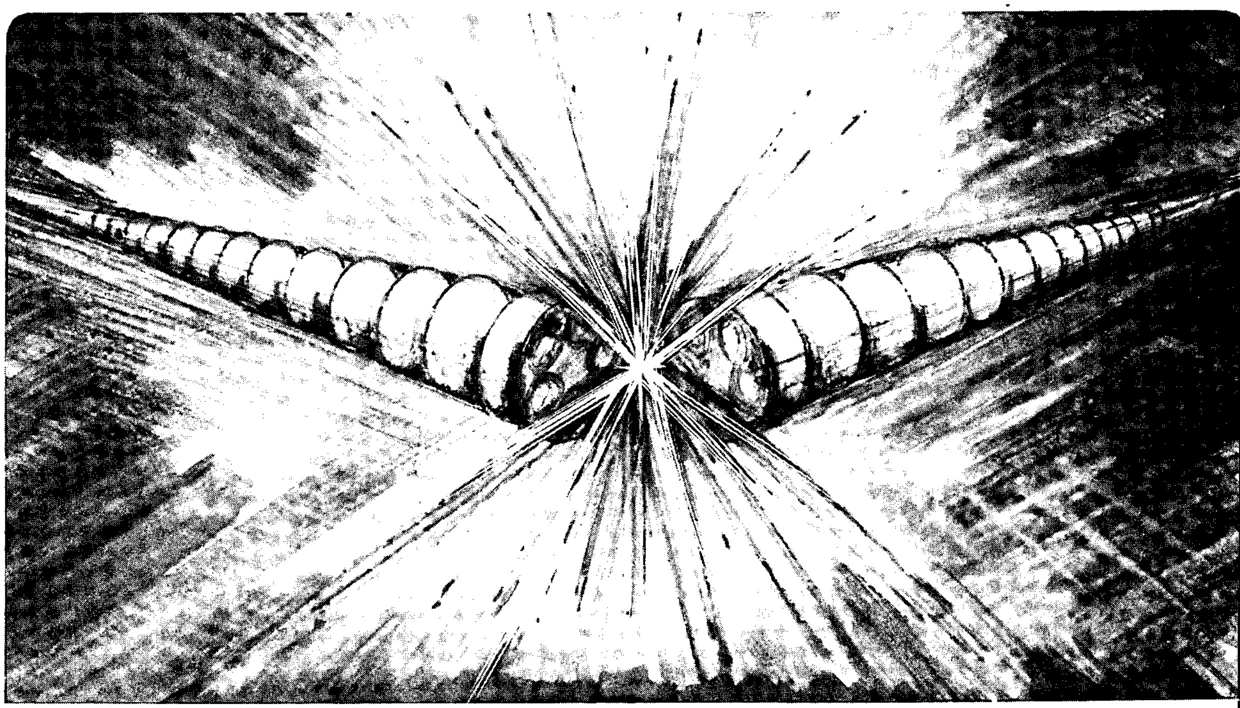

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UPGRADES TO THE LBL LATTICE PROGRAM*

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ABSTRACT

The LATTICE synchrotron and transport system design code, dating from 1976 and currently running worldwide, is a friendly, interactive first-order design and analysis code with a rich graphics environment. The code is ideal for conceptualizing and designing beam optics systems quickly and intuitively. Recent additions to the code include a tracking module for determination of dynamic aperture and small amplitude tune shift including random element errors to 12-pole, automatic translation of LATTICE data files to input files to several other design codes for higher-order analysis, and additional graphics software. A companion code with the same data and command structure, QUICKTRAN, uses the full 6×6 σ-matrix TRANSPORT formalism to include full phase plane mixing. The two official versions run on Sun and VAX platforms: the code is in Pascal.

INTRODUCTION

LATTICE[1] is a computer program that calculates the first order characteristics of synchrotrons and beam transport systems. It is fully interactive with low and high resolution on-line graphics displays giving the user rapid visualization of the characteristics of the beam line being designed. A powerful editing facility allows beam lines to be quickly reconfigured, and up to nine completely independent problems can be manipulated and stored within the program, even more off-line.

LATTICE has two distinct modes: the *lattice* mode which finds the matched functions of a synchrotron, and the *transport* mode which propagates a beam through a sequence of transport elements. However, each mode can be used for either type of problem: the transport mode may be used to calculate an insertion for a synchrotron lattice, and the lattice mode may be used to calculate the characteristics of a long periodic beam transport system. LATTICE does not support x-y coupling: calculations requiring full 6×6 coupling for solenoids and arbitrary beam line twists are calculated with QUICKTRAN, which uses a first-order TRANSPORT-like σ-matrix formulation[2] within the LATTICE-like user environment.

An optimizer allows up to 10 parameters of a synchrotron or beam line to be set subject to 41 different types of constraints (betatron amplitudes, tunes, magnet positions, matrix elements, e.g.).

The rich graphics environment, both on-line during computation and off-line with graphics post-processors produce printer graphics, Tektronix or Postscript plots of the beam amplitudes, beamline layout, or phase space acceptance diagrams.

LATTICE will carry out two limited types of higher-order calculations. The small-ring chromaticity model (the more difficult one) is calculated correctly by

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LATTICE. A tracking module is included to permit the calculation of the dynamic aperture or amplitude dependent tune shift in the presence of multipole errors up through duodecapole. The higher-order contributions may be random as well as systematic.

LATTICE calculations may be followed up with any of several higher-order codes. LATTICE will produce input files for them, eliminating errors in manual translation. In this way, LATTICE can be used for the original conceptualization of a beam line or synchrotron to first order, and TRANSPORT, SYNCH, MAD, DIMAD or MARYLIE can continue the calculations to higher order.

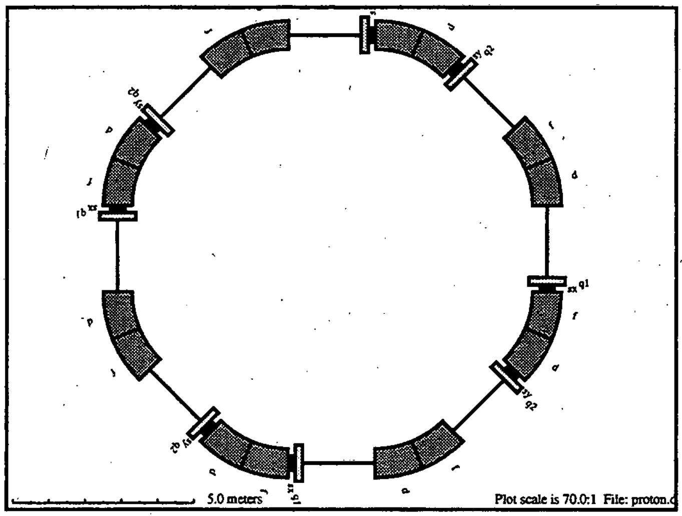
PROGRAM FEATURES

The minimum input parameters include the beam rigidity, definitions of all the elements, and the ordering of the elements in the beam line. Additionally, emittance, energy spread, comments, periodicity and graph scales can be entered, otherwise the default values are used. The 17 element types presently supported are:

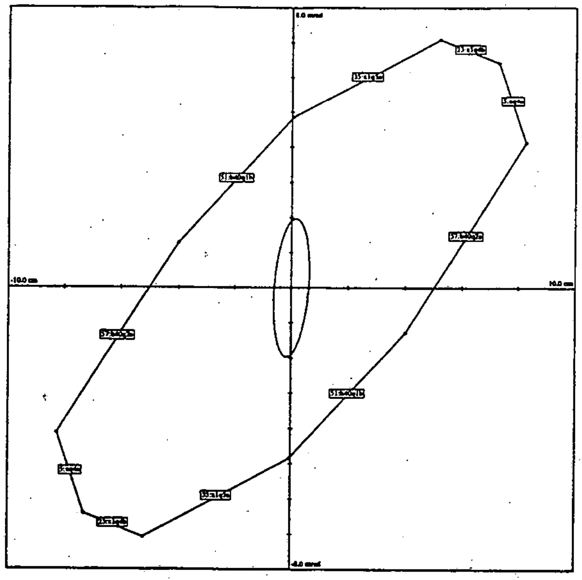
Element	Attributes				
drift	L			a_x	a_y
quadrupole	L	B'		a_x	a_y
skew quadrupole (new)	L	B'		a_x	a_y
sextupole	L	B''		a_x	a_y
octupole	L	B'''		a_x	a_y
decapole	L	B^{iv}		a_x	a_y
duodecapole	L	B^{v}		a_x	a_y
horizontal bend	L	B	n	a_x	a_y
horizontal magnet edge	θ	B	g/2	a_x	a_y
vertical bend	L	B	n	a_x	a_y
vertical magnet edge	θ	B	g/2	a_x	a_y
einzel-type lens	L	s		a_x	a_y
arbitrary matrix	(mtx)			a_x	a_y
beam line rotation	ϕ			a_x	a_y
solenoid	L	B		a_x	a_y
undulator (new)	L	B	L_c	a_x	a_y
electron accelerator cavity (new)	L	dE/dL		a_x	a_y

The attributes are length, field, angle, half-gap and field index. In addition, each element can have an x- and y-aperture which determines the geometric acceptance of the beam line. The higher order elements and skew quad are significant only when used for amplitude-dependent tune shift or dynamic aperture calculations, otherwise they are replaced by drifts. They may have zero or non-zero lengths. The solenoid and beam rotation elements are significant only in QUICKTRAN, and are replaced by drifts in LATTICE. The anharmonicity, or tune shift normalized by circulating emittance, is calculated to first order. Sextupoles are incorporated in the chromaticity calculation and the strengths to give required chromaticities can be found with the sextupole optimizer module.

The lattice or beam line is built up by a list of element names, the elements having been defined previously. To manipulate the lattice, editing commands are provided to add, remove or replace sections, invert the beam line, or save segments or even entire beamline descriptions in nine independent storage registers. Any number of external files can be selectively read into or written from the registers during program execution.



The rich graphics environment for beam line visualization includes on-line printer graphics for minimal terminal environments, or Tektronix graphics for more capable terminals. For publication-quality graphics, post-processors provide plots of beam amplitudes, beamline geometric layout, or phase space acceptance in printer, Tektronix or Postscript format. The geometric layout plot is a 2-D projection scale drawing that can be copied to a transparency and then overlaid onto a building plan. A developmental post-processor, VIEWXYZ provides a 3-D wireframe perspective representation of complex beamlines that occupy 3-space. The upper illustration shows the layout of a small proton synchrotron: the lower one the phase space acceptance of a beam line.



For extraction studies, LATTICE helps prepare an input file for the code EX6, which simulates resonant extraction for half, third, and higher integer orders. The multipole elements are carried over to EX6 from LATTICE so their effects on the extraction orbits may be studied.

The optimizer module allows up to 10 variables to be set to satisfy the same number of constraints (relaxed Newton-Raphson iteration). Any attribute of any first order element (sextupole use a separate optimizer module for chromaticity correction) can be set. The constraints are:

Matrix elements in x and y subblocks and m_{16}–m_{56} (13)
$\beta_{x,y}$, $\alpha_{x,y}$, $\eta_{x,y}$ $\eta'_{x,y}$ (8)
tunes $nux_{x,y}$ (2)
position and running H and V magnet deflection angle (3)
γ_{tr} (1)
Transport variables x, y, x' y', r_{12}, r_{34} (6)
Composite matrix elements m_{16rev}, m_{26rev}, m_{36rev}, m_{46rev} (4)
Combinations $\alpha_x - \alpha_y$, $\beta_x - \beta_y$, trace$_{x,y}$ (4)

where, for example, $m_{16rev} = m_{12}m_{26} - m_{16}m_{22}$ is the m_{16} element of the *reversed* beam line. The constraints can be set at the exit of any element along the beam line.

LATTICE can reverse beam lines, end-for-end, and also chop beam lines up, storing the beam parameters at the beginning and end of each piece for segmentation, and can even store the parameters of reversed beam lines. This is useful when starting a design at each end and working toward the middle.

The phase space acceptance is calculated by transforming all defined apertures to the beginning of the beamline and finding the smallest enclosed polygon. This can also be done for off-momentum beams in which case the effect of dispersion in dipoles may cause an off-axis shift of downstream polygons and chromatic effects in the focusing elements change the aperture transformation to the beginning of the beam line. By reversing the lattice, the acceptance can be projected to the far end of a beam line. A phase space acceptance diagram is shown on a previous page.

The physical layout is calculated by following the beam line axis in 3-space for the on-momentum particle. A direction cosine matrix is calculated (which is stable even if the beam is vertical: TRANSPORT has trouble with this case) which gives the beam direction in terms of three angles. This calculation can produce a file which is used in the 3-D wireframe visualization graphics post-processor as shown on a subsequent page.

NEW CAPABILITY

Since the last report[1], LATTICE has had a number of improvements, some of which were alluded to above. LATTICE has been used to design and verify a FEL line with cavities and an undulator, gantry-based beam transport system for radiotherapy applications, a heavy-ion mass separator, the extraction and beam transport systems of the HIMAC accelerator complex, among others.

A new support code, LAT2X translates a LATTICE file to the input format of the following higher-order codes: SYNCH, MAD, DIMAD, TRANSPORT and MARYLIE. The following example shows the automatic translation for a small synchrotron from LATTICE to SYNCH format.

LATTICE format:

```
* biomed 10
b 8.12600 10.00000 2.00000 0.00000
t off
sc 5.00000 5.00000 5.00000 5.00000
e
b      b 2.1 3.545636 1.200000 0.000000 0.000000 0.000000
l      d 1.1 2.327181 0.000000 0.000000 0.000000 0.000000
o      d 0.0 0.600000 0.000000 0.000000 0.000000 0.000000
f      q 3.2 0.300000 8.237382 0.000000 0.000000 0.000000
d      q 4.2 0.300000 -9.023549 0.000000 0.000000 0.000000
e      e 0.0 0.000000 1.200000 0.000000 0.000000 0.000000
sx     s 0.0 0.600000 3.354135 0.000000 0.000000 0.000000
sy     s 0.0 0.600000 -10.445238 0.000000 0.000000 0.000000
end
l
  l       f       sx      e       b       e       sy
  d       o       e       b       e       o       f
  l       l       d       l
end
p 6
```

SYNCH format:

```
       RUN          biomed 10
C
C Input file biomed10 translated to SYNCH format by lat2x.
C
C234567890123456789012345678901234567890123456789012345678901
C         1         2         3         4         5         6
 BRHO  =                8.12600
 B     MAG              3.54564  -0.00000BRHO         1.20000   0.00000   0.00000
 L     DRF              2.32718
 O     DRF              0.60000
 F     MAG              0.30000   8.23738BRHO
 D     MAG              0.30000  -9.02355BRHO
 SX    SXTP             0.60000   3.35413BRHO
 SY    SXTP             0.60000 -10.44524BRHO
C
 ACC   BML           L    F    SX   B    SY   D    O    B    O    F
                     L    L    D    L
       CYC         6 ACC
       FIN
       STOP
```

LATTICE is now fully operational on Sun SPARC computers in a C environment. LATTICE is still written in Pascal, but a preliminary version written in C is being developed. The Sun version makes use of the multiple window environment operating under OpenWindows.

The tracking module calculates the dynamic aperture and small amplitude tune shift in the presence of multipole elements up to duodecapole. A small ensemble of particles on the emittance shell at the design momentum are tracked around the ring, with the multipole elements acting as zero-length nonlinear kicks. The resulting tune spectrum is Hanning filtered, FFT analyzed and the shifted tune extracted. The same module calculates dynamic aperture by placing a monitor at each sextupole to detect unstable growth. The anharmonicity, or the tune shift normalized by the circulating emittance, is also calculated.

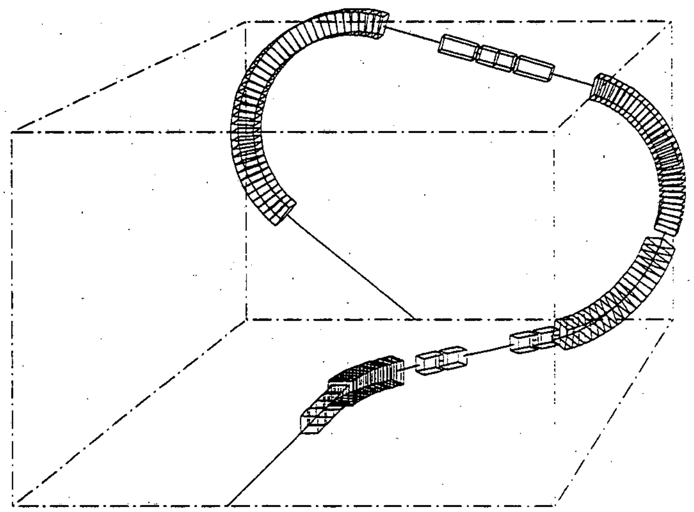
A thin skew quad element has been added to investigate the effect of x-y coupling on the dynamic aperture and tune shift.

Random perturbations to all elements from quadrupole to duodecapole have recently been added. A peak random field amplitude is assigned to each element which is then multiplied by a random quantity uniformly distributed in the range [-

1..1], unique for each element in the lattice, even if they have the same name. Distributed multipoles in long dipoles can be built up from a number of zero-length multipole kicks spread along a dipole, for example. Systematic errors can be built up in the same way. This way, dynamic aperture can be determined using realistic error models to establish the maximum allowable random and systematic errors allowed.

LATTICE generates an input file for the extraction code EX6 including all of the random and systematic errors defined above. The EX6 code also includes kicker dipoles, and the effect of the random and systematic errors on the extraction trajectories and on the closed orbit can be calculated.

New undulator and electron accelerator (β=1) elements have been added. The cavity model is very simple: it just models the r.f. defocusing at the gap. The undulator element simulates a periodic dipole sequence, which is a drift in the gap plane, but which acts as a periodic transport system in the perpendicular plane. As this periodic system has a matched betatron amplitude, this matched betatron amplitude can be specified directly, as an alternative to the peak poletip field.



A new off-line graphics processor, VIEWXYZ, provides a wireframe perspective view of beam lines of complex geometry, as shown to the right.

Two new fitting constraints have been added: $\beta_x - \beta_y$ and $\alpha_x - \alpha_y$, used for the purpose of prescribing a round beam without specifying the actual betatron amplitudes. This was needed to fix the beam at a variable twist in a transport system. The flexibility and modularity of LATTICE allows additional complex types of constraints to be easily added to the source code, which must then be recompiled.

REFERENCES

1. LATTICE...A Beam Transport Program, J. Staples, LBL-23939, June 1987
2. A First and Second-Order Matrix Theory..., K. L. Brown, SLAC-75, July 1967

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