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AGILE, A TOOL FOR INTERACTIVE LATTICE DESIGN

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Abstract

AGILE is a program that works in the IBM-PC, MS-Windows environment and is dedicated to the interactive design of alternating-gradient lattices for synchrotrons and transfer lines. The program was originally intended as a teaching tool, but has been used mostly for professional design work and is subject to continuous development. It contains original algorithms for coupling, scattering and eddy currents, and some slightly unusual algorithms for off-axis orbits and space charge. There are also additional features such as engineering design aids, calculators for relativistic and synchrotron radiation parameters, expert routines for optimising slow extraction, fitting and matching, and the internal storage of constants for over 1000 stable and quasi-stable charged particles. The program is object-oriented and fully integrated into the Windows environment - it is not a shell. Apart from office work, AGILE is ideal for home use, design workshops and when travelling. It is particularly suited to practical problems in small and medium-sized rings and transfer lines. Operation is largely intuitive and supported by an on-line help facility.

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1 INTRODUCTION

The original aim of the AGILE program was to provide a simple tool for teaching accelerator lattice design. The IBM-PC, MS-Windows environment was adopted since almost all sectors of society, both private and professional, have experience of this computing platform. This creates confidence in new users and makes many of the basic operations, such as searching help files, automatic. The universal use of the IBM PC means that the user can get access to facilities at almost any time and place. As the program developed, it was used more and more for professional design work and workshops, but its simplicity, portability, rapid interactive interface and built-in graphics have remained its key advantages.

AGILE uses a database in global memory that serves a master program running a number of *application objects* and their *windows*. The *windows* form a logical 'star structure' with the *Main Window* at the centre. The *Main Window* performs basic tasks as well as acting as a gateway to the other *windows* that are dedicated to specific purposes such as lattice editing, ring calculations, transfer line calculations, numerical matching, analytic matching and so on. The current version handles up to 5000 elements.

2 COMPUTATIONAL FACILITIES

2.1 Basic facilities

The program is centred around the calculation of the linear lattice functions on orbits with up to ±4% momentum deviation. The philosophy for off-axis beams is to find the orbit by dipole tracking in the hard-edged magnet model. The geometry of the track and the model are then used to create a new hard-edge model that is centred on the track. Thus, an *off-axis* beam in a quadrupole becomes an *on-axis* beam in a dipole. The focusing is then calculated using first-order matrices in the new lattice. This avoids expansions using second-order matrices, which are especially sensitive around edge-angles. In principle, the precision is the same for all orbits whatever the momentum deviation. The program is currently limited to ±4% momentum error, until an improved geometric tracking routine can be installed. The linear lattice functions are complemented by a number of linear calculations such as orbit bumps, closed-orbit correction, envelopes and so on. For tracking, resonance excitation and other non-linear functions, the program takes into account normal and skew multi-poles up to decapole, and solenoids.

Graphs can be plotted directly on the Windows default printer, or exported as postscript files. Similarly, numerical results can be printed directly or exported in files with standard spreadsheet format. A useful feature is that rows, columns and arbitrary rectangular blocks in numerical displays can be highlighted and copied to the Windows clipboard. Input files can also be created for the MAD program [1].

2.2 Animations

The beam can be represented by a particle distribution, or by envelopes, together with the vacuum chamber wall and can be visualised in a dynamic way as the observer travels around a ring or down a transfer line. Space charge can be included, loss plots can be made along the lattice and, in transfer lines, scatterers can be placed in the beam path. There is also an expert routine for multi-turn injection. When large numbers of turns are to be considered, it is quicker to use phase-space maps that show how the beam evolves when viewed at one specified position in a ring. One application of phase-space maps is an expert routine for the design of third-integer, slow-extraction schemes. In this case, the routine shows the

search for unstable orbits and the plotting of the phase-space separatrices as an animated display (see Fig. 1).
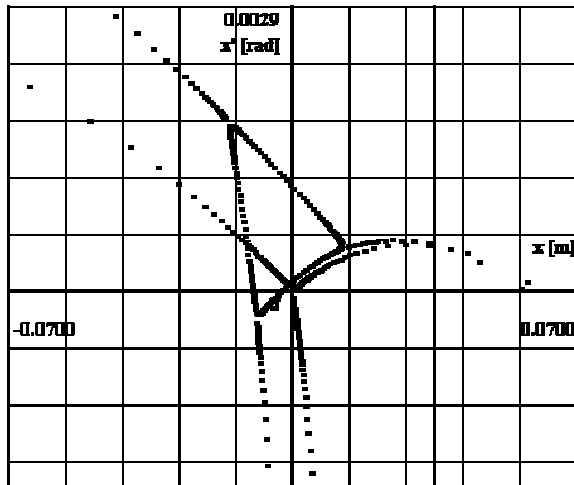

Figure 1: Final screen display from routine for optimisation slow extraction

2.3 Interactive lattice design

The interactive design of a lattice is supported by fitting and matching routines. The former optimise geometry, set tunes, set chromaticities and set the driving terms of coupling resonances. The latter includes several analytical matching routines based on thin-lens modules (one doublet, three triplet and two quadruplet routines) as well as numerical matching by minimisation. The progress of numerical matching can be watched on-line as the graphical representation of the lattice parameters changes (see Fig. 2).
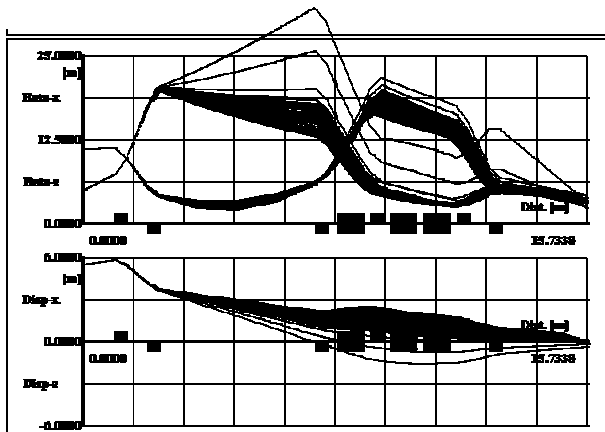

Figure 2: Screen display during numerical matching
[Processed to give a b/w line image]

2.4 Space charge

Space charge can be treated in three ways. Firstly, incoherent and coherent space charge can be included in the Twiss optics, but these two space-charge regimes can only exist separately. Numerical matching and fitting can also be carried out with the incoherent space charge applied when on central orbit. The program automatically inhibits those calculations that are not appropriate for the type of space charge being used. The third method for calculating space charge is by tracking particle distributions with direct particle-particle forces, which allows all non-linearities, scattering and coupling to be included. This is an experimental routine that is being developed to investigate self-space-charge forces at MeV energies and images are not included (see Fig. 3). Typically the routine could be applied to a multi-turn injection scheme. For space-charge calculations, the program stores parameters for over 1000 particle species that include most stable or quasi-stable ions and exotic particles.
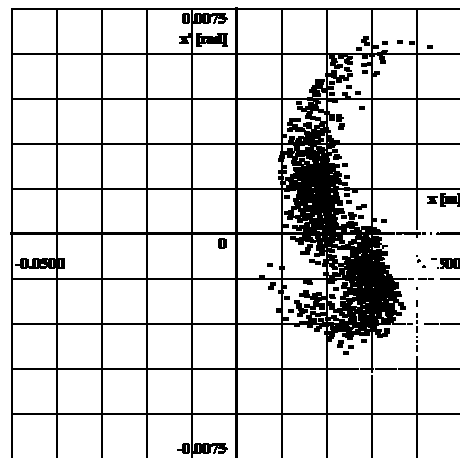

Figure 3: Screen display of three bunches injected with space charge after losses on the vacuum chamber
[Processed to give a b/w line image]

2.5 Coupling

The tracking of single particles and distributions includes solenoids and all skew elements up to decapole in rings and transfer lines. In rings, the linear coupling can be treated either with the sigma matrix formalism that gives beam sizes, the Teng-Edwards formalism that derives the normal modes, or as a perturbation to the linear lattice by evaluating the driving terms of the sum and difference, second-order coupling resonances. There are several routines for designing coupling compensation schemes that are based on a very recent theory concerning resonance families [2]. Solenoids can also be given end plates with slots rather than round beam holes. In transfer lines, only the sigma matrix formalism is used.

One extra feature is the calculation of sections of transfer lines that rotate on their axis. This is basically a coupling problem and has been included for the calculation of gantries and rotators in medical facilities.

2.6 'Distorted' orbits

In some cases, it is necessary to take into account perturbations in the lattice functions on orbits that are strongly distorted. For this condition, the program creates a special lattice for the 'distorted' orbit. An example,

could be an injection or extraction orbit that passes close to the edge of the aperture and then crosses to the axis. In this case, the special lattice section can be added to the transfer line in the normal way, so that the beam can be tracked right up to the central orbit of the ring.

2.7 Kicks

Dipole kicks, quadrupole kicks and skew quadrupole kicks can be created randomly or systematically to estimate the effects of errors. Statistics for up to 1000 randomly-generated 'machines' can be produced for several different types of errors.

2.8 Design

Calculators are included for relativistic parameters, synchrotron radiation parameters and lattice parameters, and specialised design aids are included for magnets, water-cooled coils and the field distortion due to eddy currents in laminations, end-plates and vacuum chambers [3].

2.9 Scattering

One of the more unique features of the program is the treatment of scatterers. Scatterers can be introduced into transfer lines for all the beam particles available in the program, except electrons, H^- ions and H_2^+ ions. The program can treat the scattering data in two ways. The first method modifies the Twiss functions to calculate beam envelopes with the scattering included [4]. The beam envelopes, beam emittances, average momentum loss, increase in momentum spread and transmission efficiency are tabulated along the whole lattice. It is also possible to use the thickness of the scatterers as a matching variable and to match the beam parameters and beam sizes (or emittances) in the numerical matching routine. The second method for treating scattering is to track particle distributions. The principal scattering effect is multiple coulomb scattering, but nuclear elastic scattering can be added for protons when in the tracking mode.

3 SOME PROGRAM DETAILS

The program, its help file and some example lattices can be down-loaded from

http://bryant.home.cern.ch/bryant/

It is suggested that a directory named WINAGILE be created and the program file (WINAGILE.EXE), its help file (WINAGILE.HLP) and example lattice files (*.LAT) be placed in that directory. The program can be started in all the standard ways, including by double clicking on a lattice file, providing Windows has been made aware of the association. Please note that with Windows NT, the program and all its files MUST be in the same folder. The opening screen is the 'Main Window', which initially contains a short welcome message. In the menu bar, click the 'File Menu', which among several possibilities offers 'New' for creating a new lattice and 'Open' for finding existing lattice files. Assuming that a lattice file exists, this can be loaded and its data will appear in the 'Main Window'. If, by chance, the lattice file is incomplete, or unchecked, the program will prompt you to click 'Edit' and to correct the problem. Now click on the 'Calculation Menu' and choose what you would like to do with the lattice. If 'Ring' or 'Line' is chosen, then the program calculates the matrices, the geometry and the Twiss functions, either with periodicity imposed (a ring or matched section) or with initial conditions (a line). The Ring or Line Window will now be shown and further calculation options will be made available. The Help File contains details of element definitions, sign conventions, etc. If you would like to do something specific, you may find an account of the steps in a "How To..." topic. To exit click the Exit button near the top left of the display.

Many of the commands have standard keyboard shortcuts. In 'spreadsheet' displays, the mouse can be used to select single cells, sets of lines, sets of rows or arbitrary blocks of data for copying to the Windows clip board. Double clicking the left-hand button activates data entry and variable selection in the appropriate Windows. Double clicking the right-hand button in the Match Window selects link variables. In 'graph windows' the right-hand button is used to stop animated displays (except in one case that has a dedicated button). Full details can be found in the Help.

4 SUMMARY

AGILE has proven to be a convenient tool that is complementary to the older command-line, batch-job programs that are customarily used for accelerator design. Users have found that the interactive style allows them to follow ideas quickly and the graphical interface helps the rapid appraisal of results. New routines have been added to the program steadily over more than a decade, which has resulted in a code that can tackle a wide range of problems, some of them unique. This process will continue and the intention is to equip AGILE with radio-frequency cavities in the near future.

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