Journal of the Arkansas Academy of Science

Volume 56 Article 11

2002

Simulation Video Electric Single Particle Aerodynamic Relaxation Time Analyzers

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Simulation of Video Electric Single Particle Aerodynamic Relaxation Time Analyzers

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Abstract

The simulation of physical parameters provides a virtual environment for the design and optimization of instrumentation. Applying physical laws and theorems to natural phenomena defines the behavior of analytical processes. Simulation provides a means for the adjustment of specific operating parameters while maintaining the repeatability of constant parameters. The Video Electric Single Particle Aerodynamic Relaxation Time Analyzer (VESPART) is an instrument that provides the diameter and charge-to-mass (q/m) ratio of particles. The simulation of the VESPART requires the modeling of the physical environment and application of modeling to simulations. Simulation includes characterization of the various natural forces that affect particle motion within the instrument. These natural forces can be modified to determine the impact each has on particle motion. The graphical user interface is created in MS Visual Basic providing an MS Windows compatible simulating environment. The output of the simulator is a virtual, illuminated particle track similar to the actual particle track acquired by the VESPART. This paper presents the parameters of simulation as well as the output virtual particle track. Also, the benefits of simulation are presented relative to research and development projects.

Introduction

The modeling and simulation of physical environments is an expanding and widely applied research area used in almost every segment of technology. Modeling and simulation allow the development of an advanced virtual research environment used to analyze physical parameters and optimize process applications without the modification of hardware and software. Specifically, modeling is introduced to establish operational parameters allowing computers to implement parameters as determined through simulation.

The Video Electric Single Particle Aerodynamic Relaxation Time (VESPART) analyzer concept creates an electric field that excites charged particle motion and captures the particle motion with a CCD camera (Mu 1994). The charged particle, size ranges 1 to 100 mm diameter, is introduced into one end of a flow chamber. At the other end of the flow chamber is a blower creating laminar flow conditions that gently guide the particle into the sampling volume. As the particle passes through the chamber, an applied electric potential, on the order of 20×10^3 Volts peak-to-peak and modulated at 50 to 255 Hz sinusoidal, excites particle motion. The horizontal component of the electric field (x-axis force) is over seven orders of magnitude greater than the vertical component of the electric field (z-axis force). The particle is driven by the strong horizontal electric field to create an amplitude and velocity phase of the oscillatory motion of the particle that are characteristic of the particle's charge and diameter. The particles pass through the sampling volume of the flow chamber as it moves from one end to the other. The sampling volume is a 2mm x 2mm flat area where the field of laser illumination intersects the focal-field of a CCD camera. As the particles pass through this region, the lasers are turned on for exactly two cycles of electric field to illuminate particle movement. The CCD camera and frame grabber acquires an image of the particle's illuminated path and transfers the frame to C++ routines for analysis. The particle track amplitude and velocity phase calculations are solved, the charge and diameter of the particle are calculated, and data is stored and displayed. The input and output (I/O) of the VESPART to the host computer is accomplished via a serial cable from the CCD camera to the frame grabber in the computer. The instrument, in this configuration, is not portable and cannot be non-intrusively introduced into most process applications due to its bulky size, weight and manual adjustments.

The VESPART operation is simulated to allow the application of varying electric-field frequencies, airflow velocities, particle sizes, particle charges, chamber diameters and applied electric potential to analyze their affect on instrument charge-to-mass and diameter calculations (Farmer 2002).

Materials and Methods

Modeling the physical environment facilitates the development of simulations by defining, developing and understanding the forces and their limitations driving the charged particle movement within the VESPART. Modeling also provides virtual design and development flexibility to alter physical parameters and analyze their affect on charged particle movement. The electric field, created by sinusoidally modulating the applied electric potential to the deflector plates, is modeled (in the DC state) to analyze the electric field driving forces, create a polynomial representation of these forces for simulation and to facilitate design and development of a smaller diameter flow chamber.

Modeling the VESPART electric field is accomplished using a commercially available software package, *Lorentz 2D*, available from Integrated Engineering Software, Inc., Manitoba, Canada. The *Lorentz 2D* software begins with a user interface to the geometry of the VESPART: a cylindrical tube (flow chamber) and two metal plates that match the radius of the chamber with 180-degree separation.

Next, 'elements' are placed along the geometry to divide the model into sub regions along the geometryís boundaries. The *Lorentz 2D* uses the Boundary Element Method (BEM): BEM transforms *differential* operators defined *in* the geometry volume into *integral* operators defined *on* the geometry boundary. This makes the geometry 'meshing' simple, the calculations fast and utilizes precise integration to generate values. The VESPART chamber geometry, with boundary elements, is shown in Figure 1.

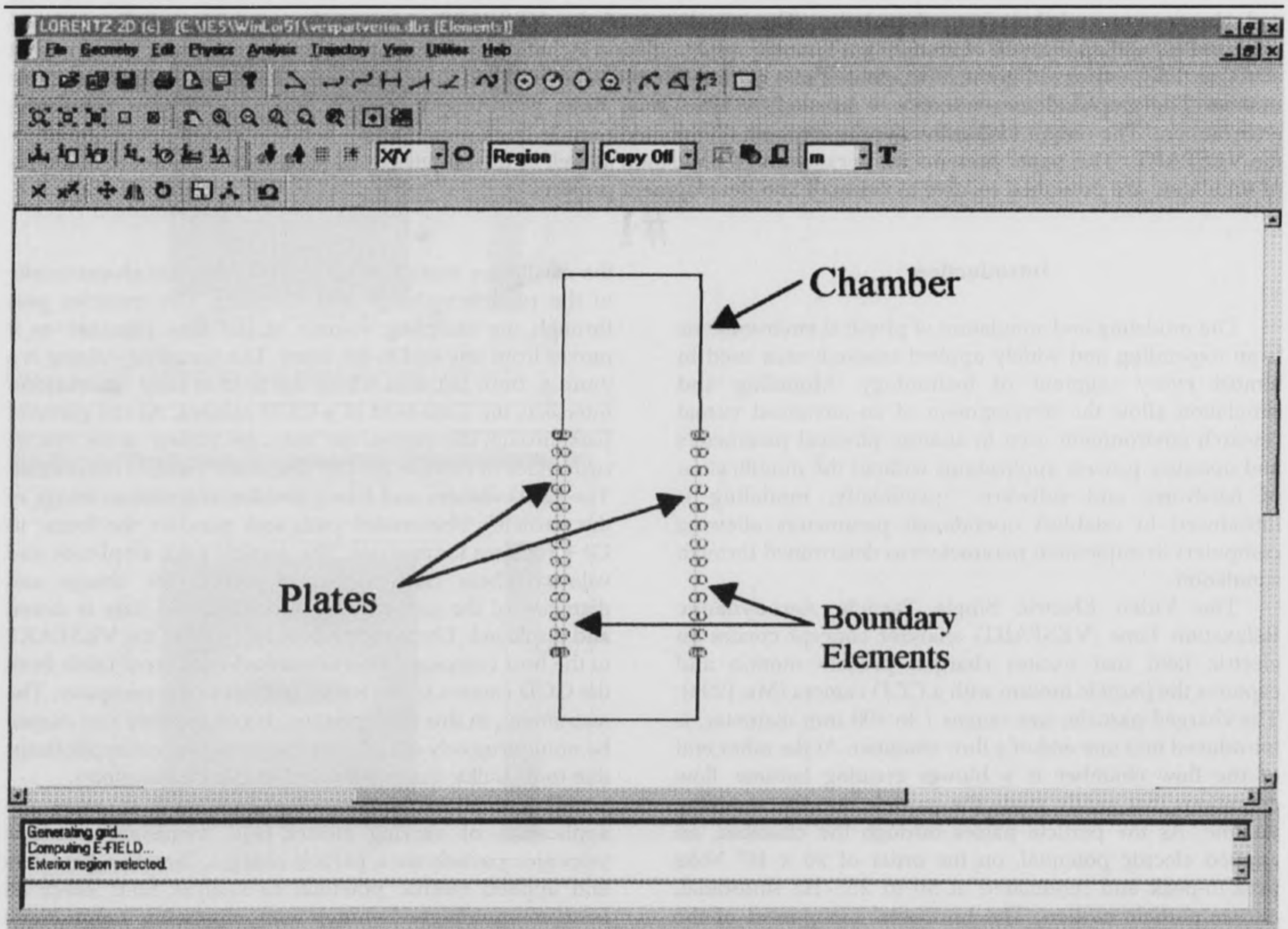

Fig. 1. Lorentz 2D VESPART Flow Chamber with Boundary Elements.

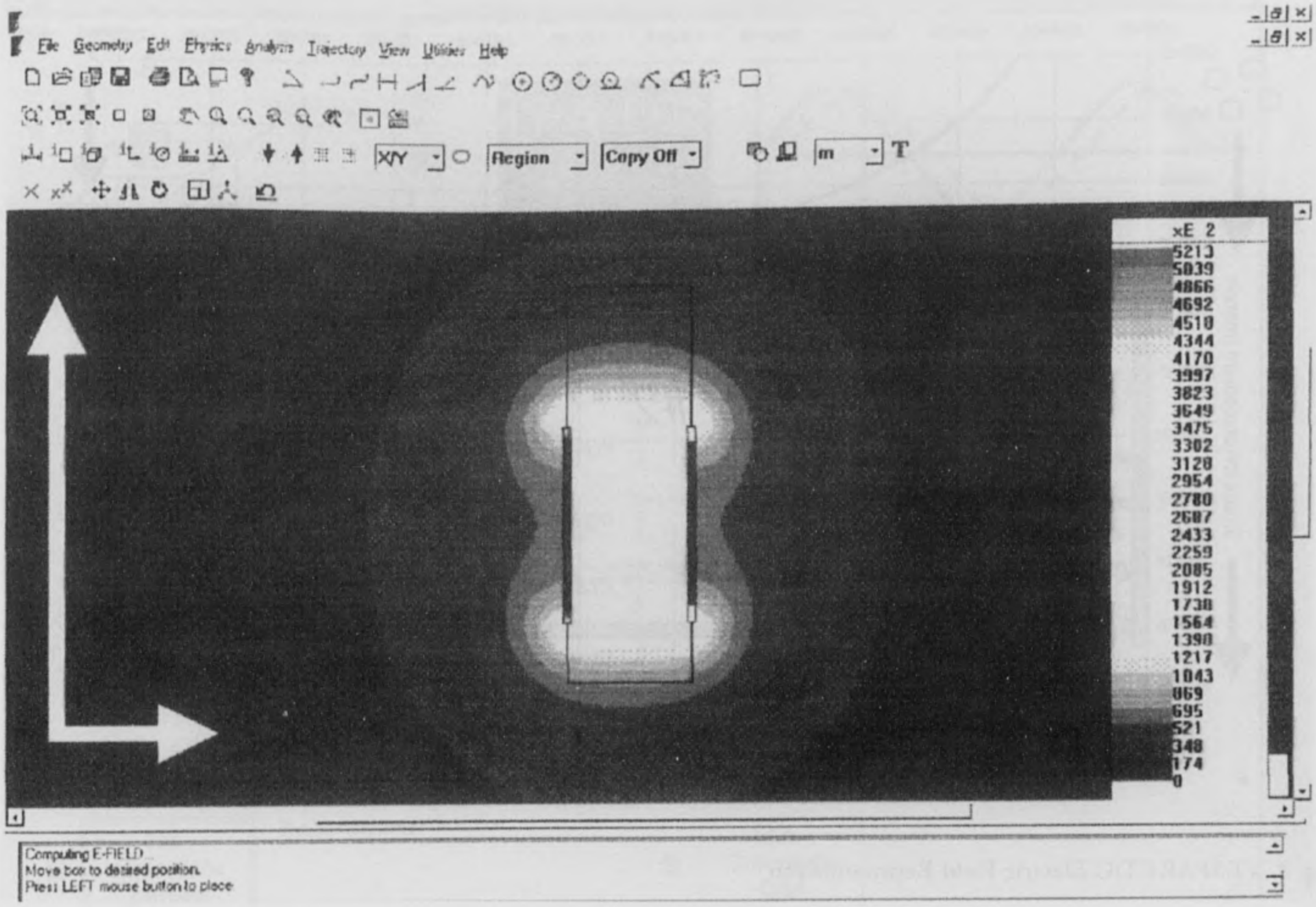

Fig. 2. Lorentz 2D Model of Electric Field (0.0955 meter plate separation) Volts/meter

The boundary conditions are modeled on the electric plates at −10kVDC potential to one plate and +10kVDC to the other. These physical parameters are applied to the VESPART chamber as it exists in original geometry. The original geometry has a flow chamber diameter of 0.0955 meters. After analysis, the DC electric field intensity is shown in Fig. 2 in 'solid' mode. The scale of electric field intensity is shown on the right side of the model where varying shades demonstrates the varying intensity of the electric field within the chamber. The high-intensity regions, represented by contrasting colors, are evident along the edges of the deflector plates; specifically at the corners of the plates. The corners of the deflector plates create the relatively high-intensity DC electric fields shown the Fig. 2.

The data from the *Lorentz 2D* graph is imported into Excel to interpolate linear curves and their outputs. The linear curves are used in the simulation to determine x- and z-component forces on the particle depending on where the particle is located in the flow chamber during simulation. The curves, shown in Fig. 3, represent the DC amplitude of the component force that the electric field exerts on the particle depending on the position and time relationship (elapsed time of simulation from $t = 0$ at the start) of the particle to the flow chamber.

During simulation, these DC-magnitude representations are utilized to develop the AC electric field driving forces on the particle along the x-axis direction by sinusoidal modulation while assigning polynomial representations of the electric field (volts/meter).

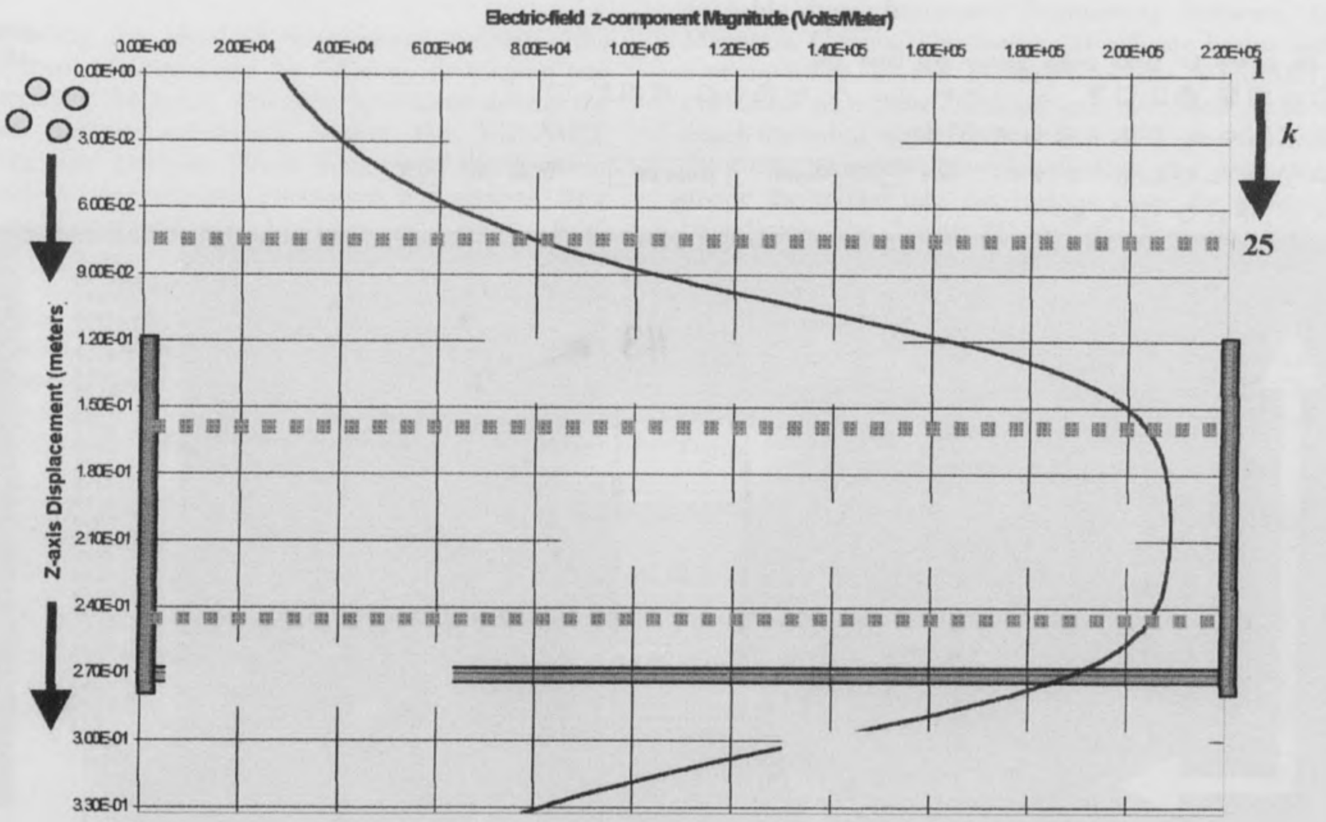

Fig. 3. VESPART DC-Electric Field Representation

Results

The programming structure of the simulator was first developed using *MATLAB*, available from The MathWorks, Inc., Natick, Massachusetts. This provided confirmation of the algorithms and testing methodology before the user-interface version was programmed using *Visual Basic 6.0* because of ease of creating the graphical user interface (GUI) as shown in Fig. 4.

The virtual particle track resulting from simulation is shown in Fig. 5. The six key points, shown as "*", represent the position of the particle used to determine particle phase lag and amplitude. The phase lag and amplitude are then used to determine charge-to-mass calculations.

Conclusions

The *Lorentz 2D* model provides a graphical representation of DC electric field values that, when sinusoidally modulated, create an AC driving force on the charged particle as it is passes through the VESPART flow chamber. The graphical representation is characterized by polynomials and natural-log functions that are applied to the charged particle simulator for simulation and illuminated particle track capture. The illuminated particle track, identical to the track acquired by the VESPART, is stored in an *Excel* file for analysis. The simulator provides an important analytical virtual tool for the validation of application parameters and VESPART processing algorithms. Simulation requires minutes to complete and precisely repeats the physical parameters of particle charge, particle size, frequency, airflow velocity, chamber diameter and electric potential in each simulation. Modeling and simulation eliminate modification to the instrument's physical environment by providing a virtual design and development environment thereby eliminating the need for vast resources and eliminating potential repeatability errors.

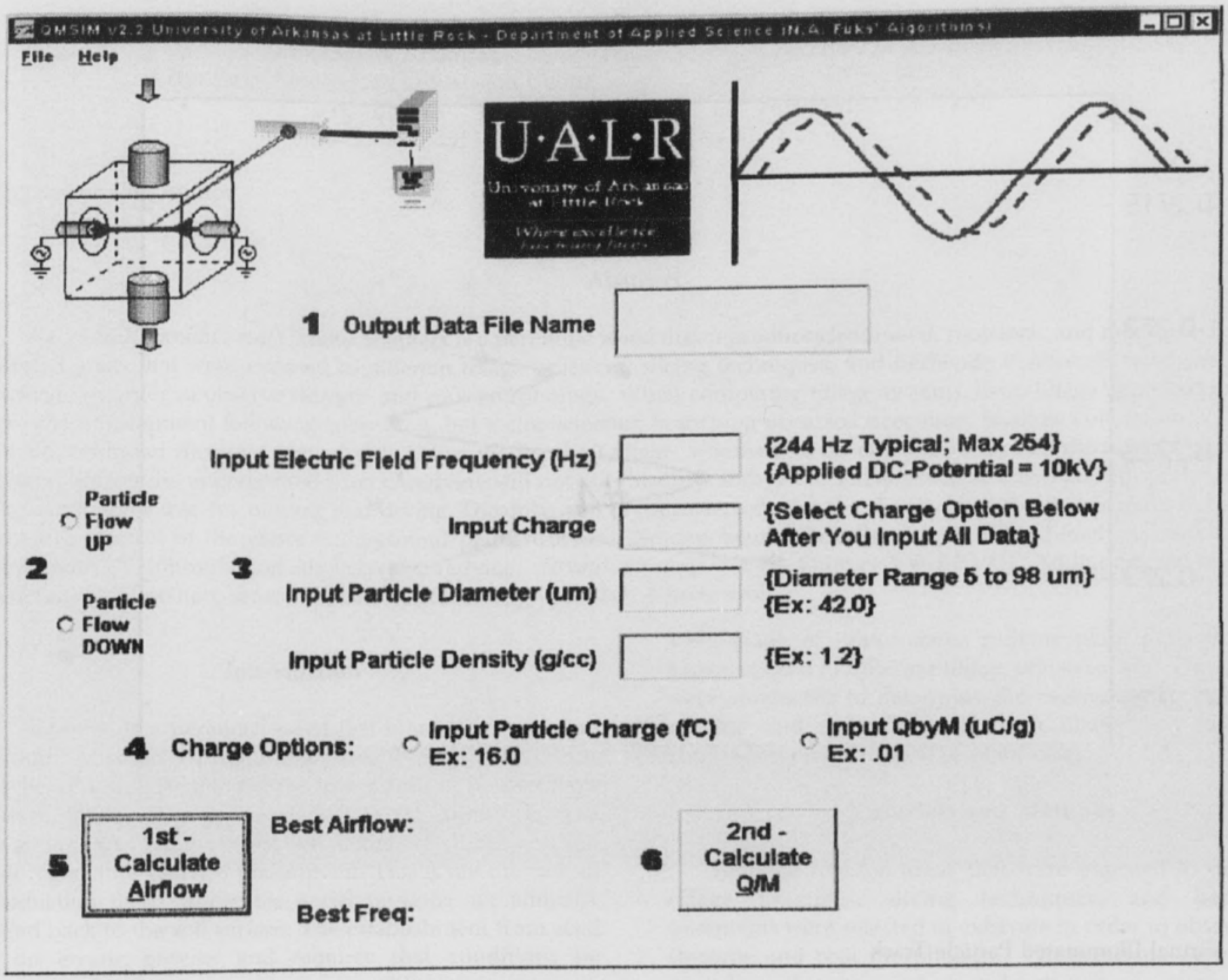

Fig. 4. Graphical User Interface

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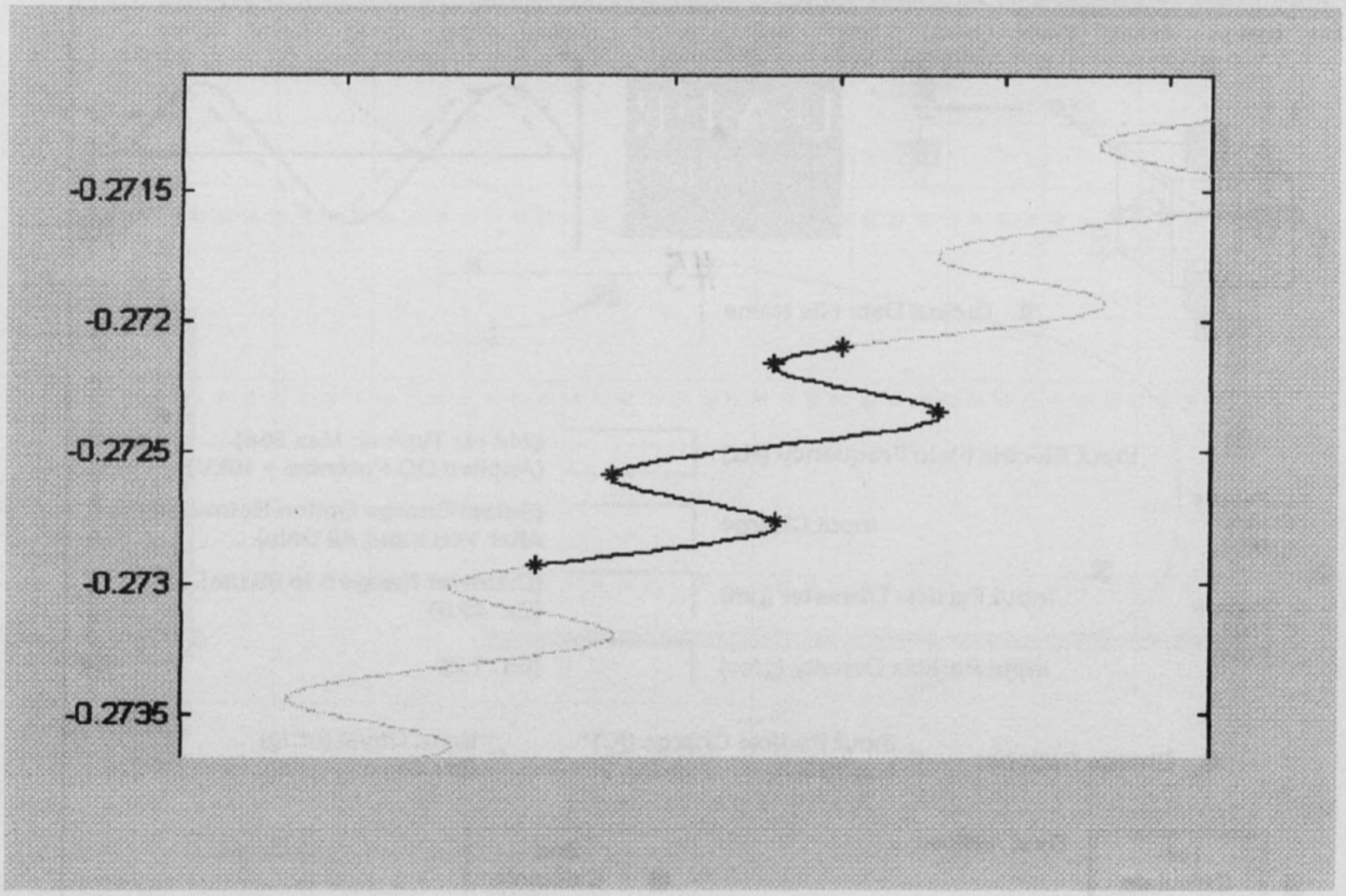

Fig. 5. Virtual Illuminated Particle Track