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Iconic Representation of Particle Beams Using Personal Computers

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Abstract

The idea of representing the character of a charged particle beam by means of its emmittance ellipses, is essentially a mathematical one. For quick understanding of the beam character in a more user-friendly way, unit beam cells with particles having a uniform nature, have been pictured by suitably shaped 3-D solids. The X and Y direction momenta at particular cell areas of the particle beam combine together to give a proportionate orientation to the solid in the pseudo 3-D world of the graphic screen, creating a physical picture of the particle beam. This is expected to facilitate the comprehension of total characteristics of a beam in cases of online control of transport lines and their designs, when interfaced with various ray-tracing programs. The implementation is done in an IBM-PC environment.

Introduction

The practice of representing particle beam in terms of the phase-space figures at an axial location of the beam, is well-established. The phase-space diagrams can be either a plot between x/y and p_x/p_y, where p_x and p_y denote momenta in x and y directions respectively. Consequently these 2-dimensional figures, are used to convey informations about an entity which exists in reality, in a 4-dimensional phase-space consisting of x, p_x, y and p_y as the dimensions. Beam-line designers as well as operators optimizing transport of particles through beam-line elements, very often refer to these 2 dimensional projections idealised to ellipses, to study and optimise the transport of a particle-beam. Any of these ellipses, eg. x vs θ (= p_x/p, where p is the longitudinal momentum), though conveys the information about distribution of a particle-population with specific ranges of x momenta, as a function of x, but it does not immediately produce any idea about their correlations with the y-axis. Conversely, the same inadequacy applies for the y vs ϕ ellipse. Therefore as far as qualitative understanding of the beam is concerned, as a first impression, views of the ellipses are not complete enough. The mental process of a person doing the optimizations has to be only analytical, which is not a very comfortable situation. Consequently, it was thought that a more expressive diagram, which will convey a qualitative idea about all the 4 dimensions of the beam-ellipsoid, should contribute as a more friendly feedback to the user of a transport-optimization procedure.

With the vastly expanding use of computers with image graphics capabilities by transport-line designers and graphic workstations as operators' consoles in accelerator control, the 3-D graphic generation capabilities of these computers, can be tapped in such a situation. The particle beam, if could be made visible together with all its angle,

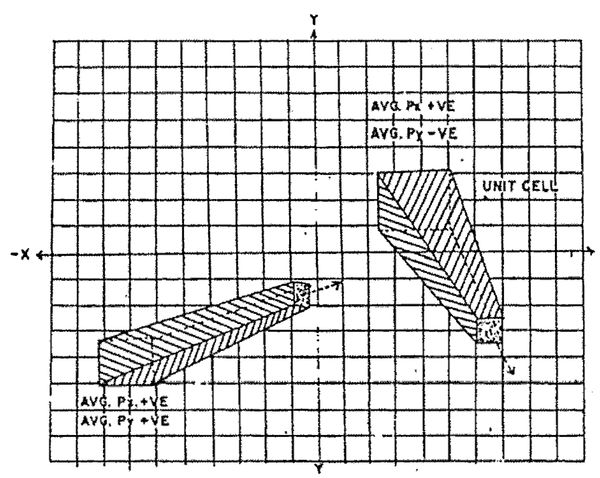

Figure 1. Two beamlets with different momenta

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should give a feel and a consequent instantaneous understanding of the beam-parameters to any kind of user.

IMPLEMENTATION-PLAN

The total transverse cross-section of a beam can be thought of as composed of a large number of cells, through each of which a beamlet can be thought to be emitted. Particles occupying a particular cell are characterised by θ_{av} (ie. $p_{x(av)}$ / p) and ϕ_{av}(ie. $p_{y(av)}$ / p) and hence the direction of beamlet is represented by these two averaged quantities.

Now each beamlet can be represented by the figure of a solid (Figure 1) of the shape of a truncated rectangular pyramid. This bucket-like figure is capable of creating the impression of a directional movement of the beamlet. The presentation being 3-dimensional, the orientation of the beamlet in both x and y directions can be depicted. Reducing the arbitrary cross-sectional area of the cell and thereby increasing the number of beamlets over the transverse section of the beam can create a picture in more detail.

The number of cells can be optimally chosen to produce a suitably accurate picture with sufficient details and yet at the same time care is taken so that the buckets do not obscure one another to a large extent. In order to bring home the effect of orientation of the buckets in 3-dimensional space, the four lateral surfaces and the front surface of the buckets are all to be painted in five distinctly seperate colours (Figures 2 & 3).

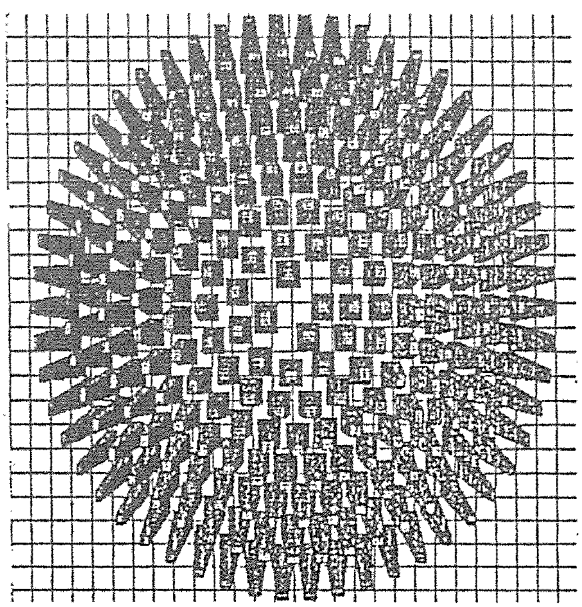

Figure 2. A diverging beam

PROGRAM-DETAILS

The data about the particle density and their momentum distribution, as obtained either from the on-line emittance measurement devices or from transport optimization codes (eg. TRANSPORT, TURTLE, GIOS etc.), is assumed to be present in disk file. The data file should be actually re-organized as an array of records, each record having four fields.

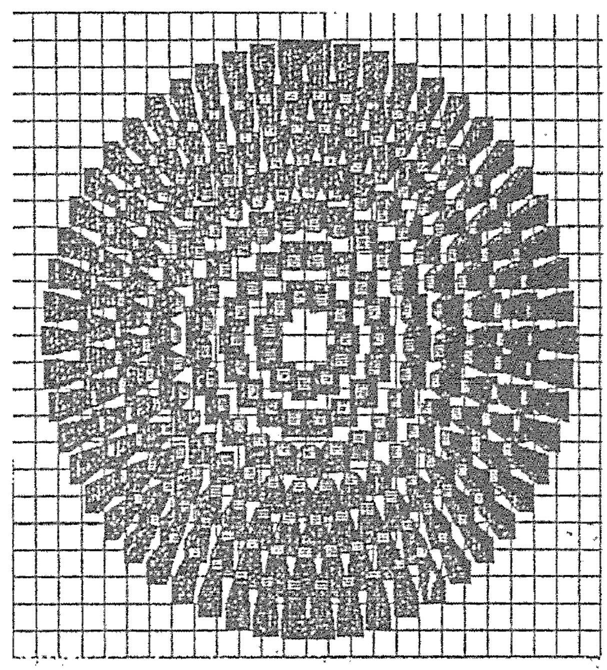

Figure 3. A converging beam

The field designators are as follows.

posn : { Array of X and Y co-ordinates of the centre of a unit cell on the transverse plane of the beam }

xmom : { Computed average momentum in x-direction of all the particles in the unit cell }

ymom : { Computed average momentum in y-direction of all the

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particles in the unit cell }

density : { Total number of particles in the unit cell}

Some additions in the standard transport calculation programs or emittance-data acquisition programs are done to organize the data in above format.

In reality, the momentum angle variations are typically in the range of 100 milliradian, a much too small quantity to be visually resolvable. Hence, for the purpose of our picture-generation, this quantity has to be scaled up by a suitable factor (typically 300) and a proportionate variation in the angles of buckets can then be made recognisable on the screen.

In the present version, in absence of 3-D graphic generation routines, procedures were written in Turbo-Pascal language to independently generate the X and Y-rotation effects on the bucket and then to combine to create resultant solid figure. Standard algorithm was utilized to eliminate drawing of hidden surfaces of a bucket at various orientations [1].

It was felt that though perspective views of the buckets can give a clearer perception, but with a little experience this loss of visual perception will not be too damaging, to warranty taking up these time-consuming computations in a personal computer. The other problem was to keep the consistency of depth-perception when buckets of varying orientations, overlap one another. In other words, the sequence in which buckets should be drawn would have to be a difficult and lengthy algorithm, in absence of any depth information of the image. This information is not kept in the present version, since insufficiency of frame buffer memory in our PC does not allow any benefit from this information, during 3-D image generation. A simpler scheme has been devised to give satisfactory results. Based on the relative co-ordinate displacement of the tip of the bucket with respect to its base, the bucket parameter records are divided into two groups, named arbitrarily as 'converging' and 'diverging'. Then each group is internally sorted according to increasing radial distance of the centre point of the base of the bucket. For 'converging' group, buckets are drawn starting from the beam-centre of the cross-sectional area towards the periphery whereas for the 'diverging' set, they are drawn in the reverse sequence. As far as the individual sets are concerned, buckets within that set overlap in the right way.

FUTURE EXPANSION

A 'zoom' option will allow a progressive blowing up of the figure, enabling more detailed observation of selected zones of the beam-section. This option will be helpful if the buckets fill up the space too densely so as to obstruct view of the buckets in the background.

A cross-hair cursor (figure 4) can be taken to any point on the figure and clicked. There would be two output windows which will show the particle population distribution along the x-axis and that along the y-axis of the current cursor position, thus creating the scope for realisation of relative distribution of particles also. Two other output windows

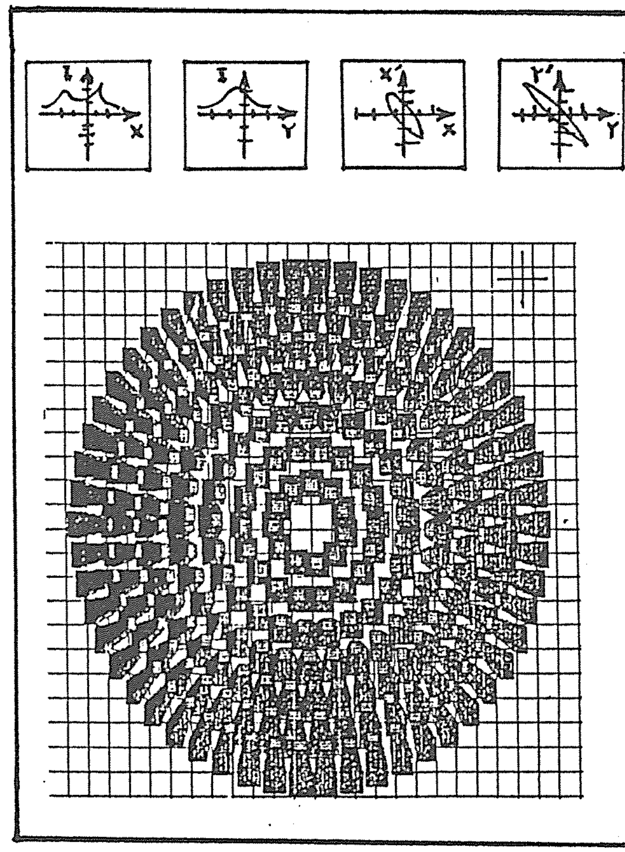

Figure 4. An integrated beam-view

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can give the output in the form of the standard phase-space ellipses, for the total beam at the particular longitudinal location in the beam-line, thus creating an integrated view of all parameters of interest of a particle beam.

In suitable cases, animated movie-frames [2] can be generated to simulate the dynamically changing beam characteristics, because of disturbances introduced naturally or otherwise.

Discussions

The idea of the development is to incorporate the comparatively easier accessibility of 3-D graphics in the user-interface area of certain computer programs used in accelerator design and control, and to re-inforce the standardized outputting style with a more physically revealing style. The results obtained in the current work, though, are sufficiently useful for trained eyes, yet for those who can afford using powerful graphic workstations, they can apply the same idea and can get more realistic 3-dimensional views.

Such views are expected to give an immediate impression about a beam at any place and can trigger the intutive process of manipulative operations necessary on the beam. In other words, the idea is a step in the line that a computer should provide the designer as well as the operator, facilities to visualise the beam in an integrated way to closely match his own way of percieving the beam.

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[1] N.M. Moris, *Computer Graphics & CAD Fundamentals*, BBC Microversion, p.159

[2] Alfredo Luccio, "Algorithms and Modelling For The AGS Booster", Nucl. Instr. and Meth., Vol. A293 (1990), pp.460 - 463