PROPER INPUT PHASE-SPACE FILLING FOR ACCURATE BEAM-DYNAMICS CODES*

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Summary

In the future, more attention will be required concerning the filling of the input phase space used by particle-simulation codes. The prospect of greatly improved particle-tracking codes implies that code input distributions must be accurate models of real input distributions. Much of present simulation work is done using artificial phase-space distributions (K-V, waterbag, etc.). Real beams can differ dramatically from such ideal input.

We have already developed a method[1] for deriving code input distributions from measurements. This paper addresses the problem of determining the number of pseudoparticles needed to model the measured distributions properly.

Introduction

A major use of beam-dynamics codes is for accelerator design. Codes are used to predict how closely a machine configuration will come to producing the desired physical results. The real test for such codes is the computational reproduction of measured results. Bench marking of this type is more believable when the code and accelerator are working with quite similar input beams. For dc input beams, the proper initial energy and phase are easily reproduced, but the transverse phase-space filling is harder. The code's transverse-beam input coordinates must be assembled in such a way as to reproduce measurements of the real transverse input coordinates.

A typical transverse measurement is made by a beam scanner that samples the beam intensity in each of the two transverse phase planes. The two planes are treated independently. In effect, the scanner measurement results in discrete probabilities of finding a particle in a particular rectangular bin centered on a specified point in one of the transverse phase planes.

We have already developed a method for generating code input from such measurements[1] but need to investigate how well the derived distributions reproduce the measured distributions.

Visual Approach

A standard method for displaying scanner measurements is by contour plots that enable a visual rating of the goodness of the derived distribution fit. Figure 1 shows a contour plot of a scanner measurement. Figures 2 and 3 show contour plots made from derived distributions of 2 000 and 50 000 pseudoparticles, respectively. All plots have the same scale, although the scale isn't shown, and the same orientation. Contours start at 10% and are at 10% intervals.

These figures show that the 2 000 pseudoparticle group gives a poor representation but that the 50 000 particle group seems adequate. However, a closer look at the 50 000 particle group shows that it also has deficiencies. Figures 4 and 5 show 1 and 5% contours for the measured distribution and for the 50 000 particle-derived distribution. In each figure, the dotted curve is the 5% contour. Comparison of these figures shows that the area inside the 1% contour for the measured distribution becomes a group of 1% islands in the contour for the derived distribution and that there are regions inside the 5% contour for the measured distribution that show populations of 1% or less in the derived-distribution contour.

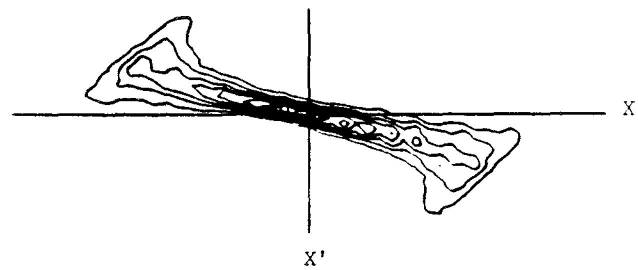

Fig. 1. Contour plot of scanner measurement.

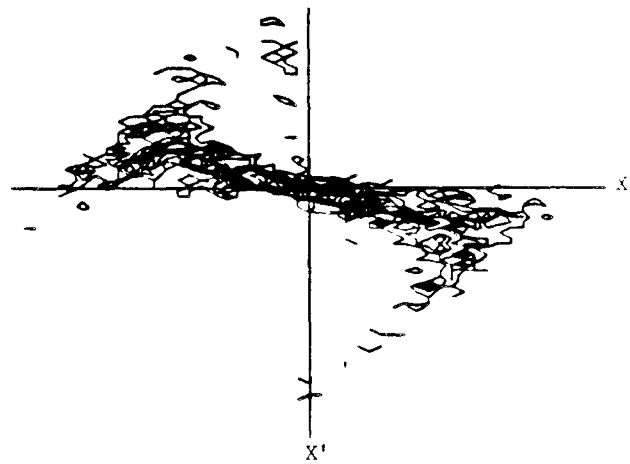

Fig. 2. Contour plot made from 2 000 pseudoparticle-derived distribution.

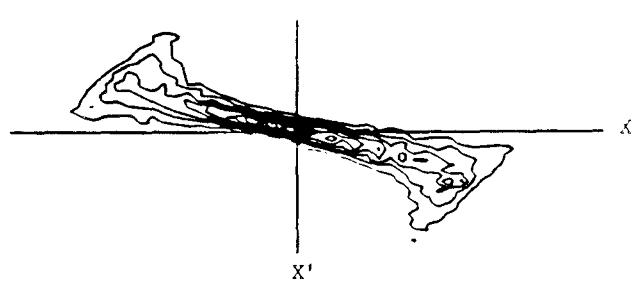

Fig. 3. Contour plot made from 50 000 pseudoparticle-derived distribution.

This example shows that there are at least 4% variations between the derived and measured distributions even using 50 000 pseudoparticles. Moreover, there may be regions with even greater variation. Therefore, we felt that a more quantitative measure of the goodness of fit would be desirable.

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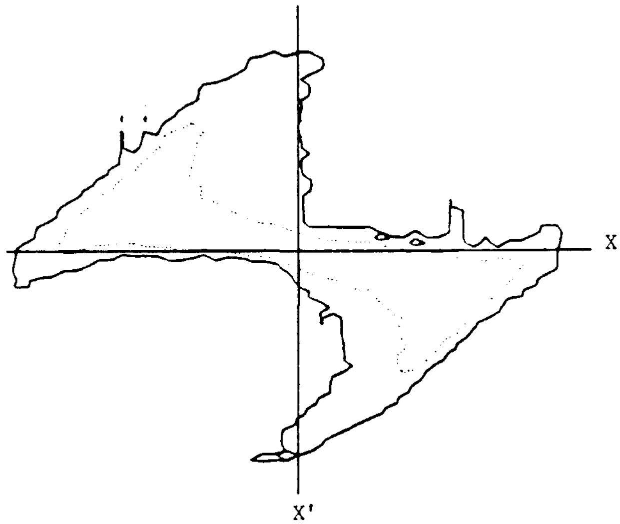

Fig. 4. The 1% (solid line) and the 5% (dotted line) contours for the measured distribution.

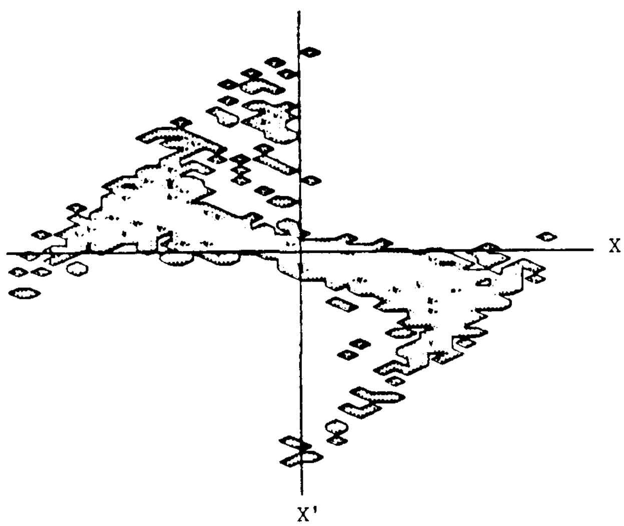

Fig. 5. The 1% (solid line) and the 5% (dotted line) contours for the 50 000 particle-derived distribution.

Quantitative Approach

The best particle-tracking-code input that could be obtained from a scanner measurement of the physical input beam would be one for which the number of pseudoparticles in each region of the X-X' and Y-Y' planes was in the same proportion to the total number of pseudoparticles as was the measured current in each region to the total current. The quantitative measure of goodness of fit should test the derived distribution to determine how close to the ideal condition it comes. A way to do this is to count the number of occupied measured regions (bins) that have equivalent derived regions within a given percentage of the measured value. In fact, it is possible to do this for a range of measured value percentages and to get a curve that characterizes the fit of a given derived distribution. Unoccupied regions in the measurement are also unoccupied in the derived distribution because of the method used to build the derived distribution. The unoccupied regions will always agree, and they should not be counted because they could give an erroneously high score for derived beams that are very different from the measured beam.

Figure 6 gives examples of the characteristic curves obtained for the X-X' and Y-Y' planes for a 5 000 pseudoparticle distribution. The characteristic curve for an ideal fit would correspond to 100% of occupied bins having 0% deviation from the measured value. Thus, the ideal characteristic would rise vertically from the point (0, 0) to the point (0, 100) and then extend horizontally to the point (100, 100).

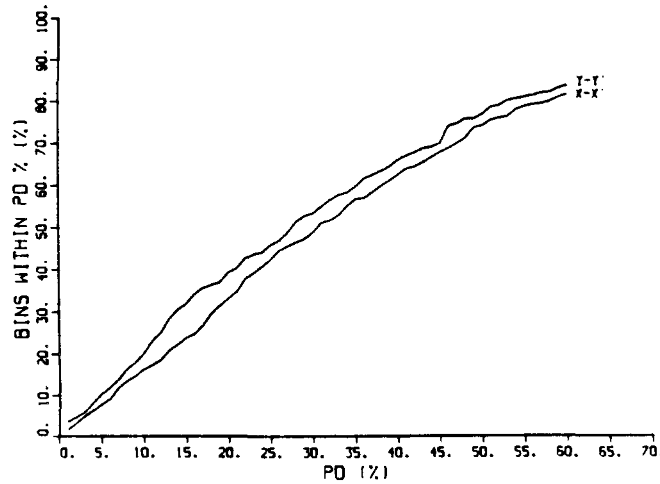

Fig. 6. Percent of occupied measured bins having the derived distributions within PD percent of the measured value. Note that the characteristic curves are different in the two phase-space planes.

We have examined how well our derived distributions fit underlying measurements. Figure 7 shows a family of characteristics for derived distributions obtained from the same measurement. The derived distributions differ in the total number of pseudoparticles used. As expected, the greater the number of particles used to form the derived distribution, the closer the derived-distribution characteristic approaches the ideal characteristic. What is perhaps not expected is how poorly even 100 000 particles fit the measurement. For instance, only 74% of occupied bins have derived values within 20% of the measured value, and only 29% have derived values within 5%.

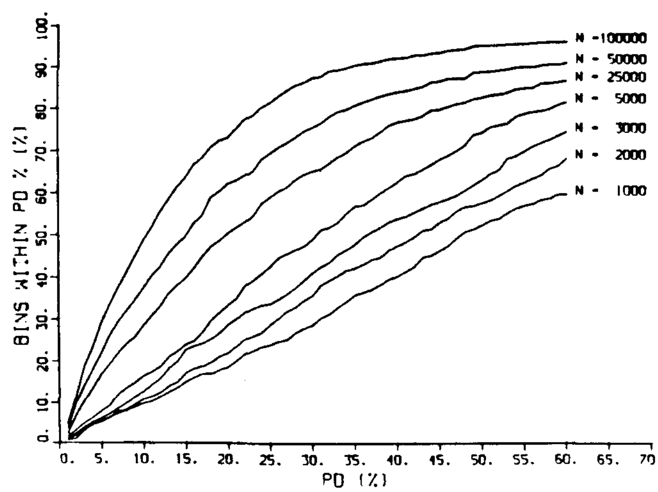

Fig. 7. Family of characteristics obtained for same measurement. Lowest curve is for an N = 1 000 particle distribution. Topmost is for an N = 100 000 particle distribution.

A second point to be noted is that the use of a sufficient number of particles to give a good fit in one plane does not guarantee a good fit in the other plane. When differences in fit occur, they appear to be due to unusual measured distributions in the more poorly fit plane. The number of particles should be chosen to give an adequate fit in both transverse planes.

Conclusion

A quantitative method for judging how well a derived distribution models a scanner measurement of a beam has been developed and examples of fits given. The remaining question concerning how serious an effect the known departures from measurement have on computed accelerator results has not been addressed.

Acknowledgment

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Reference

1. G. P. Boicourt, O. R. Sander, and T. P. Wangler, "Comparison of Simulation with Experiment in an RFQ," IEEE Trans. Nucl. Sci., 32 (5), 2562 (1985).