SYNRAD, a Montecarlo Synchrotron Radiation Ray-Tracing Program

Roberto Kersevan
Superconducting Super Collider Laboratory*
2550 Beckleymeade Avenue, Dallas, TX 75237 USA

Abstract

A new module, SYNRAD, has been added to the MOLFLOW [1] software package, allowing the Montecarlo (MC) simulation of synchrotron radiation (SR) emission. The geometrical three-dimensional (3D) distribution of the photons, power and energy, and spectra can be calculated. A model of the vacuum chamber is generated, and the profiles of SR-induced desorption are obtained by means of SYNRAD. These desorption profiles are then embedded in the vacuum chamber model and the MC program for the calculation of UHV molecular flow is used for obtaining relevant quantities such as, among others, pressure profiles, pumping speed efficiencies and conductances. Results of the application of SYNRAD and MOLFLOW, and comparison with some published data will be given.

I. INTRODUCTION

A source of SR can be described giving the kind of particle, electron or proton, and its energy E, beam emittance and beta functions, together with the magnetic field distribution [2]. SYNRAD calculates the trajectory of the beam for the given magnetic field and generates photons, in a selected energy range (ε_{min}, ε_{max}), according to the real distributions [2, 3]. A ray-tracing algorithm is implemented which follows the photons' trajectories and keeps track of their scoring on planar facets. These planar facets can be defined using an editor program [1] by means of which 3D models of any shape can be analysed. Analytical formulas describing the emission of SR do exist, but their application to real life geometries is not always straightforward. For instance the assumption of infinite distance from the source point, in order to use tabulated angular spectral distributions, isn't applicable in general. In addition to that, the spectral distributions are usually given only for the vertical angle Ψ [2] (i.e. the emission angle measured in a plane orthogonal to the local plane of the orbit), and little or no mention of the horizontal distribution angle χ can be found [4], since usually an integration over χ is considered.

II. THEORY OF SR AND COMPUTATIONAL ALGORITHM

With reference to Fig. 1, four angles θ, ϕ, Ψ,and χ can be defined, and will be used in the following. For a given beam energy, the local radius of curvature ρ as a function of the magnetic field B is computed at each point of the beam trajectory, and the critical energy ε_c is obtained by using the formula $\varepsilon_c[\mathrm{eV}] = 2.960 \cdot 10^{-7} \gamma^3 / \rho[\mathrm{m}]$, where γ is the relativistic factor. Then the normalized energy $\varepsilon/\varepsilon_c$, is generated following the real SR distribution, according to the function ($d\alpha$ is the trajectory arc element)

$$\begin{cases} \dfrac{dF}{d\alpha} = 2.457 \cdot 10^{10}\, E[\mathrm{GeV}]\, G_1(y) & (1) \\ G_1(y) = y \displaystyle\int_y^{\infty} K_{5/3}(\eta)\, dy \qquad y = \varepsilon/\varepsilon_c & (2) \end{cases}$$

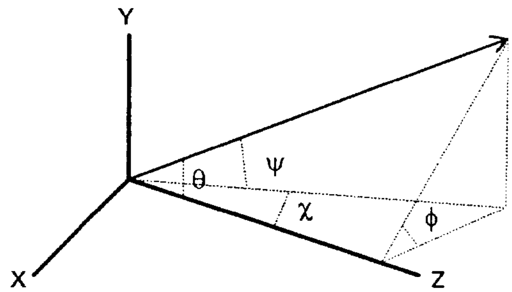

Fig. 1. Definition of the angles θ, ϕ, Ψ and χ.

in units of photons·s^{-1}·(mradα)$^{-1}$·mA^{-1}·(0.1% bandwidth)$^{-1}$, and the vertical angle Ψ is generated with distribution [3]

$$\begin{cases} F(\Psi) = F_p + F_o & (3) \\ F_p(\Psi) = (1+\gamma\Psi)^2 K_{2/3}^2 \left\{ \dfrac{\varepsilon}{2\varepsilon_c} \left[1+(\gamma\Psi)^2\right]^{3/2} \right\} & (4) \\ F_o(\Psi) = (\gamma\Psi)^2 (1+\gamma\Psi)^2 K_{1/3}^2 \left\{ \dfrac{\varepsilon}{2\varepsilon_c} \left[1+(\gamma\Psi)^2\right]^{3/2} \right\} & (5) \end{cases}$$

where F, F_p and F_o are the functions giving the vertical distributions for the total SR emitted at $\varepsilon/\varepsilon_c$ and for the two components whose polarizations are parallel and orthogonal to the local plane of the orbit, respectively[2]. At this point the horizontal angle χ is needed. To obtain it, the following formula [3] giving F_o as a function of θ and ϕ is used

$$F = \left(1+\gamma^2\theta^2\right)^{-6} \left[\left(1-\gamma^2\theta^2 + 2\gamma^2\theta^2 \sin^2(\phi)\right)^2 + \right.$$
$$\left. + \gamma^4\theta^4 \sin^2(\phi)\cos^2(\phi) \right] \qquad (6)$$

where θ and ϕ are converted to Ψ and χ using the equations

*Operated by URA, Inc., for the U.S. Dept. of Energy under Contract No. DE-AC02-89ER40486

$$\begin{cases} \theta = \cos^{-1}\left(\cos(\Psi)\cos(\chi)\right) & (7) \\ \phi = \tan^{-1}\left(\tan(\Psi)/\sin(\chi)\right) & (8) \end{cases}$$

This algorithm allows the generation of each photon after calling two routines which generate the vertical and horizontal distributions separately, instead of setting the values for χ and Ψ from a bi-dimensional distribution. This procedure is faster, and gives good agreement with the figures reported in literature. If a cone with angular aperture $|\theta|<1/\gamma$ about the tangent to the point of emission is considered, 7/32 of the total intensity should be emitted out of it; 17/112 for the parallel polarization and 11/16 for the orthogonal one [3]. In a benchmark run, SYNRAD generated some 300,000 photons, in about 5 hours running on a 50 MHz 486 personal computer, and the SR power emitted out of the cone was 0.22403 of the total, a factor 1.024 times greater than the theoretical value of 7/32.

Fig. 2 shows the scoring of the SR flux, in the photon energy interval $(10^{-4},10)\varepsilon_c$, on a facet orthogonal to the beam trajectory, at a distance of 1000 cm. The horizontal and vertical width of the figure covers angular intervals of ± 4.6 for both $\gamma\chi$ and $\gamma\Psi$. Note the presence of two minima in the plane $\Psi=0.0$, at $\gamma\chi= \pm1.0$, according to Ref. 5, pag. 39.

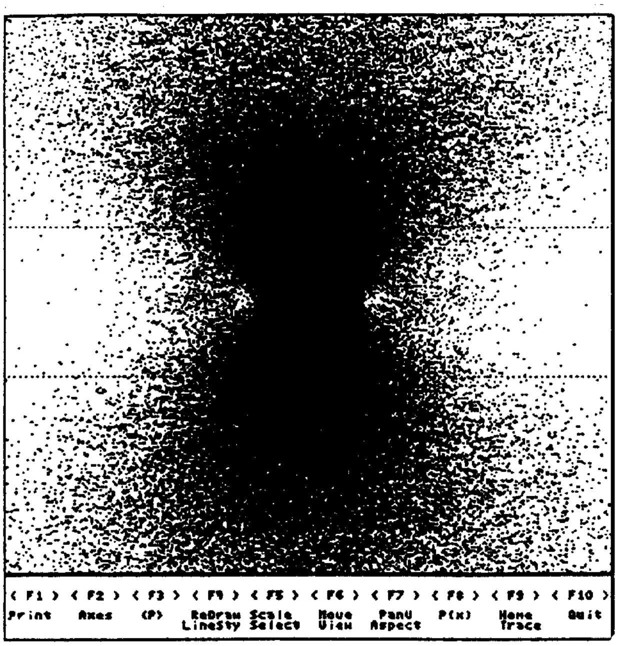

Fig. 2

Usually only the vertical power distribution can be found in literature. It is easy to calculate the spectral distributions, i.e. at selected photon energies ε_i, just choosing the photon energy interval about ε_i, with appropriate bandwidth. Each facet in the model can record one out of four different quantities relevant to the photon energy interval $(\varepsilon_{min}, \varepsilon_{max})$: the SR power, the SR flux, the SR power spectrum and the SR flux spectrum. This is obtained setting appropriately some attributes of the facet called transparency and sticking.

III. APPLICATIONS

Fig. 3 shows two different SR flux spectra for the SSC at a proton beam energy of 20 TeV, and a magnetic field of 6.6 T, in the photon energy interval $(10^{-4},10)\varepsilon_c$, $\varepsilon_c=284$ eV.

Fig. 4 shows the SR power spectra for the same parameters.

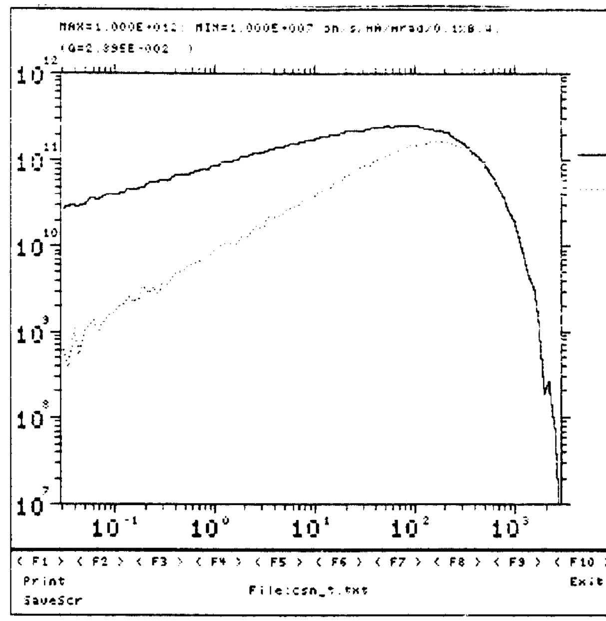

Fig. 3 Solid line: total spectrum; dotted: within $1/\gamma$ cone.

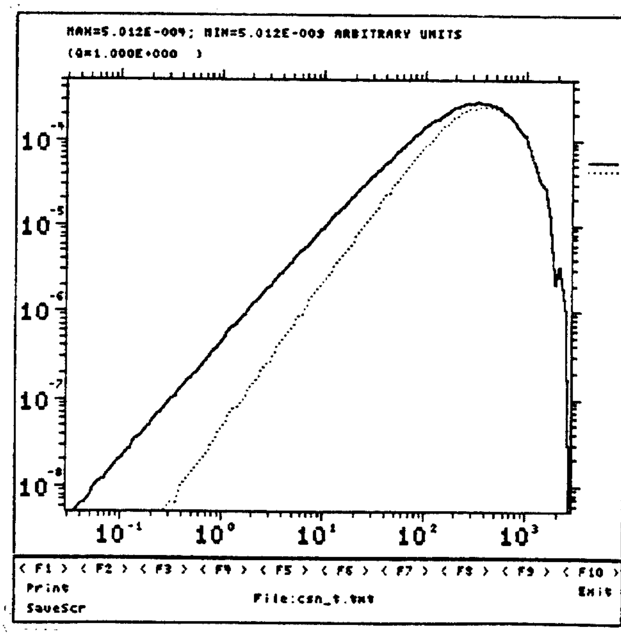

Fig. 4 Solid line: total spectrum; dotted: within $1/\gamma$ cone.

Fig. 5 and Fig.6 give the normalized horizontal and vertical distributions for the SR flux and the SR power, respectively. The angular intervals are ±2.5 mrad for both χ and Ψ. The small decrease in the horizontal distributions around $\chi=0$ is under investigation. Nonetheless, the overall accuracy of these results is good when compared to analytical calculations [6].

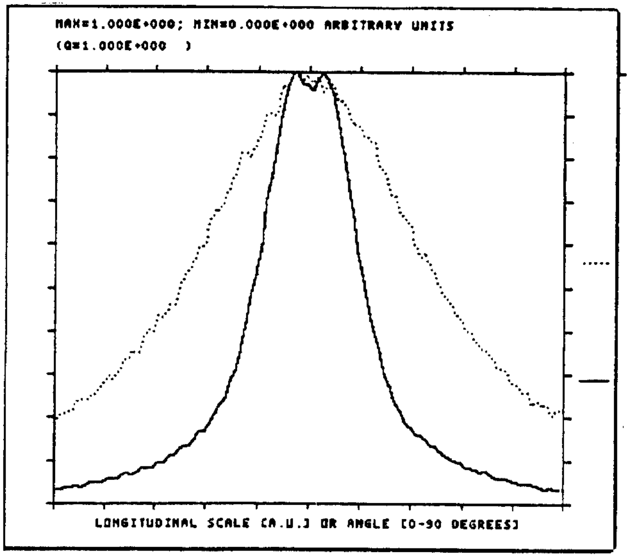

Fig. 5 Normalized SR flux spectrum in (0.0284, 2840) eV. Solid:horizontal; dotted:vertical

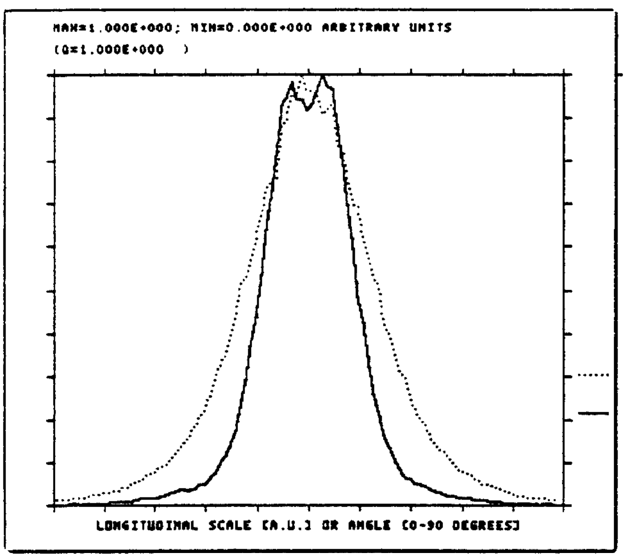

Fig. 6 Normalized SR power spectrum in (0.0284, 2840) eV Solid:horizontal; dotted:vertical

The emission of SR in a two meter long section of the SSC bore tube in the arc section [7] has been simulated, Fig.7, in order to calculate the height of the strip which is directly illuminated by SR photons. The subtended arc is 0.198 mradians, and the 3D model is given by two-one meter long straight sections placed with a small angle, 0.099 mradians, between them. in order to simulate the SSC's radius of curvature of 10100 m, with the Z axis coincident with the proton beam direction. Photons exiting from the second section re-enter the first section, with proper direction.

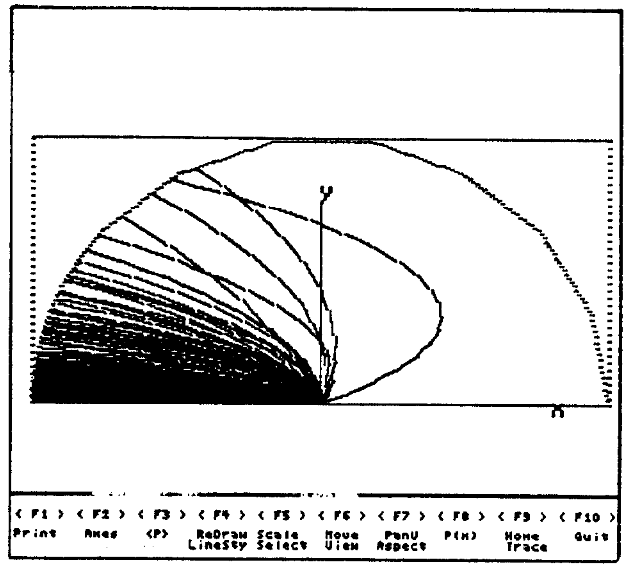

Fig. 7 XY-view of the model. XZ=symmetry plane.

IV. CONCLUSIONS

Some of the possibilities of a novel program for the calculation of SR-related quantities have been described.

SYNRAD runs on 486-based personal computers under DOS. Its speed has not been optimized so far, and translation into FORTRAN language for portability to faster processors will be implemented in the future.

SYNRAD allows a simple determination of SR fluxes and powers under different assumptions for the photon source, and when used in conjunction with MOLFLOW provides a unique tool for the analysis of SR-induced pressure profiles.

V. ACKNOWLEDGMENTS

The author grsatefully acknowledges H. Humstätter for providing a fast routine, based on Chebischev polynomials, for the evaluation of the SR spectrum.

VI. REFERENCES

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