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SYNCHROTRON LIGHT SOURCE DATA BOOK

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FOREWORD

The *"Synchrotron Light Source Data Book" is as its name* implies a collection of data on existing and planned synchrotron light sources. The intention was to provide a compendium of *tools for the design of electron storage rings as synchrotron* radiation sources. The slant is toward the accelerator physicist as other booklets such as the X-Ray Data Booklet, edited by D. Vaughan (LBL PUB-490), address the 'use' of synchrotron radiation. It is hoped that the booklet serves as a pocket sized reference to facilitate back of the envelope type calculations. It contains some useful formulae in 'practical units' and a brief description of many of the existing and planned light source lattices.

I welcome corrections and suggestions for improvement. If a particular machine is missing it is because I did not have ready access to the data. Additional machines will be added as the data becomes available.

I would like to thank my colleagues for providing the data for the various lattices. In particular I would like to thank Dr. Yukihide Kamiya (KEK) for gathering the information on most of the Japanese machines. The computer code LEDA authored by Dr. Gaetano Vignola (BNL) was used to generate the lattice displays.

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Nomenclature

α	momentum compaction	β_i	betatron functions
η	dispersion function	$\alpha_i, \beta_i, \gamma_i$	Twiss parameters
ν_i	betatron tune	λ_c	critical wavelength
ε_c	critical energy	ρ	dipole bending radius
τ_i	damping time	B	magnetic field
C	circumference	E	energy
σ_ε	energy spread	ε	emittance
J_i	partition functions	U_0	radiation loss/turn
H	Courant-Snyder Invariant	N_s	superperiods
P_T	Total Power	ξ_i	chromaticity
χ	emittance coupling	ε_{RF}	RF acceptance
$\sigma_{x,y}$	rms beam size	$\sigma'_{x,y}$	angular spread
n	field index	K^2	quadrupole strength
h	RF harmonic number	N_k	photon flux
λ_U	undulator period	K	undulator parameter

Physical Constants[Ro1]

Physical Quantity	Symbol	Value	SI Units
Elementary Charge	e	1.6022×10^{-19}	C
Electron Mass	m_e	9.1095×10^{-31}	kg
Proton Mass	m_p	1.6726×10^{-27}	kg
Planck Constant	h	6.6262×10^{-34}	joule sec
Speed of Light	c	2.9979×10^{8}	meter/sec
Classical Electron Radius	r_e	2.8179×10^{-15}	meter
Fine Structure Constant	α	1/137.04	
Boltzman Constant	k	1.3807×10^{-23}	joule/°K
Permittivity of Free Space	ε_0	8.8542×10^{-12}	farad/m
Permeability of Free Space	μ_0	$4\pi\times10^{-7}$	henry/m
Impedance of Free Space	Z_0	376.73	ohms

Some Useful Formulae

$$E\,[GeV] = .3\,B\,[T]\,\rho[m]$$

$$\lambda_c\,[\AA] = \frac{18.64}{B\,[T]\,E^2\,[GeV]}\,, \qquad \varepsilon_c\,[KeV] = .665\,E^2\,[GeV]\,B\,[T]$$

$$\frac{dN}{d\theta}\Big|_{\lambda_c}\left[\frac{photons}{amp\ sec\ mrad\theta\ 1\%BW}\right] = 1.6\times10^{13}\,E\,[GeV]$$

$$U_0\,[KeV] = \frac{88.5\,E^4\,[GeV]}{\rho\,[m]}\,, \qquad P\,[KW] = U_0\,[KeV]\,I\,[Amp]$$

$$\tau_\varepsilon\,[ms] = \frac{C\,[m]\,\rho[m]}{13.2\,J_\varepsilon\,E^3[GeV]}$$

$$K = .934\,B_0\,[T]\,\lambda_U\,[cm]$$

$$\lambda[\AA] = \frac{13.056\,\lambda_U\,[cm]}{E^2\,[GeV]}\left(1 + \frac{K^2}{2} + \gamma^2\theta^2\right)$$

$$P_T\,[W] = \frac{7.26\,E^2\,[GeV]\,I\,[Amp]\,N_U\,K^2}{\lambda_U\,[cm]}$$

Orthogonal Curvilinear Coordinates[Ref 1] $\underline{r} = \underline{r}(u_1, u_2, u_3)$

$$d\underline{r} = \frac{\partial \underline{r}}{\partial u_1} du_1 + \frac{\partial \underline{r}}{\partial u_2} du_2 + \frac{\partial \underline{r}}{\partial u_3} du_3$$

$$= h_1 du_1 \underline{e}_1 + h_2 du_2 \underline{e}_2 + h_3 du_3 \underline{e}_3$$

Arc Length & Volume Element

$$ds^2 = h_1^2 du_1^2 + h_2^2 du_2^2 + h_3^2 du_3^2 \qquad dV = h_1 h_2 h_3 du_1 du_2 du_3$$

Gradient

$$\nabla\Phi = \frac{1}{h_1}\frac{\partial\Phi}{\partial u_1}\underline{e}_1 + \frac{1}{h_2}\frac{\partial\Phi}{\partial u_2}\underline{e}_2 + \frac{1}{h_3}\frac{\partial\Phi}{\partial u_3}\underline{e}_3$$

Divergence

$$\nabla\cdot\underline{A} = \frac{1}{h_1 h_2 h_3}\left[\frac{\partial}{\partial u_1}(h_2 h_3 A_1) + \frac{\partial}{\partial u_2}(h_3 h_1 A_2) + \frac{\partial}{\partial u_3}(h_1 h_2 A_3)\right]$$

Curl

$$\nabla\times\underline{A} = \frac{1}{h_1 h_2 h_3}\left[h_1 \underline{e}_1\left(\frac{\partial}{\partial u_2}(h_3 A_3) - \frac{\partial}{\partial u_3}(h_2 A_2)\right) + \textit{permutations}\ \right]$$

Laplacian

$$\nabla^2\Phi = \frac{1}{h_1 h_2 h_3}\left[\frac{\partial}{\partial u_1}\left(\frac{h_2 h_3}{h_1}\frac{\partial\Phi}{\partial u_1}\right) + \textit{permutations}\ \right]$$

Coordinate System	h_1	h_2	h_3	u_1	u_2	u_3
Cartesian	1	1	1	x	y	z
Cylindrical	1	r	1	r	θ	z
Spherical	1	r	r sinθ	r	θ	φ
Frenet-Serret	1	1	(1 + x/ρ)	x	y	s

Synchrotron Radiation Integrals[Ref]

$$I_1 = \int_{dipoles} \frac{\eta}{\rho} ds\ , \quad I_2 = \int_{dipoles} \frac{1}{\rho^2} ds\ , \quad I_3 = \int_{dipoles} \frac{1}{|\rho^3|} ds$$

$$I_4 = \int_{dipoles} \frac{(1-2n)\eta}{\rho^3} ds\ , \quad I_5 = \int_{dipoles} \frac{H}{|\rho^3|} ds$$

where

$$H = \frac{1}{\beta}(\eta^2 + [\beta\eta' - \frac{1}{2}\beta'\eta]^2) = \gamma_x \eta_x^2 + 2\alpha_x \eta_x \eta_x' + \beta_x \eta_x'^2$$

1) Momentum compaction: $\alpha = \frac{I_1}{C}$

2) Energy loss per turn: $U_0 = \frac{2r_e E^4}{3(mc^2)^3} I_2$

3) Damping partition functions: $J_x = 1 - \frac{I_4}{I_2}$ and $J_\epsilon = 2 + \frac{I_4}{I_2}$

4) Energy spread: $\sigma_\epsilon^2 = \frac{55}{32\sqrt{3}} \frac{\hbar}{mc} \left[\frac{E}{mc^2}\right]^2 \frac{I_3}{2I_2 + I_4}$

5.) Emittance: $\epsilon = \frac{55}{32\sqrt{3}} \frac{\hbar}{mc} \left[\frac{E}{mc^2}\right]^2 \frac{I_5}{I_2 - I_4}$

6) Damping times: $\tau_i\ [ms] = \frac{C[m]\,\rho[m]}{13.2\, J_i\, E^3[GeV]}$

Closed Orbit Errors[Co 1,Sa 1,Wi 2]

A single point kick of strength, ψ, at s = 0 along the circumference of a storage ring gives rise to a closed orbit displacement at position s,

$$\zeta(s) = \frac{\psi}{2}\sqrt{\beta(0)\beta(s)}\frac{\cos[\phi(s) - \pi\nu]}{\sin\pi\nu}, \qquad \zeta = x \text{ or } y,$$

where $\beta(0)$ and $\beta(s)$ are the betatron functions at the location of the kick and the observation point respectively, $\phi(s)$ is the phase advance from the kick to the observation point and ν is the betatron tune.

The angular deviation is obtained simply by differentiation,

$$\zeta'(s) = \frac{\psi}{2}\sqrt{\frac{\beta(0)}{\beta(s)}}\frac{\sin[\phi(s)-\pi\nu] - \alpha(s)\cos[\phi(s)-\pi\nu]}{\sin\pi\nu}$$

where $\alpha(s) = -\beta'(s)/2$.

Kicks can arise from dipole trim magnets or errors in the main magnets. The table below lists some of the kicks due to magnet errors assuming the betatron phase advance across the displaced element is small.

Element Type	Source of Kick	ψ	Plane
Quadrupole of Length, L, & Strength, K^2	Displacement by $\Delta_{x,y}$	$K^2 L \Delta_{x,y}$	x,y
Dipole of Angle, ϕ	Rotation by θ	$\phi\theta$	y
Dipole of Angle, ϕ	Field Error, $\frac{\Delta B}{B}$	$\phi\frac{\Delta B}{B}$	x

If the phase advance along the kick is not small, i.e. $\psi(s') \neq \psi\delta(s')$, the closed orbit must be determined from the more general equation for an extended kick,

$$\zeta(s) = \frac{\sqrt{\beta(s)}}{2\sin\pi\nu}\int_C \psi(s')\sqrt{\beta(s')}\cos[\phi(s) - \phi(s') - \pi\nu]\,ds'$$

The closed orbit blows up for integer tunes indicating the existence of a resonance for ν = integer.

The betatron tune shift due to a gradient error δK^2 is given by

$$\Delta\nu_i = \frac{1}{4\pi}\int \beta_i(s')\, \delta K^2(s')\, ds'.$$

The change in the betatron function is given by

$$\Delta\beta(s) = \frac{\beta(s)}{2\sin 2\pi\nu}\int_C \delta K^2(s')\beta(s')\cos 2[\phi(s) - \phi(s') - \pi\nu]ds'.$$

The betatron functions blow up for half integer tunes indicating the existence of a resonance for ν = integer/2.

Random Errors: Closed Orbit Amplification Factors[Co1,Gy1]

P_x and P_y, are defined to be the ratio between the closed orbit distortion at a particular location which will not be exceeded with 98% probability, to the 'rms error' in alignment of the elements.

For quadrupoles, the error is the rms displacement of the element assumed to be the same for all quads,

$$P_{x,y}^{quad}(s) = \frac{\sqrt{\beta_{x,y}(s)}}{\sin(\pi\nu_{x,y})}\left[\sum_{quads} K_j^4 L_j^2 <\beta_{x,y}>_j\right]^{1/2}.$$

For dipoles of bend angle ϕ_j, P_x is the 98% ratio between closed orbit distortions in meters and the relative rms field errors $\Delta B/B$; similarly P_y is the ratio between closed orbit distortions in meters and the rms tilt of the dipoles,

$$P_{x,y}^{dip}(s) = \frac{\sqrt{\beta_{x,y}(s)}}{\sin(\pi\nu_{x,y})}\left[\sum_{dips} \phi_j^2 <\beta_{x,y}>_j\right]^{1/2}.$$

Emittance In An Electron Storage Ring

In an electron storage ring, with an isomagnetic guide field, the horizontal emittance of the electron beam is given by[8a)],

$$\varepsilon = C_q \frac{\gamma^2}{\rho J_x} \frac{1}{2\pi\rho} \int_{dipoles} H \, ds = C_q \gamma^2 \frac{I_5}{I_2 - I_4} , \qquad (1)$$

where $H = \gamma_x \eta_x^2 + 2\alpha_x \eta_x \eta_x' + \beta_x \eta_x'^2$.

$$J_x(\delta) = 1 - \frac{1}{2\pi\rho^2} \int_{dipoles} \eta_x (\delta - 2n) \, ds \qquad (2)$$

$$with\ \delta = \begin{cases} 1 & \text{for a sector magnet} \\ 0 & \text{for a parallel magnet} \end{cases} \qquad (3)$$

and

$$n \equiv -\frac{\rho}{B}\frac{dB}{dx}, \quad C_q \equiv \frac{55\hbar}{32\sqrt{3}mc} = 3.84\times10^{-13} m-rad. \qquad (4)$$

In general a light source lattice is constructed from 'basic cells'. A cell contains dipoles, quadrupoles and sextupoles and *is usually bounded by dispersion free drift spaces for insertion* devices.

To explore the differences between the various types of lattices it is useful to rewrite (1) as

$$\varepsilon = F(\nu_x, lattice) \frac{E^2 [GeV]}{J_x N_d^3} \ m-rad \qquad (5)$$

where N_d is the number of dipole magnets, E is the energy in GeV.

For a fixed N_d & E the main variation in (5) is due to $F(\nu_x$, lattice), since $0 < J_x < 3$ and is typically $J_x \sim 1$-2. The following table lists the approximate minimum values of F (ν_x) for several types of lattices. A realistic lattice will have a slightly higher value than the theoretical minimums given here. The table also mentions an example of each lattice type to give the reader an idea of the basic cell and the betatron and dispersion functions. The emittances for these example rings are not necessarily given by the minimum value.

Lattice Type	F_{min}	N_d/cell	Example
FODO*	7.282×10^{-4}	2	PEP
Chasman-Green	2.36×10^{-5}	2	NSLS VUV
Triple Bend Achromat		3	BESSY II
Theor. Minimum Emit.*	7.84×10^{-6}	1	

* dispersion suppressors must be added to yield $\eta = 0$ insertions
References: He2, Ka1, Ri1, So1, Te1, Wi1

Beam Size and Angular Divergence

The horizontal and vertical beamsizes are given by,

$$\sigma_x = \sqrt{\varepsilon_x \beta_x + \sigma_\varepsilon^2 \eta_x^2} \qquad \sigma_y = \sqrt{\varepsilon_y \beta_y} \ .$$

The horizontal and vertical angular divergences are given by,

$$\sigma_x{}' = \sqrt{\varepsilon_x \gamma_x + \sigma_\varepsilon^2 \eta_x{}'^2} \qquad \sigma_y{}' = \sqrt{\varepsilon_y \gamma_y} \ .$$

where $\gamma_i = \dfrac{1+\alpha_i^2}{\beta_i}$, $\alpha_i = -\beta'_i/2$, $\varepsilon_y = \dfrac{\chi\varepsilon}{1+\chi}$, $\varepsilon_x = \dfrac{\varepsilon}{1+\chi}$, and χ is defined to be the emittance coupling.

Electron Beam Optics & Twiss Parameters[Ref 1]

The particle position and angular deviation are given by,

$$x(s) = \sqrt{\varepsilon\beta(s)}\cos[\psi(s) + \phi]$$

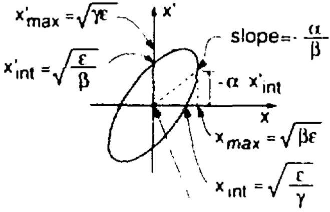
$$x'(s) = -\sqrt{\frac{\varepsilon}{\beta(s)}}\Big[\alpha(s)\cos[\psi(s) + \phi] + \sin[\psi(s) + \phi]\Big]$$

$$= \sqrt{\varepsilon\gamma(s)}\cos[\chi(s) + \phi]$$

where $\psi(s) = \int_0^s \frac{d\tau}{\beta(\tau)}$, $\alpha(s) = -\frac{\beta'(s)}{2}$, $\gamma(s) = \frac{1 + \alpha^2(s)}{\beta(s)}$ and $\chi(s)$ satisfies $\tan[\psi(s) - \chi(s)] = \frac{1}{\alpha(s)}$. The trio (α, β, γ) are referred to as the Twiss parameters.

The invariant emittance ellipse is given by

$$\gamma(s)x^2 + 2\alpha(s)xx' + \beta(s)x'^2 = \varepsilon$$



To transform the ellipse to a circle the following normalized variables are useful,

$$X = \frac{x}{\sqrt{\beta}} \quad \& \quad X' = \alpha\frac{x}{\sqrt{\beta}} + \sqrt{\beta}x'$$

Magnetic Multipoles[Br 1,Wi 2]

For a magnetic field with 'median plane symmetry', the field can be expressed, in the source free region, as $B = \nabla\Phi$, where Φ is a solution of the 3 dimensional Laplace equation $\nabla^2\Phi = 0$ in curvilinear coordinates.

Two Dimensional Ideal Multipole Magnets

For an ideal multipole, assuming the magnet is straight ($\rho = \infty$) and ignoring fringing fields, the magnetic field is purely transverse (2 dimensional) and the solution to the Laplace equation can be written as,

$$\Phi = \sum_{m=0}^{\infty} r^m [a_m \cos(m\theta) + b_m \sin(m\theta)]$$

Two classes of multipoles arise naturally from this expansion and they are catalogued in the table below for m = 1, 2, 3.

Pure Regular Multipoles ($a_m = 0$, $b_m \neq 0$)

Multipole	Φ	B_x	B_y
Dipole	$b_1 y$	0	b_1
Quadrupole	$2b_2 xy$	$2b_2 y$	$2b_2 x$
Sextupole	$b_3(3x^2y - y^3)$	$6b_3 xy$	$3b_3(x^2 - y^2)$

Pure Skew Multipoles ($a_m \neq 0$, $b_m = 0$)

Multipole	Φ	B_x	B_y
Dipole	$a_1 x$	a_1	0
Quadrupole	$a_2(x^2 - y^2)$	$2a_2 x$	$2a_2 y$
Sextupole	$a_3(x^3 - 3xy^2)$	$3a_3(x^2 - y^2)$	$-6a_3 xy$

A regular multipole is oriented such that it produces only a vertical field component in the median plane ($y = 0$). A regular multipole with 2m poles is transformed to a skew multipole by a rotation of $\theta = \pi/2m$ about the axis of the magnet.

Errors in Multipole Magnets[Co 2]

If the symmetry of the $2m$ pole magnet is preserved during construction and the imperfections are due only to the truncation of the equipotential surface of the iron lamination, the allowable multipole errors contain $2n = 2m(2k + 1)$ poles with $k = 1, 2$. For example:

Multipole	Allowable Errors
Dipole	Sextupole (6 pole), Decapole (10 pole), etc.
Quadrupole	Dodecapole (12 pole), (20 pole), etc.
Sextupole	(18 pole), (30 pole), etc.

If the symmetry of the magnet is broken the type and number of multipole errors can be much greater and each case must be examined in detail.

Radio Frequency System[Sa 1]

1.) Synchronous Phase, ϕ_s:

$$\phi_s = \sin^{-1}\left[\frac{U_0}{eV_{RF}}\right] = \sin^{-1}\left[\frac{1}{q}\right] \qquad (1)$$

2.) RF Acceptance, ε_{RF}:

$$\varepsilon_{RF} \approx \pm\left[\frac{2U_0}{\pi\alpha h E}\left(\sqrt{q^2-1} - \cos^{-1}(1/q)\right)\right]^{1/2} \qquad (2)$$

3.) Synchrotron Tune, ν_s:

$$\nu_s = \frac{\Omega_s}{\omega_0} = \left[\frac{\alpha h\cos\phi_s}{2\pi}\,\frac{eV_{RF}}{E}\right]^{1/2} \qquad (3)$$

4.) Bunch Length, σ_L:

$$\sigma_L = \frac{\alpha c}{\Omega_s}\,\sigma_E = \left[\frac{2\pi h\alpha c^2}{\omega_{RF}^2\cos\phi_s}\,\frac{E}{eV_{RF}}\right]^{1/2}\sigma_\epsilon \qquad (4)$$

Chromaticity[Ba 1]

$$\xi_x = \frac{1}{4\pi}\int_0^L ds\ [\beta_x\ (K^2 - 2h^2 - 2K^2 h\eta_x - r\eta_x - h'\eta_x') +$$

$$\beta_x' h\eta_x (h^2 - K^2) + \gamma_x h\eta_x].$$

$$\xi_y = \frac{1}{4\pi}\int_0^L [\beta_y\ (-K^2 + K^2 h\eta_x + r\eta_x + h'\eta_x') + \gamma_y h\eta_x]\ ds\ ,$$

where $K^2 = \frac{1}{(cp/e)}\frac{\partial B}{\partial x}$, $h = \frac{1}{\rho(s)}$, $r = \frac{1}{2(cp/e)}\frac{\partial^2 B}{\partial x^2}$.

Betatron Resonances[Br 2]

Resonances in the particle's betatron motion occur when the tunes satisfy:

$$m\nu_x + n\nu_y = p\ N,$$

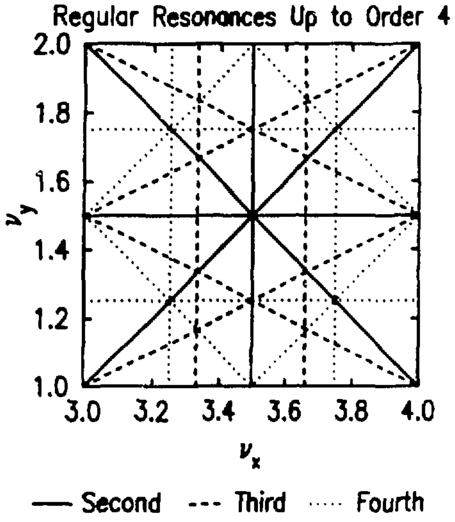
where m,n,p & N are integers, $|m| + |n|$ is the order of the resonance and

$$N = \begin{cases} N_s & \textit{structure resonances}, \\ 1 & \textit{non-structure resonances} \end{cases}$$

Resonances are further classified as 'regular' or 'skew' depending on whether the resonance is driven by a regular or skew multipole. Sum resonances are of greater concern than difference resonances. The accompanying figure is a typical tune diagram indicating all regular multipole resonances up to order 4 assuming N = 1.

For a low emittance light source lattice the most important resonances are the third order regular sextupole driven resonances:

$$3\nu_x = pN \qquad \& \qquad \nu_x + 2\nu_y = qN$$


Regular Resonances Up to Order 4
2.0
1.8
1.6
1.4
1.2
1.0
ν_y
3.0
3.2
3.4
3.6
3.8
4.0
ν_x
Second
Third
Fourth

Electron Beam Lifetime[Le 1,Br 2]

The gas scattering lifetime has contributions from elastic scattering of the stored beam on nuclei,

$$\frac{1}{\tau_{scat}} = \frac{4 r_e^2 Z^2 \pi \rho c}{2\gamma^2} \left[\frac{<\beta_x>\beta_{x,max}}{a^2} + \frac{<\beta_y>\beta_{y,max}}{b^2} \right]$$

and due to bremsstrahlung on nuclei,

$$\frac{1}{\tau_{brem}} = \frac{16 r_e^2 Z^2 \rho c}{411} \ln \left[\frac{183}{Z^{1/3}} \right] (-\ln \varepsilon_{RF} - 5/8)$$

where ρ and Z are the nuclei density and charge respectively, a and b are the horizontal and vertical stay clear apertures and ε_{RF} is the radio frequency acceptance.

The Touschek lifetime is given by,

$$\frac{1}{\tau_T} = \frac{\sqrt{\pi}\, r_e^2\, c\, N\, C(\zeta)}{\sigma_x'\, \gamma^3\, (\varepsilon_{acc})^2\, V}$$

where $V = 8\pi^{3/2} \sigma_x \sigma_z \sigma_l$, $\zeta = \left[\frac{(\varepsilon_{acc})}{\gamma \sigma_x'} \right]^2$, N is the number of electrons per bunch and

$$C(\zeta) = -\frac{3}{2} e^{-\zeta} + \frac{\zeta}{2} \int_{\zeta}^{\infty} \frac{\ln u}{u} e^{-u} du + \frac{1}{2}(3\zeta - \zeta \ln \zeta + 2) \int_{\zeta}^{\infty} \frac{e^{-u}}{u} du$$

The smaller of the physical, radio frequency or dynamic acceptance should be substituted for ε_{acc}. Because the Touschek lifetime depends on the machine functions it should be computed as a weighted average around the entire ring.

The quantum lifetime is given by,

$$\tau_q = \frac{\tau_\varepsilon}{2} \frac{e^{\xi}}{\xi}$$

where $\xi = \varepsilon_{RF}^2 / 2\sigma_\varepsilon^2$.

Synchrotron Radiation [Gr1,Ja1,Kr2]

The radiation emitted by a relativistic electron in a magnetic field is called synchrotron radiation. The radiation emitted has a broad spectrum for low photon energies and falls off exponentially above the critical photon energy, $\varepsilon_c = \hbar\omega_c = 3\hbar c\gamma^3/2\rho$.

$$\varepsilon_c\,[KeV] = .665\,B\,[T]\,E^2[GeV], \tag{1a}$$

$$\lambda_c\,[\AA] = \frac{18.64}{B\,[T]\,E^2\,[GeV]} \tag{1b}$$

Half of the total power is radiated above the critical photon energy and half below. Due to the relativistic motion of the electron the radiation is highly collimated in the forward direction with a characteristic vertical opening angle,

$$\psi(\omega) \simeq \begin{cases} \dfrac{1}{\gamma}\left(\dfrac{\omega_c}{\omega}\right)^{1/3}, & \omega \ll \omega_c \\ \dfrac{1}{\gamma}, & \omega \simeq \omega_c \\ \dfrac{1}{\gamma}\left(\dfrac{\omega_c}{\omega}\right)^{1/2}, & \omega \gg \omega_c \end{cases} \tag{2}$$

The spectral and angular distribution of photons is given by:

$$\frac{dN}{d\Omega} = \frac{3\alpha\gamma^6}{4\pi^2}\left(\frac{\omega}{\omega_c}\right)^2\left(\frac{1}{\gamma^2} + \psi^2\right)^2 \times \tag{3}$$

$$[K^2_{2/3}(\xi) + \frac{\psi^2}{1/\gamma^2 + \psi^2}K^2_{1/3}(\xi)]\ \frac{I}{e}\ \frac{\Delta\omega}{\omega}$$

with units of [photons/sec/steradian], I in amps, e = 1.6×10^{-19} C and where $\xi = \omega(1 + \gamma^2\psi^2)^{3/2}/2\omega_c$. The first term in the square bracket corresponds to radiation polarized in the plane of the orbit and the second term to radiation polarized perpendicular to the plane.

In the forward direction ($\psi = 0$) the above can be written in practical units as:

$$\frac{dN}{d\Omega} = 1.325\times10^{16}\ \frac{\Delta\omega}{\omega}\ E^2[GeV]\ I\ [Amp]\ H_2(y,0) \qquad (4)$$

with units of [photons/sec/mradθ/mradψ], $y = \omega/\omega_c = \lambda_c/\lambda$ and $H_2(y,0) = y^2K^2_{2/3}(y/2)$ is plotted in the accompanying figure.

If eqn. (3) is integrated over all vertical angles one obtains the flux per milliradian of horizontal arc,

$$\frac{dN}{d\theta} = \frac{\sqrt{3}\alpha\gamma}{2\pi\times10^3}\ \frac{\Delta\omega}{\omega}\ \frac{I}{e}\ (\frac{\omega}{\omega_c})\int_{\omega/\omega_c}^{\infty} K_{5/3}(x)dx, \qquad (5)$$

with units of [photons/sec/mrad θ], I in Amp & $e = 1.6\times10^{-19}$ C.

In practical units this can be written as

$$\frac{dN}{d\theta} = 2.457\times10^{16}\ E\ [GeV]\ I\ [Amp]\ G_1(y)\ \frac{\Delta\omega}{\omega}, \qquad (6)$$

with units of [photons/sec/mrad θ] and where

$$G_1(y) = y\int_y^{\infty} K_{5/3}(x)\ dx \qquad (7)$$

Figure 1 is a plot of the functions $H_2(y,0)$ and $G_1(y)$. Figure 2 is a plot of $dN/d\theta$ as a function of photon energy for radiation from a representative range of storage rings.

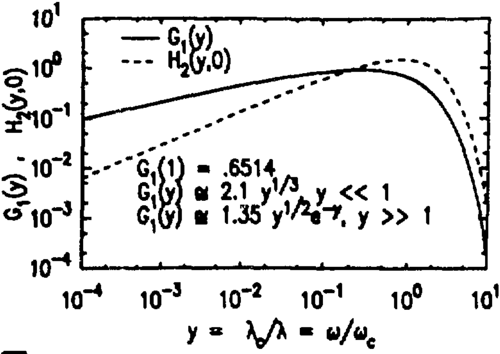
The total power radiated is given in SI units by,

$$P_T = \frac{4\pi r_e mc^2}{3e}\ \frac{\gamma^4}{\rho}\ I \qquad (8)$$

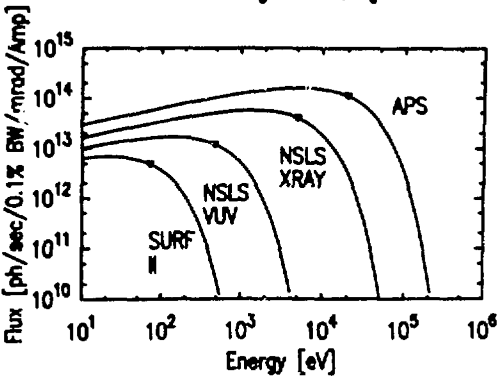
or in practical units by,

$$P_T\,(KW) = U_0[KeV]\ I\,[Amp] = \left[\frac{88.5\ E^4[GeV]}{\rho[m]}\right] I\,[Amp]. \qquad (9)$$

The power per milliradian of horizontal arc is obtained by dividing (8) or (9) by $2\pi\times10^3$.



G1(y)
H2(y,0)
G1(1) = .6514
G1(y) ≈ 2.1 y^1/3, y << 1
G1(y) ≈ 1.35 y^1/2 e^-y, y >> 1
G1(y) , H2(y,0)
y = λc/λ = ω/ωc



APS
NSLS
XRAY
NSLS
VUV
SURF
II
Flux [ph/sec/0.1% BW/mrad/Amp]
Energy [eV]

Helical Undulator$^{K<1}$

1. Idealized Field

$$\vec{B} = B_U [\cos(k_U z)\,\vec{x} + \sin(k_U z)\,\vec{y}] .$$

2. Realistic Field

$$B_r = B_U [I_0(k_U r) + I_2(k_U r)]\sin(\phi - k_U z) ,$$
$$B_\phi = B_U [I_0(k_U r) - I_2(k_U r)]\cos(\phi - k_U z) ,$$
$$B_z = -2B_U I_1(k_U r)\cos(\phi - k_U z)$$

3. Electron Orbit In Idealized Field

$$x = \frac{K}{\gamma k_U \beta_0}\sin(k_U c \beta_0 t) + x_0 ,$$
$$y = \frac{K}{\gamma k_U \beta_0}\cos(k_U c \beta_0 t) + y_0 ,$$
$$z = c\beta_0 t + z_0 , \qquad \beta_0 = \left(1 - \frac{1+K^2}{\gamma^2}\right)^{1/2}$$

4. Radiated Wavelength

$$\lambda(\theta) = \frac{\lambda_U}{2\gamma^2}(1 + K^2 + \gamma^2\theta^2) , \qquad K = \frac{eB_U}{mc^2 k_U} < 1$$

5. Spectral and Angular Distribution (Forward Dir.)

$$\frac{dN}{d\Omega}\Big|_{\theta=0} = \frac{2\alpha N_U^2 \gamma^2 K^2}{(1+K^2)^2}\,\frac{I}{e}\,\frac{\Delta\omega}{\omega}\,\frac{\sin^2(x/2)}{(x/2)^2}$$

with units of [photons/sec/steradian], I in Amp, $e = 1.6\times10^{-19}$C, $\alpha = 1/137.04$ and $x = 2\pi N_U(\omega - \omega_r)/\omega_r$. The spectrum is centered about $\omega_r = 2ck_U\gamma^2/(1+K^2)$ with a (FWHM) linewidth of $\Delta\omega/\omega = 1/N_U$.

Planar Undulator

1. Idealized Field

$$\vec{B} = B_U \cos(k_U z)\,\hat{y}$$

2. Realistic Field

$$B_x = 0\,,$$

$$B_y = B_U \cosh(k_U y)\cos(k_U z)\,, \qquad B_z = -B_U \sinh(k_U y)\sin(k_U z)$$

3. Electron Orbit In Idealized Field

$$x = \frac{K}{\gamma k_U \beta_0}[\cos(k_U c\beta_0 t) - 1] + x_0\,, \qquad y = y_0$$

$$z = c\beta_0 t + \frac{K^2}{8\gamma^2 k_U \beta_0^2}\sin(2k_U c\beta_0 t) + z_0\,, \qquad \beta_0 = \left(1 - \frac{1+K^2/2}{\gamma^2}\right)^{1/2}$$

4. Radiated Wavelength

$$\lambda_n(\theta) = \frac{\lambda_U}{2n\gamma^2}(1 + K^2/2 + \gamma^2\theta^2), \qquad K = \frac{eB_U}{mc^2 k_U}$$

5. Spectral and Angular Distribution (Forward Dir.)

$$\frac{dN_n}{d\Omega}\Big|_{\theta=0} = \alpha N_U^2\gamma^2 \frac{I}{e}\frac{\Delta\omega}{\omega}F_n(K)\frac{\sin^2(x_n/2)}{(x_n/2)^2}$$

with units of [photons/sec/steradian], I in Amp, $e = 1.6\times10^{-19}$ C,

$$F_n(K) = \frac{n^2K^2}{(1+K^2/2)^2}\left[J_{\frac{n+1}{2}}\left(\frac{nK^2}{(4+2K^2)}\right) - J_{\frac{n-1}{2}}\left(\frac{nK^2}{(4+2K^2)}\right)\right]^2$$

where n = 1,3,5, ..., $\alpha = 1/137.04$ and

$$x_n = 2\pi N_U n\left(\frac{\omega-\omega_n}{\omega_n}\right), \quad \omega_n = \frac{2nck_U\gamma^2}{(1+K^2/2)} \quad \& \quad \frac{\Delta\omega}{\omega} = \frac{1}{nN_U}$$

6. Central Cone Radiation Opening Angle

$$\sigma_r' = \frac{1}{\gamma}\left[\frac{(1 + K^2/2)}{2nN_U}\right]^{1/2} = \left[\frac{\lambda_n}{L}\right]^{1/2}$$

Using this definition of the radiation opening angle the spectral and angular distribution in the forward direction at $\omega = \omega_n$ can be rewritten as

$$\frac{dN_n}{d\Omega}\Big|_{\omega = \omega_n} = \frac{N_n}{2\pi\sigma_r'^2}$$

where

$$N_n = \pi\alpha N_U \frac{I}{e}\frac{\Delta\omega}{\omega}F_n(K)\frac{(1 + K^2/2)}{n}$$

7. On Axis Peak Brightness At $\omega = \omega_n$

$$B_n = \frac{N_n}{4\pi^2\Sigma_x\Sigma_x'\Sigma_y\Sigma_y'} < \frac{N_n}{\pi^2\lambda_n^2}$$

where $\Sigma_{x,y} = \sqrt{\sigma_{x,y}^2 + \lambda L/(4\pi)^2}$ & $\Sigma_{x,y}' = \sqrt{\sigma_{x,y}'^2 + \sigma_r'^2}$.

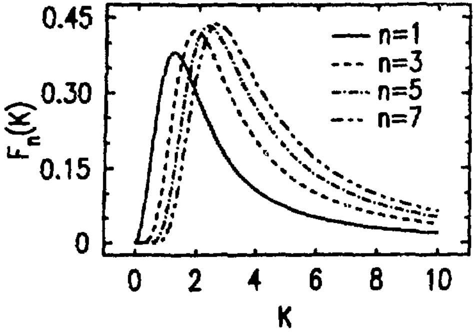
8. Optimum Beta & Dispersion Function In Insertion

$$\beta_{x,y} = \frac{N_U\lambda_U}{2}, \qquad \eta_{x,y} = 0$$

9. Total Power Radiated

$$P_T\,[W] = \frac{4\pi^2 r_e m_e c^2 K^2\gamma^2 N_u}{3\lambda_u}\frac{I}{e}$$

$$= \frac{7.26\,E^2\,[GeV]\,I\,[Amp]\,N_U\,K^2}{\lambda_U\,[cm]}$$



Planar Wiggler[K>2Kr]

For K ≫ 1 an insertion is called a wiggler. The properties of wiggler radiation are akin to those of arc sources. The critical energy of the photons depends on the angle of observation,

$$\varepsilon_c(\theta) = \varepsilon_{c0}\left[1 - (\theta\gamma/K)^2\right]^{1/2},$$

where

$$\varepsilon_{c0}\,[KeV] = .665\,B[T]\,E^2[GeV] \quad \& \quad K = .934\,B[T]\,\lambda_w[cm]$$

The flux and total power radiated are given by,

$$Flux = 2N_w \times (arc\ source\ flux\ of\ same\ \varepsilon_c),$$

$$P_T\,[W] = \frac{7.26\,E^2[GeV]\,I[Amp]\,N_w\,K^2}{\lambda_w\,[cm]}.$$

Permanent Magnet Undulator Field Versus Gap[Ha 1,Ki 3]

1. Pure $SmCo_5$

$$B_0\,[T] = 1.55 e^{-\pi g/\lambda_u}$$

where g is the gap of the undulator.

2. Hybrid Undulators

$$B_0\,[T] = 0.95\, a\, \exp\left[-\frac{g}{\lambda_u}\left(b - c\frac{g}{\lambda_u}\right)\right]$$

where a, b and c are given in Table 1 for two types of materials with the restriction, $0.07 \le g/\lambda_U \le 0.7$.

Parameter	$SmCo_5$	Nd-Fe-B
a	3.33	3.44
b	5.47	5.08
c	1.8	1.54

Table 1

Effects of Planar Insertions on the Ring

1.) No Net Deflection or Displacement of e^- Beam Requires:

$$\int_{-L/2}^{L/2} B_y(s)\,ds = 0, \qquad B_y(-z) = B_y(z)$$

2.) Betatron Tune Shift, $\Delta\nu$:

$$\Delta\nu_x = 0, \qquad \Delta\nu_y \approx \frac{\pi L <\beta_y> K^2}{2\lambda_u^2\gamma^2}$$

3.) Maximum Distortion of the β Functions, $\Delta\beta/\beta$:

$$\frac{\Delta\beta_x}{\beta_x} \approx 0, \qquad \frac{\Delta\beta_y}{\beta_y} \approx \frac{2\pi\Delta\nu_y}{\sin(2\pi\nu_y)}$$

4.) Effect of Wigglers & Undulators on the Energy Spread, σ_ϵ:

$$\frac{\sigma_{\epsilon w}^2}{\sigma_{\epsilon o}^2} = \frac{1 + \dfrac{\sqrt{2}\pi^2 N \rho_o^2 K^3}{\lambda_w^2\gamma^3}}{1 + \dfrac{\pi N \rho_o K^2}{\lambda_w \gamma^2}}, \qquad \frac{\sigma_{\epsilon u}^2}{\sigma_{\epsilon o}^2} = \frac{1 + \dfrac{112\sqrt{3}\pi^2 N \rho_o^2 K^2}{275\lambda_u^2\gamma^3}}{1 + \dfrac{\pi N \rho_o K^2}{\lambda_u \gamma^2}}$$

5.) Effect of Damping Wigglers on the Emittance, ϵ:

$$\frac{\epsilon_w}{\epsilon_o} = \frac{1 + \dfrac{2\sqrt{2}\pi^3 \rho_o^3 K^3 <H_w>}{\lambda_w^3\gamma^3 <H_o>}}{1 + \dfrac{\pi N \rho_o K^2}{\lambda_w \gamma^2}}$$

where $<H_{w,o}> = \dfrac{1}{C}\oint \dfrac{ds}{\beta}[\eta^2 + (\beta\eta' - \frac{1}{2}\beta'\eta)^2]$, subscripts 'w,u,o' denote wigglers, undulators & dipoles respectively and C is the ring circumference. References: Ho1, Ka2, Wi1.

Synchrotron Light Sources Worldwide

Ring	Location	Status	E [GeV]	λ_c [Å]
BRAZIL				
LNLS	Campinas	D, UC	2.	
FRANCE				
ACO	Orsay	D	.54	39
SUPERACO	Orsay	D	.8	18.6
DCI	Orsay	D	1.85	3.4
ESRF	Grenoble	D, UC	6.	.6,1.3
GERMANY				
COSY	BESSY	D, UC	.6	11.8
BESSY I	BESSY	D	.8	19.4
KSSQ	KFK	D, PL	1.2	2.3
BESSY II	BESSY	D, PL	1.5	6.3
DORIS	DESY	P	5.	.55
ITALY				
ADONE	Rome	P	1.5	8.3
ELETTRA	Trieste	D, UC	2.	3.8
JAPAN				
SOR	Tokyo Univ.	D	.38	112
NTT-II	Atsugi	D, UC	.55	16.8
NIJI-II	Tsukuba	D, UC	.6	36.2
UVSOR	IMS	D	.6	57
AURORA	SHI	D, UC	.65	10.2
LUNA	Tsukuba	D, UC	.8	21.8
NTT-I	Atsugi	D, UC	.8	20.2
TERAS	ETL	D	.8	21.8
SORTEC-I	Tsukuba	D, UC	1.0	15.6
HISOR	Hiroshima	D, PL	1.5	7
PH.FACT.	KEK	D	2.5	3.1

6 GeV	RIKEN	D, PL	6.	.6
TRISTAN AR	KEK	P	6.5	48
TRISTAN MR	KEK	P, PL	10.	1.38
PEOPLE'S REPUBLIC OF CHINA				
HESYRL	Hefei	D, UC	.8	24.3
BEPC	Beijing	P	2.8	2.6
SOUTH KOREA				
PLS	Pohang	D, PL	2.	3.8
SWEDEN				
MAX	Lund	D	.55	42.8
TAIWAN				
SRRC	Taipei	D, PL	1.3	8.9
UNITED KINGDOM				
HELIOS	Oxford Ins.	D, UC	.7	8.1
SRS	Daresbury	D	2.	3.9
USA				
SURF II	NBS	D	.3	173
SXLS	NSLS	D, UC	.7	9.8
VUV	NSLS	D	.75	25
ALADDIN	Wisconsin	D	.8	22.7
CAMD	LSU	D, PL	1.2	9.5
ALS	LBL	D, UC	1.5	8.1
XRAY	NSLS	D	2.5	2.5
SPEAR	SSRL	D	3.	2.6
CHESS	Cornell	P	5.	1.5
APS	ANL	D, PL	7.	.64
PEP	SLAC	P, PL	8.	1.8
USSR				
SIBERIA I	Kurchatov	D	.45	

VEPP 2M	Novosibirsk	D	.67	
S60	Moscow	P	.68	35.2
SIRIUS	Tomsk	P	1.36	9.4
YPI I	Yerevan	D, PL	1.8	3.2
VEPP 3	Novosibirsk	D	2.2	4.2
SIBERIA II	Kurchatov	D	2.5	1.8
ARUS	Yerevan	P	4.5	1.04
VEPP 4	Novosibirsk	D	6.25	

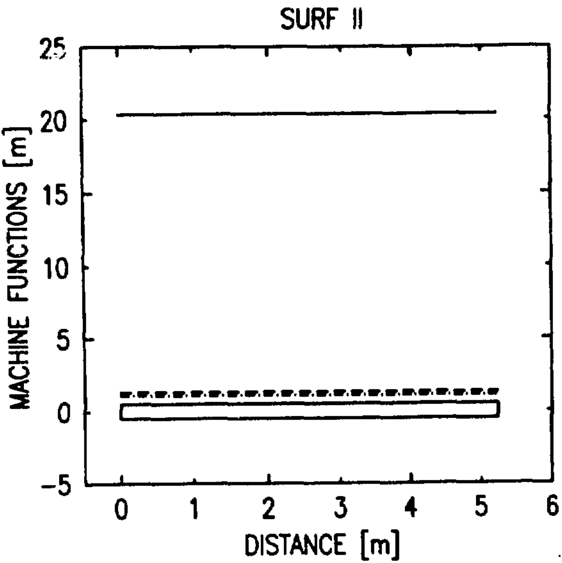
D= Dedicated P= Parasitic
PL= Planned UC= Under Construction

Light Source Lattices

The following pages contain a picture of the canonical lattice for many of the existing and planned synchrotron light sources. A MAD[31] data set for each ring is also included. The sextupole strengths and locations are included where known.

The symbols and units are as follows:

Symbol	Physical Quantity	Units
E	Energy	GeV
N_s	Number of Superperiods	- - rell.
ν_x	Horizontal Betatron Tune	
ν_y	Vertical Betatron Tune	
α	Momentum Compaction	
ε	Emittance	m rad
ξ_x	Natural Horizontal Chromaticity	- -
ξ_y	Natural Vertical Chromaticity	



$E=$ 0.300	$\alpha=$ .244E+01	—— $10\eta_x$
$N_s=$ 1	$\epsilon=$ .350E−06	- - - β_x
$\nu_x=$ 0.640	$\xi_x=$ −1.79	-·-·- β_y
$\nu_y=$ 0.768	$\xi_y=$ 1.49	

```
TITLE, "SURF II"
!       :Field Index, n= .59, one 360 degrees dipole
!       :B= 1.2 Tesla, rho =.833 m
!       :DATA COURTESY OF R. MADDEN AT NBS
B       :SBEND,L=5.23598,K1=-.8496,ANGLE=TWOPI
HSUP    :LINE=(B)
USE,HSUP
PRINT,#S/E
TWISS,TAPE
STOP

TITLE, "SUMITOMO AURORA"
!       :Field Index, n= .25, one 360 degrees dipole
!       :N. Takahashi, NIM B24/25 p. 425 (1987).
B       :SBEND,L=PI,K1=-1.,ANGLE=TWOPI
HSUP    :LINE=(B)
USE,HSUP
PRINT,#S/E
TWISS,TAPE
STOP
```

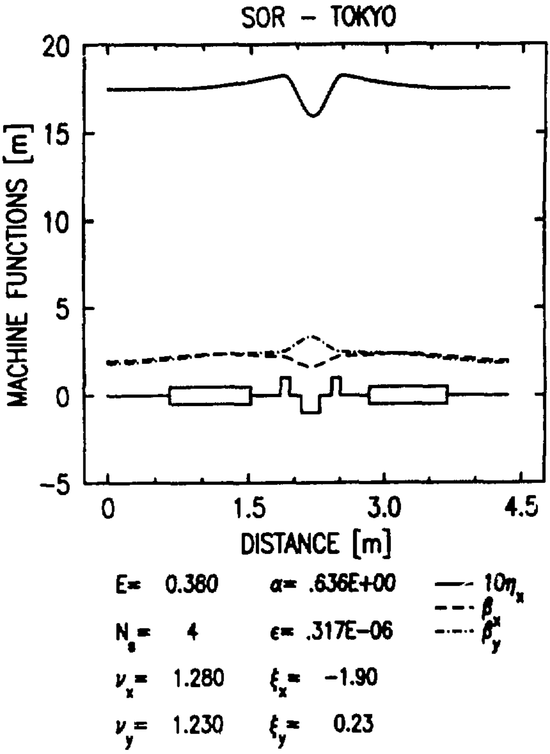
Properties of Weak Focusing Rings ($n \equiv -\frac{\rho}{B}\frac{\partial B}{\partial x}$)

$$\nu_x = \sqrt{1-n} \qquad \nu_y = \sqrt{n} \qquad \beta_x = \frac{\rho}{\sqrt{1-n}} \qquad \beta_y = \frac{\rho}{\sqrt{n}}$$

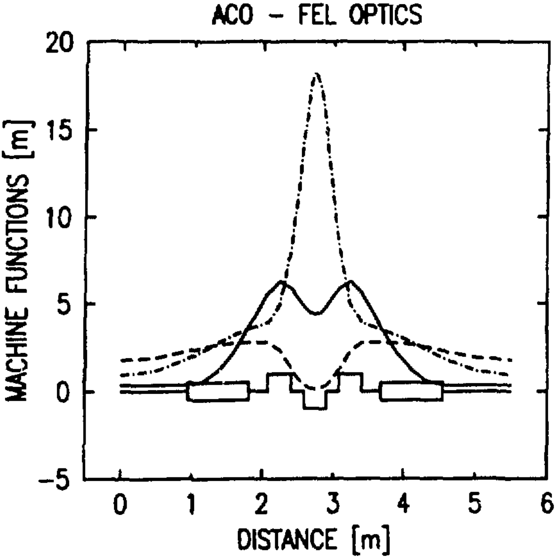
$$\eta = \frac{\rho}{1-n} \qquad \alpha = \frac{1}{1-n} \qquad J_x = \frac{n}{1-n} \qquad J_y = \frac{3-4n}{1-n}$$

$$\alpha_x = \alpha_y = 0 \qquad \xi_x = -\frac{1}{2}\frac{n(1+n)}{(1-n)^{3/2}} \qquad \xi_y = \frac{1}{2}\frac{n(1+n)}{\sqrt{n}\,(1-n)}$$

$$\varepsilon\,[m-rad] = \frac{C_q \gamma^2}{n(1-n)^{1/2}}$$


SOR - TOKYO
MACHINE FUNCTIONS [m]
20
15
10
5
0
-5
0
1.5
3.0
4.5
DISTANCE [m]
E= 0.380
α= .636E+00
10η_x
β_x
β_y
N_s= 4
ε= .317E-06
ν_x= 1.280
ξ_x= -1.90
ν_y= 1.230
ξ_y= 0.23

```
TITLE, "SOR RING, TOKYO"
!       DATA COURTESY OF Y. KAMIYA AT KEK, JUNE 1988
QF      :QUADRUPOLE, L=.1, K1=6.08691786
QD      :QUADRUPOLE,L=.1,K1=-6.2452322
BD      :SBEND,L=.863937,K1=-.3719008,ANGLE=TWOPI/8.
D1      :DRIFT,L=.655
D2      :DRIFT,L=.325
D3      :DRIFT,L=.13
HSUP    :LINE=(D1,BD,D2,QF,D3,QD)
USE,HSUP,SYMM,SUPER=4
PRINT,#S/E
TWISS
STOP
```



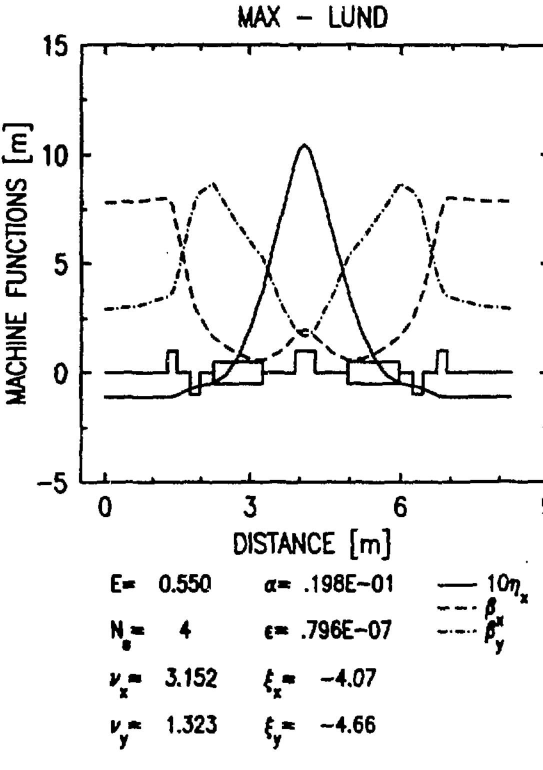
E= 0.536 α= .417E-01 —— $10\eta_x$

N_s= 4 ϵ= .192E-06 - - - β_x

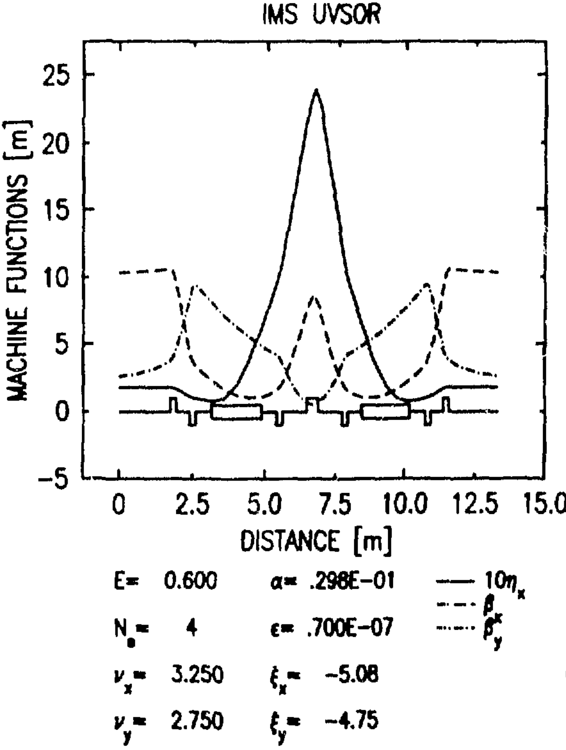
ν_x= 2.816 ξ_x= -3.56 -·-·- β_y

ν_y= 1.631 ξ_y= -8.79

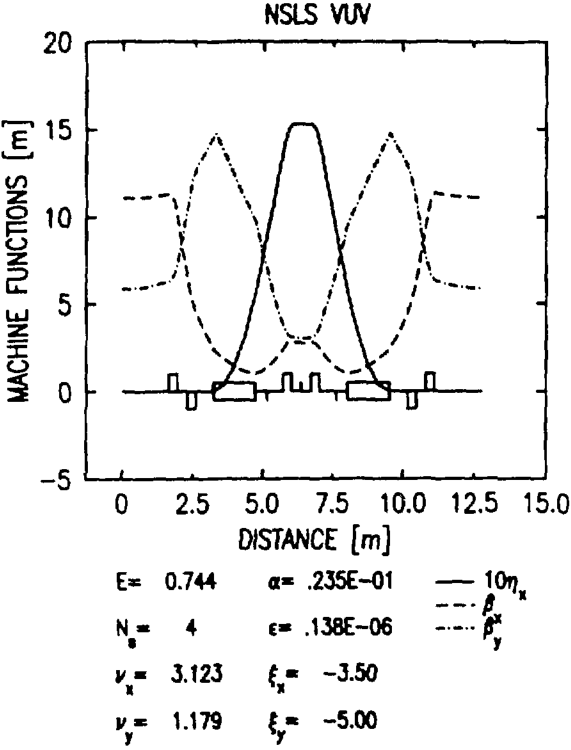
```
TITLE, "ACO FEL OPTICS"
!      : M. SOMMER, BNL REPORT 51959, P. 114 (1985).
Q1     :QUADRUPOLE, L=.33, K1=6.53807350
Q2     :QUADRUPOLE, L=.154,K1=-8.432918
BD     :SBEND,L=.871792,K1=-.405811,ANGLE=.7853981
SF     :MULTIPOLE,K2L=0.
SD     :MULTIPOLE,K2L=0.
D1     :DRIFT,L=.94
D2     :DRIFT,L=.27
D3     :DRIFT,L=.183
HSUP   :LINE=(D1,BD,D2,Q1,D3,Q2,Q2,D3,Q1,D2,BD,D1)
USE,HSUP,SUPER=4
PRINT,#S/E
TWISS
STOP
```


MAX - LUND
MACHINE FUNCTIONS [m]
15
10
5
0
-5
0
3
6
9
DISTANCE [m]
E= 0.550
α= .198E-01
N_e= 4
ε= .796E-07
ν_x= 3.152
ξ_x= -4.07
ν_y= 1.323
ξ_y= -4.66
$10\eta_x$
β_x
β_y

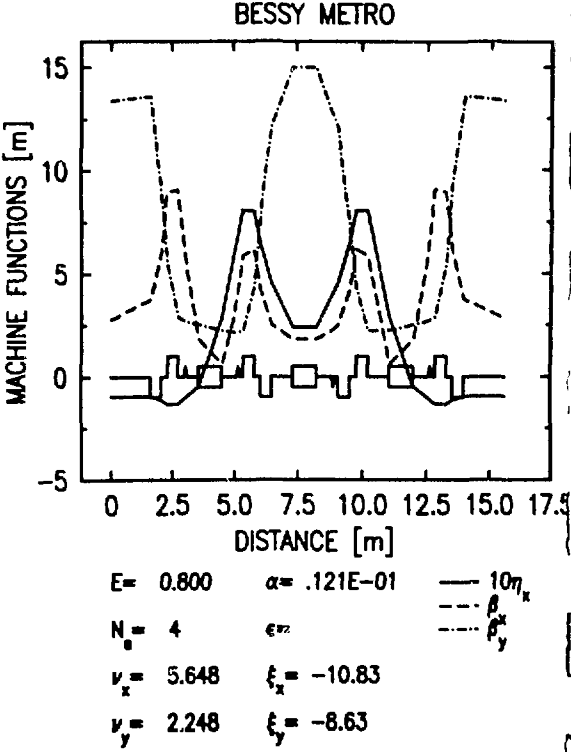
```
TITLE, "MAX"
!     DATA COURTESY OF M. ERIKSSON AT LUND
Q1      :QUADRUPOLE, L=.2, K1=4.42
Q2      :QUADRUPOLE,L=.2,K1=-3.14
Q3      :QUADRUPOLE,L=.2,K1=4.35
BD      :RBEND,L=1.,ANGLE=TWOPI/8.
SF      :MULTIPOLE,K2L=0.
SD      :MULTIPOLE,K2L=0.
D1      :DRIFT,L=1.3
D2      :DRIFT,L=.275
D3      :DRIFT,L=.657
HSUP    :LINE=(D1,Q1,D2,Q2,D2,BD,D3,Q3)
USE,HSUP,SYMM,SUPER=4
PRINT,#S/E
TWISS
STOP
```


IMS UVSOR
MACHINE FUNCTIONS [m]
25
20
15
10
5
0
−5
0
2.5
5.0
7.5
10.0
12.5
15.0
DISTANCE [m]
E= 0.600
α= .298E−01
10η_x
β_x
β_y
N_s= 4
ε= .700E−07
ν_x= 3.250
ξ_x= −5.08
ν_y= 2.750
ξ_y= −4.75

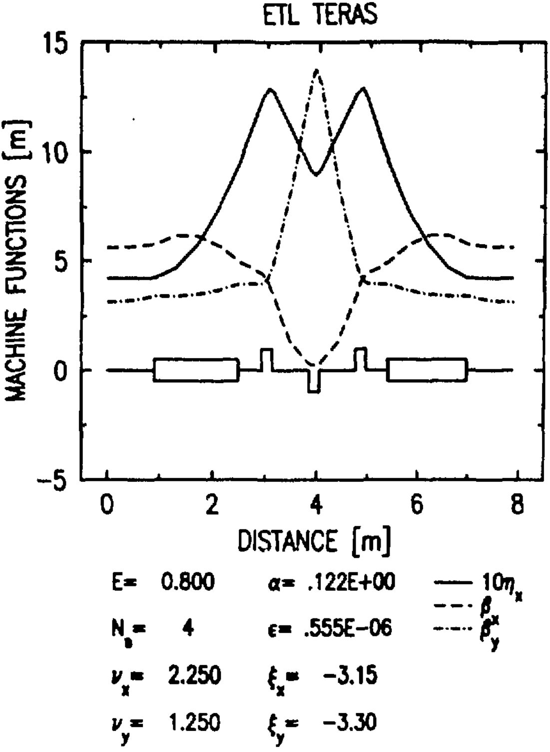
```
TITLE, "UVSOR"
!    DATA COURTESY OF Y. KAMIYA AT KEK
Q1     :QUADRUPOLE, L=.2, K1=3.38405
Q2     :QUADRUPOLE,L=.2,K1=-3.6245
Q3     :QUADRUPOLE,L=.2,K1=-2.92
Q4     :QUADRUPOLE,L=.4,K1=2.7
BD     :SBEND,L=1.7278759,ANGLE=.7853981
SF     :MULTIPOLE,K2L=0.
SD     :MULTIPOLE,K2L=0.
D1     :DRIFT,L=1.232
D2     :DRIFT,L=.5
D3     :DRIFT,L=.45
D4     :DRIFT,L=.55
D5     :DRIFT,L=.52
D6     :DRIFT,L=.435
HSUP   :LINE=(D1,D2,Q1,D3,Q2,D4,BD,D5,Q3,D6,D6,Q4,D6, &
         D6,Q3,D5,BD,D4,Q2,D3,Q1,D2,D1)
USE,HSUP,SUPER=4
PRINT,#S/E
TWISS
STOP
```


NSLS VUV
MACHINE FUNCTIONS [m]
20
15
10
5
0
−5
0
2.5
5.0
7.5
10.0
12.5
15.0
DISTANCE [m]
E= 0.744
α= .235E−01
— 10η_x
--- β_x
-··-·· β_y
N_s= 4
ε= .138E−06
ν_x= 3.123
ξ_x= −3.50
ν_y= 1.179
ξ_y= −5.00

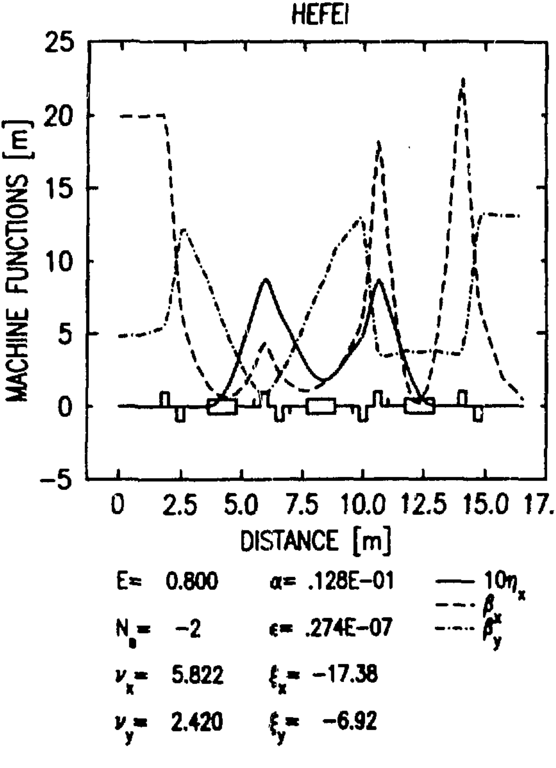
```
TITLE, "NSLS VUV"
!      DATA COURTESY OF G. VIGNOLA AT BNL
Q1     :QUADRUPOLE,L=.3,K1=1.80943467
Q2     :QUADRUPOLE,L=.3,K1=-1.120912
Q3     :QUADRUPOLE,L=.3,K1=1.8797615
BD     :RBEND,L=1.5,K1=-.026784185,ANGLE=.785398163
SF     :SEXTUPOLE,L=0.,K2=0.
SD     :SEXTUPOLE,L=0.,K2=0.
D1     :DRIFT,L=1.628
D2     :DRIFT,L=.35
D3     :DRIFT,L=.65
D4     :DRIFT,L=.41
D5     :DRIFT,L=.59
HSUP   :LINE=(D1,Q1,D2,Q2,D3,BD,D4,SD,D5,Q3,D2,SF)
USE,HSUP,SYMM,SUPER=4
PRINT,#S/E
TWISS
STOP
```


BESSY METRO
MACHINE FUNCTIONS [m]
15
10
5
0
−5
0
2.5
5.0
7.5
10.0
12.5
15.0
17.5
DISTANCE [m]
E= 0.800
α= .121E−01
10η_x
β_x
β_y
N_s= 4
ν_x= 5.648
ξ_x= −10.83
ν_y= 2.248
ξ_y= −8.63

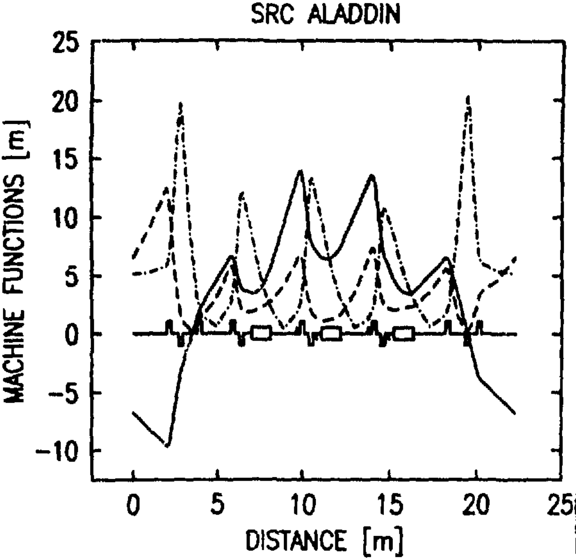
```
SETOPTS, ECHO, -SYNCH
TITLE, BESSY METRO OPTICS
! DATA COURTESY OF B. SIMON AT BESSY
DQU1:QUADRUPOLE,L=.44,K1=-1.89315
DQU2:QUADRUPOLE,L=.44,K1=+3.01445
AQU1:QUADRUPOLE,L=.44,K1=+3.37020
AQU2:QUADRUPOLE,L=.44,K1=-1.62679
SX1:SEXTUPOLE,L=.25,K2=0
SF1:SEXTUPOLE,L=.25,K2=67.6973
SD1:SEXTUPOLE,L=.25,K2=-32.0252
DDR0:DRIFT,L=1.634
DDR1:DRIFT,L=.25
DDR2:DRIFT,L=.835
DSXA:DRIFT,L=.12
DSXB:DRIFT,L=.465
ADR1:DRIFT,L=.835
ADR2:DRIFT,L=.25
ADR3:DRIFT,L=.835
HB:SBEND,L=.9341,ANGLE=.5235987,E1=.1726682,E2=.1726682, &
     HGAP=0.03,FINT=-1.2888046
DOU:LINE=(DDR0,DQU1,DDR1,DQU2,DSXA,SX1,DSXB)
ACH:LINE=(HB,DSXB,SF1,DSXA,AQU1,ADR2,AQU2,ADR3,HB,&
      DSXB,SD1,DSXA,AQU2,ADR2,AQU1,ADR1,HB)
B1:LINE=(DOU,ACH,-DOU)
USE,B1,SUPER=4
PRINT,#S/E
TWISS,TAPE
STOP
```


ETL TERAS
MACHINE FUNCTIONS [m]
DISTANCE [m]
15
10
5
0
-5
0
2
4
6
8
E= 0.800
α= .122E+00
10η_x
β_x
β_y
N_s= 4
ε= .555E-06
ν_x= 2.250
ξ_x= -3.15
ν_y= 1.250
ξ_y= -3.30

```
TITLE, "TERAS"
!       DATA COURTESY OF T. TOMIMASU AT ELECT LAB
Q1      :QUADRUPOLE, L=.2, K1=4.6060386
Q2      :QUADRUPOLE, L=.2,K1=-5.45185
BD      :SBEND,L=1.5707963,K1=0.,ANGLE=.7853981,&
        E1=.2042,E2=.2042
SF      :MULTIPOLE,K2L=0.
SD      :MULTIPOLE,K2L=0.
D1      :DRIFT,L=.9
D2      :DRIFT,L=.445
D3      :DRIFT,L=.715
HSUP    :LINE=(D1,BD,D2,Q1,D3,Q2,D3,Q1,D2,BD,D1)
USE,HSUP,SUPER=4
PRINT,#S/E
TWISS
STOP
```

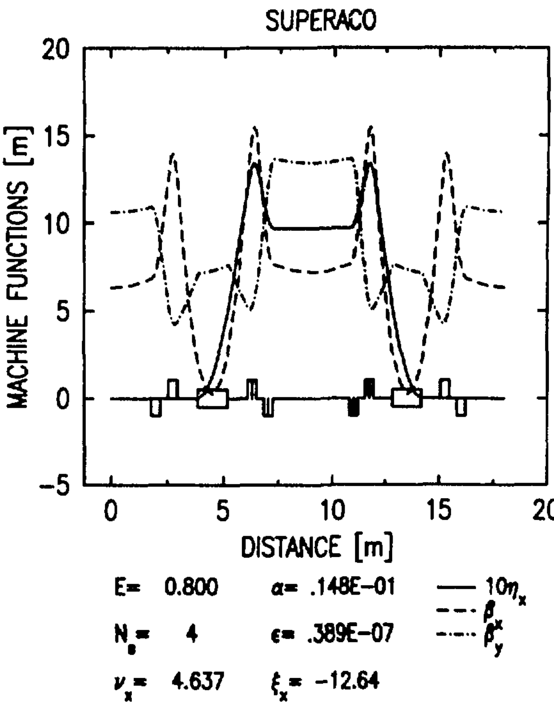

HEFEI
MACHINE FUNCTIONS [m]
25
20
15
10
5
0
−5
0
2.5
5.0
7.5
10.0
12.5
15.0
17.5
DISTANCE [m]
E= 0.800
α= .128E−01
10η_x
β_x
β_y
N_s= −2
ε= .274E−07
ν_x= 5.822
ξ_x= −17.38
ν_y= 2.420
ξ_y= −6.92

```
TITLE,"HESYRL HBLS"
!  DATA COURTESY OF H. DUOHUI AT HESYRL
Q1   :QUADRUPOLE, L=.3, K1= 2.494447
Q2   :QUADRUPOLE, L=.3, K1=-2.526518
Q3   :QUADRUPOLE, L=.3, K1= 3.820103
Q4   :QUADRUPOLE, L=.3, K1= -.74767
Q5   :QUADRUPOLE, L=.3, K1=-3.107723
Q6   :QUADRUPOLE, L=.3, K1= 4.821645
Q7   :QUADRUPOLE, L=.3, K1= 4.633252
Q8   :QUADRUPOLE, L=.3, K1=-2.76564
B    :RBEND, L=1.1635, ANGLE= TWOPI/12.
SF   :SEXTUPOLE, L=0., K2=0.
SD   :SEXTUPOLE, L=0., K2=0.
DL   :DRIFT, L=1.6811
DQ   :DRIFT, L= .32
DBQ  :DRIFT, L=1.
DSB  :DRIFT, L= .72
DQS  :DRIFT, L= .28
HSUP  :LINE= (DL,Q1,DQ,Q2,DBQ,B,DSB,SF,DQS,&
          Q3,DQ,Q4,DQS,SD,DSB,&
          B,DSB,SD,DQS,Q5,DQ,Q6,DQS,&
          SF,DSB,B,DBQ,Q7,DQ,Q8,DL)
RING  :LINE= (HSUP,-HSUP,HSUP,-HSUP)
USE, RING
PRINT, #S/E
TWISS
STOP
```

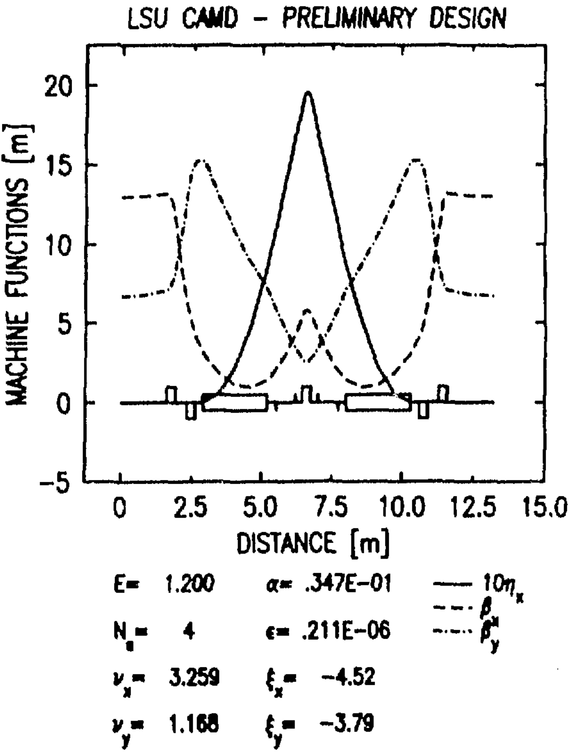


E= 0.800	α= .339E-01	—— $10\eta_x$
N_s= 4	ϵ= .976E-07	– – – β_x
ν_x= 7.132	ξ_x= -11.93	–·–·· β_y
ν_y= 7.237	ξ_y= -23.80	

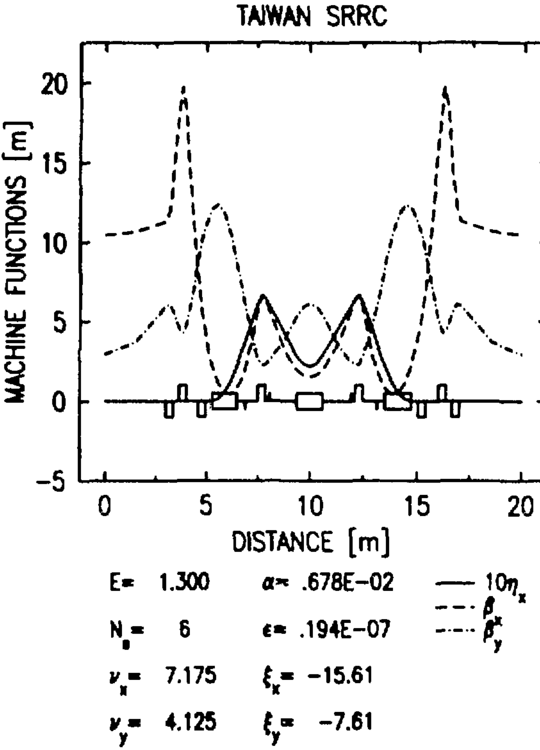
```
TITLE, "ALADDIN"
!     ALADDIN DATA COURTESY OF I. HSU AT SRC
Q1    :QUADRUPOLE,L=.25,K1=4.651721
Q2    :QUADRUPOLE,L=.25,K1=-5.566506
Q3    :QUADRUPOLE,L=.25,K1=4.682208
Q4    :QUADRUPOLE,L=.25,K1=5.313864
Q5    :QUADRUPOLE,L=.25,K1=-5.614159
BD    :RBEND,L=1.09083,ANGLE=.5235987
SF    :SEXTUPOLE,L=.0,K2=0.
SD    :SEXTUPOLE,L=.0,K2=0.
D1    :DRIFT,L=0.2
D2    :DRIFT,L=.449
D3    :DRIFT,L=.873
D4    :DRIFT,L=1.73
D5    :DRIFT,L=.25
D6    :DRIFT,L=.5
D7    :DRIFT,L=1.55
D8    :DRIFT,L=.2
D9    :DRIFT,L=.3
D10   :DRIFT,L=1.83
D11   :DRIFT,L=2.
FSUP  :LINE=(D11,Q1,D2,Q2,D3,Q3,D4,Q4,D5,Q5,D6,BD,&
        D7,SF,D8,Q4,D5,Q5,D1,SD,D9,BD,D7,SF,&
        D8,Q4,D5,Q5,D1,SD,D9,BD,D10,Q3,D3,Q2,D2,&
        Q1,D11)
RING  :LINE=(4*FSUP)
USE,RING
PRINT,#S/E
TWISS
STOP
```


SUPERACO
MACHINE FUNCTIONS [m]
DISTANCE [m]
20
15
10
5
0
−5
0
5
10
15
20
E= 0.800
α= .148E−01
10η_x
β_x
β_y
N_s= 4
ε= .389E−07
ν_x= 4.637
ξ_x= −12.64
ν_y= 1.420
ξ_y= −5.93

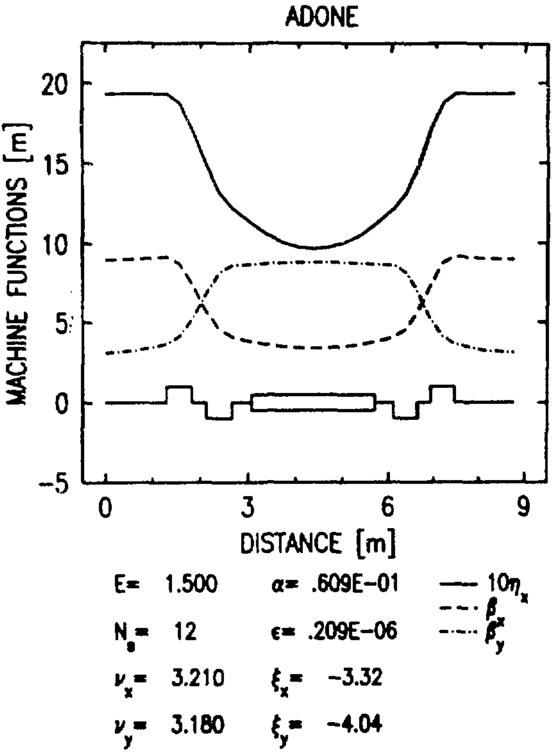
```
TITLE, "SUPERACO"
!      : M. SOMMER, BNL REPORT 51959, P. 188 (1985).
Q1     :QUADRUPOLE, L=.4, K1=-1.4753974
Q2     :QUADRUPOLE,L=.4,K1=2.79922985
Q3     :QUADRUPOLE,L=.4,K1=2.70282392
Q4     :QUADRUPOLE,L=.4,K1=-1.47539743
BD     :RBEND,L=1.335177,ANGLE=.7853981
SF     :MULTIPOLE,K2L=0.
SD     :MULTIPOLE,K2L=0.
D1     :DRIFT,L=1.785
D2     :DRIFT,L=.35
D3     :DRIFT,L=.9
HSUP   :LINE=(D1,Q1,D2,Q2,D3,BD,D3,Q3,D2,Q4,D1, &
         D1,Q4,D2,Q3,D3,BD,D3,Q2,D2,Q1,D1)
USE,HSUP,SUPER=4
PRINT,#S/E
TWISS
STOP
```


LSU CAMD - PRELIMINARY DESIGN
MACHINE FUNCTIONS [m]
DISTANCE [m]
20
15
10
5
0
-5
0
2.5
5.0
7.5
10.0
12.5
15.0
E= 1.200
α= .347E-01
10η_x
β_x
β_y
N_s= 4
ε= .211E-06
ν_x= 3.259
ξ_x= -4.52
ν_y= 1.168
ξ_y= -3.79

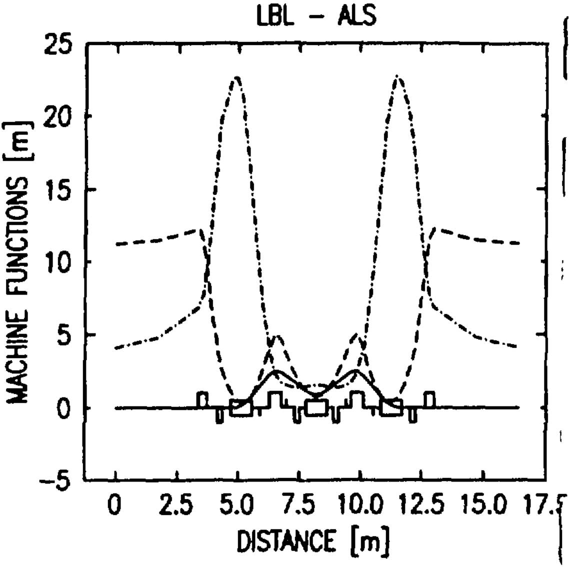
```
TITLE,    "LSU CAMD - PRELIMINARY DESIGN"
!         DATA COURTESY OF B. CRAFT AT CAMD-LSU
D1        :DRIFT, L=1.6
D2        :DRIFT, L=0.4
D3        :DRIFT, L=0.3
D4        :DRIFT, L=0.25
D5        :DRIFT, L=0.6
D6        :DRIFT, L=0.2
QA        :QUAD,  L=0.3,  K1= +2.001301
QB        :QUAD,  L=0.3,  K1= -1.563080
QC        :QUAD,  L=0.15, K1= +2.854396
SD        :SEXT,  L=0.1,  K2=-25.31921
SF        :SEXT,  L=0.1,  K2=+17.34186
BEND      :RBEND, L=2.3,ANGLE=TWOPI/8.,K1=0.
HAFSUP    :LINE=(D1,QA,D2,QB,D3,BEND,D4,SD,D5,SF,D6,QC)
USE,HAFSUP,SUPER=4,SYM
PRINT,#S/#E
TWISS
STOP
```


TAIWAN SRRC
MACHINE FUNCTIONS [m]
20
15
10
5
0
−5
0
5
10
15
20
DISTANCE [m]
E= 1.300
α= .678E−02
— $10\eta_x$
--- β_x
-·-· β_y
N_s= 6
ε= .194E−07
ν_x= 7.175
ξ_x= −15.61
ν_y= 4.125
ξ_y= −7.61

```
TITLE, "TAIWAN SRRC"
!      DATA FROM SRRC STATUS REPORT JAN 1988
Q1      :QUADRUPOLE, L=.35, K1=-1.5008449
Q2      :QUADRUPOLE,L=.35,K1=2.83385159
Q3      :QUADRUPOLE,L=.35,K1=-.758015158
Q4      :QUADRUPOLE,L=.35,K1=2.7308426
BD      :RBEND,L=1.219985,ANGLE=TWOPI/18.,K1=-.36995
SF      :SEXTUPOLE,L=.1,K2=0.
SD      :SEXTUPOLE,L=.1,K2=0.
D1      :DRIFT,L=3.
D2      :DRIFT,L=.3
D3      :DRIFT,L=.595
D4      :DRIFT,L=.325
D5      :DRIFT,L=.335
D6      :DRIFT,L=.585
D7      :DRIFT,L=.15
D8      :DRIFT,L=1.28
FSUP    :LINE=(D1,Q1,D2,Q2,D3,Q3,D4,BD,D5,SD,D6,Q4,D7,SF, &
           D8,BD,D8,SF,D7,Q4,D6,SD,D5,BD,D4,Q3,&
           D3,Q2,D2,Q1,D1)
RING    :LINE=(6*FSUP)
USE,RING
PRINT,#S/E
TWISS
STOP
```

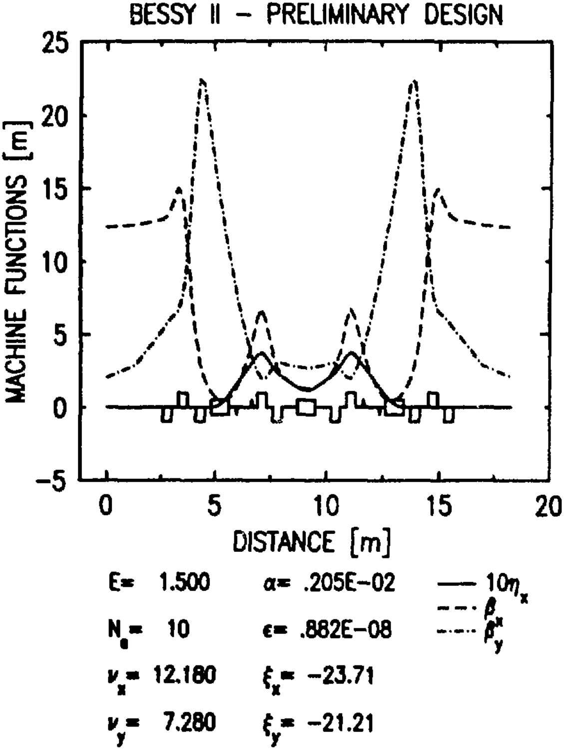

ADONE
MACHINE FUNCTIONS [m]
20
15
10
5
0
-5
0
3
6
9
DISTANCE [m]
E= 1.500
α= .609E-01
$10\eta_x$
β_x
β_y
N_s= 12
ε= .209E-06
ν_x= 3.210
ξ_x= -3.32
ν_y= 3.180
ξ_y= -4.04

```
TITLE, "ADONE"
!     DATA COURTESY OF M.PREGER AT INFN
QF     :QUADRUPOLE, L=.532, K1=.796684
QD     :QUADRUPOLE,L=.532,K1=-.781347
BD     :SBEND,L=2.618,K1=-.0216,ANGLE=.523598775
D1     :DRIFT,L=1.293
D2     :DRIFT,L=.296
D3     :DRIFT,L=.41
HSUP   :LINE=(D1,QF,D2,QD,D3,BD,D3,QD,D2,QF,D1)
USE,HSUP,SUPER=12
PRINT,#S/E
TWISS
STOP
```



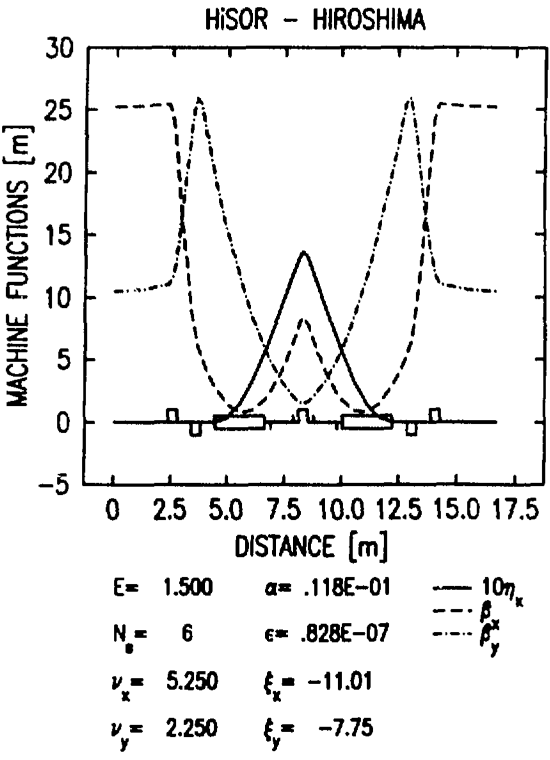
E= 1.500	α= .159E−02	—— $10\eta_x$
N_s= 12	ϵ= .340E−08	– – – β_x
ν_x= 14.266	ξ_x= −24.52	–·–·– β_y
ν_y= 8.184	ξ_y= −27.90	

```
TITLE, "ALS"
!     DATA COURTESY OF A. JACKSON AT LBL
Q1    :QUADRUPOLE, L=.35, K1=2.190899
Q2    :QUADRUPOLE,L=.2,K1=-2.051427
Q3    :QUADRUPOLE,L=.5,K1=2.620561
Q4    :QUADRUPOLE,L=.2,K1=0.
BD    :RBEND,L=.85421,ANGLE=TWOPI/36.,K1=-.81947
SF    :SEXTUPOLE,L=.0,K2=0.
SD    :SEXTUPOLE,L=.0,K2=0.
D1    :DRIFT,L=3.375585
D2    :DRIFT,L=.425
D3    :DRIFT,L=.3477
D4    :DRIFT,L=.4
D5    :DRIFT,L=.3227
D6    :DRIFT,L=.7
D7    :DRIFT,L=.2
D8    :DRIFT,L=.325
D9    :DRIFT,L=.3
D10   :DRIFT,L=.2727
D11   :DRIFT,L=.4
FSUP  :LINE=(D1,Q1,D2,Q2,D3,BD,D5,SD,D4,Q3,D7,SF,D8,&
        Q4,D10,BD,&
        D10,Q4,D8,SF,D7,Q3,D4,SD,D5,BD,D3,Q2,D2,Q1,D1)
RING  :LINE=(12*FSUP)
USE,RING
PRINT,#S/E
TWISS
STOP
```

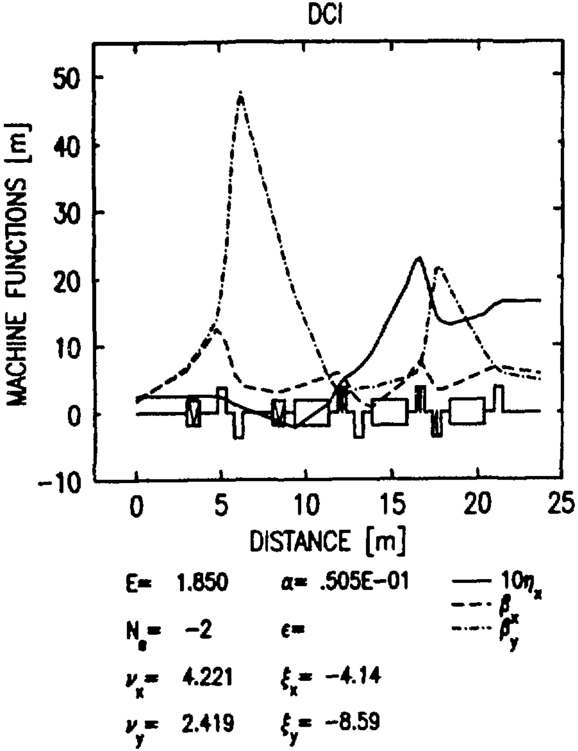

BESSY II - PRELIMINARY DESIGN
MACHINE FUNCTIONS [m]
DISTANCE [m]
E= 1.500
α= .205E-02
N_e= 10
ε= .882E-08
ν_x= 12.180
ξ_x= -23.71
ν_y= 7.280
ξ_y= -21.21
$10\eta_x$
β_x
β_y

```
SETOPTS, ECHO, -SYNCH
TITLE, BESSY II
! BESSY II DATA COURTESY OF B. SIMON AT BESSY
PARAMETER,PI=3.1415927
PARAMETER,NSUPER=10
PARAMETER,WIEVEL=3.
PARAMETER,ANZAHL=NSUPER*WIEVEL
Q1:QUADRUPOLE,L=.4,K1=-0.3049
Q2:QUADRUPOLE,L=.4,K1=2.31358
Q3:QUADRUPOLE,L=.4,K1=-2.19896
Q4:QUADRUPOLE,L=.4,K1=3.0591
Q5:QUADRUPOLE,L=.4,K1=-1.4176
SF1:SEXTUPOLE,L=.2,K2=0.
SD1:SEXTUPOLE,L=.2,K2=0.
D1:DRIFT,L=2.6
D2:DRIFT,L=.32
D3:DRIFT,L=.4
D4:DRIFT,L=.3
D5:DRIFT,L=.2
D6:DRIFT,L=.5
D7:DRIFT,L=.2
D8:DRIFT,L=.3
D9:DRIFT,L=.7
D10:DRIFT,L=1.3
HB1:SBEND,L=.4,ANGLE=PI/ANZAHL,E1=PI/ANZAHL,E2=0
HB2:SBEND,L=.4,ANGLE=PI/ANZAHL,E1=0,E2=PI/ANZAHL
IS:LINE=(D1,Q1,D2,Q2,D3,Q3,D4,HB1)
ISM:LINE=(HB2,D4,Q3,D3,Q2,D2,Q1,D1)
DS2:LINE=(HB2,D5,SD1,D6,SF1,D7,Q4,D8,Q5,D9,HB1)
DSM2:LINE=(HB2,D9,Q5,D8,Q4,D7,SF1,D6,SD1,D5,HB1)
FULLC:LINE=(IS,DS2,DSM2,ISM)
FULL:LINE=(10*FULLC)
USE,FULLC,SUPER=10
PRINT,#S/E
TWISS,TAPE
STOP
```

(a)

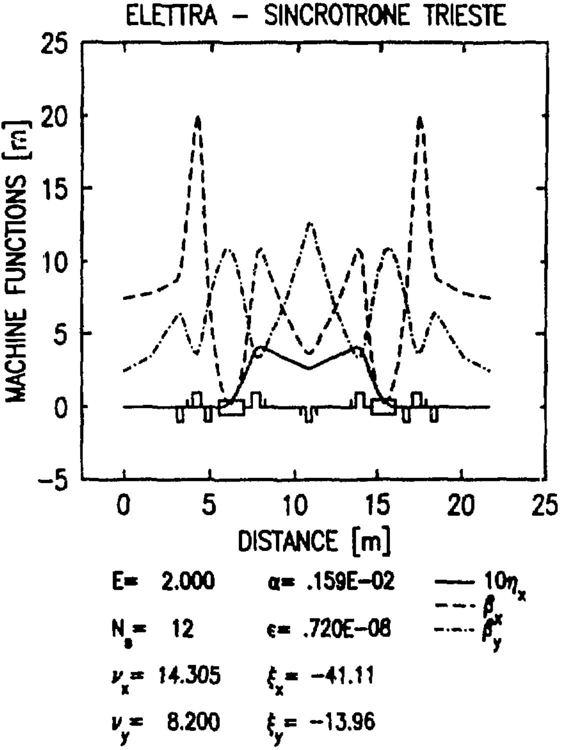

HiSOR - HIROSHIMA
MACHINE FUNCTIONS [m]
30
25
20
15
10
5
0
−5
0
2.5
5.0
7.5
10.0
12.5
15.0
17.5
DISTANCE [m]
E= 1.500
α= .118E−01
$10\eta_x$
β_x
β_y
N_s= 6
ε= .828E−07
ν_x= 5.250
ξ_x= −11.01
ν_y= 2.250
ξ_y= −7.75

```
TITLE, "HiSOR - HIROSHIMA"
!      DATA COURTESY OF Y. KAMIYA AT KEK
Q1     :QUADRUPOLE, L=.4, K1=1.28692583
Q2     :QUADRUPOLE,L=.4,K1=-1.3936996
Q3     :QUADRUPOLE,L=.4,K1=1.86385992
BD     :SBEND,L=2.18,ANGLE=TWOPI/12.
SF     :MULTIPOLE,K2L=0.
SD     :MULTIPOLE,K2L=0.
D1     :DRIFT,L=2.375
D2     :DRIFT,L=.625
D3     :DRIFT,L=.65
D4     :DRIFT,L=.25
D5     :DRIFT,L=1.
HSUP   :LINE=(D1,Q1,D2,Q2,D3,BD,D4,SD,D5,SF,D4,Q3,&
          D4,SF,D5,SD,D4,BD,D3,Q2,D2,Q1,D1)
USE,HSUP,SUPER=6
PRINT,#S/E
TWISS
STOP
```

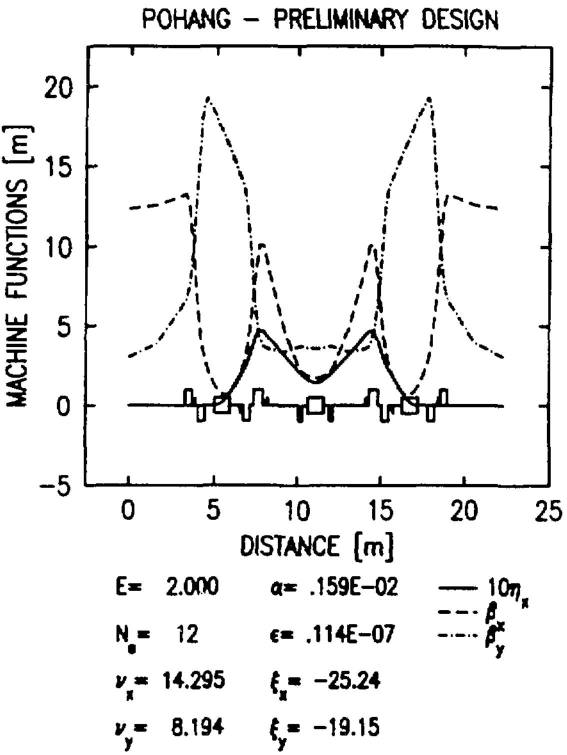


DCI
MACHINE FUNCTIONS [m]
50
40
30
20
10
0
−10
0
5
10
15
20
25
DISTANCE [m]
E= 1.850
α= .505E−01
$10\eta_x$
β_x
β_y
N_s= −2
ϵ=
ν_x= 4.221
ξ_x= −4.14
ν_y= 2.419
ξ_y= −8.59

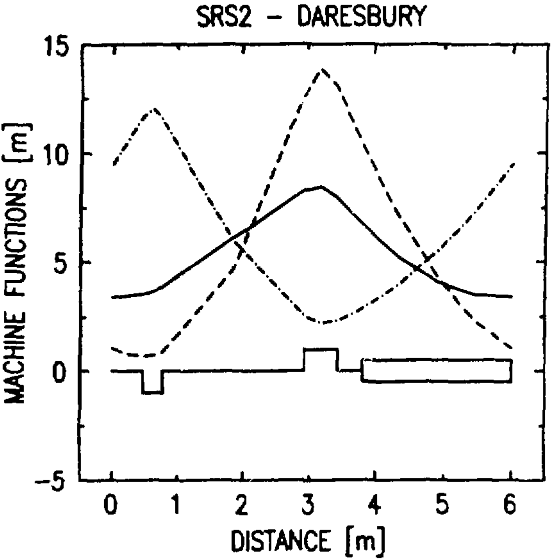
```
TITLE, "DCI"
!     DATA COURTESY OF J. LEDUFF AT LURE
!     DEFINITIONS DES ELEMENTS
D1:DRIFT,L=2.99
D2:DRIFT,L=1.077
D3:DRIFT,L=0.465
D4:DRIFT,L=1.773
D5:DRIFT,L=0.595
D6:DRIFT,L=0.528
D7:DRIFT,L=0.456
D8:DRIFT,L=0.578
D9:DRIFT,L=2.228
QF1:QUAD,L=0.526,K1=1.2258
QD2:QUAD,L=0.494,K1=-1.23199
QF3:QUAD,L=0.247,K1=1.303
QD4:QUAD,L=0.494,K1=-0.5425
QF5:QUAD,L=0.247,K1=1.5767
QD6:QUAD,L=0.247,K1=-1.39043
QF7:QUAD,L=0.494,K1=0.30547
BND:SBEND,L=2.,ANGLE=+0.5236
AY:SBEND,L=0.72,ANGLE=0.1745,TILT,E2=0.08725
AV:SBEND,L=0.71,ANGLE=-0.1745,TILT
SF:SEXT,K2=1.11366
SD:SEXT,K2=-2.15868
!     DEFINITION DE LA DEMI=MAILLE
DM:LINE=(D1,AY,D2,QF1,D3,QD2,D4,AV,D5,BND,D6,QF3,SF,QF3,&
D7,QD4,D6,BND,D6,QF5,SF,QF5,D7,QD6,SD,QD6,D6,BND,D8,&
QF7,D9)
USE,DM,SYMM,SUPER=2
PRINT,#S/E
TWISS,TAPE,CHROM
STOP
END
```


ELETTRA - SINCROTRONE TRIESTE
MACHINE FUNCTIONS [m]
DISTANCE [m]
25
20
15
10
5
0
-5
0
5
10
15
20
25
E= 2.000
α= .159E-02
10η_x
β_x
β_y
N_s= 12
ε= .720E-08
ν_x= 14.305
ξ_x= -41.11
ν_y= 8.200
ξ_y= -13.96

```
TITLE, "ELETTRA, SINCROTRONE TRIESTE"
!     DATA COURTESY OF A. WRULICH AT TRIESTE
Q1    :QUADRUPOLE, L=.34, K1=-1.58789
Q2    :QUADRUPOLE, L=.5, K1=2.2453
Q3    :QUADRUPOLE, L=.34, K1=-.896051
Q4    :QUADRUPOLE, L=.5, K1=1.80457
Q5    :QUADRUPOLE, L=.17, K1=-1.11814
BD    :RBEND,L=1.44,ANGLE=.261799,K1=-.4297
D1    :DRIFT,L=3.076
D2    :DRIFT,L=.29
D3    :DRIFT,L=.21
D4    :DRIFT,L=.475
D5    :DRIFT,L=2.094
D6    :DRIFT,L=.31
S1    :MULTIPOLE,K2L=0.
S2    :MULTIPOLE,K2L=0.
S3    :MULTIPOLE,K2L=0.
HSUP   :LINE=(D1,Q1,D2,S1,D2,Q2,D3,Q3,D4, &
          BD,D4,Q4,D2,S2,D5,S3,D6,Q5)
FSUP  :LINE=(HSUP,-HSUP)
RING  :LINE=(12*FSUP)
USE,RING
PRINT,#S/E
TWISS
STOP
```

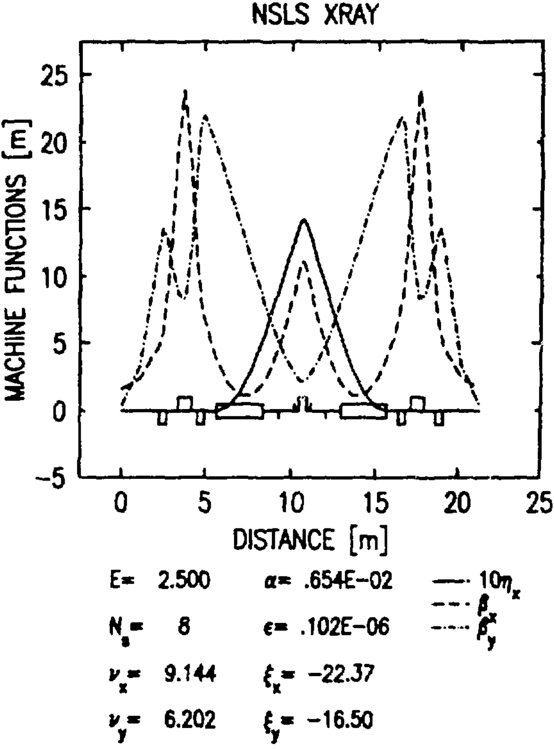

POHANG – PRELIMINARY DESIGN
MACHINE FUNCTIONS [m]
20
15
10
5
0
−5
0
5
10
15
20
25
DISTANCE [m]
E= 2.000
α= .159E−02
— 10η_x
– – – β_x
–·–·– β_y
N_s= 12
ε= .114E−07
ν_x= 14.295
ξ_x= −25.24
ν_y= 8.194
ξ_y= −19.15

```
TITLE,POHANG
! POHANG DATA FROM PLS TR/BD 88-06 NAM, ET. AL.
Q1      :QUADRUPOLE,L=.4, K1=1.748719
Q2      :QUADRUPOLE,L=.4,K1=-1.545169
Q3      :QUADRUPOLE,L=.4,K1=-1.486827
Q4      :QUADRUPOLE,L=.55,K1=1.8141255
Q5      :QUADRUPOLE,L=.2,K1=-.7163385
BD      :RBEND,L=.94,ANGLE=.1745329
SF0     :SEXTUPOLE,L=.1,K2=0.
SF      :SEXTUPOLE,L=.2,K2=0.
SD      :SEXTUPOLE,L=.2,K2=0.
D1      :DRIFT,L=3.3
D2      :DRIFT,L=.12
D3      :DRIFT,L=.13
D4      :DRIFT,L=.58
D5      :DRIFT,L=.5
D6      :DRIFT,L=.22
D7      :DRIFT,L=1.83
D8      :DRIFT,L=.35
FSUP    :LINE=(D1,Q1,D2,SF0,D3,Q2,D4,BD,D5,SD,D3,&
           Q3,D6,Q4,D3,SF,D7,Q5,D8,BD,D8,Q5,D7,&
           SF,D3,Q4,D6,Q3,D3,SD,D5,BD,D4,Q2,D3,SF0,&
           D2,Q1,D1)
RING    :LINE=(12*FSUP)
USE,RING
PRINT,#S/E
TWISS
STOP
```

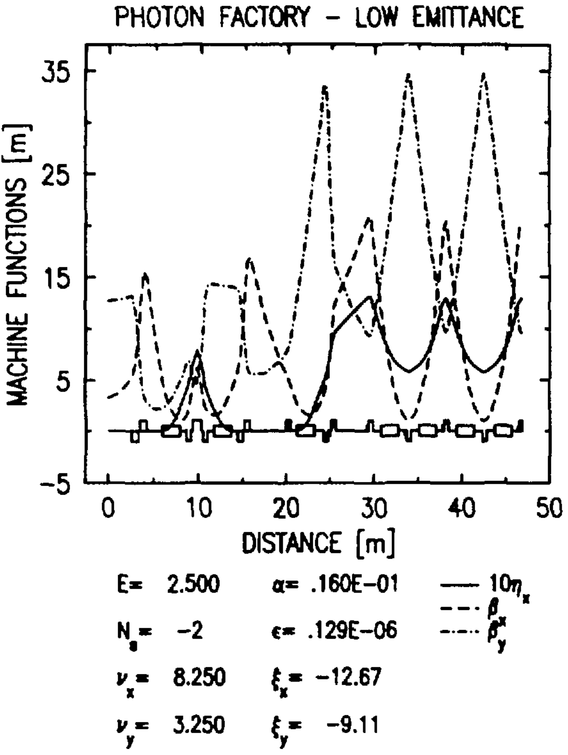


E= 2.000	α= .289E−01	—— $10\eta_x$
N_α= 16	ϵ= .108E−06	- - - β_x
ν_x= 6.250	ξ_x= −10.29	-·-·- β_y
ν_y= 3.250	ξ_y= −5.38	

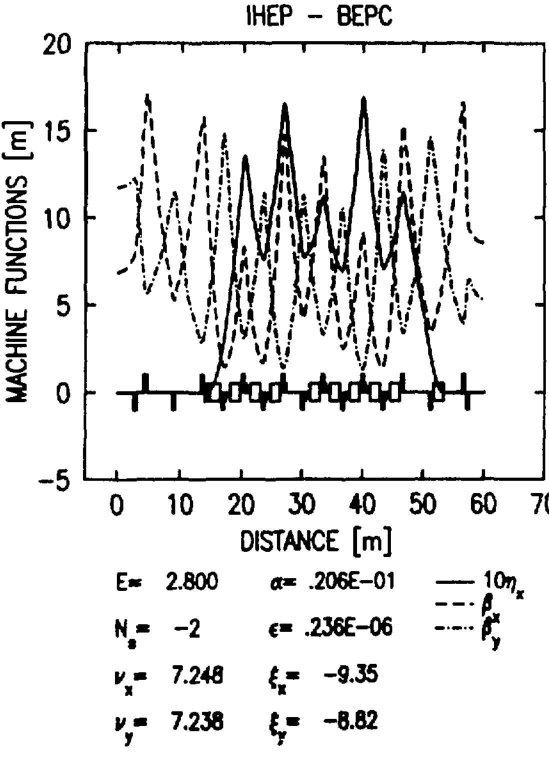
```
TITLE, "SRS2 - DARESBURY"
!      DATA COURTESY OF V. SULLER AT DARESBURY
Q1     :QUADRUPOLE,L=.3, K1=-1.5633944
Q2     :QUADRUPOLE,L=.5,K1=1.2782629
BD     :SBEND,L=2.188001,ANGLE=TWOPI/16.
SF     :MULTIPOLE,K2L=0.
SD     :MULTIPOLE,K2L=0.
D1     :DRIFT,L=.4725
D2     :DRIFT,L=2.167
D3     :DRIFT,L=.3725
FSUP   :LINE=(D1,Q1,D2,Q2,D3,BD)
USE,FSUP,SUPER=16
PRINT,#S/E
TWISS
STOP
```


NSLS XRAY
MACHINE FUNCTIONS [m]
DISTANCE [m]
-5
0
5
10
15
20
25
E= 2.500
α= .654E-02
N_s= 8
ε= .102E-06
ν_x= 9.144
ξ_x= -22.37
ν_y= 6.202
ξ_y= -16.50
$10\eta_x$
β_x
β_y

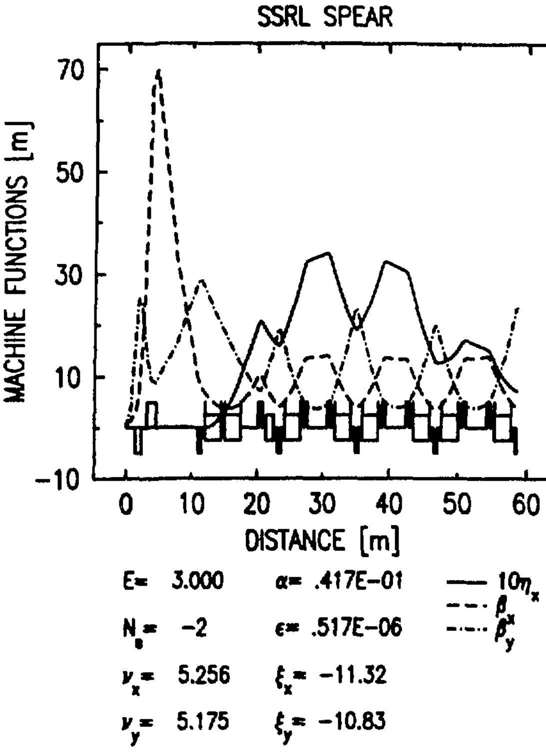
```
TITLE, "NSLS XRAY"
!      DATA COURTESY OF G. VIGNOLA AT BNL
Q1     :QUADRUPOLE,L=.45,K1=-1.50186576
Q2     :QUADRUPOLE,L=.8,K1=1.33731236
Q3     :QUADRUPOLE,L=.4132,K1=-1.4018946
Q4     :QUADRUPOLE,L=.225,K1=1.29943942
B      :RBEND,L=2.7,K1=-.026848954,ANGLE=.39269908
SF     :SEXTUPOLE,L=0.,K2=0.
SD     :SEXTUPOLE,L=0.,K2=0.
D1     :DRIFT,L=2.25
D2     :DRIFT,L=.685
D3     :DRIFT,L=.3484
D4     :DRIFT,L=.70825
D5     :DRIFT,L=.9
D6     :DRIFT,L=.25
HSUP   :LINE=(D1,Q1,D2,Q2,D3,Q3,D4,B,D5,SD,D5,SF,D6,Q4)
USE,HSUP,SYMM,SUPER=8
PRINT
TWISS
STOP
```


PHOTON FACTORY - LOW EMITTANCE
35
25
15
5
-5
MACHINE FUNCTIONS [m]
0
10
20
30
40
50
DISTANCE [m]
E= 2.500
α= .160E-01
10η_x
β_x
β_y
N_s= -2
ε= .129E-06
ν_x= 8.250
ξ_x= -12.67
ν_y= 3.250
ξ_y= -9.11

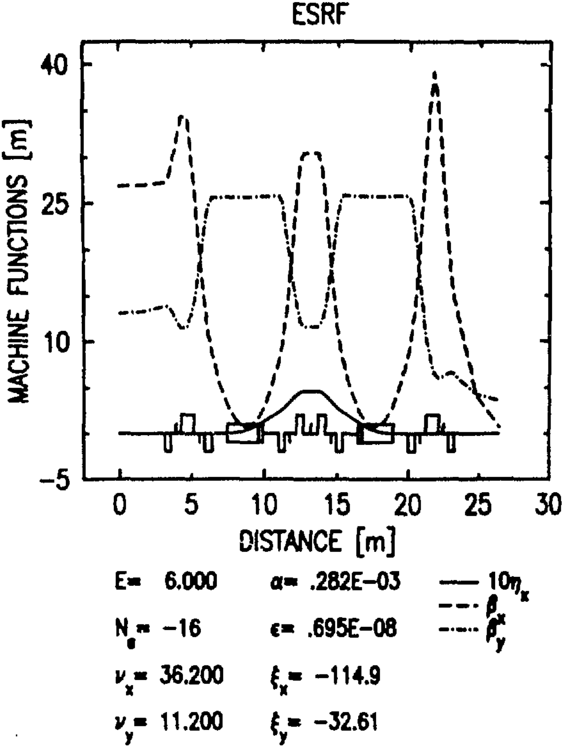
```
TITLE, "KEK PHOTON FACTORY LOW EMITTANCE"
!     DATA COURTESY OF Y. KAMIYA AT KEK
Q1     :QUADRUPOLE, L=.75, K1=-.815324
Q2     :QUADRUPOLE,L=.75,K1=1.023451
Q3     :QUADRUPOLE,L=.5,K1=-1.243955
Q4     :QUADRUPOLE,L=1.,K1=1.3817096
Q5     :QUADRUPOLE,L=.6,K1=-.798753
Q6     :QUADRUPOLE,L=.6,K1=1.06133
Q7     :QUADRUPOLE,L=.5,K1=.3537312
Q8     :QUADRUPOLE,L=.5,K1=-.994106
Q9     :QUADRUPOLE,L=.5,K1=.8806592
Q10    :QUADRUPOLE,L=.5,K1=.5808228
Q11    :QUADRUPOLE,L=.5,K1=-.4424872
Q12    :QUADRUPOLE,L=.5,K1=.9082836
Q13    :QUADRUPOLE,L=.25,K1=.9082836
B1     :RBEND,L=1.944076,ANGLE=TWOPI/28
SF     :SEXTUPOLE,L=.0,K2=0.
SD     :SEXTUPOLE,L=.0,K2=.0
D1     :DRIFT,L=2.5     D2     :DRIFT,L=.18
D3     :DRIFT,L=1.735   D4     :DRIFT,L=.725
D6     :DRIFT,L=4.23
D7     :DRIFT,L=1.075
D9     :DRIFT,L=.21
D10    :DRIFT,L=.19
D11    :DRIFT,L=3.56
D12    :DRIFT,L=.925
D13    :DRIFT,L=.735
HSUP   :LINE=(D1,Q1,D2,Q2,D3,B1,D4,Q3,D2,Q4,D2,Q3,&
         D4,B1,D4,Q5,D2,Q6,D6,Q7,D4,B1,D7,Q8,&
         D9,SD,D10,Q9,D11,SF,D10,Q10,D12,B1,&
         D13,SD,D10,Q11,D12,B1,D13,SF,D10,Q12,&
         D12,B1,D12,Q11,D12,B1,D13,SF,D10,Q13)
USE,HSUP,SYMM,SUPER=2
PRINT,#S/E
TWISS
STOP
```


IHEP - BEPC
MACHINE FUNCTIONS [m]
DISTANCE [m]
20
15
10
5
0
-5
0
10
20
30
40
50
60
70
E= 2.800
α= .206E-01
10η_x
β_x
β_y
N_s= -2
ε= .236E-06
ν_x= 7.248
ξ_x= -9.35
ν_y= 7.238
ξ_y= -8.82

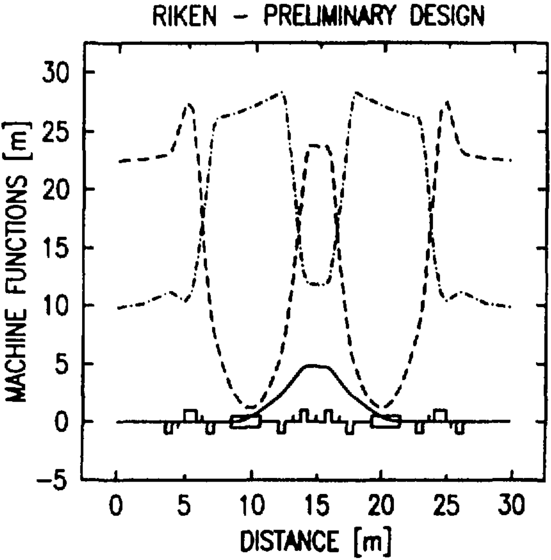
```
TITLE, "BEPC-IHEP BEIJING STORAGE RING"
!  DATA COURTESY OF S. FANG AT BEPC
!  BEWARE QUADS & DRIFTS ARE WRITTEN IN 2 COLUMNS
Q1  :QUADRU,L=.6,K1=-.408     Q8  :QUADRU,L=.4,K1=1.004
Q2  :QUADRU,L=.6,K1=.566      Q9  :QUADRU,L=.4,K1=.918
Q3  :QUADRU,L=.4,K1=-.644     Q10 :QUADRU,L=.4,K1=1.173
Q4  :QUADRU,L=.4,K1=.88       Q11 :QUADRU,L=.4,K1=.981
Q5  :QUADRU,L=.4,K1=-.935     Q12 :QUADRU,L=.4,K1=-.641
Q6  :QUADRU,L=.4,K1=1.289     Q13 :QUADRU,L=.4,K1=1.326
Q7  :QUADRU,L=.4,K1=-1.064    Q14 :QUADRU,L=.4,K1=-1.171
BL  :RBEND,L=0.5,ANGLE=.024085543
BB  :RBEND,L=1.6,ANGLE=.154671078
SF  :SEXTU,L=.0,K2=0.
SD  :SEXTU,L=.0,K2=0.
D1  :DRIFT,L=2.5    D8  :DRIFT,L=2.55
D2  :DRIFT,L=1.     D9  :DRIFT,L=.25
D3  :DRIFT,L=4.     D10 :DRIFT,L=4.25
D4  :DRIFT,L=4.2    D11 :DRIFT,L=3.1
D5  :DRIFT,L=.35    D12 :DRIFT,L=.68
D6  :DRIFT,L=.3     D13 :DRIFT,L=.32
D7  :DRIFT,L=.65
QUAT   :LINE=(IPINS,BODY,SPINS)
IPINS  :LINE=(D1,Q1,D2,Q2,D3,Q3,D4,Q4)
BODY   :LINE=(ARC1,ARC2,ARC3,ARC4,ARC5,ARC6,ARC7)
ARC1   :LINE=(D9,BL,D5,BB,D6)
ARC2   :LINE=(Q5,D13,SD,D12,BB,D6,Q6,D5,SF,D7,BB,D6)
ARC3   :LINE=(Q7,D13,SD,D12,BB,D6,Q8,D5,SF,D8)
ARC4   :LINE=(Q7,D13,SD,D12,BB,D6,Q9,D13,SF,D12,BB,D6)
ARC5   :LINE=(Q7,D13,SD,D12,BB,D6,Q10,D13,SF,D12,BB,D6)
ARC6   :LINE=(Q7,D13,SD,D12,BB,D6,Q11,D10)
ARC7   :LINE=(Q12,D6,BB,D11)
SPINS  :LINE=(Q13,D6,Q14,D8)
USE,QUAT,SUPER=2,SYMM
PRINT,#S/E
TWISS
STOP
```


SSRL SPEAR
MACHINE FUNCTIONS [m]
70
50
30
10
−10
0
10
20
30
40
50
60
DISTANCE [m]
E= 3.000
α= .417E−01
10η_x
β_x
β_y
N_s= −2
ε= .517E−06
ν_x= 5.256
ξ_x= −11.32
ν_y= 5.175
ξ_y= −10.83

```
TITLE, "SPEAR"
!      DATA COURTESY OF H. WIEDEMANN AT SSRL
Q1     :QUADRUPOLE,L=1.0,K1=-.910105
Q2     :QUADRUPOLE,L=1.34272,K1=.390514
Q3     :QUADRUPOLE,L=.51834,K1=-.245597
Q4     :QUADRUPOLE,L=.51834,K1=.564108
Q5     :QUADRUPOLE,L=.51834,K1=-.54979
Q6     :QUADRUPOLE,L=.51834,K1=.273081
Q7     :QUADRUPOLE,L=.51834,K1=.29851
Q8     :QUADRUPOLE,L=.25915,K1=-.537857
B      :RBEND,L=2.36825,ANGLE=TWOPI/34.
BHALF  :RBEND,L=1.18413,ANGLE=TWOPI/68.
SF     :SEXTUPOLE,L=0.0,K2=0.
SD     :SEXTUPOLE,L=0.0,K2=0.
D1     :DRIFT,L=1.3448
D2     :DRIFT,L=.85883
D3     :DRIFT,L=6.41438
D4     :DRIFT,L=.60668
D5     :DRIFT,L=2.818451
D6     :DRIFT,L=.611269
D7     :DRIFT,L=.30562
D8     :DRIFT,L=.303339
D9     :DRIFT,L=2.98163
D10    :DRIFT,L=1.49081
INS    :LINE=(D1,Q1,D2,Q2,D3,Q3,D4,B,D4,B,D5,Q4,D6,&
         BHALF,D7,SD,D7,Q5,D8,SD,D8,B,D8,SF,D8,Q6,&
         D9)
CELL1  :LINE=(Q7,D4,B,D8,SD,D8,Q8)
HSUP   :LINE=(INS,CELL1,-CELL1,D10,D10,CELL1,&
         -CELL1,D9,CELL1)
USE,HSUP,SYMM,SUPER=2
PRINT
TWISS
STOP
```


ESRF
MACHINE FUNCTIONS [m]
40
25
10
-5
0
5
10
15
20
25
30
DISTANCE [m]
E= 6.000
α= .282E-03
10η_x
β_x
β_y
N_e= -16
ε= .695E-08
ν_x= 36.200
ξ_x= -114.9
ν_y= 11.200
ξ_y= -32.61

```
TITLE, "ESRF"
!       DATA COURTESY OF A. ROPERT AT ESRF
QD1     :QUADRUPOLE,L=.4, K1=-.319693
QF1     :QUADRUPOLE,L=.9, K1=.52901
QD2     :QUADRUPOLE,L=.5, K1=-.52412
QD3     :QUADRUPOLE,L=.4, K1=-.69304
QF2     :QUADRUPOLE,L=.5, K1=.759003
QD4     :QUADRUPOLE,L=.5, K1=-.770779
QF3     :QUADRUPOLE,L=.9, K1=.819497
QD5     :QUADRUPOLE,L=.4, K1=-.547108
M1 :SBEND,L=2.15728,ANGLE=.092324,E1=TWOPI/128.,E2=.043237
M2 :SBEND,L=.292710,ANGLE=.00585,E1=-.0432374,E2=TWOPI/128
M3 :SBEND,L=.292710,ANGLE=.00585,E1=TWOPI/128.,E2=-.043237
M4 :SBEND,L=2.15728,ANGLE=.092324,E1=.0432374,E2=TWOPI/128
SF1     :MULTIPOLE,K2L=2.*.199969E+1
SF2     :MULTIPOLE,K2L=2.*.181036E+1
SF3     :MULTIPOLE,K2L=2.*.31030E+1
SD1     :MULTIPOLE,K2L=-.226015E+1*2.
SD2     :MULTIPOLE,K2L=-.107756E+1*2.
SD3     :MULTIPOLE,K2L=-.177512E+1*2.
D1      :DRIFT,L=3.1696
D2      :DRIFT,L=.35
D3      :DRIFT,L=.4
D4      :DRIFT,L=1.07225
D5      :DRIFT,L=1.07175
D6      :DRIFT,L=.43
D7      :DRIFT,L=.5
HSUP    :LINE=(D1,QD1,D2,SF1,D2,QF1,D3,SD1,D2,QD2,D4,&
          M1,M2,D5,QD3,D2,SD3,D6,QF2,D7,SF3,D7,QF2,&
          D6,SD3,D2,QD3,D5,M3,M4,D4,QD4,D2,SD2,D3,&
          QF3,D2,SF2,D2,QD5,D1)
USE,HSUP,SYMM,SUPER=16
PRINT,#S/E
TWISS
STOP
```



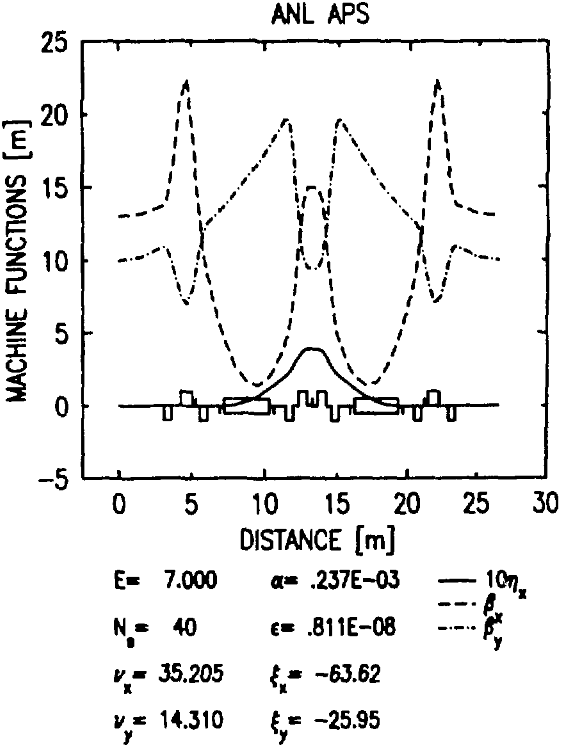
E= 6.000 α= .186E-03 —— $10\eta_x$

N_s= 36 ε= .823E-08 - - - β_x

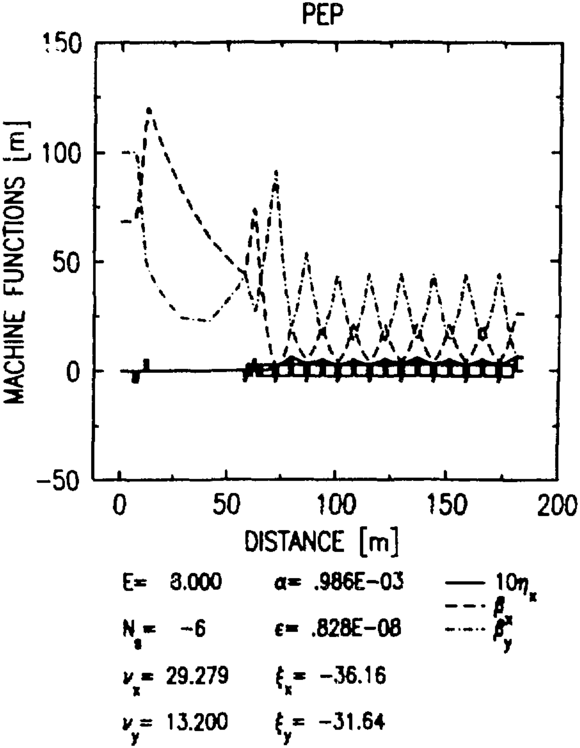
ν_x= 32.220 ξ_x= -67.89 -·-·- β_y

ν_y= 11.160 ξ_y= -28.84

```
TITLE, "RIKEN 6 GEV PRELIMINARY DESIGN"
'      DATA COURTESY OF Y. KAMIYA AT KEK
Q1     :QUADRUPOLE, L=.5, K1=-.150323
Q2     :QUADRUPOLE,L=.9,K1=.441942
Q3     :QUADRUPOLE,L=.5,K1=-.49957
Q4     :QUADRUPOLE,L=.5,K1=-.450193
Q5     :QUADRUPOLE,L=.5,K1=.606434
DI     :SBEND,L=2.18,ANGLE=TWOPI/72.
SF     :SEXTUPOLE,L=.0,K2=0.
SD     :SEXTUPOLE,L=.0,K2=.0
D1     :DRIFT,L=3.5
D2     :DRIFT,L=.42
D3     :DRIFT,L=1.29
D4     :DRIFT,L=1.4
D5     :DRIFT,L=.2
D6     :DRIFT,L=.5
D7     :DRIFT,L=.4
HSUP   :LINE=(D1,Q1,D2,SD,D2,Q2,D2,SF,D2,&
         Q3,D3,DI,D4,Q4,&
         D7,D5,SF,D5,D7,Q5,D6,D5,SF)
USE,HSUP,SYMM,SUPER=36
PRINT,#S/E
TWISS
STOP
```


ANL APS
MACHINE FUNCTIONS [m]
DISTANCE [m]
25
20
15
10
5
0
−5
0
5
10
15
20
25
30
E= 7.000
α= .237E−03
N_s= 40
ε= .811E−08
ν_x= 35.205
ξ_x= −63.62
ν_y= 14.310
ξ_y= −25.95
10η_x
β_x
β_y

```
TITLE, "ARGONNE APS"
!      DATA COURTESY OF S. KRAMER AT ANL
Q1     :QUADRUPOLE, L=.5, K1=-.4643753
Q2     :QUADRUPOLE,L=.8,K1=.676341
Q3     :QUADRUPOLE,L=.5,K1=-.453338
Q4     :QUADRUPOLE,L=.5,K1=-.809546
Q5     :QUADRUPOLE,L=.6,K1=.781528
DI     :RBEND,L=3.06,ANGLE=TWOPI/80.
S1     :SEXTUPOLE,L=.24,K2=0.
S2     :SEXTUPOLE,L=.24,K2=.0
S3     :SEXTUPOLE,L=.24,K2=.0
S4     :SEXTUPOLE,L=.12,K2=.0
D1     :DRIFT,L=3.1
D2     :DRIFT,L=.66
D3     :DRIFT,L=.13
D4     :DRIFT,L=.73
D5     :DRIFT,L=.2
D6     :DRIFT,L=.7
D7     :DRIFT,L=.37
D8     :DRIFT,L=.23
HSUP     LINE=(D1,Q1,D2,Q2,D3,S1,D3,Q3,D4,S2, &
           D5,DI,D5,S3,D6,Q4,D7,Q5,D8,S4)
USE,HSUP,SYMM,SUPER=40
PRINT,#S/E
TWISS
STOP
```


PEP
MACHINE FUNCTIONS [m]
150
100
50
0
-50
0
50
100
150
200
DISTANCE [m]
E= 3.000
α= .986E-03
10η_x
β_x
β_y
N_s= -6
ε= .828E-08
ν_x= 29.279
ξ_x= -36.16
ν_y= 13.200
ξ_y= -31.64

```
TITLE, "PEP, 100 DEG. FINAL CONFIG , AUGUST 1985"
!     DATA FROM ACD NOTE 34
! DRIFTS
DRIFT,D1,     L=6.3312299
DRIFT,D2,     L=3.1001420
DRIFT,DSEP,   L=2.5289122
DRIFT,DRF,    L=2.9706997
DRIFT,D3,     L=13.3250999
DRIFT,D4,     L=2.4425193
DRIFT,DL1,    L=0.3655194
DRIFT,DL2,    L=0.8655196
DRIFT,DL3,    L=0.5805197
DRIFT,DL4,    L=0.2099997
DRIFT,DC1,    L=0.5436340
DRIFT,DC1A,   L=0.2755196
DRIFT,DC2,    L=0.7308219
DRIFT,DC2A,   L=0.7336339
DRIFT,DC3,    L=0.7608219
DRIFT,DC4,    L=0.2236341
DRIFT,DC4A,   L=0.2255196
DRIFT,DS1,    L=0.9408218
DRIFT,DSH,    L=2.5108218
DRIFT,DR06,   L=0.1105
DRIFT,DR07,   L=0.2200
DRIFT,DR10,   L=0.1158
DRIFT,DR11,   L=0.1950
DRIFT,DR20,   L=0.1058
DRIFT,DR21,   L=0.4050
DRIFT,DR22,   L=0.1086
DRIFT,DR23,   L=0.1850
DRIFT,DR24,   L=0.1158
DRIFT,DR25,   L=0.1950
DRIFT,DR26,   L=0.6058
DRIFT,DR27,   L=0.0850
DRIFT,DSS,    L=0.1
! QUADS
```

```
QUAD,Q1H,    L=1.018770, K1=-0.0315621884
QUAD,Q2H,    L=0.771088, K1=0.04128253
QUAD,Q3,     L=0.998961, K1=-0.08010629
QUAD,QF1,    L=0.998961, K1=0.151392309
QUAD,QD1,    L=0.558356, K1=-0.2293545
QUAD,QF2,    L=0.998961, K1=0.244097344
QUAD,QF3,    L=0.732732, K1=0.26610075
QUAD,QFH,    L=0.366366, K1=0.27871304
QUAD,QS2,    L=0.732732, K1=-0.208721687
QUAD,QD,     L=0.558356, K1=-0.2414289345
QUAD,QS1,    L=0.558356, K1=0.182092775
! BENDING MAGNETS
SBEND,BB,    L=5.4,ANGLE=.0326249,E1=0.0163125,E2=0.0163125
SBEND,BLF,   L=2.0, ANGLE=0.0008,E1=0.0004,E2=0.0004
! SEXTUPOLES
SEXT,SF1,    L=0.25,K2=0.0
SEXT,SD1,    L=0.25,K2=0.0
SEXT,SD2,    L=0.25,K2=-4.0
SEXT,SD,     L=0.25,K2=-3.93939
SEXT,SF,     L=0.25,K2=3.26969
SEXT,SD5,    L=0.25,K2=-0.601529
SEXT,SF6,    L=0.25,K2=4.0
SEXT,SD6,    L=0.25,K2=-3.08142
SEXT,SD7,    L=0.25,K2=-4.0
SEXT,SF9,    L=0.25,K2=0.0
!BEAMLINES
LINE,PEP=(6*SUPER)
LINE,SUPER=(DODEC,-DODEC)
LINE,DODEC=(INSERL,CELL2,CELL3,CELL4,CELL5,SYMS)
LINE,INSERL=(INSER,MATCH1,MATCH2,MATCH3,CELL1)
LINE,INSER=(D1,2*Q1H,D2,2*Q2H,DSEP,D3,9*DRF,D4,Q3)
LINE,MATCH1=(DL1,BLF,DL2,QF1,DR06,SF1,DR07,BLF,DL4)
LINE,MATCH2=(BB,DC2,QD1,DR10,DSS,SD1,DSS,DR11,BB,&
        DC4A,QF2,DC1A)
LINE,MATCH3=(BB,DC2,QD1,DR20,SD2,DR21,BB,DC4,QF3)
LINE,CELL1=(DR22,SF,DR23,BB,DC2,QD1,DR20,SD,&
```

```
        DR21,BB,DC4,QFH)
LINE,CELL2=(QFH,DR22,SF,DR23,BB,DC2,QD,DR20,&
        SD,DR21,BB,DC4,QFH)
LINE,CELL3=(QFH,DR22,SF,DR23,BB,DC2,QD,DR24,&
        DSS,SD5,DSS,DR25,BB,DC4,QFH)
LINE,CELL4=(QFH,DR22,SF6,DR23,BB,DC2,QD,DR24,&
        DSS,SD6,DSS,DR25,BB,DC4,QFH)
LINE,CELL5=(QFH,DR22,SF,DR23,BB,DC2,QD,DR24,&
        DSS,SD7,DSS,DR25,BB,DC4,QFH)
LINE,SYMS=(QFH,DR22,SF,DR23,BB,DC2A,QS2,DR22,&
        SD,DR23,BB,DR26,SP9, &
        DR27,QS1,DSH)
USE,PEP
PRINT,#S/E
TWISS
STOP
```

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