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Summary

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A SYNCHROTRON RADIATION SOURCE WITH ARBITRARILY ADJUSTABLE ELLIPTICAL POLARIZATION

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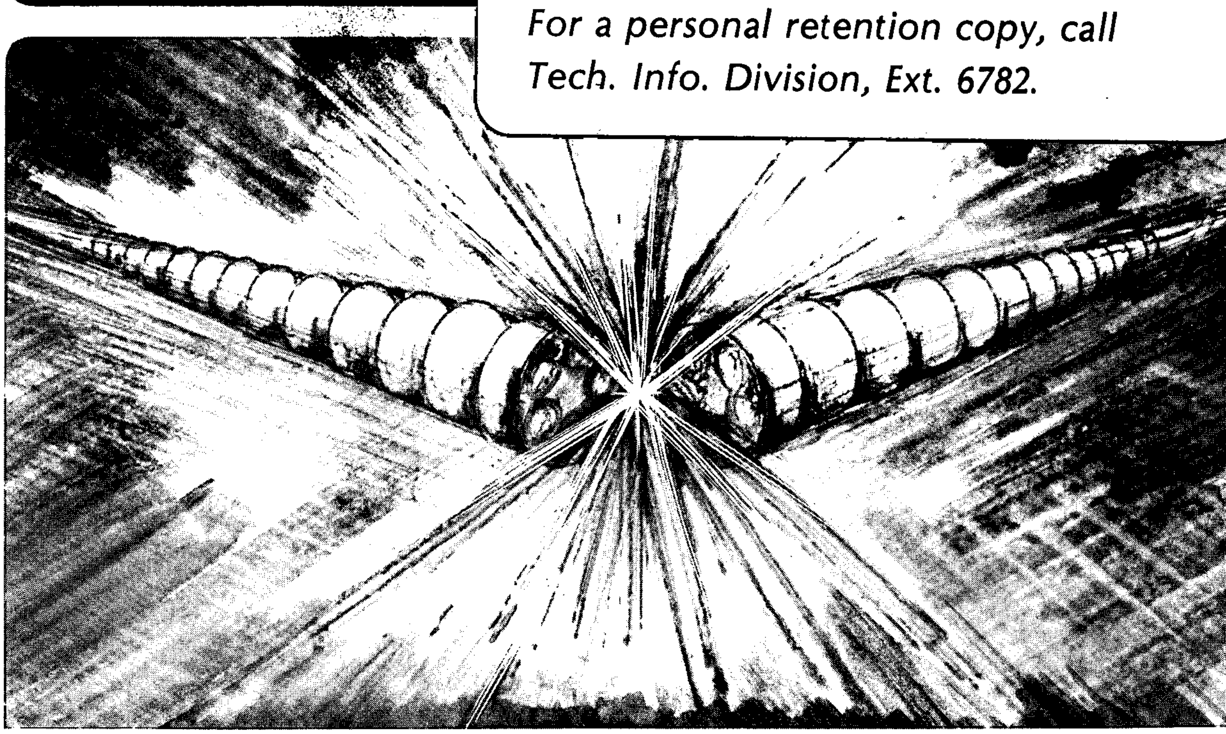

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Summary

A device that can produce synchrotron radiation whose polarization is arbitrary and adjustable is proposed here. The polarization can be linear and be switched between two mutually perpendicular directions, or it can be circular and be switched between right and left circular polarizations. The system works on electron storage rings with small electron beam emittance, and can cover a wide range of photon energies.

A schematic of the proposed system is shown in Fig. 1. It consists of two identical parts, one of which is rotated 90° relative to the other. Each part consists of a planar N period undulator with period length λ_u and an additional magnet, which will be referred to as the modulator (shown in the figure as the shaded block). The modulator can be considered as a variable field single period undulator of period length λ_M.

An electron passing through the system will give rise to a radiation with the following polarization vector

$$\underset{\sim}{\varepsilon} = \frac{1}{\sqrt{2}} (x + e^{i\alpha} y) \quad . \tag{1}$$

Here α is given by

$$\alpha = \frac{\pi}{\lambda\gamma^2} \left(N\lambda_u \, (1 + K^2/2) + \lambda_M (1 + K_M{}^2/2) + D \right), \tag{2}$$

where λ is the wave length of the observed photons, $D = D_1 + D_2$, and K and K_M are the deflection parameters of the undulator and the modulator respectively. The deflection parameter is defined to be 0.934 times the peak magnetic field in tesla times the undulator period in cm. The radiation is peaked at

$$\lambda = \lambda_u(1 + K^2/2)/(2\gamma^2 n) \quad , \qquad (3)$$

where n is a positive integer. In this note, only the first harmonic n = 1 is considered.

If the two undulators are placed parallel rather than perpendicular to each other, the polarization will be linear. However, the radiation intensity will have an interference pattern due to the factor $|1 + e^{i\alpha}|^2$ superimposed on the undulator spectrum. The system then becomes identical to the optical klystron.

Equation (1) corresponds to the general case of elliptically polarized light. As one varies α between 0 and 2π, the polarization ellipse changes as shown in Fig. 2. Therefore, one can obtain any desired polarization by adjusting α.

The phase α can be changed by either of the following two methods: First, the distance D can be changed mechanically. The advantage of this method is that the radiation intensity remains constant during the modulation of the polarization. However, this method cannot exceed a frequency of polarization change much greater than 1 Hz. Alternatively, the magnetic field of the modulator can be changed. This can be done at a rate of 1 kHz or more. However, the radiation intensity changes as α changes. If the distance between the first undulator and the modulator D_1 is chosen properly, the relative intensity variation $\Delta I/I$ can be minimized and is given by

$$\frac{\Delta I}{I} \approx \frac{1}{N^2K^2} \frac{\lambda_u}{\lambda_M} (1 + K_M{}^2/2) \quad . \tag{4}$$

The variation of α by π is assumed here.

The angular spread of the electron beam limits the degree of the obtainable polarization P. It can be shown that

$$1 - P = \frac{1}{2}\left(\alpha_0 \frac{\sigma_\lambda}{\lambda}\right)^2 + \left(2\pi\eta \frac{\gamma^2\sigma_\theta{}^2}{1 + K^2/2}\right)^2 \tag{5}$$

Here α_0 is the phase of the ideal case given by Eq (1), σ_θ is the $1 - \sigma$ value of the electron angle with respect to the z-axis and

$$\frac{\sigma_\lambda}{\lambda} = \sqrt{\left(\frac{\Delta\lambda}{\lambda}\right)^2 + 4\left(\frac{\sigma_\gamma}{\gamma}\right)^2}$$

$$\eta = N + \frac{\lambda_M + D}{\lambda_u} \quad .$$

In the above, $\Delta\lambda$ is the monochromator band-pass and σ_γ is the $1 - \sigma$ electron energy spread.

(1 - P) in Eq. (5) gives merely the fraction of the unpolarized part of the total flux, and has nothing to do with the shape of the polarization. If P = 0.8, for example, the polarization is only 80%. However, the polarization ellipse can be of any shape. In particular it can be exactly circular.

Eq. (5) requires the angular spread σ_θ to be small in order to have the large N value. Recall that N needs to be large in the method of the magnetic modulation to minimize the intensity variation given by Eq. (4).

Table I gives parameters of two example systems, the first based on the VUV ring at NSLS and the second a future ring such as those proposed by LBL and SSRL. The angular spread of $\sigma_\theta = 0.02$ mrad is consistent with the emittance of these rings if a special high-β straight section is introduced. The total flux on samples is estimated to be $\geq 10^{12}$ photons per second for both examples. This estimate assumes a combined optical efficiency of $\leq 1\%$ due to reflection losses from mirrors and gratings.

In the examples, the polarization is assumed to be modulated magnetically. In the case of the mechanical modulation, the parameters are similar but the intensity variation will be zero. The modulation distance ΔD is 10 cm for the first and 3 cm for the second example. These examples show that the proposed system is potentially an extremely versatile source of polarized radiations.

Acknowledgements

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Table I. Parameters of Example Systems

	Ring	
	VUV (NSLS)	Future
E (GeV)	0.75	1.3
σ_θ(mrad)	9.0×10^{-2}	2×10^{-2}
K	$\sqrt{2}$	1
N	5	30
λ_u(cm)	10	4
λ_1(Å)	470	47
λ_M(cm)	10	4
B_{M1}(kG)[a]	2.14	2.68
B_{M2}(kG)[a]	2.62	4.23
$\Delta I/I$(%)	4	0.17
σ_λ/λ(%)	0.4	0.14
P(%)	86	84

[a]B_{M1} = lower value of modulator magnetic field; B_{M2} = upper value of modulator magnetic field.

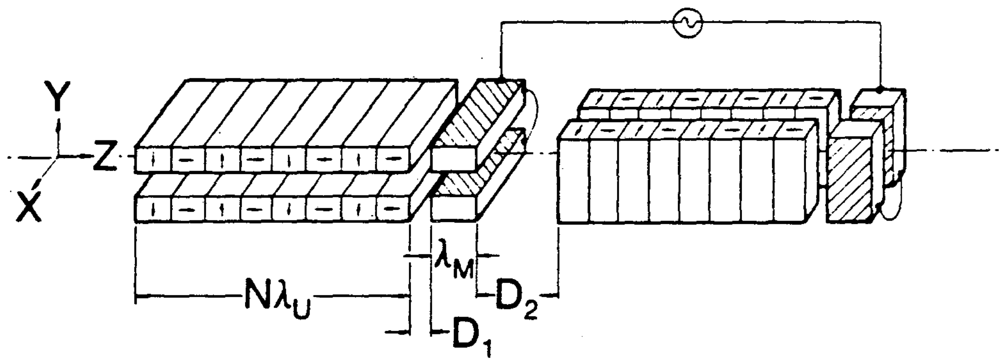

Fig. 1. Schematic of the proposed system.

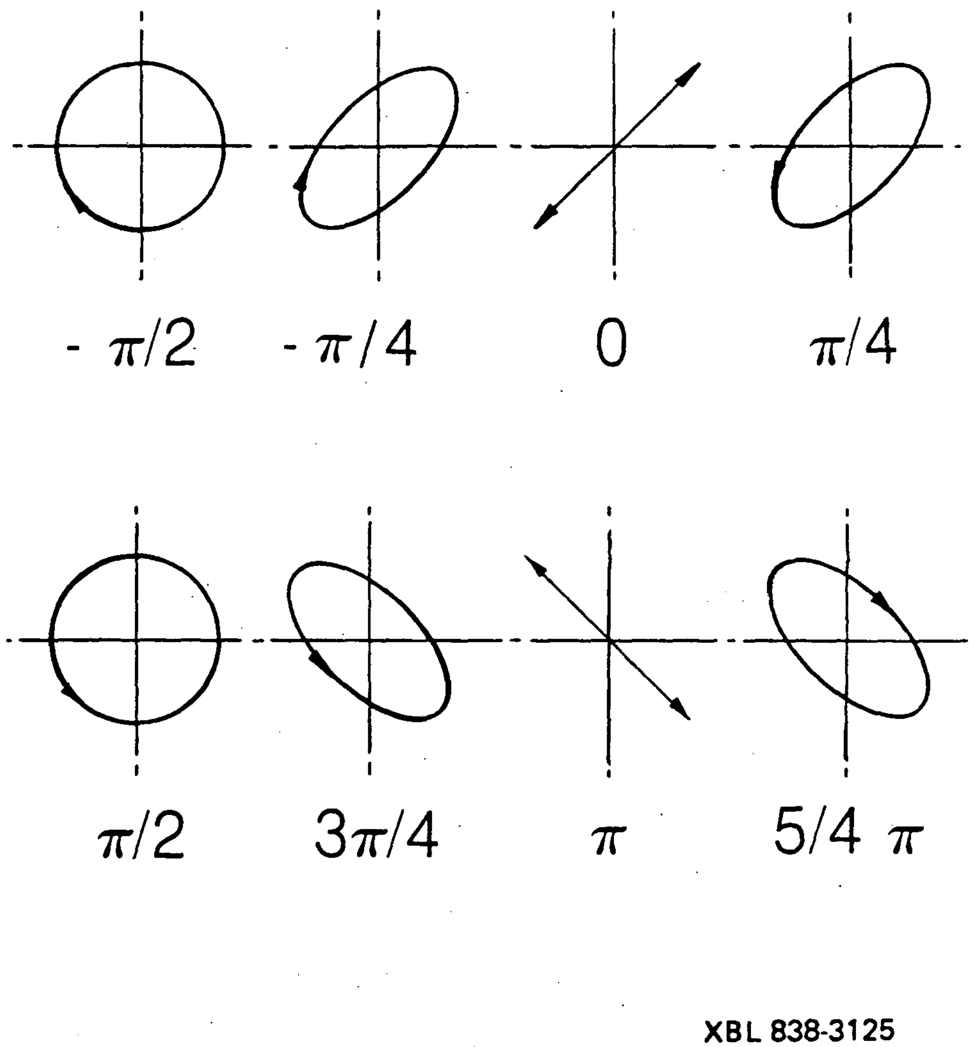

Fig. 2. Evolution of the polarization ellipse as α increases from $-\pi/2$ to $5/4\pi$. The α values are shown below the ellipses.

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