Self-Stimulated Undulator Radiation and its Possible Applications

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Abstract

The phenomena of self-stimulation of incoherent radiation emitted by particles in an undulator or in a system of undulators installed in the linear accelerators or quasi-isochronous storage rings is investigated. Possible applications of these phenomena for the beam physics and light sources are discussed.

Self-Stimulated Undulator Radiation (SSUR) is a radiation emitted by a charged particle in the field of downstream undulator and in the self-fields of its own wavelets emitted at earlier times in the same or another upstream undulators, reflected by means of mirrors, lenses and time-delay lines back to the particle's position at the entrance of the downstream undulator.

SSUR source based on the linear system of undulators.

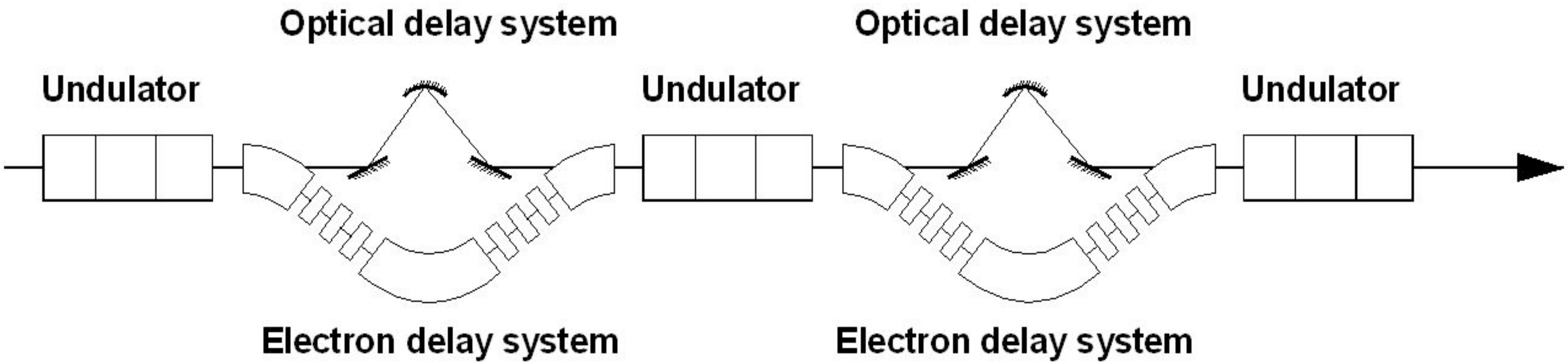


Figure 1: Schematic of the installation.

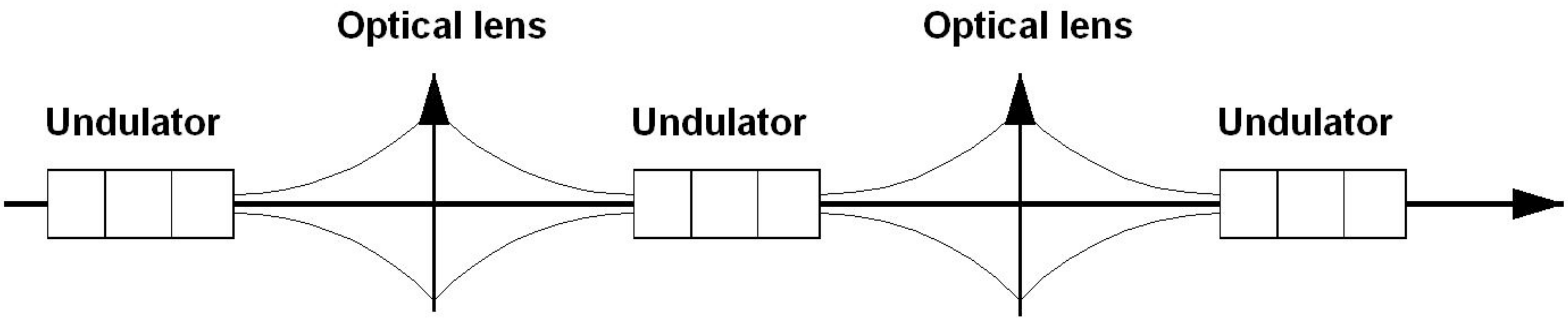


Figure 2: Equivalent optical scheme.

SSUR source based on storage rings

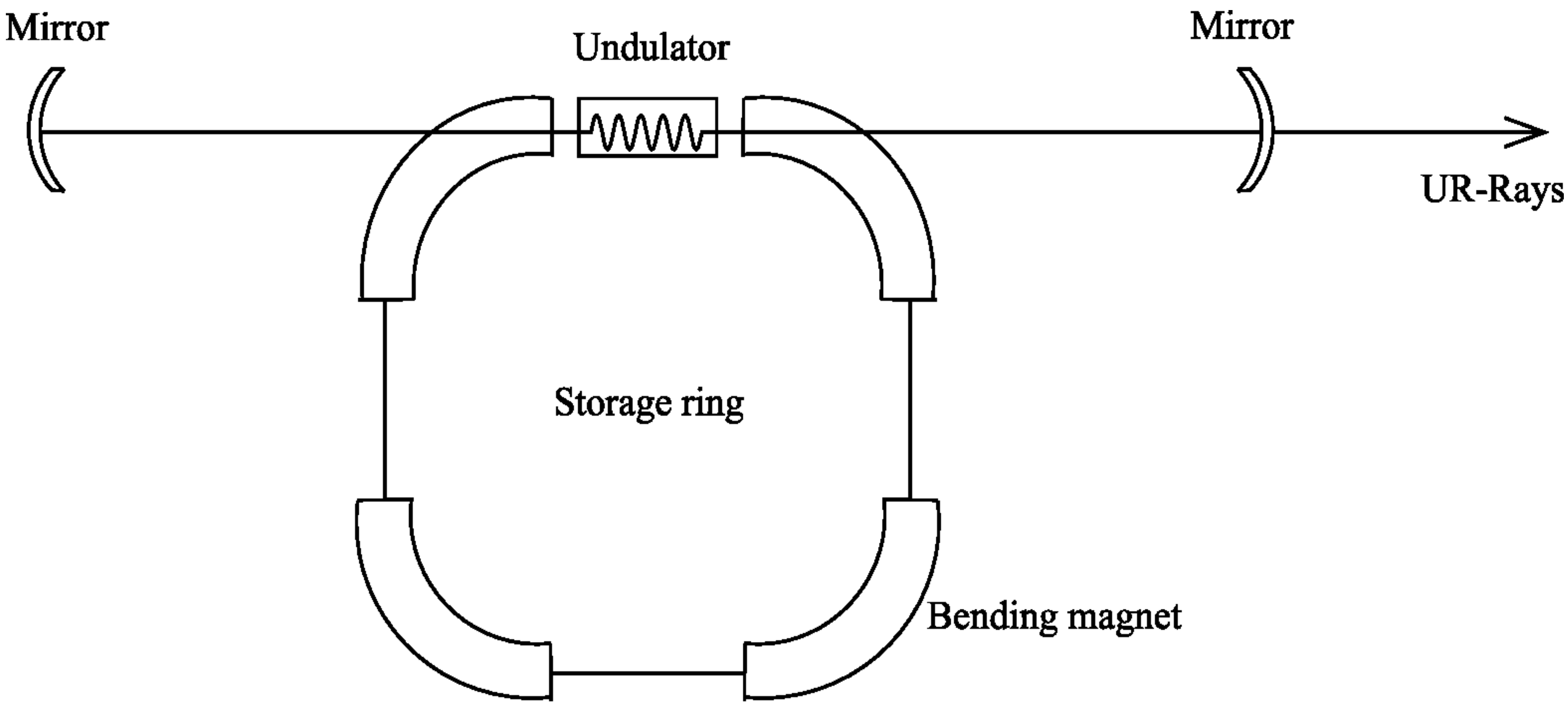


Fig.3. Schematic diagram of SSUR source built around a storage ring.

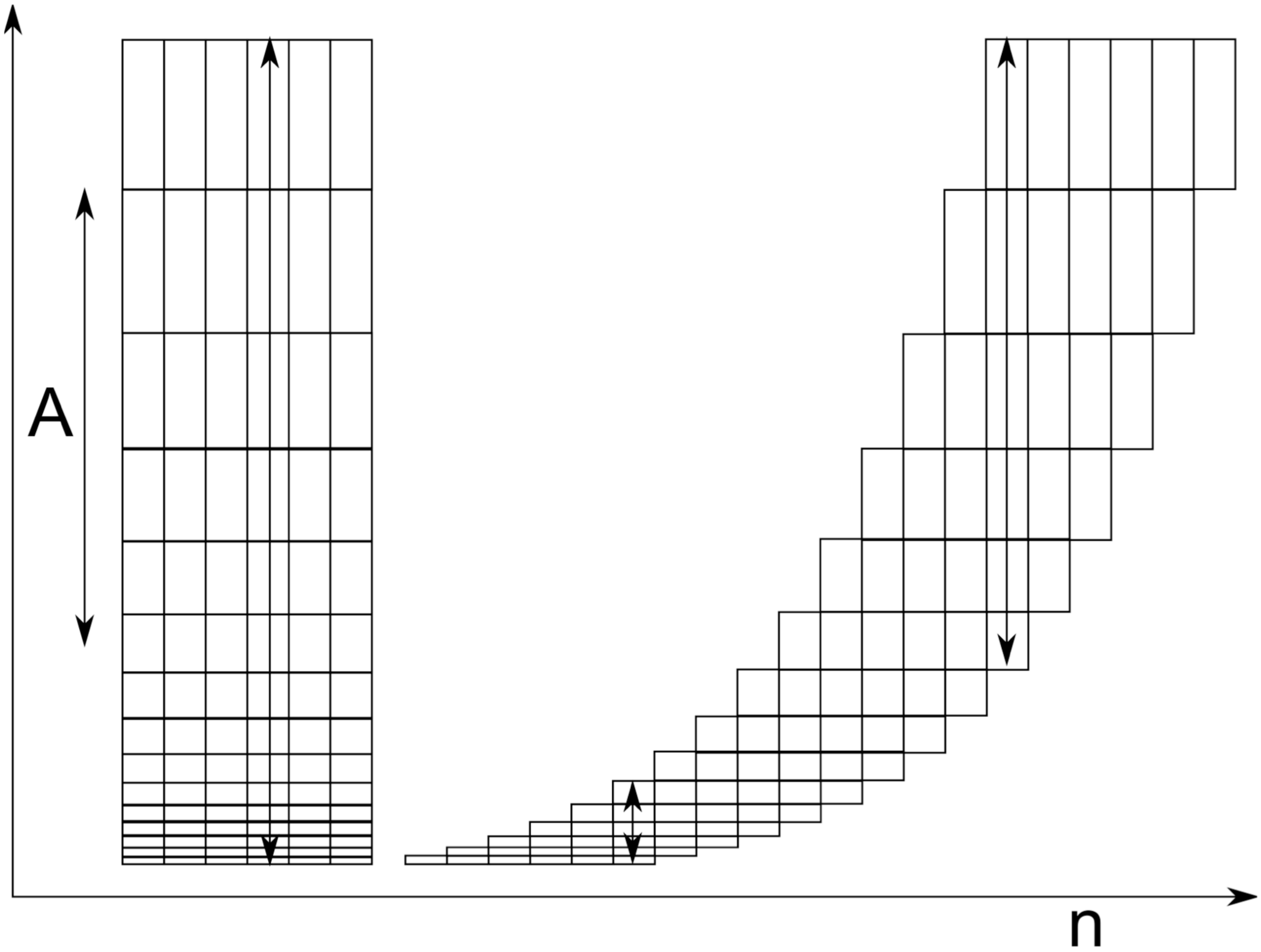


Fig.3. The evolution of the URW in the SSUR source.

The SSUR source based on a quasi-isochronous storage ring is equipped with an undulator installed in its straight section and the mirrors installed at both sides of undulators outside of the closed orbits of electrons, circulating in the ring. So the mirrors set an optical resonator. The URWs emitted by every electron are accumulated effectively in the optical resonator by the superposition one by another if theirs longitudinal shift per turn satisfies condition

$$|\Delta\, l - n\lambda_m| \le \lambda_m / F, \quad n = 0,\ \pm 1,\ \pm 2, \ldots |n| \le M,$$

where M is the number of the undulator periods, n=1 corresponds to main and n>1 to collateral synchronicity condition.

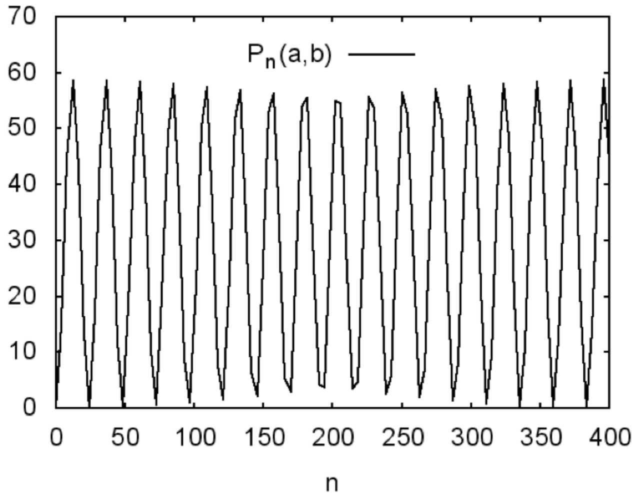
The electric field strengths of an URWs emitted by a particle during its pass through the undulator on the *n-th* turn in the storage ring can be presented by the expression .

$$E(t,n) = E_0 \sum_{n=1}^{n} \sin[\omega_1(t-(n-1)\Delta t)]\; e^{-(n-1)\beta} = E_n \sin(\omega_1 t + \xi_n),$$

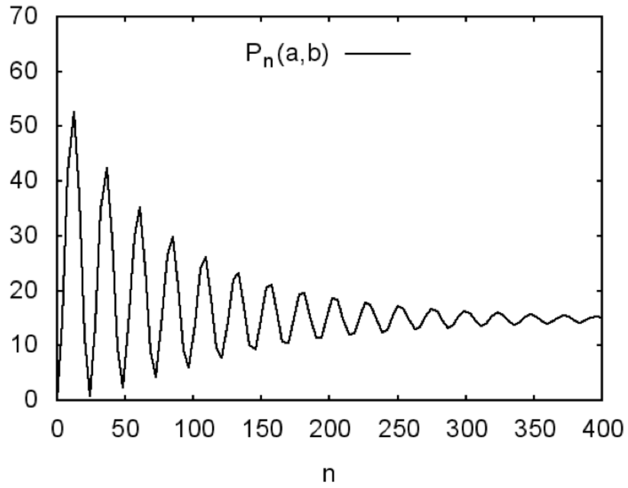
$$E_n = E_0 A_n, \quad A_n = \sqrt{a_n^2 + b_n^2}, \quad a_n = \frac{1 - e^{-\beta}\cos a - e^{-\beta n}\cos(an) + e^{-\beta(n+1)}\cos[a(n-1)]}{1 - 2e^{-\beta}\cos a + e^{-2\beta}},$$

$$b_n = \frac{e^{-\beta}\sin\alpha - e^{-\beta n}\sin(\alpha n) + e^{-\beta(n+1)}\sin[\alpha(n-1)]}{1 - 2e^{-\beta}\cos a + e^{-2\beta}}, \quad \xi_n = \arccos a_n / A_n,$$

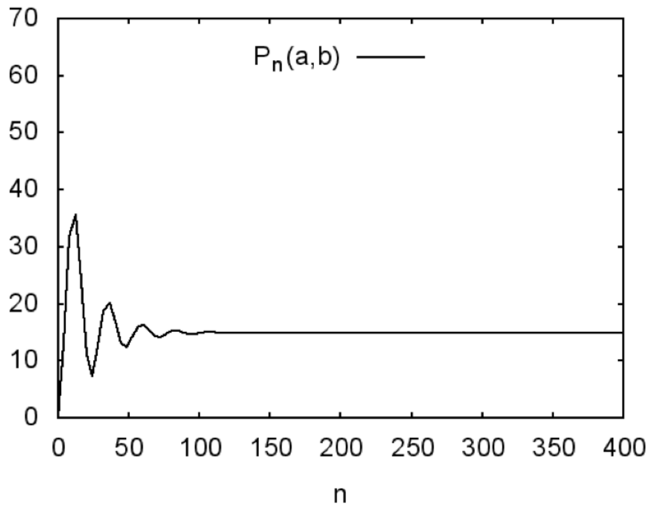
$$\alpha = \omega_1 \Delta t, \qquad \beta = 2\pi / F.$$



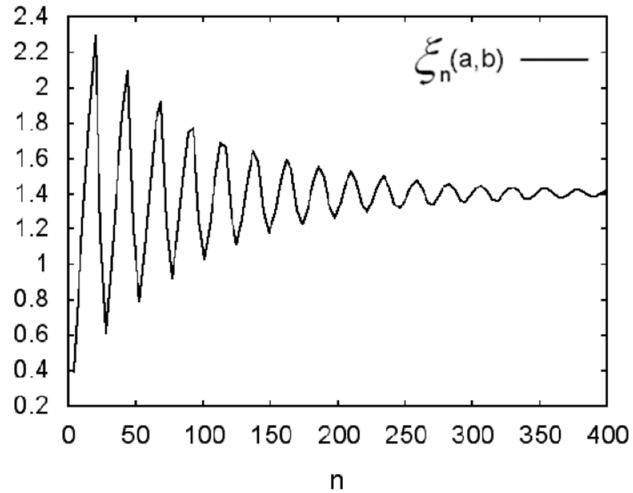
(a)



(b)



(c)



(d)

Figure 4: Time dependence of the SSUR power emitted by a particle at $n_c >> n_\tau$.

$\alpha = \pi / 12,\ \beta = 0$ (a); $\alpha = \pi / 12,\ \beta = 0.01$ (b); $\alpha = \pi / 12,\ \beta = 0.05$ (c), $\alpha = \pi / 12\ \ \beta = 0.01,$ (d), $P_n = (A_n / A_1)^2$.

Under the main synchronicity condition *n=0* the properties of the spontaneous incoherent UR emitted by electrons are not changed, except intensity, which becomes higher by $F/2\pi$ times. At collateral synchronicity conditions the URWs are shifted by the distances multiple to the wavelength for the next URW relative to previous one, the intensity is dropped, but the monochromaticity is increased with the number *n*.

Synchronicity condition determines the limiting energy spread, amplitudes of betatron oscillations and emittance of the electron beam: $\Delta\varepsilon_r/\varepsilon < \lambda_m/CF\eta_c$,

$$A_{b,x,z} < \sqrt{\lambda_m \lambda_{x,z}/F\nu_{x,z}}/\pi, \qquad \in_{x,z} < 2\lambda_m/\pi F\nu_{x,z}. \qquad \Delta\varepsilon_b/\varepsilon < 2M\lambda_m/C\eta_c.$$

Frictional cooling of electron and ion beams

There are two ways to the particle beam cooling. They are based either on friction or on the limiting the inter-particle spacing (follow the particle of the beam and force the particle to shift to the center of the beam). According to the generalized Robinson damping criterion

$$\alpha_{6D} = (1 + \frac{1}{\beta^2})\frac{\overline{P}_{Fr}(\varepsilon)}{\varepsilon} + \frac{\partial \overline{P}_{Fr}(\varepsilon)}{\partial \varepsilon}.$$

Resume

SSUR source based on either the ordinary and compact storage rings using the static or laser undulators, electron or ion beams, ordinary or Bragg resonators are able to generate both short and continuous, quasi-monochromatic light beams in the optical to X-ray regions.

The schematic SSUK could be used effectively in different methods of optical cooling of particle beams (ion, muon) in ordinary (non isochronous) damping rings. So these systems can serve as an effective pick-up undulator, for example.

According to optical cooling principle the optical parametric amplifier(s), controllable screens and kicker undulators could be located in the subsequent straight sections.

SSUKs could be used effectively both in ordinary and pre-bunched FELs.

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2) http://arxiv.org/abs/1003.3747

3) http://arxiv.org/abs/1009.3724

Thank you for the attention