A PULSED SOFT X-RAY SOURCE WITH TUNABLE REPETITION RATE

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Abstract

We present the conceptual design of a scheme to produce pulses of soft x-ray radiation from a storage ring at a tunable repetition rate which can be much lower than the machine revolution frequency, while simultaneously providing high average flux photon beams for the remaining beamlines. We propose to use a set of four fast kicker magnets to displace the electron beam in the vertical plane as it traverses an undulator magnet and modulate the photon beam intensity at the desired frequency by means of a narrow slit located in the soft x-ray beamline downstream of the undulator. In order to reduce the stringent requirements on kicker strength, kicker locations are optimized, a low vertical beta is used in the undulator straight section and the x-ray optics in the beamline is set to form an image of the electron beam at the position of the slit.

1 INTRODUCTION

The time structure of the radiation produced in a synchrotron light source is a copy of the time structure of the electron beam circulating in the storage ring. In the case of the Brazilian Synchrotron Light Source, the circulating electrons are grouped in up to 148 bunches with a bunch-to-bunch spacing of about 2 ns, corresponding to the 311 ns revolution period. As a result, when all bunches are filled, light pulses are observed in the beamlines at a 476 MHz repetition rate. In some applications however (e.g. time-of-flight spectroscopy), lower repetition rates are required and those needs are often satisfied by operating the storage ring in single-bunch mode, which makes the photon repetition rate equal to the machine revolution frequency. In some machines, this special filling mode may be combined with fast x-ray shutters to provide a tunable light pulse repetition rate. However, this solution has two drawbacks: first, in some cases (particularly for small storage rings) the revolution frequency is not low enough for experimental requirements and the switching time of mechanical shutters is too long; second, single bunch operation normally prevents other users, who are only interested in high average flux, from using the machine. As a result, only few weeks of beam time each year are normally dedicated to single-bunch operation in most light sources around the world.

In this work we propose a scheme to allow full control of the light pulse repetition rate at one beamline without affecting normal operation of other beamlines.

2 PRINCIPLE OF THE METHOD

We propose to use a set of four fast kickers to displace the beam orbit vertically inside an undulator magnet so that the radiation produced by the insertion device can be intercepted by a downstream narrow slit. In this way, the electron beam displacement can be used to modulate the light flux in the undulator beamline at the desired frequency. In order to allow other beamlines to operate normally, a special bunch filling pattern is used, in which a single solitary bunch is stored diametrically opposed to a long train of bunches. The gaps between the solitary bunch and the bunch train must be long enough to allow for the kicker rise and fall times, so that only the solitary bunch is affected by the orbit deviation. Moreover, in order to avoid affecting the radiation seen by other beamlines, the orbit deflection must be localized to the undulator section.

3 REQUIRED BEAM DISPLACEMENT

The major difficulty in implementing the proposed scheme lies in obtaining the necessary kicker strengths with a short risetime, large enough repetition rate and good pulse-to-pulse repeatability. Moreover, the orbit displacement must be a closed bump and non-closedness due to various errors (systematic and random) must be kept within tight tolerances. A non-closed bump will cause the solitary bunch to undergo betatron oscillations for many turns, producing spurious light pulses at the undulator beamline and disturbing other beamlines as well. It is therefore important to choose system parameters in order to minimize the required beam displacement and the corresponding kicker strengths.

The required beam displacement is determined by the light intensity that will be allowed to pass the slit when the beam is centred on the slit as compared to the intensity that will go through when the beam is off-centre, since any light that reaches the experimental station when the beam is off-centre will simply increase the background, producing spurious counts, not related to the passage of the solitary bunch that provides the start signal for the experiment. These considerations set a maximum ratio of non-illuminated (off-centre beam) to illuminated (centred beam) conditions of 3%, or conversely a 97% reduction in beam light intensity after the slit as the beam is returned off-centre at the end of the kicker pulse.

Given a displacement y_0 of the electron beam and a vertical slit of height s, we calculate the corresponding reduction in light intensity, assuming that the beamline optics produces an image of the electron beam at the position of the slit. Since the undulator is a longitudinally extended source, and the photon beam optics is set to image the source *at the centre* of the insertion device, we first estimate an effective transverse (vertical) source size at the centre of the undulator by convoluting the electron beam spatial distribution with a projection of the radiation angular distribution. The radiation angular distribution is a result of a convolution of the electron beam angular distribution with the natural photon angular distribution. The vertical beam size and divergence along the undulator are given by

$$\sigma_y(s) = \sqrt{\varepsilon_y\left(\beta_{y0} + \frac{s^2}{\beta_{y0}}\right)}$$

$$\sigma'_y(s) = \sqrt{\frac{\varepsilon_y}{\beta_{y0}}}$$

where β_{y0} is the vertical betatron function at the centre of the undulator , ε_y is the vertical beam emittance and s is the distance from the centre of the straight section. The natural divergence of the undulator radiation is

$$\sigma'_{ph} = \frac{1}{\gamma}\sqrt{\frac{1+\frac{K^2}{2}}{2Nh}}$$

where γ is the electron beam relativistic factor, K is the undulator parameter, N is the number of periods and h is the undulator harmonic of interest. In our calculations we assume K=3.4, N=53, h=1 and a 3.0 undulator length. We can now write the effective projected RMS beam size of the light source produced by a slice of the undulator located at distance s from the centre of the undulator as:

$$\sigma_e^2(s) = \sigma_y^2(s) + s^2\left(\sigma_y'^2 + \sigma_{ph}'^2\right)$$

and consider the average along the undulator

$$\sigma_{eff}^2 = \frac{1}{L}\int_0^L \sigma_e^2(s)ds = \varepsilon_y\beta_{y0} + \frac{L^2}{3}\left\{2\sigma_y'^2 + \sigma_{ph}'^2\right\}$$

Figure 1 shows a plot of the effective beam size as a function of β_{y0} where we see the minimum at $\beta_{y0} = \sqrt{2/3}L$.

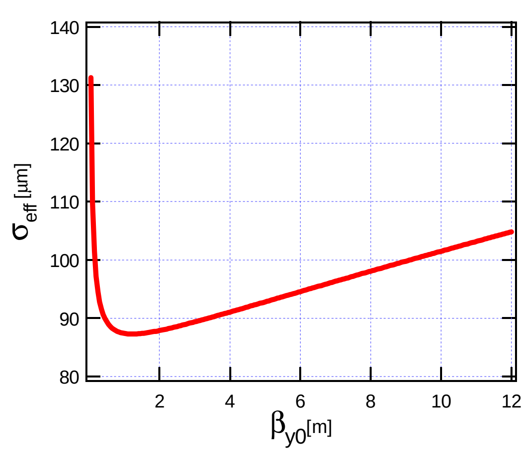

Figure 1: Effective source size as a function of the vertical beta function at the centre of undulator.

The transmission through the slit of height s for a displacement y_0 is given by:

$$I(y_0) = \frac{1}{\sqrt{2\pi}\sigma_{eff}}\int_{-\frac{s}{2}}^{\frac{s}{2}} \exp\left(\frac{-(y-y_0)^2}{2\sigma_{eff}^2}\right)dy$$

and the light obstruction associated with a displacement y_0 is given by:

$$O = \frac{I(\delta_0)(i_s + i_{bt}) - (I(y_0+\delta_0)i_s + I(\delta_0)i_{bt})}{I(\delta_0)(i_s + i_{bt})}$$

where we have introduced the currents in the solitary bunch (i_s) and in the bunch train (i_{bt}) and considered the fact that only the solitary bunch is displaced when that kickers are fired. Also, we have assumed the possibility of an initial fixed displacement δ_0 , which may be used to further reduce the required pulsed beam displacement by positioning the slit on the slope of the gaussian profile of the beam rather than on the peak of the distribution, where the intensity variation with position is minimum, at the cost of reducing the intensity during the pulses. Figure 2 shows a plot of the obstructed fraction as a function of beam displacement for four different cases: standard and low beta optics mode of the storage ring and with or without an initial fixed displacement of 150 µm. We note that the use of the low beta mode (rather than the standard mode) allows a reduction of about 20% in the required beam displacement for a given intensity obstruction. The specified 97% obstruction can be reached with a 260 µm pulsed displacement if we assume a fixed initial displacement of δ_0=50 µm and a 200 µm slit. For these parameters, $I(\delta_0) = 49\%$, i.e. , about half the radiation intensity produced by the solitary bunch in the undulator is intercepted by the slit during the kicker pulses.

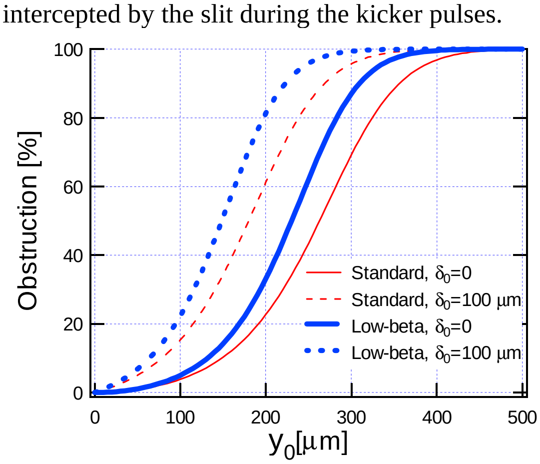

Figure 2: Obstructed fraction of light intensity as a function of pulsed beam displacement for different machine optics and different initial DC displacement δ_0.

4 KICKER STRENGTH

We consider the lay-out of one superperiod of the LNLS 1.37 GeV six-fold symmetric electron storage ring (Figure 3) and the possible locations for the fast kickers.

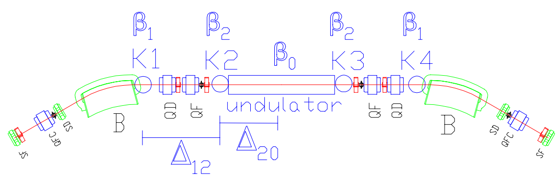

Figure 3: Lay-out of one superperiod of the LNLS storage ring. The fast kicker positions are indicated by circles.

We assume a symmetric lay-out of the kickers with respect to the centre of the straight section so that the strengths for kickers 3 and 4 are the same as 2 and 1. In order to minimize the kicker strengths we consider the best positioning for the kicker magnets as well as the possibility of changing the storage ring beam optics in the undulator straight section by adjusting the value of the beta function at the centre of the straight section. Figure 4 shows the value of the largest (in absolute value) of the two kicks as a function of β_0 for various values of the betatron phase advance Δ_{12}. The plot indicates that the kicker strength can be reduced by bringing Δ_{12} closer to 90 degrees and reducing β_0. This implies installing the first kicker as close as possible to the upstream bending magnet and implementing a low vertical beta mode for the storage ring.

Table 1 shows the parameters for such a mode and the resulting specifications for the necessary kicker strengths for a 1 mm orbit displacement. With those parameters, the kicker strength required for the 260 μm displacement specified in the previous section is 133 μrad. For comparison, note that the corresponding kicker strengths for the standard optics (β_0 = 12.3 m) with all four kickers located right beside the undulator in the field free straight section (Δ_{12}=3.7°) would be a factor 4 higher. The parameters shown here for the kicker magnets are within reach of current technology for the pulsers of travelling-wave kickers [1].

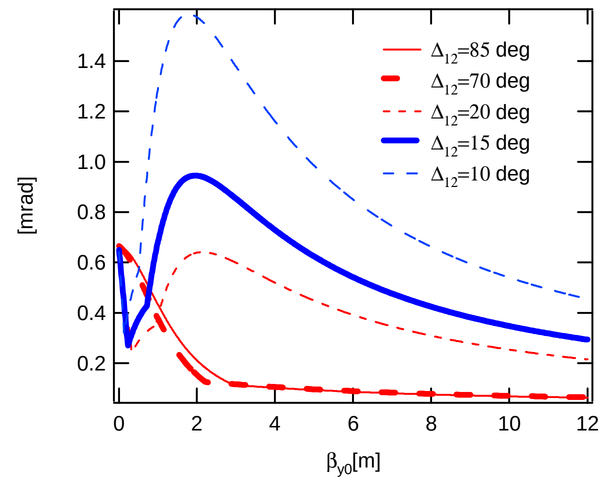

Figure 4: Maximum kicker stength per mm orbit displacement as a function of the vertical beta function at the centre of the straight section for various values of the betatron phase advance between the first two kickers.

β_{y0}	0.8	[m]
β_{y1}	21.03	[m]
β_{y2}	3.61	[m]
Δ_{12}	15.1	[deg]
Δ_{02}	61.9	[deg]
θ_1	0.44	[mrad/mm]
θ_2	-0.51	[mrad/mm]

Table 1: Kicker and optical parameters.

5 CONCLUSIONS

We have presented a proposal for a variable repetition rate soft X-ray beam line in the LNLS storage ring. Our proposal makes use of a set of four fast kickers to displace the beam orbit inside an undulator so that the radiation produced in the insertion device can be intercepted by a downstream slit. The storage ring optics and kicker positions were optimized to reduce the stringent requirements on the fast kickers and the resulting system parameters are found to be within reach of current kicker and solid state high voltage switch technologies. The method can be useful to other machines with short circumference where there is a demand for time resolved spectroscopic studies using synchrotron radiation.

REFERENCES

[1] B.L.Grishanov et at, *Very Fast Kicker with High Repetition Rate for Accelerator Applications*, NIM A 396, (1997) 28-34.