PRODUCTION OF COHERENT SYNCHROTRON RADIATION AT THE CANADIAN LIGHT SOURCE

W. A. Wurtz and L. O. Dallin, Canadian Light Source, University of Saskatchewan,
11 Perimeter Road, Saskatoon, Saskatchewan, S7N 0X4, Canada

Abstract

Preliminary observations of coherent synchrotron radiation (CSR) at the Canadian Light Source have been reported earlier. At that time a more suitable operating point was identified based on particle tracking calculations. These calculations showed that a large stable longitudinal phase space can be achieved through adjustment of the chromaticities. With the implementation of these operating conditions CSR has been produced with much improved beam lifetime. CSR has been produced both with multiple bunches at 1.5 GeV and with a single bunch at the nominal 2.9 GeV beam energy. The production of CSR with the new operating point has proven to be reliable and repeatable. Operations at the nominal beam energy allows for set-up times of under 20 minutes. With a beam lifetime (1/e) of over 7 hours single shifts dedicated to CSR production are now practical.

INTRODUCTION

In order to produce coherent synchrotron radiation (CSR) at the Canadian Light Source (CLS) we introduce negative dispersion into the straight sections in order to reduce the momentum compaction factor and produce shorter electron bunches. Previously we reported that tracking simulations indicate careful control of the horizontal chromaticity (chromaticity is defined as $\frac{d\nu}{d\delta}$) is required in order to ensure good energy acceptance during this procedure [1].

In this report we will briefly review the requirements for longitudinal stability with emphasis on what has become our normal CSR operating point. We further describe our experience in producing CSR at the CLS, making use of the former theoretical study. The end result is a reliable and repeatable algorithm for configuring the machine for CSR production.

LONGITUDINAL STABILITY

We previously reported on attempts to improve the storage ring performance for CSR production using tracking codes [1]. In this study we found that the energy acceptance of the storage ring is greatly influenced by the horizontal chromaticity. Three different operating tunes were proposed and each one required a different horizontal chromaticity to ensure good energy acceptance. In practice we have concentrated on using a horizontal tune of 10.22 and a vertical tune of 4.32, which are the tunes used for normal operations. A horizontal chromaticity of 6 was found to produce good energy acceptance when using a lattice configuration with small momentum compaction factor and these tunes. The horizontal phase space becomes heavily coupled with the longitudinal phase space when the momentum compaction factor is small. The vertical chromaticity does not have much effect on the energy acceptance as the vertical phase space is not strongly coupled to the longitudinal phase space. We use the nominal vertical chromaticity of 4.

We were able to determine the tunes and chromaticities from our models of the storage ring. However, our modelling was not able to determine what momentum compaction factor would produce useful CSR. From our operational experience, which we describe in detail in the next section, we found a useful momentum compaction factor to be 0.27×10^{-3}. Figure 1 shows how the energy acceptance of the storage ring as a function of the horizontal chromaticity when it is operated with a small momentum compaction factor. Notice how a horizontal chromaticity near 6 provides better energy acceptance. For reference, the fractional energy acceptance with the nominal momentum compaction factor of 3.77×10^{-3} is 0.015.

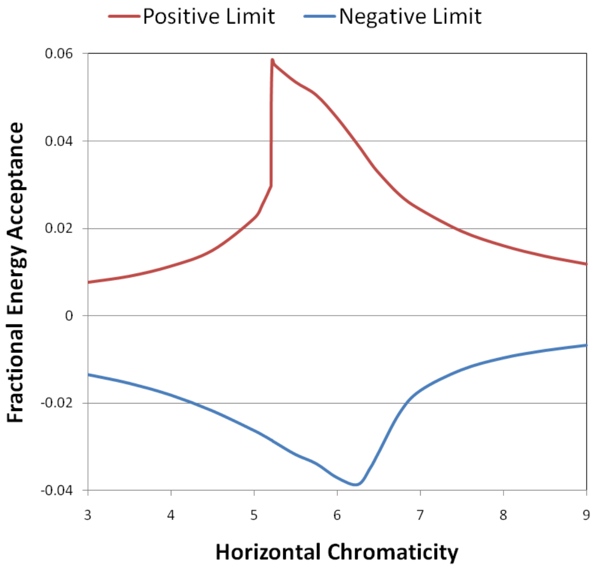

Figure 1: Model fractional energy acceptance of the CLS storage ring during CSR production as a function of the horizontal chromaticity with horizontal and vertical tunes 10.22 and 4.32 respectively, a momentum compaction factor of 0.27×10^{-3} and a vertical chromaticity of 4

When the momentum compaction factor becomes small, second-order effects play an increasingly important role in the determination of the stable area in longitudinal phase space [2]. The boundary of stable longitudinal phase space for normal operations is shown in figure 2 for comparison. This phase space diagram has a stable fixed point at (0,0) and an unstable fixed point near (-760 ps, 0). However, once we reduce the momentum compaction factor for CSR production, second-order effects introduce two new fixed points: an unstable one at (0, -0.045) and a stable one near (-760 ps, -0.045). The result is a second stable area and both the normal and second-order regions for our CSR operating point are shown in figure 3. Both these regions are stable but it is the normal region we use for CSR production. We have not yet observed the second order region at CLS. As second-order effects become more important, the normal stable area switches unstable fixed points and changes shape. Because of these second-order effects, we must give extra care in choosing chromaticities that give us good longitudinal stability.

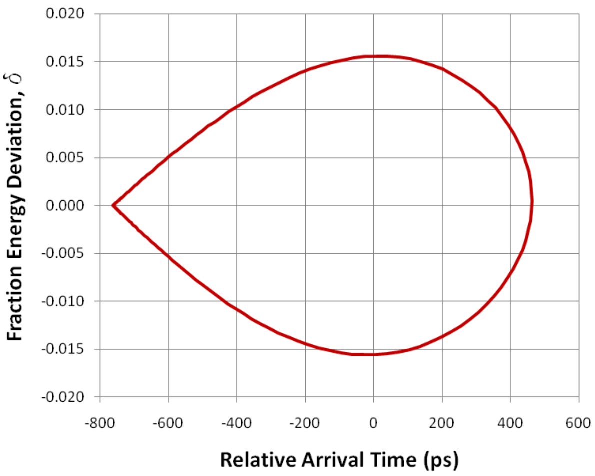

Figure 2: Boundary of stable longitudinal phase space area for normal operations

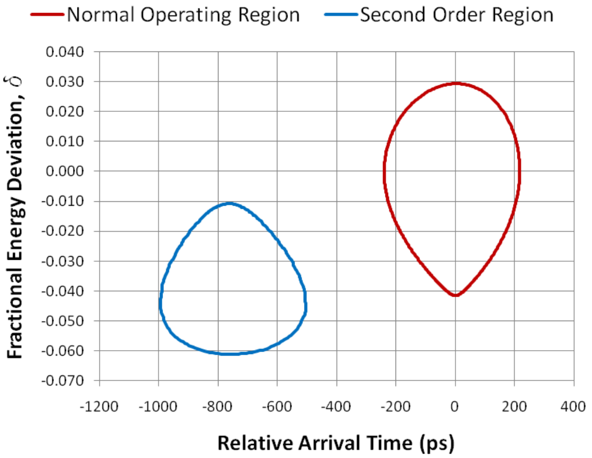

Figure 3: Boundary of stable longitudinal phase space area for CSR production with horizontal and vertical tunes 10.22 and 4.32 respectively, a momentum compaction factor of 0.27×10^{-3} and horizontal and vertical chromaticities of 4 and 6 respectively

OPERATIONAL EXPERIENCE

The production of CSR at CLS has become routine and four-to-six eight-hour shifts are assigned to dedicated CSR production each six-month operating cycle. We have produced CSR with electron beams at both the nominal 2.9 GeV energy and the lower energy of 1.5 GeV. Running at 2.9 GeV has the advantage of a shorter set-up time for the accelerator systems. Operating at 1.5 GeV has the advantage that bunches are naturally shorter as the bunch length is proportional to energy to the power $3/2$ [3]. In the past year CSR production at 2.9 GeV has been favoured due to ease of accelerator set-up; however there is no guarantee that this trend will continue.

To produce the needed short bunches we inject into a lattice configuration with the nominal bunch length and then decrease the bunch length by decreasing the momentum compaction factor. Injection into short bunches has been demonstrated at CLS, however, we are not yet able to inject into bunches short enough to produce CSR. Therefore, we begin by injecting into our nominal configuration with horizontal and vertical tunes 10.22 and 4.32 respectively and with dispersion in the straight sections of 0.15 m. This operating point has a momentum compaction factor of 3.77×10^{-3}. For operation at 2.9 GeV we typically inject into one or two bunches with about 8 mA per bunch. We use the bunch cleaning capabilities of our transverse feedback system [4] to ensure that we keep only the bunches with the most current as any low-current bunches will not produce CSR.

Next we adjust the horizontal chromaticity from its nominal value of 2 to 6, which gives us good energy acceptance for our CSR operating point. The vertical chromaticity is not changed.

Once we have set the chromaticities we begin lowering the momentum compaction factor by introducing negative dispersion into the straight sections while holding the tunes and chromaticities constant. This requires changes to the focusing strengths of all three quadrupole and the two chromatic sextupole families (the CLS lattice has no geometric sextupoles). The changes to the quadrupole strengths must be made in small steps to ensure that the beam is not lost. We are able to perform orbit corrections for most intermediate configurations but find that corrections at the CSR operating point are difficult and are generally avoided.

During this procedure we measure the synchrotron tune in order to determine the momentum compaction factor. The synchrotron tune is easy to measure using a vector signal analyser. We begin with a synchrotron frequency of 19 kHz, a momentum compaction factor of 3.77×10^{-3} and a bunch length of 33 ps. We routinely use a synchrotron frequency of 5.3 kHz for the production of CSR. Given that the momentum compaction factor is proportional to the square of the synchrotron frequency [5] we find that the momentum compaction factor for the production of CSR is 0.27×10^{-3}. The theoretical bunch length for the CSR operating point in the zero current limit is 7.0 ps. However, the actual bunch length is much longer due to the effects of potential well distortion [3]. Using a streak camera we measured a bunch length of 25 ps for a single bunch with 7.5 mA of current. Measuring the synchrotron frequency gives a simple and reliable metric for configuring the lattice for CSR production.

It is interesting to note that we have not been able to store more than 7.5 mA in a single bunch when we run at the new CSR operating point. Any attempt to store more current than this in a single bunch causes the excess current to be lost. Once the CSR operating has been reached, the 1/e lifetime is typically 7 hours.

By following this procedure the generation of CSR at the CLS with beam energy 2.9 GeV has become both reliable and repeatable. Because of our success with making short bunches for CSR, our single-bunch users have indicated a desire for running with short bunches in order to improve their timing resolution. These users do not need as low a momentum compaction factor as the CSR users because potential well distortion does not allow the real bunch length to be reduced beyond a certain value. A synchrotron frequency of 11 kHz, corresponding to a momentum compaction value of 1.2×10^{-3}, is sufficient and injection into this configuration has been demonstrated.

FUTURE PLANS

CSR producing shifts are expected to continue into the future and there are a number allocated on the present schedule. Work will continue to better understand this operating point and to improve production of CSR for our users. Given that injection into short bunches has been demonstrated, we will continue to work toward injection into bunches short enough to produce CSR. Once we can inject into the CSR operating point and no longer have to change quadrupole magnets while storing beam, we will work to implement orbit correction for the CSR operating point.

The 7.5 mA maximum current per bunch limit is not sufficiently well understood and we will be working to obtain a better understanding of the root causes and, if possible, eliminate them. We will also explore the different operating points outlined in our previous report [1] to see if these operating points can give us increased performance. Given our successes with reliably and repeatedly producing CSR at the nominal beam energy of 2.9 GeV, we desire to return to the lower energy of 1.5 GeV in order to apply our new operational experiences to this lower energy.

SUMMARY

Reducing the momentum compaction factor by introducing negative dispersion into the straight sections is the method that we use at CLS for creating short bunches used in producing CSR. By carefully controlling the horizontal chromaticity while we shorten the bunch, we are able to observe improved energy acceptance in our models. We have put this theory into practice and we have routine shifts dedicated to the production of CSR. We have had good success in developing a reliable and repeatable method for producing CSR. In the future we will continue to serve dedicated CSR shifts and will further develop and improve our methods for producing CSR.

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