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FIRST RESULTS OPERATING A LONG-PERIOD EPU IN UNIVERSAL MODE AT THE CANADIAN LIGHT SOURCE

W. A. Wurtz*, C. K. Baribeau, D. Bertwistle, M. J. Sigrist
Canadian Light Source, Saskatoon, Saskatchewan, Canada

Abstract

The Quantum Materials Spectroscopy Centre beamline at the Canadian Light Source (CLS) requires photons with energies as low as 15 eV with circular polarization at the end station. This energy range is accomplished on the 2.9 GeV CLS storage ring using an elliptically polarizing undulator (EPU) with a 180 mm period, which we call EPU180. In order to realize circular polarized photons at the end station with this low energy, we must overcome two technical issues. First, the beamline optics distort the polarization of the light, so we compensate by providing light with a flattened, tilted polarization ellipse at the source point – a mode of operation known as universal mode. Second, the device has a strong effect on the electron beam due to dynamic focusing and is capable of reducing the injection efficiency to zero. We overcome this non-linear dynamic focusing using current strips adhered to the vacuum chamber. In this report, we present the first results with operating EPU180 in universal mode and we recover the dynamic aperture using the current strips.

INTRODUCTION

Simulations predicted that EPU180 will have a significant effect on the storage ring beam dynamics [1]. To correct these issues we implemented active compensation using current strips adhered to the vacuum chamber [1–9].

This correction scheme is further complicated as EPU180 will operate in universal mode [3] where we break girder symmetry to produce arbitrary polarized photons. The beamline optics distort the photon polarization ellipse. Universal mode operation can compensate to provide circularly polarized photons at the beamline endstation [3, 10, 11].

To configure the EPU, we use the elliptical, ϕ_E and linear, ϕ_L phases as described[1] in [1]. For example, if we set the EPU180 gap to 29.83 mm with ϕ_E = -51.29 mm and $\phi_L = 0$, the EPU will output circularly polarized 21 eV light with Stokes parameter ideally $S3/S0 = +1$. However, the beamline polarimeter [12] measured $\sqrt{S1^2 + S2^2}/S0 = 0.413$ and $S3/S0 = 0.868$. Note that $(S1^2 + S2^3 + S3^2)/S0^2 < 1$ possibly indicating an unpolarized contribution or a measurement uncertainty. The goal is to minimize the linear contribution $\sqrt{S1^2 + S2^2}/S0$. By setting EPU180 to ϕ_E = -55.31 mm, adding a linear component with ϕ_L = -29.50 mm and adjusting the gap to 23.06 mm to maintain the 21 eV energy [13], the polarimeter measured $\sqrt{S1^2 + S2^2}/S0 = 0.015$ and $S3/S0 = 0.920$.

The above discussion uses the first polarimeter data taken at that energy and polarization. Subsequent measurements with better alignment and improved techniques produced improved results with less uncertainty. The beamline group is preparing a publication which will describe the polarimeter measurements in detail.

By distorting the polarization ellipse at the EPU, we have obtained circularly polarized light at the end station.

IMPLEMENTATION

In order to compensate for the strong dynamic focusing of EPU180, we use a model of the EPU and calculate kickmaps [14]. The EPU model consists of a single girder field, which we superimpose four times to model all four girders. We assume that we can add the field contributions in a linear superposition and the contributions from girders affecting each other is negligible. To create the model, we adjusted parameters in a RADIA [15] model to better match Hall probe measurements [16] and exported the single girder field. We calculate the kickmaps online at a rate of 10 kickmaps per second using a custom C code that we validated against RADIA.

We also implement a model of the current strips that will give us the magnetic field contribution of each strip. If we create a response matrix of such fields, we can invert it to find the strip currents that will provide the opposite kick to the beam as the dynamic focusing kickmap on the $z = 0$ plane. For this initial work, we used a current strip model with perfectly aligned strips of finite (as opposed to infinitesimal) dimensions.

Our implementation uses 12 strips on top of the vacuum chamber and 12 strips on the bottom. Because we are operating in universal mode with ϕ_E and ϕ_L simultaneously nonzero, we are not able to take advantage of symmetry and each strip requires its own power supply.

We implemented the full kickmap calculation in the control system so that, if a girder was commanded to make an illegal move not allowed by the (ϕ_E, ϕ_L) parameterization, the resulting correction would still be valid. An alternative implementation could be to perform the calculations offline and use a 3-dimensional lookup table with input parameters gap, ϕ_E and ϕ_L and output parameters the current strip currents.

TUNE MEASUREMENTS

The strong dynamic focusing of EPU180 can cause very large tune shifts. In principle, the current strips can cancel

* ward.wurtz@lightsource.ca

[1] In [1] we used the term “composite linear phase” with symbol ϕ_L^c, and this is equivalent to the “linear phase” of the present paper with symbol ϕ_L.

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the horizontal tune shift. Even in the ideal case there will be a residual vertical tune shift, similar to an ideal, planar insertion device.

The tune shift is worst for the vertically polarized mode, where we set $\phi_E = \pm 90$ mm. Figure 1 shows the measured tune shifts with and without current strip correction, and a simulated tune shift calculated using `elegant` [17] and the EPU180 model without current strips. The uncorrected horizontal tune shift is very large. The simulation has the same general trend as the measurement, but the simulation underestimates the horizontal tune shift. The current strips can significantly reduce the tune shifts, but there is an undesirable residual horizontal tune shift. This measurement suggests that we can expect to further reduce the horizontal tune shift by improving the models used in the correction calculation.

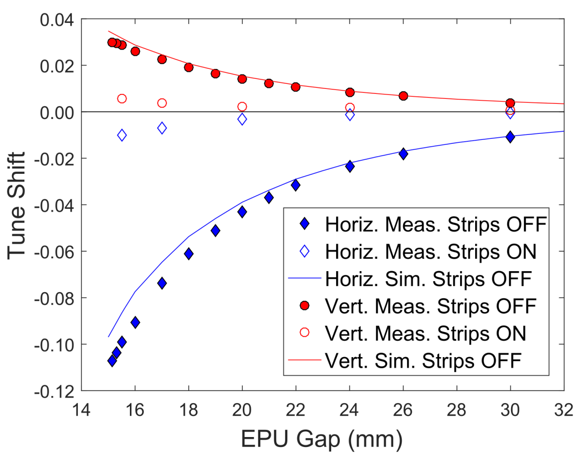

Figure 1: Measured (diamonds/circles) and simulated (lines) horizontal and vertical betatron tune shifts in vertical polarization mode with $\phi_E = 90$ mm and $\phi_L = 0$ with and without current strip correction.

We show the results for the vertical polarization mode because they are the most dramatic. The correction works similarly over several tested polarization modes with the horizontal tune shift being reduced but not yet eliminated.

INJECTION MEASUREMENTS

The strong, nonlinear dynamic focusing of EPU180 can severely impact the dynamic aperture. We see in Fig. 2 that EPU180 can reduce the injection efficiency to zero. Here, injection efficiency is defined as the fraction of electrons that are present in the booster ring just before extraction and are captured in the storage ring. At the time of these measurements it was nominally about 65%.

The current strips are able to mostly, but not entirely, restore the injection efficiency at a 15.5 mm gap. This is not surprising as simulations show that even in the ideal case, dynamic aperture is not fully restored [1]. Measurements at a 21.0 mm gap show complete restoration of injection efficiency.

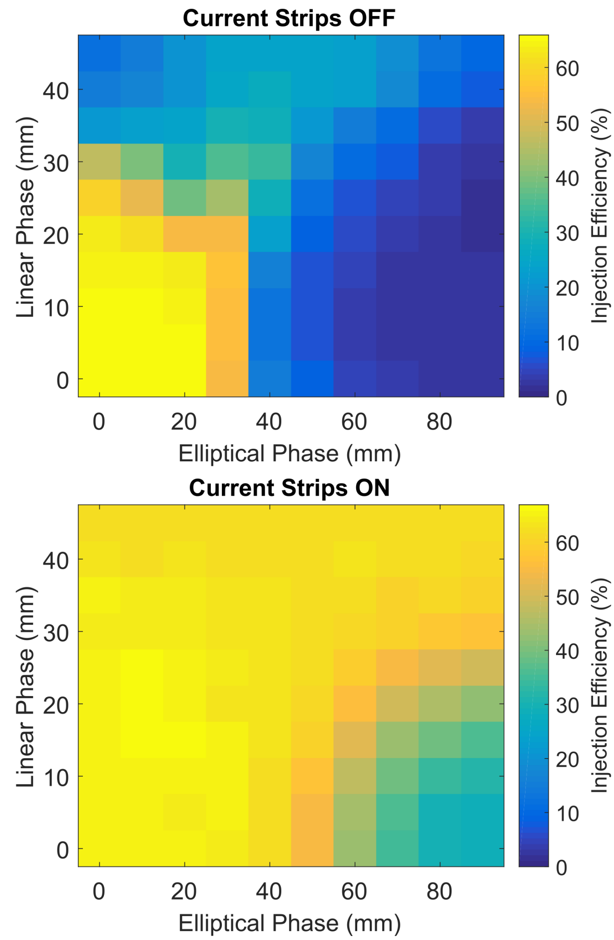

Figure 2: Injection efficiency measurements in the positive (ϕ_E, ϕ_L) quadrant at minimum gap 15.5 mm.

BEAM PROFILE MEASUREMENTS

We wish to minimize beam size variation due to EPU180. Uncoupled linear focusing, which generates the tune shift in Fig. 1, distorts the betatron functions. Horizontal-vertical coupling affects the vertical emittance. The coupling effect is especially important when $\phi_L \neq 0$ as the kickmaps show strong $x - y$ coupling in these modes.

We use the pinhole camera on the XSR diagnostic beamline [18] to measure the beam profile. The major and minor axes are the horizontal and vertical axes respectively, if the beam tilt is zero. In general, the beam viewed by the XSR camera is tilted a few degrees due to coupling in the storage ring.

We show the case for vertical polarization mode in Fig. 3 and see that the current strips can bring the beam size variation to be less than 10% for this mode. However, our camera shows only one location, and we have not yet disentangled global and local beam size effects to ensure that the variation is less than 10% around the entire ring. The unusual behavior at low gaps without current strip correction occurs when the horizontal tune approaches the integer resonance.

We show a scan of the minor axis beam size in the positive and negative (ϕ_E, ϕ_L) quadrants in Fig. 4. These are the two

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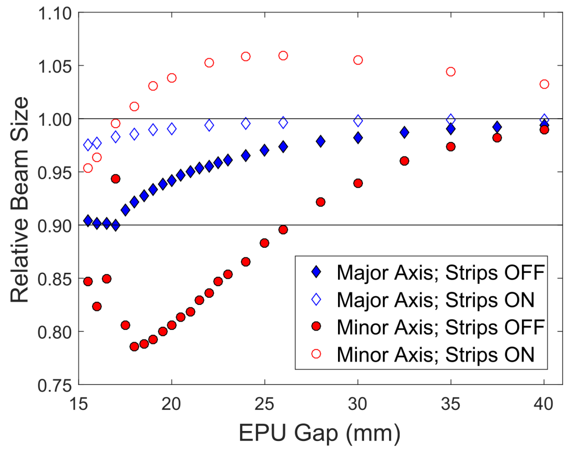

Figure 3: Relative beam size for the EPU in vertical polarization mode at $\phi_E = 90$ mm and $\phi_L = 0$ with the 0.90 relative beam size limit marked.

useful quadrants for this beamline, as they produce left and right circularly polarized photons at the end station. We do not expect to use the cross-quadrants. The relative beam size, compared with the EPU open case, varies in a non-trivial way with ϕ_E and ϕ_L and exceeds 10% for some configurations. At the moment we have placed restrictions on the available operating configurations of EPU180 in order to reduce its impact on beam size. Future models used in the correction will lessen the beam size variation, with the caveat that we cannot completely eliminate the vertical focusing using the current strips.

DISCUSSION

It is clear that the current strips drastically reduce the impact of EPU180 on the ring, but significant room for improvement remains. Our first step will be to implement an improved model of EPU180, created by further adjusting a RADIA model to better match measured Hall probe data, including off-axis data across various gap and polarization modes.

We also need to improve the model of the current strips. Our deployed current strip model assumes perfectly aligned strips at theoretical positions. Our previous attempts at creating an effective model [19] that would more accurately model the current strips was hampered due to a degeneracy in calculating strip positions from measured ratio matrices. Since the matrices themselves do not impose a length scale, they can determine the relative location of each strip but not the absolute locations. We plan to resolve this degeneracy by imposing a fixed separation between adjacent strips, which is reasonable, as the strips are implemented using a flexible printed circuit board. We also found that it is important to run the orbit correction system in the orthogonal plane when measuring ratio matrices.

We plan to implement universal mode operation for a second EPU, which has a 142 mm period and is less than half the

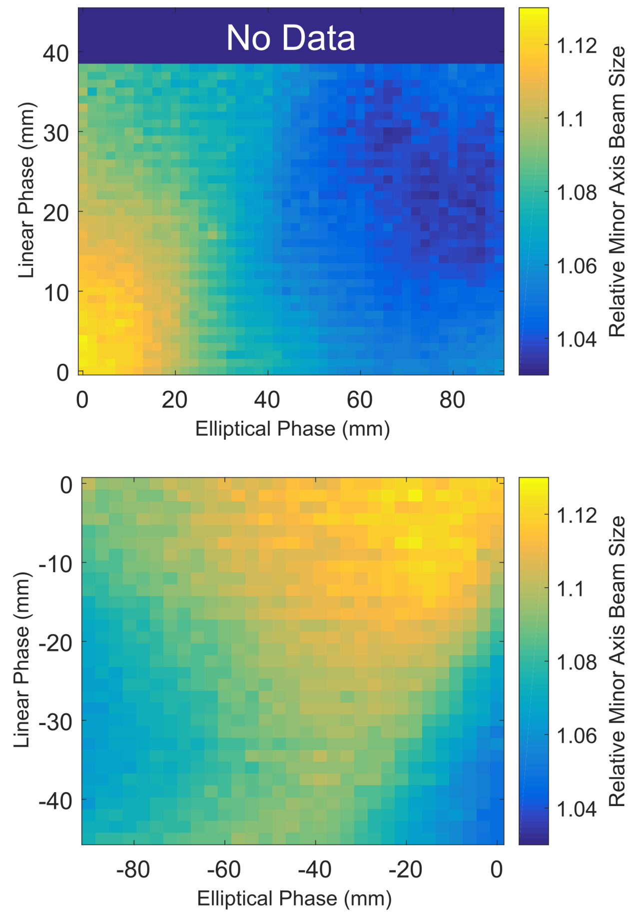

Figure 4: Minor axis beam size, relative to the EPU open case, in the positive and negative quadrants at 21 mm gap with the current strips on.

length of EPU180 [16]. This EPU142 is installed, but currently only operates in planar mode, producing horizontally polarized photons.

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