

First Test Results for an Adjustable Phase Undulator

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Abstract

We have installed and tested an Adjustable Phase Undulator (APU) on beamline 5 of the SPEAR storage ring. The APU has the same magnetic structure as a conventional adjustable gap undulator (AGU), but its magnetic field is varied by changing the longitudinal position between the rows of magnets, while keeping the gap between them fixed. The tests described here show that this undulator performs according to our theoretical predictions [1] and numerical models [2]. We predicted that the APU would produce x-rays similarly to an AGU, but that it would perturb the electron beam less. The main reason to consider a phase adjustable design is the substantial reduction in size, complexity, and cost over comparable conventional designs.

When the phase of the test device is changed full scale, it requires much smaller magnetic trim compensation than when the gap is changed full scale. Similarly, we found that the APU's motion requires much smaller steering corrections at other beamlines, so it can be tuned without disturbing other users of a storage ring. When the APU was adjusted out of phase to null the magnetic field on-axis, we were able to inject into SPEAR without interference; thus gap adjustability is not required for accelerator operations. We also found that the x-ray spectral output is the same as when the device operated as an AGU, except that there is a redshift when the electron beam is steered off-axis.

1. INTRODUCTION

This paper is a description of tests we have performed on the first realization of an Adjustable Phase Undulator (APU). Our device consists of two rows of SmCo magnet blocks, one above and one below a flat section of the SPEAR electron beam pipe.

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The APU was installed on the SPEAR storage ring at the Stanford Synchrotron Radiation Laboratory in November 1991. The blocks are arranged just as in a conventional Halbach Adjustable Gap Undulator (AGU) [1], but the APU's magnetic field on the electron beam axis is varied by adjusting the relative longitudinal phase position between the two rows of magnets. Figure 1 shows the device geometry:

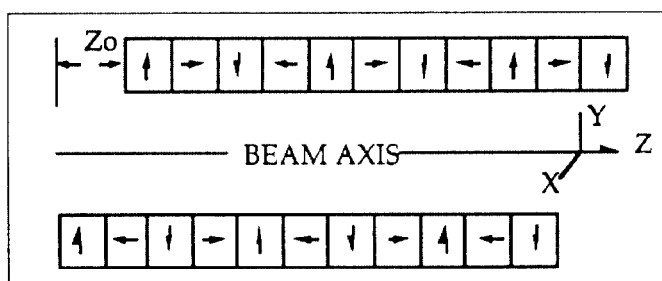


Figure 1: Schematic side view of three periods of an APU, with arrows showing direction of easy axis of field in magnet blocks. For an AGU, the phase difference Z_0 remains zero.

We developed the theory of this device in an earlier paper [2], and presented the results of numerical modeling in reference [3]. Those papers contain expressions and simulations for the magnetic fields, the trajectories of electrons, and for the x-ray spectrum that the device is expected to create.

The results we report here are those of experimental tests of our theoretical and numerical models. The important questions are: 1) How does the APU interact with the electron beam in the storage ring? We predict that it interferes with the electron beam less than an AGU. 2) Can one inject electrons into an APU when its phase is adjusted so that the vertical fields are nulled on axis? If one can inject without changing the gap, the construction and operation of an APU are vastly simplified. 3) Is the x-ray spectrum of the device as predicted?

2. EXPERIMENT

The APU we constructed was described in reference [3]. It consists of 23 periods of pure SmCo magnets. Each 77 mm period consists of 8 magnet blocks, 4 above and 4 below the electron beam, and each block has a square cross section 19.25 mm on a side. The blocks are 75 mm long, and have a mean remanent field of 0.966 T. They were originally installed in the PEP1B undulator on the PEP storage ring at SLAC.

We removed the magnets from the PEP1B undulator in keepers of 12 blocks' capacity (except for the end blocks), and installed them on stainless steel 'I' beams. These beams were then placed onto the beamline 5 undulator mover at SPEAR, which is described in reference [4]. The undulator mover carries one of 5 undulators horizontally to the SPEAR beampipe; the APU was installed as a fifth device. The mover is designed to vary simultaneously the gap of all the undulators, so we could change the gap of the APU for this test. However, a pure APU design would normally not have gap variability. The ability to move the APU out of range of possible interference with the electron beam was valuable for tests because it made the accelerator engineers less apprehensive.

The top row of magnets was mounted on a fixed beam; the bottom beam was mounted at the Airy points upon two precision slides, and could be driven longitudinally by means of an electromechanical actuator. The stepping motor and encoder of this actuator were connected to a CAMAC based control system, and to the SPEAR control computer. The full range of an APU is one-half the period length (38.5 mm in our case), since this gives a range of magnetic fields from maximum to zero on-axis.

We added to the SPEAR control software the capacity to move the longitudinal actuator, and to coordinate this motion with trim compensation coil settings. These two trim coils are fixed over the SPEAR beampipe at each end of the insertion region, and there are compensation current settings for each undulator at all gap settings. The trim coils are designed to offset electron beam deflections caused by integrated dipole errors in the insertion devices. Their settings are established by minimizing the beam deviation in a nearby downstream photon position monitor at SPEAR. The two trim coils are wired in series so that their net correction adds, but is opposite in sign to the dipole error in the insertion device; the net effect is a three pole bump.

3. RESULTS

Our first experiment was to verify that the APU could be moved over its whole range without affecting the electron beam in SPEAR. As we did this, we took readings of trim coil currents in the manner noted above, and put these values into the SPEAR control data base. We found that moving the APU had only a minimal effect on SPEAR, even at the minimum gap. The results of the trim coil measurements are shown in figure 2:

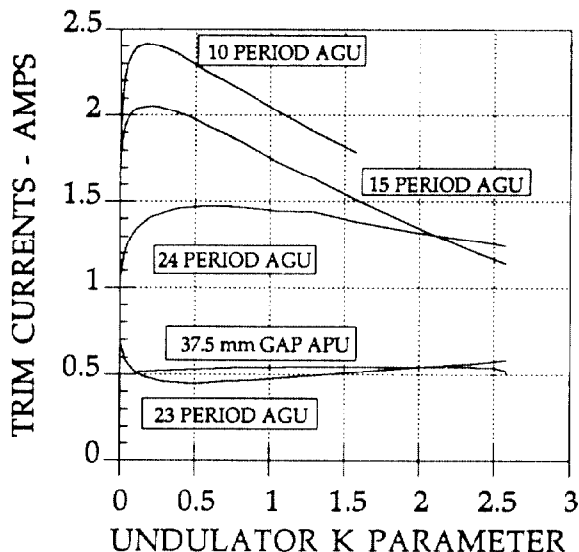


Figure 2: Dipole error compensation current for various beamline 5 undulators. The 23 period AGU is the APU device when operated in adjustable gap mode.

The trim coil settings are plotted for equivalent values of the undulator strength parameter, K . An APU's K parameter is related to an AGU's K parameter by:

$$K_{APU} = K_{AGU} \sqrt{\cosh^2(2\pi y/\lambda) - \sin^2(\pi Z_0/\lambda)} \quad (1)$$

where λ is the period length and y is the vertical displacement of the electron beam off-axis. [3] We suspect that the slight bending of the APU's compensation current curve at maximum K is due to the change of proximity of the endpoles of the device to the change of proximity of the endpoles of the device to the soft iron 'C's of the trim magnets. These would attract some flux when the SmCo materials are nearby; the SmCo is farther away at lower K .

From our theoretical work and numerical calculations [2,3], we expect the APU not to shift the vertical tune in SPEAR as the field is changed, because the vertical focusing strength of an APU is independent of phase. This is in contrast to the AGU case, where the vertical focusing strength depends exponentially on the gap. However, for this device in SPEAR, with a 3 GeV electron beam, the expected vertical tune shifts are too small (.0001) to observe, particularly now that we operate SPEAR at lower emittance (≈ 130 nm-rad) than previously (≈ 510 nm-rad).

We were able to observe beam displacements with a pinhole camera diagonally across SPEAR. We saw negligible horizontal displacement there when we changed the APU's phase full scale. Also, we watched for the displacement of the beam in the vertical with the help of a user of another beamline, who had a vertical beam intensity profile display 50 microradians high. We could easily resolve displacements 10% of this, but saw none when we changed the APU's phase.

One would expect magnet and trajectory aberrations, if present, cause beam loss, but we observed no harm to the SPEAR beam lifetime at any value of phase, including the fully out-of-phase setting.

Next, we took x-ray spectral scans using a photodiode with an aluminum target. Figure 3 shows these results:

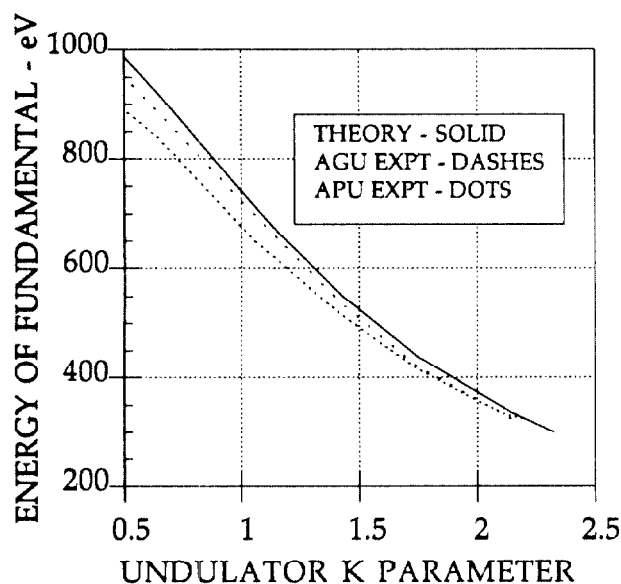


Figure 3: The energy of the fundamental spectral peak as a function of equivalent K parameter

The redshift of the variable gap curve may be the result of an angle between the beam axis and the

monochromator axis, but the additional redshift in the APU curve is probably due to missteering of the electron beam off the undulator axis. The redshift of the AGU spectrum can be accounted for by an angular misalignment of 35 microradians between the monochromator and the electron beam axes. The additional redshift of the APU spectrum can be accounted for by an average vertical offset of about 2.4 mm of the electron beam with respect to the undulator axis. Both the spectral peak energy and the flux intensity measurements show the correct functional dependence over the whole range of K values.

Finally, we injected several times into the APU at 2.35 GeV, and ramped the SPEAR beam to 3 GeV, with no apparent ill effect on injection rate, or lifetime. The APU was set so that it was out of phase, with like magnetic poles facing each other, to null the vertical magnetic field on axis. This may be an unnecessary precaution, because it is possible on SPEAR to inject into several of the insertion devices when they are at full field. But the ability to inject into an APU at minimum gap means that the full simplicity of construction may be exploited; if one had to preserve gap variability, the construction complexity would be much greater.

In conclusion, the APU was tested for its effects on the electron beam, both in normal operation and at injection, and they were found to be very minimal. Its x-ray spectrum is as expected, though the redshift underscores the desirability of keeping the beam on axis. Given this performance and the simplicity of the APU design, it may be an interesting choice for future undulators.

4. ACKNOWLEDGEMENTS

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5. REFERENCES

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