THE 90-mm PERIOD UNDULATOR FOR SRRC

D.C. Quimby, S.C. Gottschalk, D.R. Jander, T.E. DeHart,
K.E. Robinson, * A.S. Valla, + and J.F. Zumdieck
STI Optronics, Inc., Bellevue, WA 98004 USA

Abstract

The U9/SRRC undulator has recently been completed by STI Optronics, Inc. (STI) for use at the Synchrotron Radiation Research Center (SRRC) in Hsinchu, Taiwan, R.O.C. This 4.5-m long, 90-mm period wedged-pole hybrid undulator builds on several aspects of previous STI designs [1] while including a number of significant enhancements. The magnetics are based on the wedged-pole geometry [2] with additional side magnets. At the 19-mm minimum gap the peak field is in excess of 1.28 T with less than 3 degrees of optical phase error. The magnetic structures are mounted on stainless-steel strongbacks and are connected to the gap separation structure in a method to specifically reduce optical phase errors. The magnetic structure is positioned by four closed-loop servomotors within cast aluminum C-frames. The entire structure is mounted onto a retraction system to easily move away from the vacuum chamber for servicing. The device is controlled by a real-time VME-based control system capable of autonomous local and remote operation.

1 DEVICE DESCRIPTION

Parameters of the U9/SRRC undulator system are summarized in Table 1. An overview of the undulator is shown in Figure 1. The gap separation structure consists of the C-frame necessary to support the magnetic structure and the drive train for adjusting the gap between the upper and lower jaws of the magnet structure. The range of motion of the drive train allows for a minimum gap of 19 mm and a maximum service gap exceeding 220 mm.

Table 1: U9/SRRC Undulator Parameters

Length	4.5 m
Period	90 mm
Minimum Gap	19 mm
Peak Field (max)	1.28 T
Spectral Tuning Range	K = 1.0 to 10.30
Number of poles	100
1st and 3rd Harmonic Spectral Intensity	>95% of ideal # throughout tuning range
Gap Encoder Resolution	1 μm
Gap Setting Repeatability	$\lvert\Delta g\rvert$ < 5 μm unidirect $\lvert\Delta g\rvert$ < 10 μm bi-direct
Maximum Service Gap	>220 mm
Weight	9,050 kg
Mount/Retractor Positioning Repeatability	≤30 μm, 3-axes

Ideal spectrum based on 94 full field strength poles

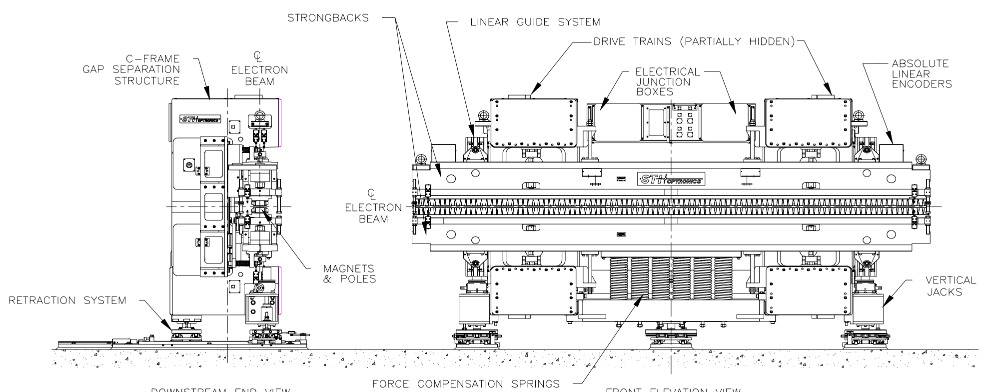

Figure 1. U9/SRRC Undulator.

* Presently with Lawrence Berkeley National Laboratory
+ Presently with AVALLA Design, Inc.

Four servomotors drive precision acme lead-screws via precision enveloping-worm gear drives. The low-lead-error acme screws assure that the system is non-backdriving so no motion occurs when power is cut to the motors. Coil springs acting on the lower strongback assure that the drive trains are loaded unidirectionally over the entire range of operation. Travel time from minimum to maximum gap is less than 4 minutes and the gap setting repeatability is within ±0.01 mm bi-directionally. The drives also meet a unique high-acceleration requirement for a 0.1 mm gap move within 0.5 sec. Each drive is independently calibrated in order to achieve the specified position at its respective end of each jaw. Thus the four motors allow adjustment and control of the gap, gap centerline shift, and gap taper. Incremental linear encoders and absolute rotary encoders gauge the position of each drive. The gap at each end of the device is measured directly using absolute linear encoders. Encoder readings are compared continuously to monitor for inadvertent jaw taper during motion. While jaw taper is not an intended operating condition for this device, the strongback mounts and guides allow compliance for misalignments of ±6 mm and ±3 degrees, thus avoiding binding and damage in the unlikely event of excessive jaw taper.

The C-shaped support structure allows the undulator to be retracted from the vacuum chamber with minimal effort and without breaking vacuum. The undulator structure is supported at three points in a kinematic manner. Approximately equal loading occurs at each support point. Three-axis adjustments are provided for aligning the device to the beam line. This support system includes earthquake restraint and a motorized retraction system [3] for moving the undulator away from the beam line. SRRC requested a support system allowing the undulator to be retracted, dismounted from the floor supports, removed for service using an overhead crane, reinstalled on the floor supports, and moved back into position on the beam line without realignment. Measurements show that the positioning of the kinematic mount and retraction system is sufficiently repeatable that the device maintains alignment to within 30 μm in all axes following such an operation.

A key specification for this device is that the on-axis spectral intensity in the first and third harmonics is to be within 90% of the ideal peak value at all gaps over the K = 1 to 10.3 tuning range. To achieve this the budgeted variance in the deflection of the strongbacks is limited to 50 μm peak-to-peak (total gap) while the magnetic attractive force between the jaws varies from zero and 12.5 metric tons. This low value of strongback deflection is accomplished within the limited available envelope size using stainless-steel material together with hangers that distribute the support of each strongback to four points rather than two.

The U9/SRRC magnetic structure is a high-precision wedged-pole hybrid permanent-magnet array made up NdFeB magnets and vanadium permendur poles. Side magnets are provided to increase peak field without degrading pole saturation or transverse roll-off. The ends are terminated with partial strength and partial volume magnets to achieve near-zero displacement conditions [4] for the entrance and exit electron trajectory throughout the gap tuning range. The measured electron trajectory at two gaps is shown in Figure 2. Also shown are corresponding optical spectra as calculated using the MA code [5]. The undulator field distribution was specifically tuned to meet third harmonic spectral requirements. Over much of the tuning range the optical phase errors are less than 2 degrees, so that the peak on-axis spectral intensity exceeds 90% of ideal to high harmonics. At minimum gap the optical phase error remains less than 3 degrees in spite of the effects of gap-dependent strongback deflection.

Table 2 lists the range of measured first and second magnetic field integrals and other integrated higher-order moments at all gaps. The device was passively pre-tuned at the STI site to specifically account for the ambient field at the SRRC straight section and the gap-dependent penetration of that ambient field to the beam line. Fully passive tuning is used for the horizontal field, B_x, while compensation of the vertical field, B_y, is supplemented with active fixed-gap saddle-coil end correctors. Rather than using passive tuning for the B_y first integral, the tuning strategy requested by SRRC was to passively minimize the shift of the optical axis of the undulator radiation throughout the spectral tuning range. The end correctors are used to select the angle of the optical axis and to minimize the change of the first integral relative to the ambient value. This places the peak of the spectral intensity on axis and makes the undulator as transparent as possible with regard to the storage-ring beam dynamics.

Table 2: Measured Beam Dynamic Quantities

Quantity	Specification	Measurement
First Integral:^		
B_x, passive	≤50 G-cm	–5 to 13 G-cm
B_y, active correction	≤50 G-cm	–5 to 3 G-cm
Second Integral:^		
B_x, passive	≤50,000 G-cm^2	≤30,000 G-cm^2
B_y, active correction	≤50,000 G-cm^2	≤15,000 G-cm^2
Integr. Normal Moments:		
Quadrupole	≤50 G	≤24 G
Sextupole	≤200 G/cm	≤7 G/cm
Octupole	≤300 G/cm^2	≤38 G/cm^2
Integrated Skew Moments:		
Quadrupole	≤50 G	≤37 G
Sextupole	≤100 G/cm	≤11 G/cm
Octupole	≤300 G/cm^2	≤19 G/cm^2

^ Excludes ambient field at SRRC site

The VME-based control system is interfaced directly with the SRRC central control system and services the functions of gap motion, corrector current tracking, and interlock monitoring. Fiber-optic data links are used where possible for noise immunity of critical encoder circuits. The interlocks are designed for multiple levels of defense to prevent possible damage to the vacuum chamber or undulator. The levels of protection include (1) gap command limits, (2) software limits, (3) hardware end-of-travel limit switches, (4) end-of-travel hardstops, and (5) end-of-jaw emergency-stop switches. The latter disable all motion independent of the control system if the jaws come too close to the vacuum chamber or to each other.

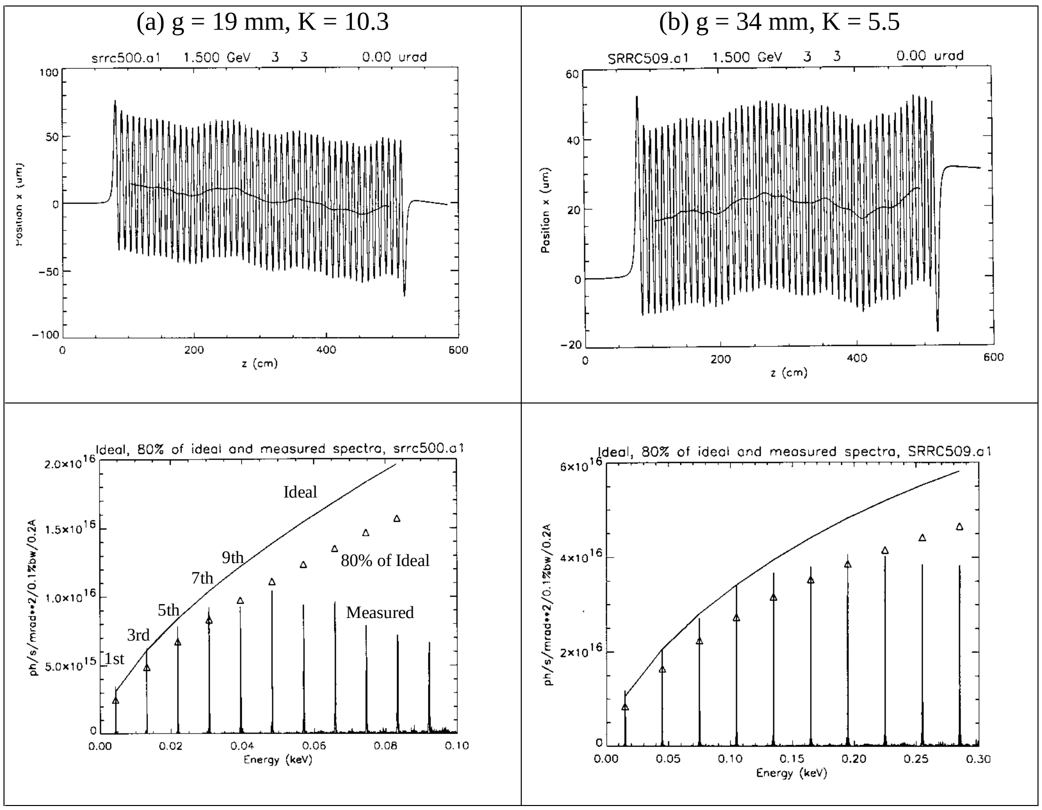

Figure 2. Measured electron trajectories and calculated spectral intensity at gaps = 19 mm and 34 mm.

2 SUMMARY

The U9/SRRC undulator project has satisfied a number of challenging requirements for positioning repeatability and spectral quality in a long, heavy device with large magnetic attractive forces. The high-precision undulator retraction system, harmonic spectral tuning, and pre-tuning of trajectory for ambient field effects prior to delivery represent significant accomplishments for commercially available undulators.

3 ACKNOWLEDGEMENTS

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