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CONTROL OF SYNCHROTRON RADIATION EFFECTS DURING RECIRCULATION*

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Abstract

We use results by Di Mitri et al. [1] as the basis of a method for suppression of synchrotron-radiation-driven beam quality degradation during recirculation.

Use of second-order achromatic superperiodic recirculation transport based on individually isochronous and achromatic superperiods of low-quantum-excitation lattices is found to provide control of both emittance degradation from coherent synchrotron radiation (CSR) and microbunching instability (μBI) gain. Use of such low excitation lattices and choice of sufficiently large bend radius also insures incoherent synchrotron radiation (ISR) driven effects are well-managed.

METHODS FOR CSR/ISR CONTROL

Di Mitri *et* al. have derived conditions under which CSR-induced emittance growth can be suppressed during transport through bending systems [1]. We apply these conditions using a simple methodology to generate a design for a recirculation transport line giving little emittance growth even at high bunch charges, and exhibiting low microbunching instability gain.

The method (described in more detail elsewhere [2]) is as follows: utilize superperiodic recirculation transport phased as in a second-order achromat, with individually isochronous and achromatic superperiods. Each superperiod is to be based on low-quantum-excitation structures of familiar types, such as three-bend achromats (TBA), Chasman-Green (two-bend) achromats, or theoretical-minimum-emittance cells (TME). Modulation of focusing, choice of betatron phase advance, dispersion modulation, or other means is then used to make individual superperiods achromatic and isochronous. Use of low excitation lattices and sufficiently large bend radius then insures ISR effects are well-managed.

Choice of rational period tune with overall second-order achromatic structure – coupled with individual period isochronicity – then insures that the conditions for the suppression of CSR-driven emittance growth as described in [1] are met. This was observed in earlier studies [3], but in addition to the control of CSR-induced emittance degradation we have found that this also suppresses microbunching instability gain over a broad range of parameter space [4].

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The suppression of microbunching gain appears to relate to limits placed on modulation of momentum compaction by the use of periodically isochronous transport. As will be seen from the examples below, the gain is very low for a periodically isochronous arc with small compaction modulations and modest R_{51}, R_{52}, and R_{56}, while similar, but aperiodic, structures with large compaction oscillations have high gain.

Control of ISR

As noted above, ISR control can be provided by use of an appropriate combination of a low-quantum-excitation transport lattice architecture and adequately large dipole bending radii [5].

APPLICATION OF DESIGN METHODOLOGY

Nearly all requirements for CSR suppression in a recirculator are met by the original design concept for the CEBAF arcs [6]. Control can be enhanced by adding provisions for small bend-plane beam envelope in the dipoles and provision for control of terms such as T_{566} (though this is in principle possible with only minor modification of the "stock" CEBAF transport system [7]).

We have thus generated a slightly modified version of the CEBAF arc transport line, based on TME focusing cells [8]. When four cells – each with 90° betatron tune – are concatenated, an achromatic (to second order) but nonisochronous superperiod results (Figure 1).

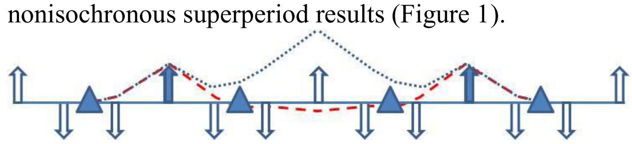

Figure 1: TME-cell-based superperiod structure for recirculation arc concept design. Natural dispersion of second order achromat – dotted blue line; modulated dispersion of isochronous linear achromat – dashed red.

By increasing the strength of the highlighted quadrupoles (which have 180° betatron phase separation), the dispersion can be driven down in the inner dipoles, the tunes split, and a linearly achromatic, isochronous superperiod obtained. As with CEBAF, optimization using all quad families then allows choice of tune, matched envelopes, enforced achromaticity, and selection of momentum compaction. Choice of rational superperiod tune and corresponding multiplicity then gives – with appropriate sextupole correction – a second-order

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achromatic arc structure, which, as noted, will meet conditions for the suppression of CSR-driven emittance growth.

Design and Performance Analysis

A 180° 1.3 GeV arc solution was generated, giving the parameters in Table 1. Chromatic effects (including T_{566}) were sextupole-compensated; chromaticity was zeroed and T_{566} was set to a value typical of that needed for RF curvature compensation [9].

Table 2: TME-Based Isochronous Arc Parameters

Energy	1.3 GeV	Per. disp. η_x/η'_x	0 m/0 rad
$L_{superperiod}$	40 m	Period R_{56}, T_{566}	0 m, 0.878 m
ρ_{bend} (m)	3.614	Arc structure	6 period
θ_{bend}	7.5°	Arc length	240 m
Per. ν_x/ν_y	7/6, 5/6	Arc ave. rad.	76.3 m
β_x/β_y (m)	65/2.5	Arc angle	180°
Chrom x/y	0/0	Arc tune ν_x, ν_y	7, 5

Elegant [10] was used to evaluate machine performance with both ISR and CSR. Transport of a 0.25 mm-mrad transverse normalized/35 keV-psec longitudinal emittance bunch was modelled; Figures 2 and 3 present results for a range of parameters. Virtually no emittance growth occurs – even at quite high charge – at a bunch length of 3 psec, despite significant loss of energy to CSR (Figure 4).

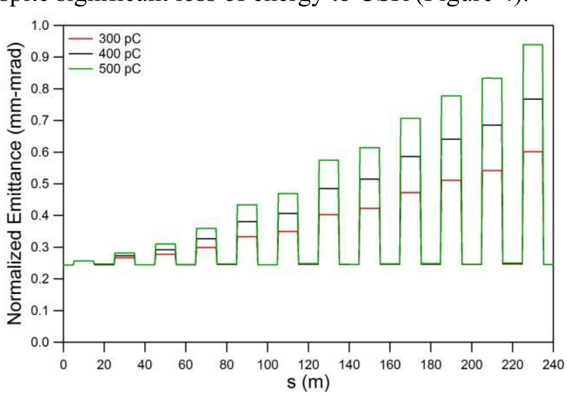

Figure 2: Transverse normalized emittance along the arc at three bunch charges (initial bunch length 3 psec rms).

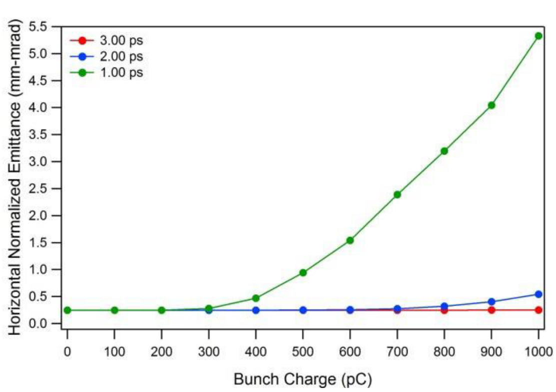

Figure 3: Final transverse emittance as a function of charge for at three initial bunch lengths.

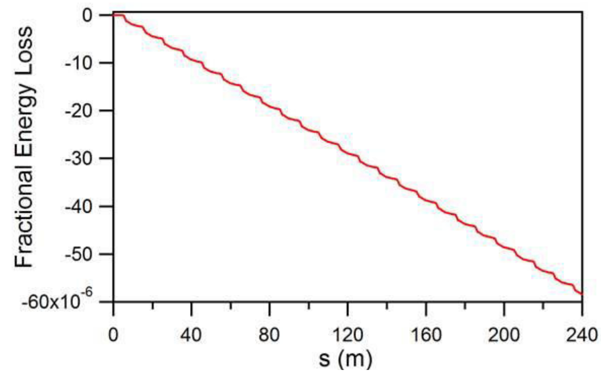

Figure 4: Central energy offset as a function of positio through arc, showing uniform loss to CSR emission.

Figure 5 presents the final longitudinal phase space at 500 pC, which exhibits no microbunching despite the high charge. An analysis of instability gain [11] has determined that the gain is indeed quite low. The CSR-wake-induced distortion of the longitudinal phase space can be corrected during bunch acceleration, transport, and compression by proper choice of RF phases and lattice nonlinearities (T_{566}, W_{5666},…).

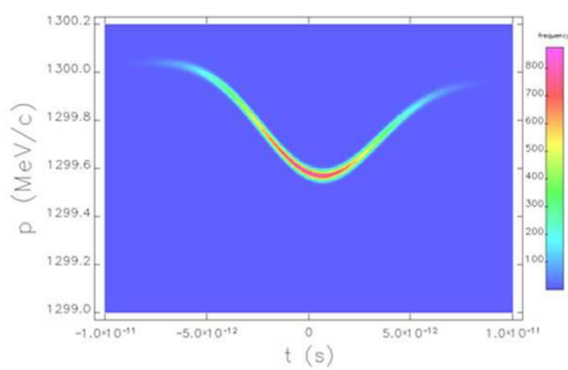

Figure 5: Final longitudinal phase space at 500 pC for initial bunch length of 3 psec rms.

APERIODIC ARC

The symmetric, periodicity, and small modulation of momentum compaction in the example arc appear to provide excellent suppression of CSR and the microbunching instability (μBI). To explore possible sensitivities, we retuned the focusing structure – retaining the periodicity and phasing, but allowing individual superperiods to be dispersive. This tuning is similar to the "high dispersion" mode of CEBAF [12]. The transport is achromatic and isochronous only over the entire length, and dispersive and compressional terms undergo large oscillations. Chromatic correction was performed as before. Simulation of the retuned lattice shows that emittance compensation degrades (Figure 6) and that the μBI is evident for charges at which the periodic structure is immune (Figure 7). An evaluation of microbunching gain show that it is quite high [13], suggesting that

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correlated behaviour in both transverse and longitudinal transport are required for effective CSR/μBI control.

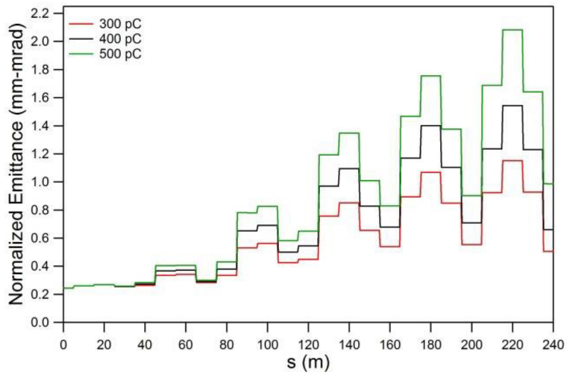

Figure 6: Transverse normalized emittance along aperiodically tuned arc at three bunch charges (initial bunch length 3 psec rms). Breakdown of emittance compensation is evident.

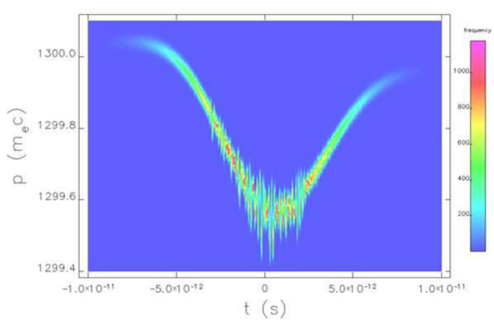

Figure 7: Longitudinal phase after transport of 500 pC through aperiodic arc. Onset of μBI is evident.

EXPERIMENTAL TESTS

Laboratory-Directed Research and Development funds have been provided for planning of an experimental test of CSR suppression in CEBAF [14] to be performed over the next three years. Initial considerations have generated a set of challenges that will be addressed:

- The source and injector must be retuned or modified to generate bunches of adequate brightness and charge to drive observable effects. Legacy JLab FEL studies [15] provide an existence proof for an injector architecture; studies of feasibility using the installed hardware are underway.
- Longitudinal matches [16] observant of CEBAF-lattice driven constraints (particularly from compaction evolution through the injection chicane and staircase spreader) are being developed.
- Wake effects – the interaction of the high brightness beam and the long superconducting linac – are being evaluated.
- The resolution of the required transverse and longitudinal phase space characterization measurements must be established, and procedures using existing hardware developed.

ACKNOWLEDGMENT

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REFERENCES

[1] S. Di Mitri *et al.*, Phys. Rev. Lett. 110, 014801, 2 January 2013.
[2] D. Douglas *et al.*, “Control of Coherent Synchrotron Radiation and Micro-Bunching Effects During Transport of High Brightness Electron Beams”, JLAB-ACP-14-1751, 1 March 2014; http://arxiv.org/abs/1403.2318
[3] M. Borland et al., “Potential and Challenges of Upgrading the Advanced Photon Source to an Energy Recovery Linac”, Proc. AccApp'07, p.196-203; Pocatello, Idaho, July 29-August 2, 2007.
[4] C.-Y. Tsai *et al.*, "CSR Induced Microbunching Gain Estimation Including Transients in Transport and Recirculation Arcs”, these proceedings, MOPMA025, IPAC’15, Richmond, VA USA (2015).
[5] C.W. Leemann *et al.*, Ann. Rev. Nuc. and Part. Sci. 51 (2001), 413.
[6] D. Douglas, “Optics of Beam Recirculation in the CEBAF CW Linac”, Proc. Linac’86, SLAC-R-303.
[7] S. Chen and D. Douglas, “Investigation on Cromatic [*sic*] Correction for the First Pass of the CEBAF Beam Transport System”, CEBAF-TN-94-005, 10 January 1994.
[8] D. Einfeld *et al*, “A Lattice Design to Reach the Theoretical Minimum Emittance for a Storage Ring”, EPAC’96, Sitges, June 1996; www.JACoW.org
[9] D. Douglas *et al.*, “High Average Power UV Free Electron Laser Experiments At JLab”, IPAC’12, New Orleans, May 2012, p. 2111 (2012); www.JACoW.org
[10] M. Borland, “elegant: A Flexible SDDS-Compliant Program for Accelerator Simulation,” APS Light Source Note LS-287, September 2000.
[11] C.-Y. Tsai *et al*, *op. cit.*
[12] Douglas, D., “Second Order Achromatic High Dispersion Configuration for Low Energy Beam Lines”, CEBAF-TN-90-197, 4 January 1990.
[13] C.-Y. Tsai *et al*, *op. cit.*
[14] C.W. Leemann *op. cit.*
[15] G. Neil *et al.*, “Status Report on the CEBAF IR and UV FELs”, CEBAF-PR-92-029, August 1992.
[16] D. Douglas *et al.*, “High Average Power UV Free Electron Laser Experiments At JLab”, *op. cit.*