A Proposed Experiment for Beam Conditioning*

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ABSTRACT

An experiment on beam conditioning [1] is proposed for the Accelerator Test Facility (ATF) at Brookhaven National Laboratory. The proposed demonstration will employ the already approved Harmonic Generation FEL [2] experiment (HGFEL) at the facility. The HGFEL experiment will use a 30 MeV electron beam from the ATF and a seed laser to produce a 3.4 micron radiation from a superconducting wiggler with a 1.8 cm period. In the proposed experiment, the beam energy is reduced to 17 MeV, and only the second wiggler of the HGFEL is employed. Resonance is made at 10.6 microns. The demonstration involves spoiling the emittance to drastically reduce the output power. A beam conditioning section introduces momentum variations correlated with betatron amplitude. This correlation will correct the deleterious effects of the artificially introduced emittance increase thus providing a clear demonstration of the conditioner.

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1. Introduction

The concept of beam conditioning, i.e., introducing a correlation between particle energy and particle amplitude so as to reduce the intrinsic spread in longitudinal velocity, has been proposed by Sessler, Whittum, and Yu[1] and, independently, by Derbenev [1]. Following this work, Wang has shown how to condition a low energy beam by means of transverse electric fields [2]. In this paper we take the original concept of Ref. [1]; namely the use of longitudinal fields, and design an experiment that can be used to explore the concept.

The proposed experiment is built upon the Harmonic Generation FEL experiment (HGFEL) at the Brookhaven Accelerator Test Facility [3]. The elements going into the design are presented in Section 2. In the next section, Section 3, we present parameters for the proposed experiment.

2. Design Elements

The FODO channel of Ref. [1] is taken as the transport element of the beam. In order to fully condition a beam, as pointed out in Ref. [1], four (4) periods of a FODO channel are required, combined with RF cavities, as shown in Fig. 1. For a FODO channel, and in the thin-lens approximation, in the absence of RF cavities a matched beam will have maximum $\langle x^2 \rangle_+$ at the focusing lenses and minimum $\langle x^2 \rangle_-$ at the defocusing lenses where, in terms of the lens strength f and separation L we have

$$\langle x^2 \rangle_{\pm} = 2f\epsilon_x \sqrt{\frac{2f \pm L}{2f \mp L}} \equiv \epsilon_x \beta_{\pm},$$

where ϵ_x is the beam emittance. The orthogonal $\langle y^2 \rangle$ will be exactly the same, but $\langle y^2 \rangle$ will be largest at the defocusing lenses.

Since in the TM₂₁₀ mode, at the appropriate phase, there is predominantly E_z , and no deflecting fields (we ignore fringe fields), to a good approximation a particle passing through the RF cavity at the focusing lens has its transverse motion unaffected, but gains energy $\Delta\gamma_+ = \alpha(x^2 - y^2)$, with a constant that depends on cavity parameters. Similarly, with a 180° phase change, at the defocusing lens $\Delta\gamma_- = -\alpha(x^2 - y^2)$. After passing through four periods, as shown in detail in Ref. [1], the energy gain is

$$\Delta\gamma_{\text{perfect}} = \alpha(\beta_+ - \beta_-)N,$$

where $N=4$ is the number of periods.

The requirement for a conditioner is given in Ref. [1] as

$$\alpha = \left(\frac{\gamma k_s k_\beta}{2k_w} \right) \left[\frac{1}{N(\beta_+ - \beta_-)} \right],$$

where the first factor contains only properties of the FEL. The k-factors are the wave numbers of the signal (k_s), the betatron oscillations (k_β), and the wiggler period (k_w).

For RF cavities we employ the "muffin tin" design which is shown in Fig. 2 and greatly improves coupling impedance, between the beam and the RF fields, as compared to that of a right circular cylindrical cavity [4]. Employing Ref. [4] we have a direct (but numerical) relation between a and RF cavity properties (such as peak surface field, energy stored in the cavity, power required, etc.).

3. Parameters

The FEL of the harmonic generation experiment has a wiggler period of 1.8 cm and produces 3.4 micron radiation [3]. For the conditioner experiment proposed here, we envision use of the second wiggler in the harmonic

generation experiment. Thus the bunches and the first wiggler are turned off. Furthermore, the beam energy is reduced so that the second wiggler resonates at 10 microns (not 3.4 microns) so that an input CO₂ laser can be employed as a seed for an amplifier experiment. Finally, it is proposed to spoil the beam emittance so as to more dramatically demonstrate the efficacy of a conditioner..

The experimental set-up is set up conveniently, for conditioning at a point just after the gun and before the beam is accelerated in the linac. At this point the beam is 5 MeV and the available free space is 7.0 m. Our conditioner is designed to fit into this space and has parameters, determined using the procedures of the last section, shown in Table 1.

As one can observe in Table 1, the power e-folding length is reduced from 31.9 cm to 18.7 cm after conditioning. In the experiment this would lead to a dramatic increase in the output power of the beam-conditioned FEL, comparable to the performance of a beam with a much smaller emittance.

References

- [1] A.M. Sessler, D.H. Whittum and L.H. Yu, Phys. Rev. Let. **64**, 309 (1992);
L.-H. Yu, A. Sessler and D.H. Whittum, "Free-Electron Laser Generation
of VUV and X-Ray Radiation Using a Conditioned Beam and Ion-Channel
Focusing", Proceedings of the 13th International Free Electron Laser
Conference, Santa Fe, NM, Aug. 25-30, 1991, to be published in Nuclear
Instruments & Methods (1992), Lawrence Berkeley Laboratory Report
LBL 31198; A.M. Sessler, "Beam Conditioning for Free-Electron Lasers",
Proceedings of the Workshop on 4th Generation Light Sources, Feb. 24-
27, 1992; Y. Derbenev, private communication.
- [2] C. Wang, "Conditioner for a Helically Transported Electron Beam",
Lawrence Berkeley Laboratory Report LBL 32222, May 1992,
Proceedings of Workshop on Advanced Accelerator Concepts, Pt.
Jefferson, NY, June 14-20, 1992.
- [3] I. Ben-Zvi, A. Friedman, C.M. Hung, G. Ingold, S. Krinsky, K.M. Yang,
L.H. Yu, I. Lehrman and D. Weissenburger, Proc. 1991 Int. FEL Conf.
Santa Fe, New Mexico, Brookhaven National Laboratory Report BNL-
46690.
- [4] R. Govil, A.M. Sessler and H.G. Kirk, "Design of RF Conditioner Cavities",
in these Proceedings.

Table I. Parameters for a Proposed Conditioner Experiment

	<u>No Conditioning</u>	<u>Conditioning</u>
<u>Beam</u>		
Normalized emittance, ϵ_n	$30\pi \times 10^{-6}$ m-rad	$30\pi \times 10^{-6}$ m-rad
Energy, E	17.6 MeV	17.6 MeV
Peak current, I	110 A	110 A
Energy spread, $\Delta E/E$	0.2%	0.2%
Betatron wavelength, λ_b	1.45 m	1.45 m
<u>FEL</u>		
Radiation wavelength, λ_s	10 mm	10 mm
Undulator field, B	5.2 kG	5.2 kG
Undular wavelength, λ_w	1.8 cm	1.8 cm
Undulator length, L_w	1.5 m	1.5 m
Power e-folding length, LG	31.9 cm	18.7 cm
Saturated power, P_s	0.49 MW	4.2 MW
Change in gamma required		0.367
<u>Beam Transport</u>		
FODO period length		50 cm
Quadrupole focal length		26 cm
FODO β_+	371.3 cm	371.3 cm
FODO β_-	7.3 cm	7.3 cm
Maximum spot size		0.598 cm
<u>Conditioner</u>		
Length		4 m
Number of periods		4
RF frequency		2.8 GHz
Number of cavities		8
Cavity radius		6.0 cm
Muffin-tin displacement		1.5 cm
Muffin-tin radius		0.75 cm
Gap spacing		4 mm
Beam port radius		0.5 - 1.0 cm
Total power loss on surfaces in 8 cavities		239 kW

Figure Captions

- Fig. 1. A diagram showing one period of the conditioner. A period consists of two focusing lenses (each of strength $f/2$), two defocusing lenses (each of strength $-f/2$), and three RF cavities each operating in the TM_{210} mode.
- Fig. 2. A diagram showing one end plate and a side view of a RF cavity with muffin-tin indentations.

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