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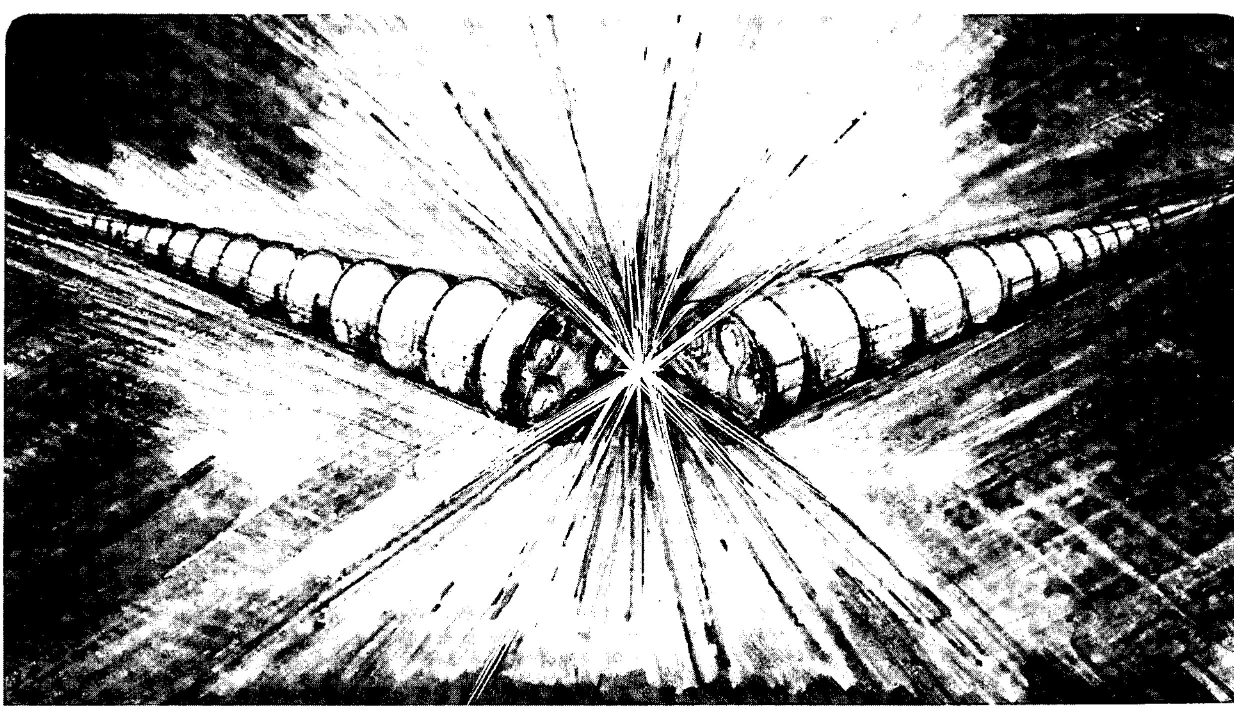

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Wavelength and power stability of the Stanford infrared SCA/FEL operating with the TRW wiggler have been measured using a high-resolution spectrometer and an image dissector system [1]. The image dissector is capable of reading the spectrum of every single micropulse at 12 MHz throughout a macropulse of up to 2 ms duration. The intrinsic wavelength and power stability of the SCA/FEL are found to be $\delta\lambda/\lambda$=0.035% and $\delta P/P$=18%. The use of a feedback control system to stabilize the wavelength, and an acousto-optic modulator for output power smoothing, improves the performance to $\delta\lambda/\lambda$=0.012% and $\delta P/P$=7%.

1. Introduction

Characterization of Free Electron Laser (FEL) performance in terms of wavelength and power stability is often crucial for FEL users. At the Stanford SCA/FEL the time evolution of the spectrum during a macropulse has been measured using a high-resolution spectrometer with an image dissector [1] as readout system. The image dissector divides the (dispersed) output of the spectrometer into small intervals of wavelength (referred to as bins) and introduces a small time interval between these bins (in our case, 3.5 ns). These bins are then measured by a single element detector.

The measurements presented in this paper have studied the effect of two features incorporated in the SCA/FEL to improve stability: a wavelength feedback system which stabilizes the center wavelength by adjusting the beam energy via the amplitude of the RF power flowing into the accelerator [2]; and an acousto-optic modulator, referred to as power clipper, which imposes an upper limit on the FEL output power.

2. Measurements and Data Analysis

The measurements were performed with the Super-Conducting Accelerator driven FEL at Stanford University. The FEL used a 3.6 cm period wiggler with 120 periods (referred to as TRW wiggler), and was set to run at a center wavelength of 4.08 μm with a macropulse duration of 2 ms. We used a 1 m focal length spectrometer with a 300 grooves/mm grating, and its output light was divided by the image dissector into nineteen bins. Each wavelength bin was measured to be 2.5 nm wide, yielding a total wavelength span of 47.5 nm, or $\Delta\lambda/\lambda$=1.2%.

Because the image dissector separates the wavelength bins temporally, a single detector is sufficient to record the FEL spectrum. A single element cooled HgCdTe detector with 800 ps rise time was used to measure the nineteen wavelength bins of each micropulse spectrum throughout a macropulse. The output of the detector was recorded by a 2 Gs/s oscilloscope, and the data sent to a 486PC for storage and analysis. The measured signal for two typical micropulses is shown in Fig. 1.

To reconstruct the spectra of the 23,000 micropulses within a macropulse of the FEL, a dedicated C program has been written to analyze the 4 MB of data recorded by the oscilloscope for each macropulse. A sophisticated algorithm, searching all the spectra, enables the program to detect pulses one or two counts above the noise level.

The program corrects for the different attenuations that each bin undergoes in the image dissector (caused by the multiple reflections in the image dissector cavity). It also corrects for the spill-over of light from one bin to the adjacent ones (caused by aberrations in the image dissector mirrors). We measured the square matrix **A**, where element A_{ij} is the intensity of bin number i when light corresponding to bin number j was sent into the image dissector. It was found that **A** is a diagonal dominated tridiagonal matrix where the largest off-diagonal element is about 25% of the nearest diagonal elements.

The total power and the center wavelength are calculated for the spectra of every micropulse within a macropulse. They are filtered with a Butterworth lowpass filter to reduce sampling noise. In order to eliminate the start up and turn off effects of the FEL, the first and last 5000 micropulses of each macropulse are not taken into account when calculating the wavelength and power stability.

3. Wavelength and Power Stability

Figures 2 and 3 show typical temporal profiles of the center wavelength and output power during a macropulse, with and without the presence of the two stabilizing features of the SCA/FEL, namely, the wavelength feedback control and the acousto-optic modulator. The graphs indicate a much greater stability of the FEL output, in terms of power and wavelength, when the feedback system and the acousto-optic modulator are operated.

The effect of the wavelength feedback control and acousto-optic modulator on the stability of the FEL is summarized on Tables 1 and 2. The tables are constructed by calculating the wavelength and power stability ($\delta\lambda/\lambda$ and $\delta P/P$) for a macropulse, and then taking the average over five macropulses. The values inside the parentheses are the corresponding standard deviations. The results show that the feedback system and the acousto-optic modulator are very effective in stabilizing the output of the SCA/FEL. Not only the wavelength and power become more stable throughout the macropulses, but also the variations from macropulse to macropulse decrease considerably.

The measurements have indicated that the spectral width of the emitted radiation is not affected by the operation of the wavelength feedback system and acousto-optic modulator. The FWHM of the pulses remain at approximately 23 nm, or $(\Delta\lambda/\lambda)_{FWHM} =$ 0.55%.

4. Conclusion

We have measured the spectrum and the output power of the Stanford SCA/FEL on a micropulse to micropulse basis. The measurements have verified the efficacy of an incorporated RF feedback system and an acousto-optic modulator in stabilizing the wavelength and output power of the FEL. These two features improve the wavelength stability ($\delta\lambda/\lambda$) from 0.035% to 0.012%, and the power stability ($\delta P/P$) from 18% to 7%.

Acknowledgments

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References

[1] W.P. Leemans et al., Nucl. Instr. and Meth. A 331 (1993) 615 and Nucl. Instr. and Meth. A 341 (1994) 473.

[2] A. Marziali and T.I. Smith, Nucl. Instr. and Meth. A 331 (1993) 59.

Table 1: Wavelength stability $\delta\lambda/\lambda$ (10^{-4})

	Feedback system off	Feedback system on
Power clipper off	3.5 (0.8)	1.1 (0.1)
Power clipper on	2.1 (0.9)	1.2 (0.1)

Table 2: Power stability $\delta P/P$ (10^{-1})

	Feedback system off	Feedback system on
Power clipper off	1.8 (0.5)	1.1 (0.1)
Power clipper on	1.0 (0.4)	0.7 (0.1)

Figure captions

Figure 1: Detector signal for two selected micropulses.

Figure 2: Center wavelength for consecutive micropulses along a macropulse: (a) with both the wavelength feedback system and the power clipper off; (b) with both on.

Figure 3: Power for consecutive micropulses along a macropulse: (a) with both the wavelength feedback system and the power clipper off; (b) with both on.

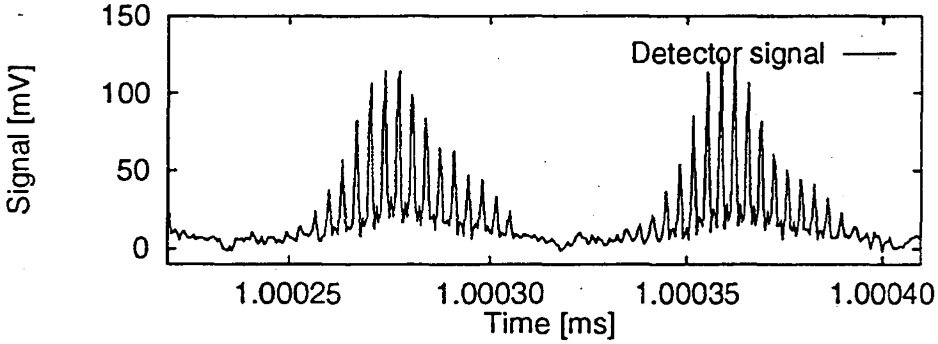
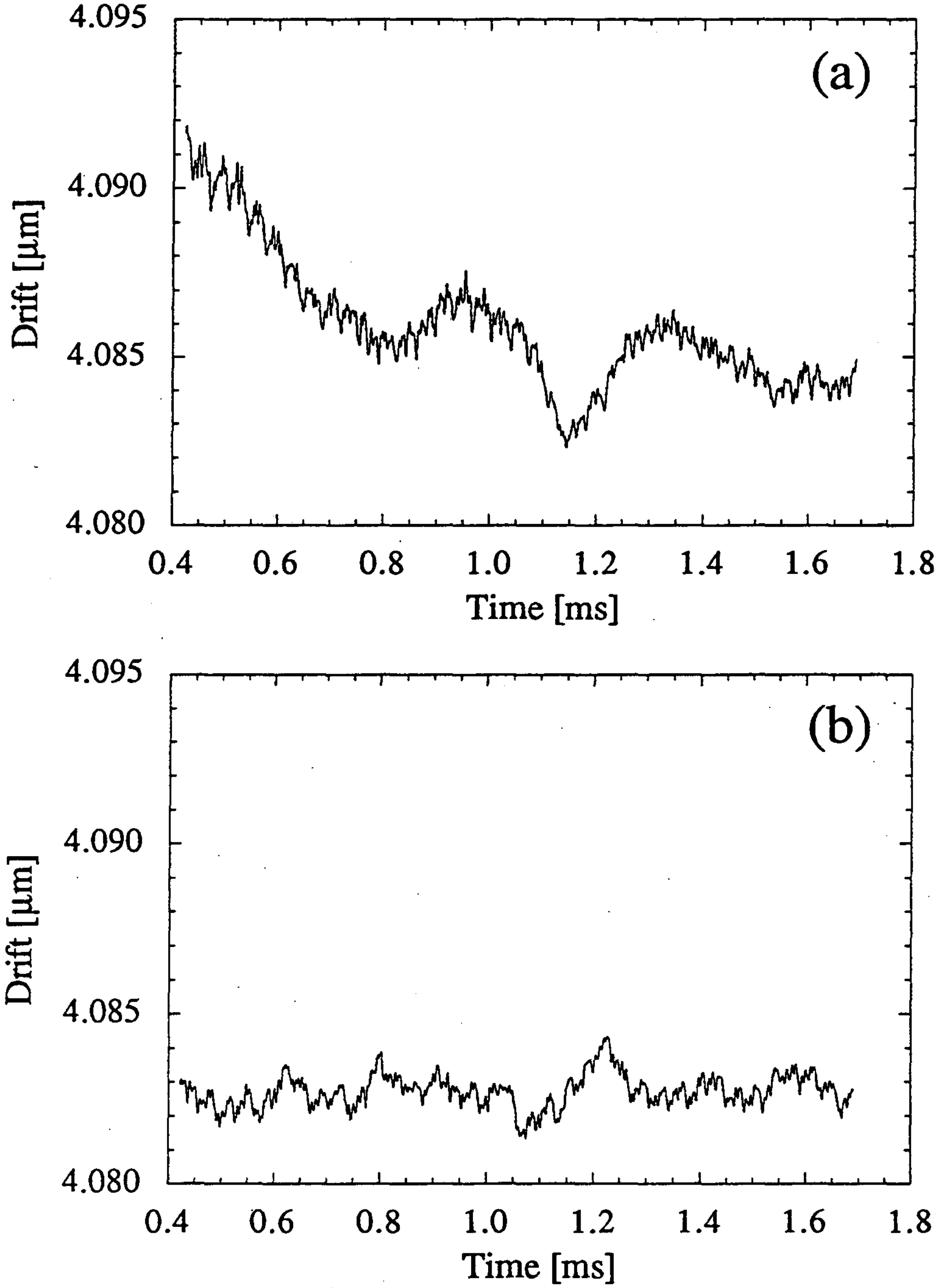

150
100
50
0
Signal [mV]
Detector signal
1.00025
1.00030
1.00035
1.00040
Time [ms]

Figure 1



(a)
4.095
4.090
4.085
4.080
Drift [µm]
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
Time [ms]
(b)
4.095
4.090
4.085
4.080
Drift [µm]
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
Time [ms]

Figure 2

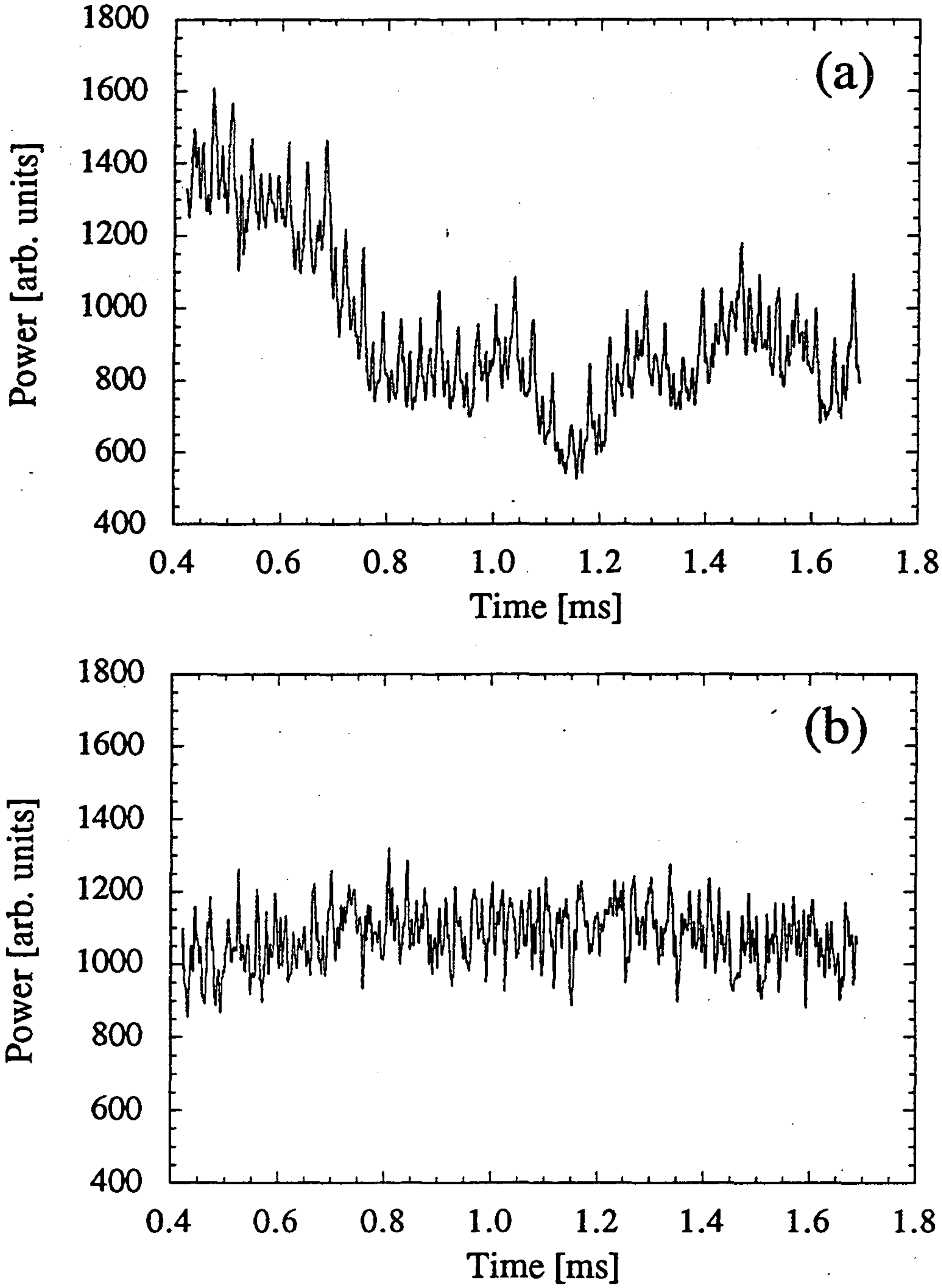

(a)
Power [arb. units]
1800
1600
1400
1200
1000
800
600
400
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
Time [ms]
(b)
Power [arb. units]
1800
1600
1400
1200
1000
800
600
400
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
Time [ms]

Figure 3

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