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DEVELOPMENT OF A SUBMILLIMETER FREE ELECTRON LASER USING A COMPACT ELECTRO-STATIC ACCELERATOR

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An experimental facilities for the studies on submillimeter wavelength free electron laser (FEL) are now under construction in our group. In this paper the possibilities for the two kinds of operation modes, which are expected to be obtained, such as the self mode-locked operations in a small net-gain region and the evolution of CW radiation in a large net-gain region, are analized.

Keywords: Free electron lasers, Electro-static accelerators, Mode-locked oscillations

1. INTRODUCTION

The free electron lasers (FEL) using an electrostatic accelerator is specified by its unique cw operating feature and its potential for high spectral purity. The self mode-locked oscillations in such an electrostatic FEL may broaden its capabilities, in addition to its cw mode of operation. The width of the mode-locked micropulses can be as short as the same order of the slippage time that is about N times of the optical wavelength where N is the number of the wiggler periods.

In this paper we numerically study the development of radiation from the spontaneous emission in both low net-gain and high net-gain regimes in the time domain. We obtain the self mode-locked oscillation in the low net-gain operation and a clear explanation is given in the time domain. In the high net-gain regime, we obtain cw radiation with complex construction in details, but the spectrum of Fourier transform shows quite good spectral purity, which indicates that the sideband instability in an FEL nonlinear regime does not develop strongly because the gain is quite small and the nonlinear regime is short in our micropulse length.

2. THEORETICAL MODEL

A 1D time-dependent FEL oscillator code including the transverse overlap between electron beam and TE_{01} mode in the waveguide is used in these simulations. The waveguide dispersion is considered in both the 1D FEL equations[1]and the feedback loop. The electron pulse is given a uniform distribution with an energy spread of 1%. The parameters used in this paper are the same as in previous papers[2,3].

3. TWO KINDS OF OSCILLATION MODES

3-1. MODE-LOCKED OSCILLATIONS

The self mode-locked FEL oscillations have been observed[4,5] An AM mode-locked FEL experiment and theoretical analysis in the frequency domain have been made[6]. We carry out our theoretical analysis in the time domain as described in Sec.2. We suppose the total loss is 20% and the output coupling is 3%. The single-pass FEL gain is about 30%, so the net-gain is about 10% and the FEL oscillator is in the low net-gain regime.

In Fig.1 we show the front 16 micropulses. A clear self mode-locked oscillation appears. The FWHM width of the micropulses almost dose not change and is about 0.26ns that approaches the twice of the slippage tmie of 0.16ns, which results from the balance between the broadening by the waceguide dispersion and the narrowing by the gain and phase modification of the FEL.

It is notable that the radiation is in the leading side of a total micropulse In time domain we can explain the mechanisms of a micropulse formation and mode-locking easily and clearly. The micropulse formation from the short and finite electron pulse has been studied deeply. The important and helpful results are that there are three regions named slippage, steady-state and escaping regions in the optical pulse amplified by the electron pulse in linear gain regime [7] The slippage region is in the leading part with a length of about slippage time and has a larger gain. The steady-state region is the middle part and has a uniform gain. The escaping region does not exist in our case because we have a cw electron pulse. Figure.2 shows the optical micropulse that develops from an initial uniform distribution after passing through the wiggler with the electrons. The steady-state region cannot develop due to a big loss and little net-gain, while the slippage region is amplified. So we obtain a short radiation with a width of about twice slippage time, which results from the broadening by the waveguide dispersion.

The self mode-locked radiation would continue to develop without any fluctuations. In a real device, it will be knocked off by the changes in parameters of electrons. So the self mode-locking occurs occasionally[4,5]. With known mode-locking techniques, which include the gain mode-locking that can be done by modulating the electron current or the cavity loss, impulse mode-locking, phase mode-locking, the mode-locked FEL oscillator can be made.

3-2. CW OPERATIONS

The power in mode-locked operation is low. With a high gain we can obtain a high power cw operating FEL oscillator. We have made simulations the in steady-state limitation (without slippage) to study the effects of total loss on the built-up time, optical power and the efficiency of RIKEN sub millimeter FEL[3] Power in a cavity of 80kW and efficiency of 0.7% may be obtained with a total loss less than 10%.

In this section we present the results of simulations with slippage and waveguide dispersion. The total loss is supposed 7% and the output coupling 3%. The net-gain is about 23%, so both slippage and steady-state regions develop.

In Fig.3 we show the evolution of radiation. There are two steps in it: the built-up of the FEL main mode until near saturation and the sideband instability in the nonlinear region after the saturation. In our FEL device, the slippage region is a very small part of total micropulse and the gain is small which means the FEL interaction is weak. The build-up time is long and a long electron pulse is necessary for the saturation of the main frequency mode. On the other hand, the sideband instability does not develop strongly due to the same reasons. In Fig.4 we plot the Fourier transfom spectrum of total macropulse. A high spectral purity is obtained, which is a good feature of the electrostatic accelerator FEL.

4. DISCUSSIONS

We have numerically studied the evolution of radiation in the RIKEN submillimeter FEL in both low and large net-gain regions, and obtained the self mode-locked and cw operation respectively.

The new FEL operating modes such as the mode-locked oscillations by means of variations of mode-locked methods may broaden the capabilities of RIKEN submillimeter FEL. The studies such as the pulse width conservation(anti-dispersion), the FEL solution, the mode-locked FEL in a large signal nonlinear regime and sideband instability may lead to new FEL phenomena and effects.

References

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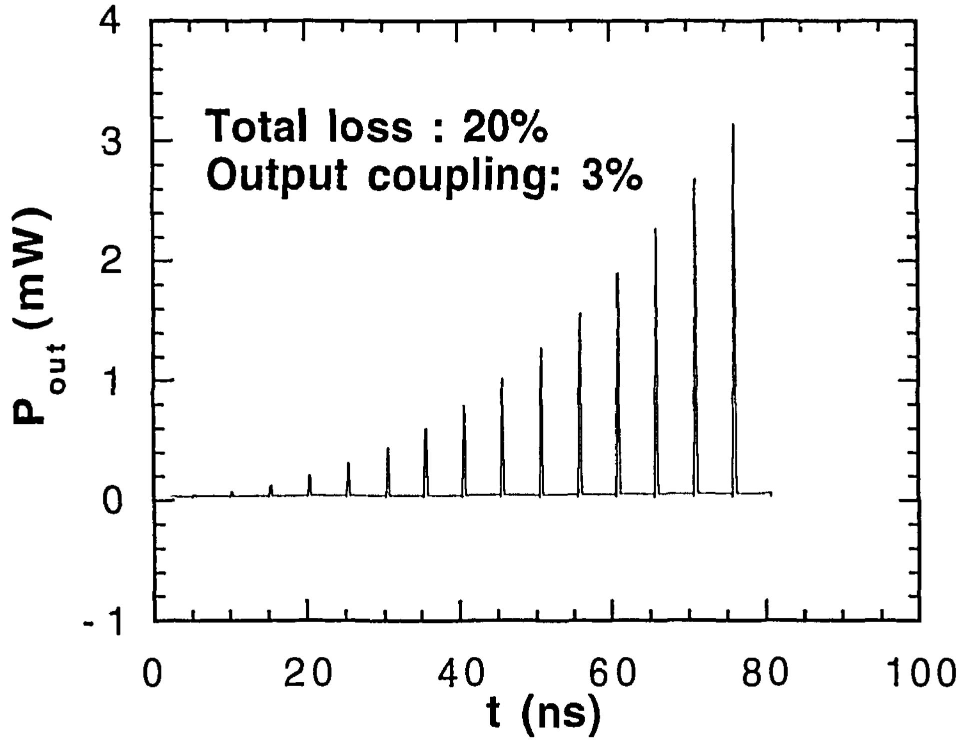

Fig. 1. The self mode-locked oscillation in a low net-gain linear region

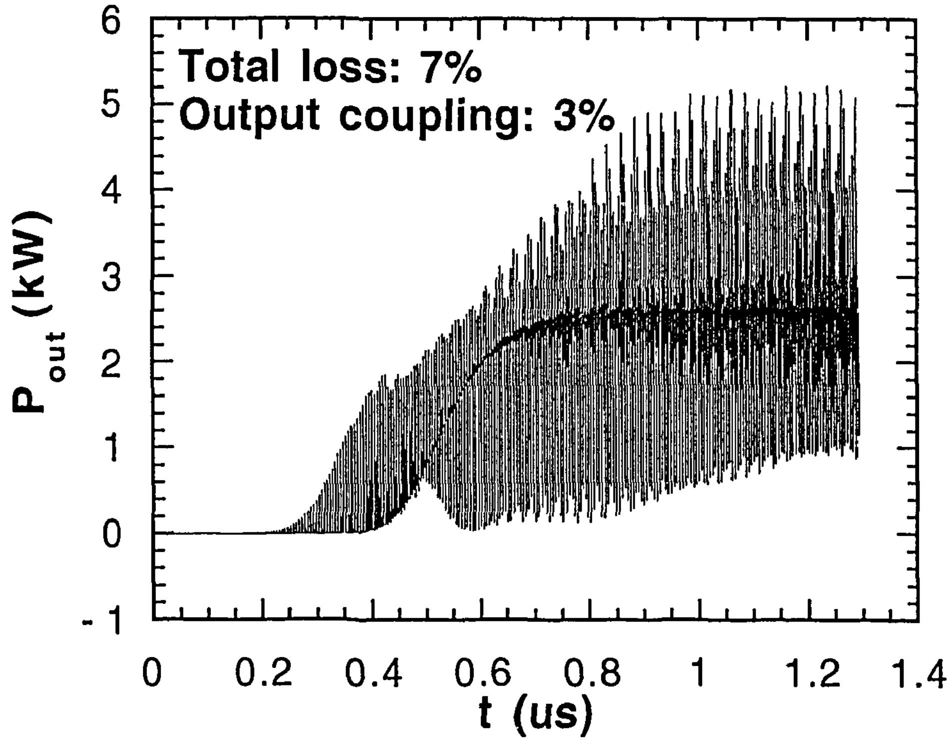

Fig. 2. The distribution of the linear gain in a micropulse

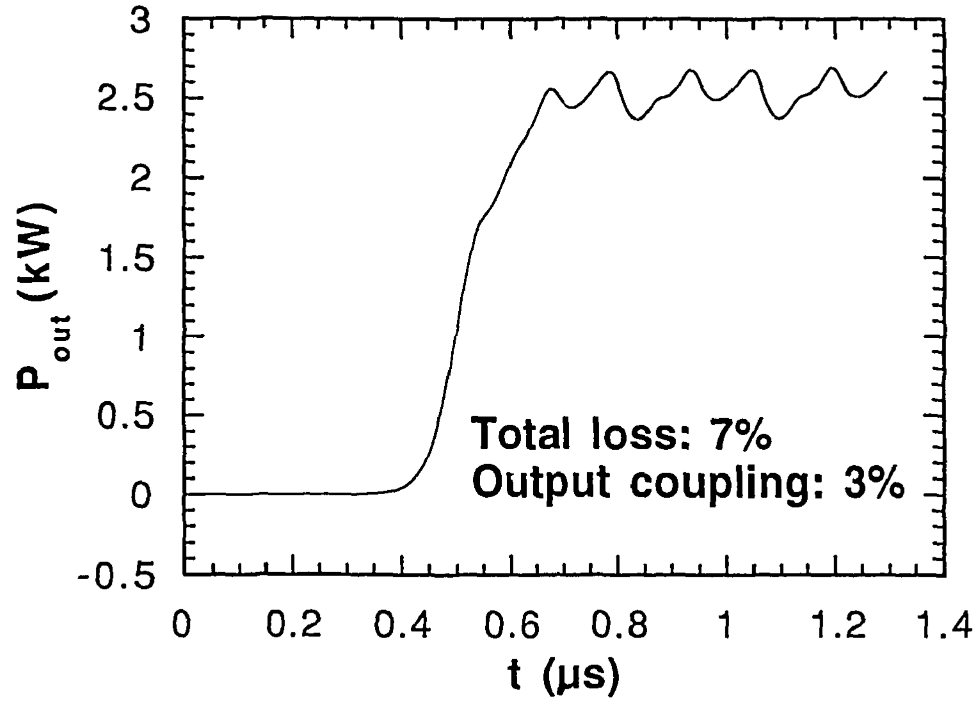

Fig. 3. The evolution of the radiation in a large net-gain operation

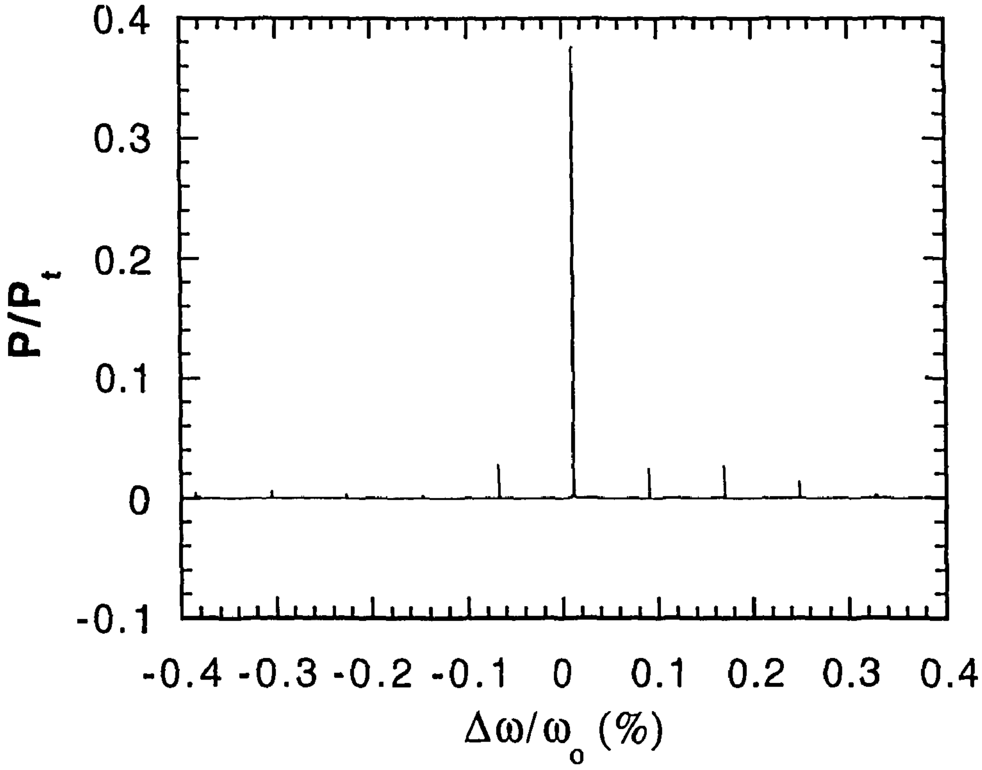

Fig. 4. The Fourier transform spectrum of the macropulse shown in Fig. 3