CHARACTERIZATION OF STORAGE RING FEL OPERATING IN THE GIANT PULSE MODE

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Abstract

In this paper we present experimental results on the storage ring free electron laser operating in giant pulse mode with variable repetition rate. The experiments were conducted through a wide range of electron beam energies from 270 MeV to 600 MeV with the giant pulses generated using a gain modulator. Dependence of the peak and average power, and the other properties and parameters of giant pulses on the pulse repetition rate were studied. In particular, it was found that the average lasing power in the giant pulse mode can reach levels of 70-90% of that in the CW power mode. Applications of such mode of operation are discussed.

INTRODUCTION

The gain modulation technique [1] was initially designed for storage ring free electron lasers (SRFEL) to satisfy user experiments demanding high peak power. Later its application was extended for generation of harmonic of fundamental free electron laser wavelength. High peak intracavity power allowed expansion of the operational range of SRFEL into the vacuum ultraviolet range [2].

Somewhat unexpected use of the giant pulse mode of operation came when OK-4/Duke FEL was generating γ-rays for HIGS users [3]. The optical power was concentrated in a series of short macropulses and small filling factor (product of the macropulse length and repetition rate) made possible to reduce a background noise by using a time gate [4].

The electron beam excitations, caused by the noise of magnetic system power supplies or RF system, can strongly affect the stability of SRFEL output [5, 6]. In order to suppress variation of the optical power the Super-ACO group implemented a few feedback systems [7, 8]. Application of the giant pulse technique may be more attractive in this case as well.

THEORETICAL CONSIDERATION

Even a small modulation of the SRFEL gain can result in significant variations of the output power. Such phenomenon arises from the significant difference of two time constants: the synchrotron damping time and FEL optical power growth. It manifests itself usually in chaotic behavior of the output power [5].

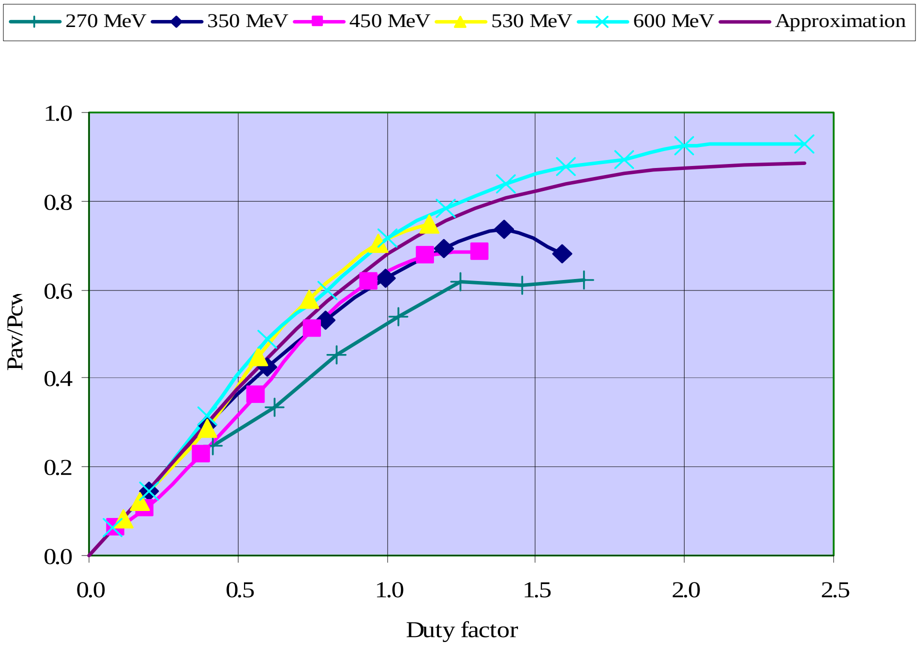

Figure 1. The dependence of the ratio of the average power in the giant pulse mode and CW power on the duty factor (product of the pulse repetition rate and synchrotron damping time). The pulse repetion frequency varies from 1 Hz at 270 MHz to 60 Hz at 600 MeV.

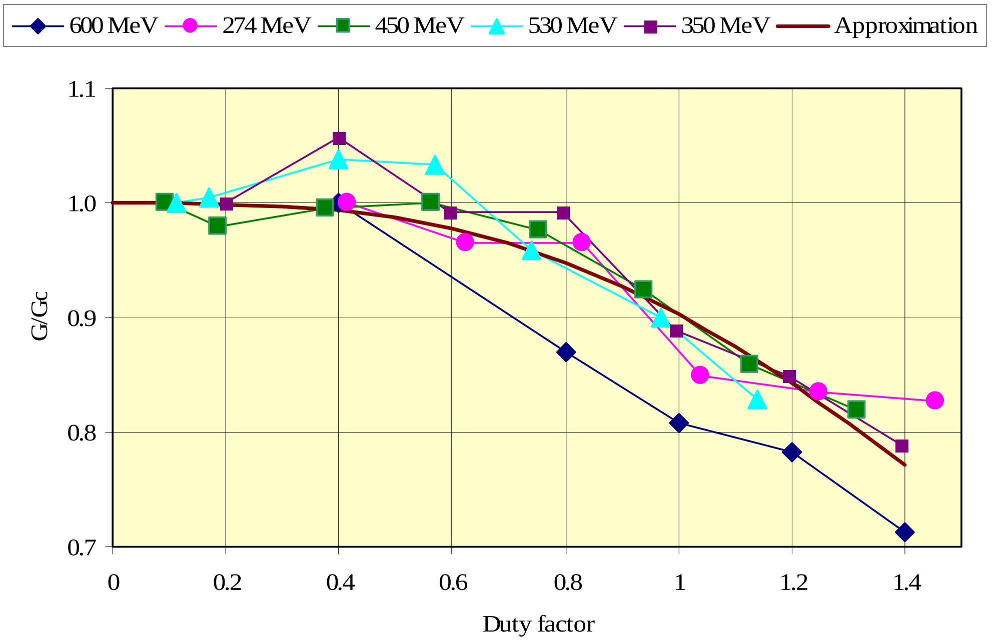

Figure 2. Dependence of the giant pulse' start-up gain on the duty factor. The gain is normalized with respect to the low repetition rate value.

Giant pulse mode of operation is an extreme case when the FEL gain is 100% modulated with relatively low frequency. However, it has the advantage of being fully controlled.

Duration of the giant pulse is much less than its repetition period. The longest duration of giant pulse during the experiments (at 10% level) was 300 microseconds, while the highest repetition frequency was 60 pulses per second. Therefore, it is possible to assume that energy spread of the electron beam instantly grows to the maximal value. The induced energy spread is directly proportional to the energy of the giant pulse [9, 10]. The synchrotron damping leads to the decay of the energy spread until the start of next giant pulse.

EXPERIMENTAL RESULTS

The experiments were conducted on the OK-4/Duke SRFEL for which the parameters were published elsewhere [11]. The operational wavelength was defined by the installed mirror set and was 450 nm. Electron beam energy varied from injection energy of 274 MeV to 600 MeV where the wiggler current reached its maximum. The synchrotron damping time changed from 416 milliseconds down to 40 milliseconds. The buncher was set at low level (N_D<7) providing maximal peak power. The RF voltage was in the 250–400 kV range well below the maximal value of 700 kV, due to the excitation of synchrobetatron oscillations. Optical losses of the cavity were 1% per roundtrip.

The radiant power meter manufactured by Oriel (model 70260) was placed downstream of the optical cavity to monitor FEL power. The silicon photodiode was used on the other side to observe envelope of the giant pulse. Malfunctioning streak-camera prevented us from measuring bunch length evolution.

All the dependencies were plotted versus duty factor *d* equal to the product of the repetition rate and synchrotron damping time. The ratio of average power in the giant pulse mode to the power in the CW mode is shown on Figure 1. At low values of duty factor, the average power

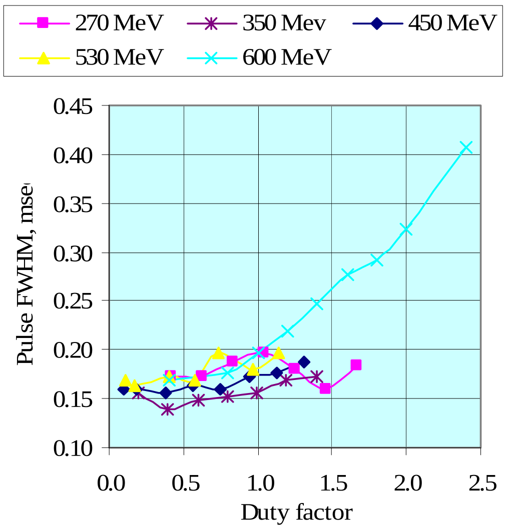

Figure 3. The dependence of the giant pulse width on the duty factor.

was proportional to the repetition rate and no changes in pulse shape were observed. With the increase of the repetition rates, the electron beam did not relax to the equilibrium energy spread and therefore the saturation was reached. This dependence has good fitting curve $P_{GP}/P_{CW}=0.75*d/(1+(d/1.2)^4)^{1/4}$.

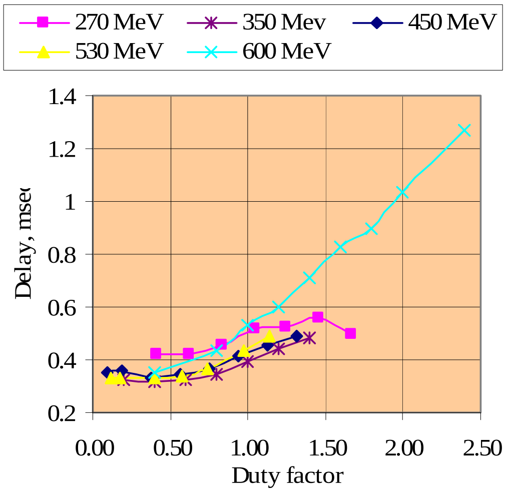

Figure 4. Dependence of the delay between giant pulse start and location of the maximal macropulse power.

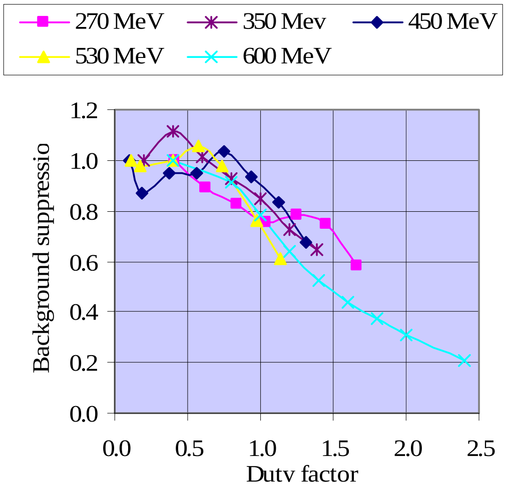

Figure 5. Dependence of the suppression of the uncorrelated background on the duty factor. The values are normalized to the level at low repetion rates. The absolute figures varies from 120 at 530 MeV to 1450 at 270 MeV.

The leading edge of the giant pulse shows exponential growth of the optical power [12]. From the time constant one can easily calculate the net gain of the FEL and knowing the optical cavity losses find its gain. Figure 2 shows changes in the start-up gain with duty factor. The FEL operation blows up energy spread to the level sufficient to suppress microwave instability especially for the giant pulse operation. This fact is very important because the major source, causing the increase of the electron bunch length, is eliminated and synchrotron damping occurs at faster rate. The evidence for this is that the initial gain G stays constant until duty factor reaches the value 0.8. With further rise of the duty factor the start up gain decreases for the same reason as mentioned earlier. This dependence can approximated with the following fit $G=G_0/(1+(d/2.1)^3)$, where G_0 is gain at low duty factor.

The reduction of the FEL gain leads to the lengthening of the giant pulse (Fig. 3) and to growth of the delay between trigger and location of the giant pulse maximum power (Fig. 4). Knowing the levels of the optical power in CW and giant pulse modes it is possible to estimate the suppression of the background noise for the HIGS experiments $S=P_{GP}/(P_{CW}*T*F_{rep})$, where T is giant pulse duration and F_{rep} is repetition rate. The normalized dependence is shown in Fig. 5. As well as the FEL gain the suppression does not change until duty factor d=0.8. Higher values of the duty factor can be used to reduce the data collection time due to growth of the average power.

CONCLUSION

Giant pulse technique can be used to obtain highly stable pulses of optical radiation from the SRFEL with average power constituting only 90% CW mode power. For the experiments requiring background reduction, the separation between giant pulses should be 0.8-1.2 of synchrotron damping time.

ACKNOWLEDGEMENT

This work is supported by DoD MFEL Program as administered by AFOSR, grant F49620-001-0370.

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