Control of rogue waves in laser with optoelectronic feedback

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ФИАН САМАРА

Abstract. The paper theoretically investigated the dynamics of a solid-state laser with positive optoelectronic feedback, which controls the quality factor of the resonator. The study was performed taking into account the delay arising from the inertia of the feedback. It was shown that the laser dynamics goes chaotic with increasing delay through a sequence of period doubling bifurcations. With a further increase in the delay, the appearance of extreme pulses with an anomalously large amplitude is observed. It is shown that the appearance of extreme pulses is associated with a crisis of a chaotic attractor.

INTRODUCTION

In recent years, optical systems have been used as convenient test laboratories for studying extreme events Such extreme events are also called “optical rogue waves” or “dissipative rogue waves” for their large amplitudes, well above the average. In addition, to date, it has been established that optical rogue waves can occur in many ways. They are quite often found in linear systems, where they are induced by random boundary conditions and multiple interference. They were also predicted, and later discovered, in nonlinear dynamical systems with modulation instability. In other words, extreme events occur in complex systems, and most of them can be described by statistical methods and described by models based on ordinary differential equations (including delayed ones) and on partial differential equations. The dynamics of narrow-aperture lasers is modeled by a system of nonlinear ordinary differential equations. Theoretical and experimental studies of recent years have shown that such models describe the occurrence of rogue waves (extremely large pulses), and the simulation results are in good agreement with experimental data. It was shown that dynamical chaos in a narrow-aperture laser with loss modulation can lead to the generation of rogue waves. Optical rogue waves were detected in narrow-aperture lasers with pump modulation and injection of external radiation , as well as in narrow-aperture lasers with a time delay . The appearance of rogue waves in lasers is associated with a crisis of chaotic attractors.

MATHEMATICAL MODEL

In the simulation, a standard laser model with delayed optoelectronic feedback was used:

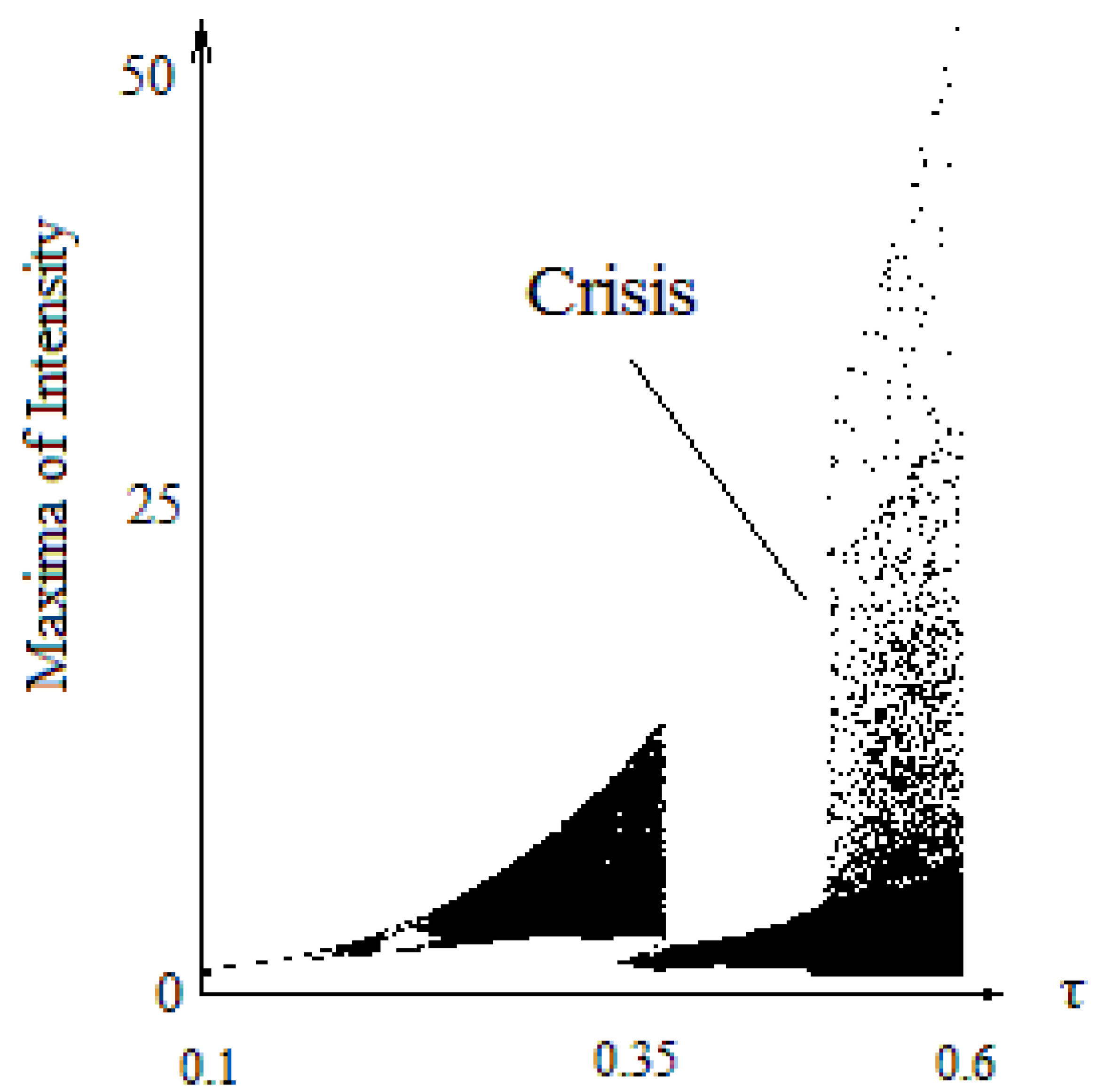
$$\begin{cases} \dfrac{dI}{dt} = GI\left[N - 1 - \varepsilon I\left(t-\tau\right)\right], \\ \dfrac{dN}{dt} = A - N\left(I+1\right), \end{cases}$$

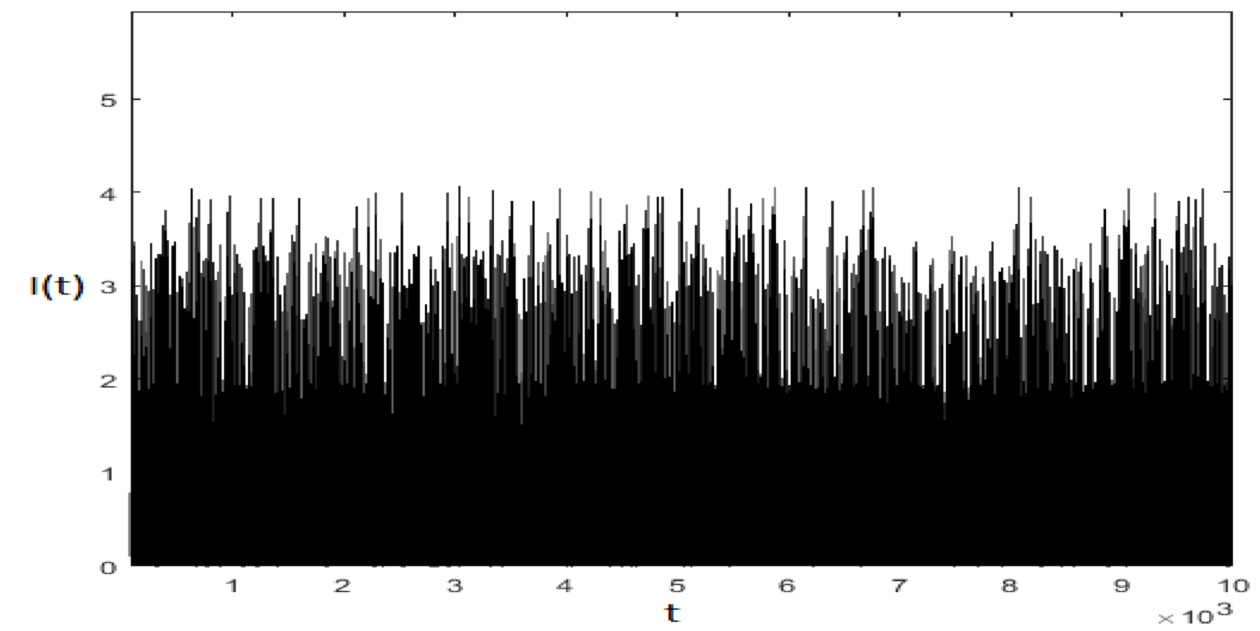
where I and N are dimensionless intensity and inversion, respectively; G=k/j, where k is the field decay rate in the resonator and j is the population inversion relaxation rate; r is the dimensionless pump parameter; ε is the strength of optoelectronic feedback.

The term εI(t-τ) corresponds to the optoelectronic feedback that controls the losses in the cavity, here τ is the delay time. The dependence of the resonator losses on the radiation intensity is ensured by using a feedback loop, consisting of a photo detector, which receives a part of the radiation, and then the signal from the photo detector is amplified and fed to the Kerr cell, which provides a change in the quality factor of the resonator. The delay in model is usually caused by natural causes and is associated with the inertia of the node that controls the quality factor of the resonator, and can also be increased additionally by artificial means. In this paper, we studied the dynamics of a laser with optoelectronic feedback for various values of the delay parameter.

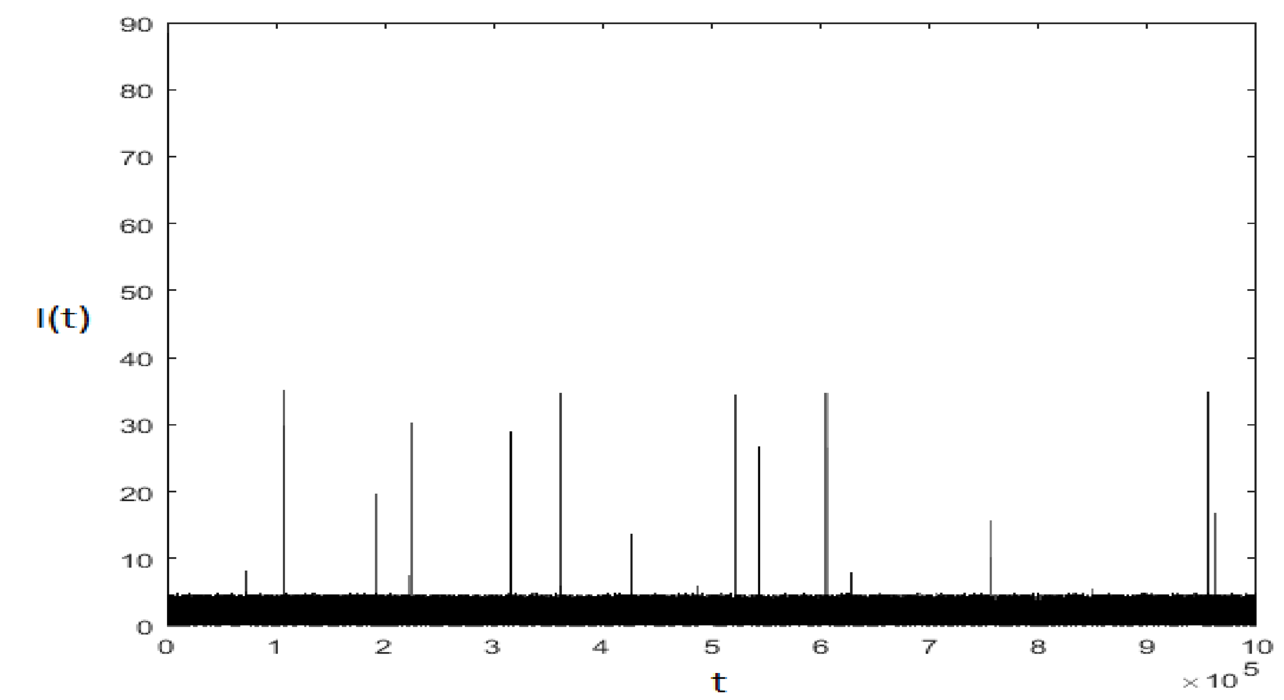
NUMERICAL RESULTS

The dynamics of a laser with optoelectronic feedback was numerically simulated for parameters corresponding to a solid-state Nd: YaG laser: G=5000 and A=1.2. The feedback strength has been selected ε=0.01. Modeling was carried out using the standard 4th-order Runge-Kutta method with an integration step of 0.0001. The dynamics was studied with a change of the control parameter , the remaining parameters was unchanged. It is shown that with an increase of the delay time τ, a transition to the regime of dynamical chaos occurs through a sequence of period doubling bifurcations. Figure 1 shows the corresponding bifurcation diagram. Dynamics of the laser becomes chaotic, for example, already at τ=0.5. From Figure 2, it is clearly seen that chaotic dynamics are present in the laser, but extreme events are not observed. With an increase in the delay time to τ=0.55, the laser dynamics changes qualitatively. In Figure 3, it is clearly seen that against the background of chaotic pulsations, rare pulses of very large amplitude appear, which satisfy the criterion of the extreme event





τ=0.5



τ=0.55