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The Role of Instability Threshold in Lorenz-Haken Laser System

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Abstract

We have investigated the role of instability-threshold (the second-threshold) on the dynamical behavior of the Lorenz-Haken laser system .Here, we report theoretical results of instabilities leading to chaos at low instability threshold , obtained through variation the laser system control parameters over a wide range of laser operating conditions.

Keywords: Laser instability, period-doubling , chaos, Lorenz-Haken model.

Introduction

Instabilities play an important role in a large number of fields for Example in hydrodynamics, ecology, economy, chemistry, biology, and semiconductor physics [1-5]. Also, in quantum optical systems, such as lasers, a great variety of instabilities can be found [6,7]. Compared to hydrodynamics, the nonlinear equations are, at least for simple models, rather simple. Therefore, the investigation of the instabilities in lasers is easier to carry out than in most other fields.

The type of instabilities in the dynamical systems depends on the control parameters and the nonlinear dynamics model used. In laser systems, the instabilities change mainly with increasing pumping strength. The variations of other laser operating parameters are also playing important roles on the dynamics of the laser system. Of these parameters are the asymmetry of the medium gain profile and the inhomogeneous broadening which is introduced in the original Lorenz-Haken equations (as additional parameters) to produce more generalized equations. Homogeneously broadened single-mode lasers are well-known to exhibit self-pulsing instabilities and chaotic dynamics under the combined conditions of large ratio of gain over losses and low cavity quality [8,9]. In fact, a two-level homogeneously broadened single-mode laser in resonance (with a symmetric Lorentzian gain profile) is realistically described by the classical Lorenz-Haken model [9-11] which has served as a prototype model for investigating instabilities and chaos in continuous dynamical systems. However, the conditions for observing instabilities in such systems require the bad-cavity condition in conjunction with a gain considerably above first (lasing) threshold, thus making the experimental realization of this unfeasible for most lasers. The above mentioned requirements for the occurrence of Lorenz-Haken instability phenomenon have been realized only in a very few laser systems of high gains and narrow linewidths, satisfying the bad-cavity condition. The ideal candidates of these lasers are the optically pumped mid and far infrared laser systems (MIR and FIR lasers) [12-14]. The single –mode semiconductor laser is also a good example that achieves the condition for the optical instabilities and can easily exhibit different types of dynamic instability (such as pulsations and chaotic behaviors) at low excitation power [5].

The bad-cavity condition was originally derived by Korobkin and Uspenskii [15] and it implies that the electric field relaxation rate (k) is more strongly than the sum of the polarization relaxation rate ($\gamma_{\perp}$) and the population inversion relaxation rate ($\gamma_{\parallel}$), i.e., $k > \gamma_{\perp} + \gamma_{\parallel}$ (or in the present paper, $\sigma > b + 1$). In contrast to the basic model of homogeneously broadened lasers, the single-mode instabilities are realized with relative ease in an inhomogeneously broadened system although the onset of instabilities still requires a bad cavity but with rates considerably reduced to those needed for the corresponding homogeneous case. As a result of this situation, it is found that, the threshold for the observation of the pulsing instabilities and chaos (or the second-threshold) in the inhomogeneously