Modelling and Specifying Dispersive Laser Cavities

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1 Introduction

Designing and building laser cavities requires a good knowledge of the physics and tolerances of their various elements. Cavities can be designed and optimized in an experimental fashion but this method takes time and is costly. A less costly (but less precise) method is to carry out a numerical simulation of the elements of the cavity and the physical laws governing the evolution of the electric field (the laser light). Modelling allows us to solve the "forward" problem, in which the characteristics of the laser light are described as a function of the cavity parameters. We are trying, however, to design and optimize cavities, which is an "inverse" problem: we seek to determine the cavity parameters that yield specific characteristics of the laser light. Further a simulation of a pulse laser (the case we are considering) may take several minutes for a typical cavity: it is then difficult to explore the parameter space exhaustively or to use numerical methods for optimizing the design.

Another approach consists of simplifying the problem in order to solve it analytically or by using a fast numerical method. The simplified model, however, must be sufficiently close to the real-world problem for the solution to describe the exploration zone of the parameters and the tolerances for the various elements.

2 Problem definition

We are considering pulsed fiber lasers, meaning that the laser pulses are confined within an optic fiber. The laser cavity is thus made of optic fiber. The elements also have input and output fibers. The fact that pulses are confined within the fiber is important, since their characteristics are modified when they propagate, which is not the case (generally speaking) when they propagate in the air. The laser cavity can thus be described as a sequence of blocks representing the elements in the cavity, as well as the fiber, as illustrated in Figure 1. Our specific interest is the dispersion-tuned actively mode-locked fiber lasers [1]. These lasers are characterized by the fact that

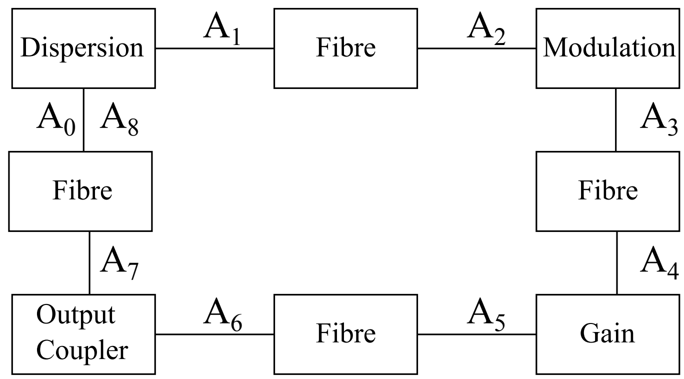

Figure 1: The cavity may be represented by several blocks.

they include an element that modulates the electric field in the time domain and a highly dispersive element that induces a different delay for each pulse frequency. The other elements (output coupler, gain) are typical for lasers.

The pulses are described by their electric fields envelope, which is a complex variable. This envelope depends upon the time (or the frequencies, by computing a Fourier transform) and the position within the cavity, both of which are real variables. The evolution of the pulses electric field through each element (and the fiber) is described either by a PDE (whose variables are the time and the position within the cavity) or by a function on the electric field. The boundary conditions are such that the field input to a block is the output of the previous block. Since the cavity is closed, the solution is an eigenmode of the system of successive PDEs. The main problem consists of determining the envelope of the electric field describing the pulse as a function of the various blocks parameters. The secondary problem consists of modelling these blocks or approximating them so as to allow an analytical (or fast numerical) solution.

3 Possible approaches

Several approaches have been proposed to solve this kind of problem, which arises for all laser cavities.

- The most widespread method is to use an average model that linearizes all the blocks, which amounts to propagating the pulse in an "average block" including all the effects. The solutions obtained by this method are thus independent of the position, which is appropriate for certain cavities (including the solitonic cavities) but not the cavities where the pulses vary a lot [2].

- Another approach is to consider only linear elements and integrate each block, in such a way that the system is described by transfer functions. The system can be solved if the shape of the electric field is known [3].

- It is also possible to "free" the equations from time or spectral dependence by postulating an *ansatz* for the electric field, which replaces the PDEs on the electric field by ODEs on the *ansatz* parameters [4].

- One variant of this approach is to consider the electric field as a square-integrable distribution (which is indeed the case since the pulses have a finite energy) and describe it using the moments of the distribution. In this fashion we obtain a system of ODEs on the moments [5].

In summary we need to determine the cavity parameters that will produce the desired optical pulse. We wish to understand the benefits and drawbacks of each method with regard to the accuracy of block modelling and the existence of analytical solutions. We already have software to simulate a given cavity and validate the analytical models at certain points. Blocks may be modelled in several ways, some of which are more detailed than others. Some features of the system may be neglected in the first models but others should be included in those models because they have an impact on the experimental results.

References

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