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Optical power meter using radiation pressure measurement

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Abstract

This paper describes a radiation pressure meter based on a diamagnetic spring. We take advantage of the diamagnetic property of pyrolytic carbon to make an elementary levitated system. It is equivalent to a torsional spring-mass-damper system consisting of a small pyrolytic carbon disc levitated above a permanent magnet array. There are several possible measurement modes. In this paper, only the angular response to an optical power single-step is described. An optical detection composed of a laser diode, a mirror and a position sensitive detector (PSD) allow measurement of the angular deflection proportional to the voltage delivered by the PSD. Once the parameters of the levitated system depending on its geometrical and physical characteristics have been determined regardless of any optical power, by applying a simple physical law, one can deduce the value of the optical power to be measured from the measurement of the first maximum of the output voltage amplitude.

Keywords

Torsional pendulum, Magnetic levitation, Radiation pressure, Pyrolytic carbon, Optical power.

1. Introduction

High power lasers (of a few kilowatts) are used in a wide range of industrial manufacturing processes ranging from welding, cutting, marking and additive manufacturing of structures made of various materials including metals. The laser is a working tool with a long lifetime, can be included in monitoring and control systems based on intelligent sensing techniques, and allows zero-fault production. This makes it necessary to improve high optical power measurement. At the same time, intermediate optical powers (from a few milliwatts to a few watts) are used in different fields such as telecommunications, alignment, laser shows, microlithography and energy sources.
The two most common techniques used to measure optical power use either non-thermal sensors based on photo-electron interaction (photodiodes for example) or thermal sensors based on thermal energy absorption (thermopile sensors). Photodiodes can be used to measure the high power by sampling only a fraction of the optical power only if the small fractional splitting ratio is known. In addition, photodiodes are sensitive to temperature and the optical power distribution. Thermopile sensors can measure high-power directly, but are somewhat slow and require the full laser power be incident on the power meter. These two measurement techniques are exclusive operations.
Measurements of laser power using radiation pressure have been reported recently [1–8]. In particular, Williams *et al.* [8] have developed a portable, high-accuracy, non-absorbing laser power measurement at kilowatt levels.
The work presented hereafter is a preliminary study of a laser power meter based on pyrolytic carbon levitation to detect the moment of force provided by radiation pressure of a laser beam. The optical power range studied is from 100 mW to 1 W. We use the strong diamagnetism of pyrolytic carbon (PyC) to carry out 6D-stabilisation of a PyC disc levitated at ambient temperature above a magnet array.
The rest of this paper is structured as follows. Section 2 briefly presents the theoretical principle of a spring-mass-damper system and an experimental set-up made from very simple and inexpensive elements. Section 3 provides some theoretical considerations used to specify the main characteristics of the system. Preliminary results are presented in Section 4. Section 5 gives some potential sources of error and uncertainties in measurement which are discussed before the conclusion in Section 6.

2. Principle of the spring-mass-damper system and experimental set-up

2.1. Radiation pressure

The concept of radiation pressure grew in the late nineteenth and early twentieth centuries starting from Maxwell's theory of electromagnetism [9,10]. Later, with the advent of quantum theory, this concept allowed one to define the linear photon momentum p $\hbar\omega/c$ where $\hbar$ is the reduced Planck constant, ω the photon frequency, and c the speed of light *in vacuo*. A perfect mirror reflecting a photon at normal incidence reverses its momentum. Consequently, the force F_R exerted by dn photons

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