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Measurement of non-compensated angular dispersion and the subsequent temporal lengthening of femtosecond pulses in a CPA laser

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Abstract

Closed analytical formulae are given for the residual angular dispersion resulted from the non-parallel surfaces of both a grating pair and a prism pair pulse compressor. Accurate measurements of the angular dispersion of pulses leaving the misaligned pulse compressors agree well with the first principle simulation curves. The corresponding lengthening of the transform limited 18 fs pulses was also determined. Finally, it is experimentally proved that by simultaneous monitoring of angular dispersion and pulse duration, the stretcher–compressor system of a chirped pulse amplification laser can be aligned very precisely.

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1. Introduction

The non-parallelism of the grating planes of a stretcher–compressor system of a high power chirped pulse amplification (CPA) laser introduces residual angular dispersion into the laser beam approaching the target. A similar effect can be observed in other experiments where femtosecond pulses directly from a laser oscillator are compressed by a prism pair with slightly non-parallel surfaces or passes through small wedges like glass filters or beam splitters.

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As it is known, angular dispersion, defined by the angle between the spectral phase fronts, makes the pulse temporally chirped and its pulse front tilted [1,2]. In case of plane waves, the former is proportional to the propagation length [3], hence can be compensated by changing the distance between the gratings only for a given target distance [4,5]. However, the pulse front tilt still remains and causes a longer illumination of the target than the pulse duration itself [6,7]. This effect is more severe for large aperture beams. Several papers have been dealing with these issues and established only theoretical tolerances for the parallelism of the gratings [8–10] and prisms [11,12] of pulse compressors. Relatively simple to use devices have been proposed for synchronous determination of pulse front tilt and pulse duration [13–16]. Since all of them are based on non-linear techniques, even the most current version is limited for pulses not shorter than 20 fs [17]. Some of them [15,16] have been already demonstrated to help in the alignment of a CPA laser system but the latter provides only qualitative information while the former is fairly inaccurate in terms of angular dispersion. For the high precision measurement of angular dispersion itself, however, linear methods have been more recently developed for both spatially Gaussian beams and for plane waves [18–20].

In this paper we present, to our knowledge, the first experimental proof of the analytical expressions of residual angular dispersion resulted from the misalignment of both a grating pair and a prismatic pulse compressor. We also present the first systematic experiment to point out that the combination of the measurement of residual angular dispersion with the synchronous monitoring of the pulse length is an efficient way for the accurate alignment of pulse compressors.

2. Residual angular dispersion

2.1. Grating compressor

Fig. 1 shows a sketch of a usual pulse compressor consisted of two identical diffraction gratings. The operation of such a system has been detailed and analyzed in several papers [2–4,7–9], so here we emphasize the basic and necessary points only. A laser beam entering the system is diffracted and angularly dispersed by the first grating. In an ideal case the second grating compensates for the angular spreading of each spectral component providing the same angular dispersion as the first grating but with an opposite sign. Hence, the spectral components propagate parallel to each other towards the end mirror M. After reflection the rays follow the same path but in reverse order, resulting in a collimated output beam and a laser pulse with substantially changed spectral phase. The second and third order derivatives of the spectral phase are the group delay dispersion (GDD) and third order dispersion (TOD), respectively, which are responsible for the temporal shape and contrast of the pulse [3,21–24].

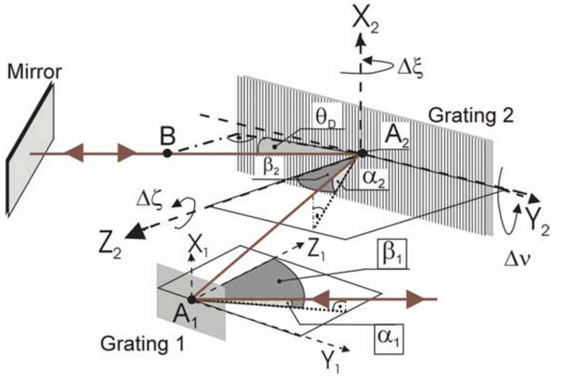

Fig. 1. A grating pair compressor with the definition of the rotation axes of the grating planes.

Problems start rising when the spectral rays leaving the second grating are not strictly parallel to each other, which means that the beam is angularly dispersed. Using the arguments and notations of [8], such residual angular dispersion of a grating pair can be calculated as follows.

Let's assume that the first grating stands in the laboratory such that the laboratory vertical axis X_1 is parallel to the grating grooves, the plane X_1–Y_1 is parallel to the grating surface, and the Z_1–Y_1 plane is parallel to the horizontal axis of the laboratory. In a well aligned case, the axes of the second grating X_2, Y_2 and Z_2 are parallel to X_1, Y_1 and Z_1, respectively. An arbitrary position of the