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In-situ metrology interferometric set-up for the diagnosis and analysis of coherent beam combining lasers

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Abstract: We present a new compact PISTIL interferometer, specifically designed for easy integration on all CBC lasers. This demonstrator enables self-referenced and accurate measurements of the near-field phase, whatever the set-point applied. © 2023 The Author(s)

1. Scientific context

The measurement of segmented wavefront surfaces has been a major challenge in recent decades, particularly in the field of coherent beam combining (CBC), which is one of the key technologies for obtaining intense laser sources with high peak and average power [1, 2]. In addition, beyond high intensity, many applications require special shaping of the combined far-field beam to optimize its interaction with the experiment (beam deflection, apodization, Orbital Angular Momentum beam shaping, etc.) [3, 4]. Given the complexity of this new type of requirement, for which the usual figures of merit (Strehl ratio, Power In the Bucket, M^2 , ...) are not necessarily suitable, a better strategy is to accurately measure the phase map of the near-field laser fiber output. The aim of this paper is to present a compact set-up of the PISTIL interferometer, suitable for this type of near-field measurement and optimized for easy integration on a CBC chain.

2. A compact PISTIL interferometer

One of the preferred ways of achieving CBC is to arrange collimated laser fibers side by side in the most compact mesh possible, and let the beams propagate in the far field. After collimation, the near-field wavefront is therefore composed of an apposition of flat surface segments whose height differences must be controlled to match the desired far-field pattern, controlled to within a small fraction of a wavelength.

The PISTIL interferometer [5, 6] is a particularly suitable candidate for accurate near-field beam phase analysis, in order to assess compliance with the phase relationship between segments for the near-field figure. Indeed, in previous studies, we have demonstrated the ability of this principle to achieve accurate absolute measurement of CBC segmented wavefronts [7, 8]. The new version of the interferometer proposed here aims to make it easier to integrate into existing laser chains, thanks to its compactness and ease of use. It is based on the coupling of a hexagonal patterned microlens array and a diffractive grating merged in a single optical element, as illustrated in Fig. 1. Each beam collimated from a laser fiber is imaged onto a hexagonal microlens of the component. The grating produces six replicas of the sub-wavefront emitted from each fiber laser, propagating in six different directions at 60° . When the observation plane is half the focal length, the support of these six replicas is reduced by a factor of two. This allows only two replicas from two neighboring sub-wavefront to interfere locally. The resulting interferogram is shown in Fig. 2.

Analysis of the orientation, position and frequency of the resulting fringes allows us to determine the phase difference between two neighboring sub-wavefronts and thus, to reconstruct the complete absolute phase map of our segmented wavefront under study. As the measurement is self-referencing and redundant, we can also obtain errors on the reconstructed phase using the measurement closure relations simultaneously. The compactness of this system means that it can be integrated into a C-mount to be mounted in a conventional video camera. The compactness of this system means that it can be integrated into a conventional C-mount to be mounted in a conventional video camera. In addition to verifying the applicability of the phase settings, this interferometer can also be used to analyze the individual behavior of open-loop fiber lasers, which is invaluable for dimensioning feedback loops.

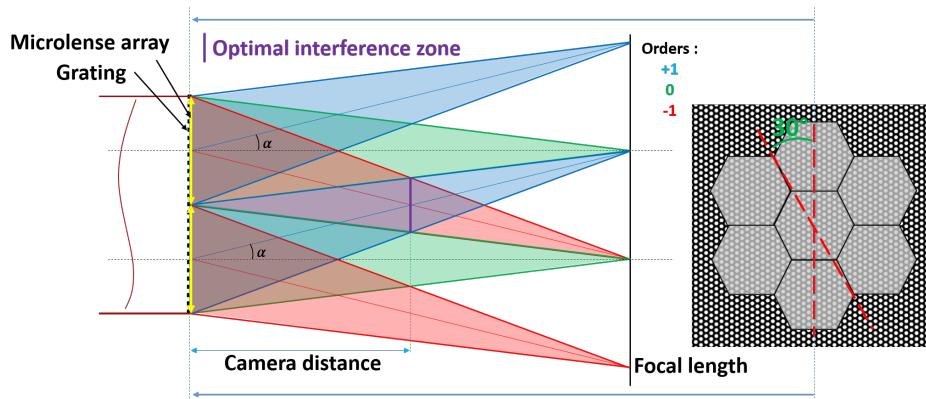


Fig. 1. Compact version of PISTIL interferometer. Left: Schematic cross-section of two beams in the pistil interferometer – Right: Illustration of the coupled hexagonal patterned microlens array and diffractive grating merged in a single optical element. Only 6 hexagonal microlens are shown for the sake of clarity.

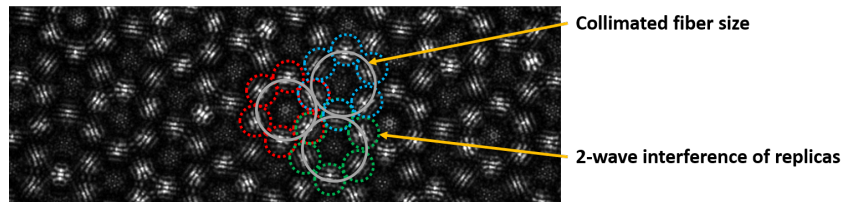


Fig. 2. Part of PISTIL interferogram. Dotted coloured circles indicate the 6 replicas of three sub-wavefronts for illustration. The grey circles are to figure the size of the beam from collimated fibers.

3. Perspectives

PISTIL is currently being studied on an initial laboratory prototype in order to test its limits and optimise it. It is also a suitable tool for real-time diagnosis and analysis, and for the development of control-command. It will then be transferred to a CBC laser (the XCAN experiment at the Ecole Polytechnique's LULI laboratory) for ultrafast laser measurements. The demonstrator presented here will shortly be transformed into a prototype which will be offered to the various teams involved in the CBC, for evaluation and feedback.

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