Filled-aperture Coherent Summation Technique for Multiple High Average Power Laser Beams

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***Abstract*—Single-detector, filled-aperture coherent beam combining technique for CW and high repetition rate ns pulse laser beams has been proposed. Proof of principle experiments have been performed for four beams. The combining efficiency for the present laser system was estimated to be 0.9. The proposed CBC technique can accommodate kW level average power beams, be integrated into various MOPA architectures and perform with high speed and accuracy.**

Keywords—coherent beam combining; high power lasers

I. Introduction

For material processing applications, we are developing single mode, 400 ps ~ 10 ns pulse duration, high repetition rate (500 kHz – 1 MHz), tunable (1040 nm ~ 1060 nm) high average power (150 W – 200 W) laser amplifier units based on Yb-doped, large mode area photonic crystal fibers. For final design of a desired laser system with kilowatts (kW) class average power, coherent beam combining (CBC) concept seems to be one of the viable choices. Technically, for far-field on axis applications, tiled-aperture (TA) CBC is better suited, because in contrast to filled-aperture (FA) techniques, in this case the central lobe intensity I is proportional to ~ N2, where N is the number of amplified beam channels. However, in practice this method is often impaired by an important factor f – aperture fill-factor, which is in most practical cases remarkably smaller than unity. The appearance of side lobes due to f < 1 makes TA designs disadvantageous for precision cutting and drilling applications on carbon fiber reinforced plastics (CFRP) or applications in micro-electro-mechanical systems. For such cases, FA CBC designs are preferred, because FA CBC is side lobe free, hence better suited for precision material processing. Here we propose a single-detector, FA CBC geometry based on beam splitters design and use of simple "climbing hill" and stochastic parallel gradient descent (SPGD) algorithms for phase locking. As a proof of a principle, it is demonstrated for four low power beams in CW regime. In the final laser system design, 3 CBC units combining four beams each (~ 600 W total power per unit) at slightly different wavelengths is planned. In the final stage, output beams of those three CBC units will be combined spectrally, delivering more than 1.5 kW average output power beam for material processing applications.

II. Results and Discussions

Laser beam from a master oscillator (~ 1064 nm) was split into four channels and aligned again in FA design. All four beams imitate "amplified" beams to be combined coherently. One channel was used as a reference. To compensate and lock the phases between the beams, a single photo-detector (PD) was placed in the path of the diagnostics (<< 1%) beam after the last beam splitter. The signal captured by PD was maximized by a feedback loop to phase-modulators located on the paths of the beams using simple algorithms. In contrast to TA CBC, no aperture in front of the PD is required for the presented FA CBC. We have tested two algorithms – one based on discrete Bernoulli distribution with zero mean value dithering SPGD, and another based on quasi-two dimensional diagonal climbing hill logic on the power-phase map. As a result, the output formed by four beams behaves as a single coherent beam. Same CBC scheme and algorithms can be used also for high repetition rate (> 500 kHz), sub-ns or longer duration pulse beams. This can be achieved by adjusting temporal overlaps of the pulses in all four beams and keeping the bandwidth of the single PD well below the pulse repetition rate, averaging and maximizing the captured signal over many pulses. The CBC efficiency in the present system was estimated to be 0.9. The phase rms deviation was better than $\lambda/25$, accounting for about 4% of the CBC efficiency drop. The remaining drop was caused by the power imbalance between individual beams, divergence, pointing and overlap mismatches. We note, that for high average power CBC, all optical components could introduce wave-front distortions, further reducing the combining efficiency. This, however, is not a CBC method specific efficiency drop, but caused by the CBC nature itself, which is essentially a "spatial coherence filter". During the presentation, factors causing the efficiency drop in binary-tree FA CBC will be discussed in detail.

For industrial applications of kW class laser beams, a simple and cost effective CBC scheme has been demonstrated.

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