Mode decomposition of laser beam propagated in a multimode fiber in the Kerr self-cleaning regime

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For a long time multimode (MM) fibers have remained unclaimed due to poor beam quality. Usually, the beam quality is inversely proportional to the number of excited modes. However, an intensive research of nonlinear effects of high-power laser beam propagation in MM graded-index (GRIN) fiber has led to the discovery of some unexpected phenomena, such as Kerr self-cleaning of the beam [1] and generation of a supercontinuum width high peak power pulses [2]. The self-cleaning mechanism is that most of the beam energy flows into the fundamental mode. This process is accompanied by redistribution of energy towards higher-order modes. An increase in the energy of the fundamental mode leads to an improvement of the beam quality. The standard way to determine beam quality is to measure the M^2-parameter (m-squared). In fact, beam rate of divergence from the Gaussian is measured. But, since self-cleaning is a nonlinear redistribution of energy carried by a large number of fiber modes, this approach is not entirely correct, and the mode decomposition of the output beam seems to be a much more informative method.

Mode decomposition is a beam analysis technique that measures the amplitudes and relative phases of the modes that the beam consists of. Existing decomposition methods are based on genetic algorithms [3], adaptive optics [4], or phase modulation [5]. The last option can be realized using a spatial light modulator (SLM). An SLM is a device that superimposes a certain form of spatial modulation (amplitude, phase, or amplitude and phase simultaneously) on the beam, and usually controlled by a computer. Existing works on mode decomposition included the analysis of the output beam from MM fibers with small number of guided modes. Our goal was to make the method suitable for GRIN fibers with a large number of modes.

The experimental setup is shown in Figure 1. Using the property of orthonormalization of fiber modes, the Jacobi-Anger expansion and the Fourier transform theorems, phase masks were formed in a such way that the center of the first diffraction order contains information about the mode amplitude or its relative phase (in relation to some mode, usually fundamental) [5]. In this work, a numerical simulation of the decomposition process for a randomly generated beam was made. The result is that the amplitudes and phases were measured with an accuracy of 10^{-7}, and the reconstructed beam was almost indistinguishable from the original one. The sampling was added in order to compare the results for 10-bit and 8-bit modulators numerically. Calculations have shown that the difference in sampling did not significantly affect the accuracy of measuring the amplitudes (~ 10^{-4}). In the case of measuring the phases, the difference is more significant, but still not critical (accuracy 10^{-3} for 10 bits, and 10^{-3} for 8 bits).

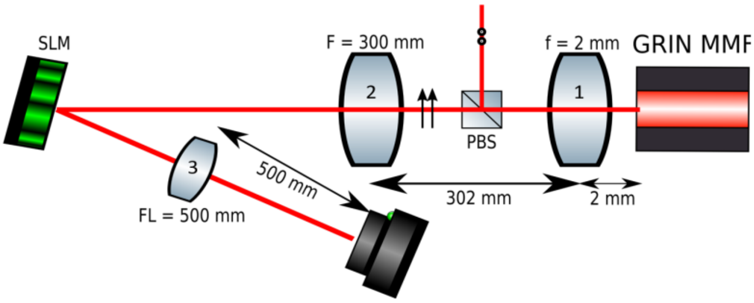

Fig. 1. Experimental setup. Lenses 1 and 2 transfer the near field distribution (from the output of the fiber) to the modulator. Lens 3 performs the Fourier transform from the modulated field (forms the far field image).

The influence of the phase mask resolution on the decomposition results was checked. We compared masks with a fundamental mode radius of 120, 90, 60 and 30 pixels. It was found that with decreasing resolution, an especially strong increase in the error occurs at a mode radius of 30 pixels (Fig. 2 (a, b)). In this case, the shape of the reconstructed beam differs slightly from the original one (Fig. 2 (c)).

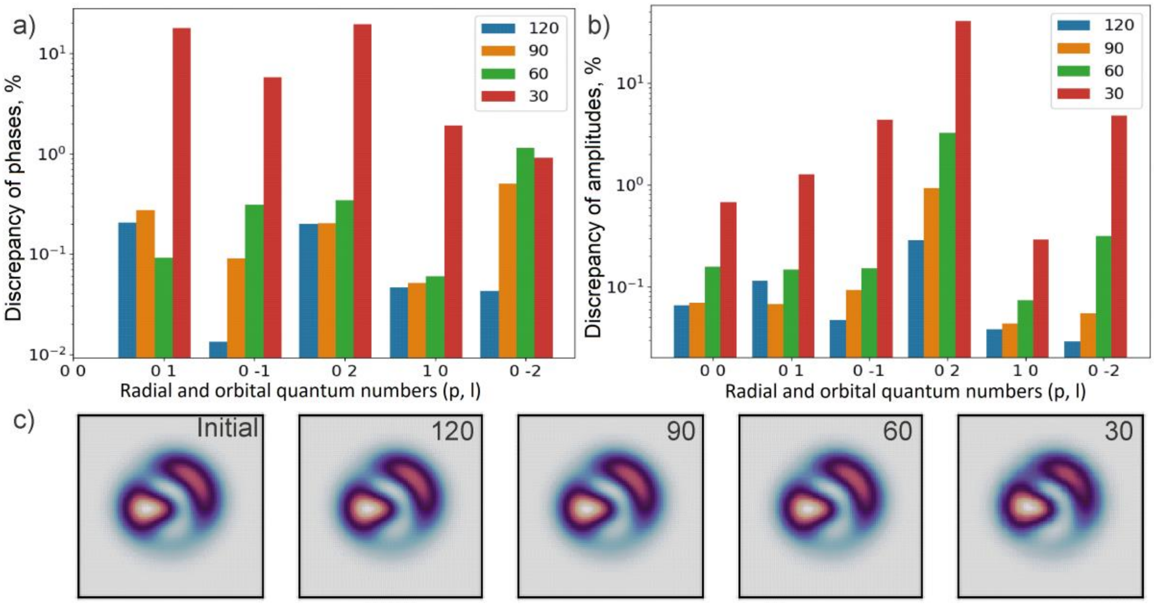

Рис. 2. a) Discrepancy of phases (logarithmic scale), calculated in the process of the decomposition simulation; b) The discrepancy of the amplitudes (logarithmic scale), calculated in the process of the decomposition simulation; c) From left to right - the original beam; a beam reconstructed as a result of decomposition with a fundamental mode size of 120 pixels; 90 pixels; 60 pixels; 30 pixels;

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References

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