High-resolution Shack-Hartmann sensor for measuring variations of high-power laser beams

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Abstract—A high-resolution Shack-Hartmann sensor is developed, which enables one to perform the fast time sampling and measuring both the wavefronts and the intensity distributions of high power lasers over the square entrance pupils up to 15x15 mm. The sensor has a flexible program interface with two built-in algorithms for reconstructing the laser wavefronts.

Keywords—Shack-Hartmann sensor, high-power lasers, phase reconstruction, intensity distribution

The experimental testing, assembling, and alignment of new high-power femtosecond laser systems based on the coherent superposition of multiple laser beams require to evaluate precisely the quality of both the separate beams in different channels and the resultant output laser beam. The first stage of this evaluation assumes a high-precision, fast, and high-resolution measurement of the transverse distributions of the phase and intensity of the beams. The necessity of this measurement is stipulated, in turn, by the effort of avoiding the emergence of hot spots within the transverse intensity distributions of laser beams and of reaching a higher level of the resultant output beam. Ideally, the central region of the beams must be free from the intensity and phase variations. Using the results of the measurement one can further perform a more accurate alignment of the spatial filters (in the form of vacuum telescopes) of the laser system in different channels and even to perform the compensation of the phase inhomogeneity of solid-state active crystals of the whole laser system by a correction phase plate. The most complicated part of the mentioned evaluation is the measurement of the phase distributions of laser beams. Due to a wide spectrum of a femtosecond laser radiation the use of classic interferometers is not feasible here and presents a real challenge. One of the most convenient tools for this measurement is a Shack-Hartmann sensor [see, e.g., 1] which is capable of operate in white light and to evaluate simultaneously both the phase and intensity maps. In the present work we report on the preliminary results of the numerical simulation of a high-resolution, fast, and wide-aperture Shack-Hartmann sensor together with describing the algorithms of reconstructing the wavefronts built-in a program interface.

A developed Shack-Hartmann sensor consists of a high-resolution commercially available camera, several replaceable microlens matrices (lenslets) adjusted before a chip of the camera and having different numbers of microlenses, and a program interface. The camera has a global shutter and a large CMOS chip with the overall dimensions of about 15x15 mm. The dimensions of the experimental lenslet matrices we used are equal to 32x32, 64x64, and 102x102. When performing the computer simulation of the process of wavefront measurement with the use of a Shack-Hartmann sensor, we have examined the main theoretical characteristics of the sensor for even higher binary dimensions of its lenslet matrices. Making the time optimization of a modal algorithm for reconstructing the wavefronts we have obtained a fast convergence of the process of approximation of the wavefronts by the Zernike polynomials. The results of the computer simulation of a method of spectral analysis with the use of N Zernike polynomials are presented in Table 1. The simulation is performed with a personal computer on the base of Intel Core 2 Duo CPU (2 GHz) running under Windows XP OS.

<table>
<thead>
<tr>
<th>Lenslet size</th>
<th>Time of calculation, ms (± 3 ms)</th>
<th>Error of phase reconstruction, in fringes (1 fringe = 2π)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>For spect.</td>
<td>For Phase</td>
</tr>
<tr>
<td>128×128</td>
<td>6</td>
<td>22</td>
</tr>
<tr>
<td>256×256</td>
<td>22</td>
<td>76</td>
</tr>
<tr>
<td>512×512</td>
<td>95</td>
<td>268</td>
</tr>
</tbody>
</table>

As it follows from the results given in Table. 1, using the maximum acceleration of the process of calculation at 128x128 time samplings, one can perform the high-resolution real-time measurement of arbitrary laser wavefronts at 25 frames per second.

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