Beam diagnostics and adaptive optics for PHELIX

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PHELIX (Petawatt High Energy Laser for Heavy Ion Experiments) is designed to be a versatile laser capable of supplying a few Kilojoule, ns pulses as well as Petawatt level, fs pulses to the experiments. To achieve a focal spot size close to the diffraction limit it is required to optimize the beam quality of PHELIX. Spatial wave front aberrations increase the spot diameter in the focal plane. In addition they result in undesired optical path differences of the laser beam within the grating compressor, which lead to an increased pulse duration [1] and thus lower peak power.

The NOVA amplifiers exhibit mainly three different types of wave front aberrations: static aberrations, pump shot aberrations and long term thermal aberrations. The main purpose of the adaptive optics system is to correct for the thermo-optical aberrations in the main amplifier, in order to maintain the beam quality for the next shot without having to wait close to 10 hours as required for a complete return to the initial conditions.

The adaptive optics system comprises an actively controlled bimorph adaptive mirror and a static deformable HR-mirror in the main amplifier. The bimorph adaptive mirror consists of a dielectric coated glass substrate that is attached with its backside to a stack of two piezo discs. The piezo discs themselves are coated with 31 electrodes. In addition to the actively controlled bimorph mirror in the pre-amplifier, the retro reflecting mirror of the double pass amplifier can be deformed by four micrometer screws. This will allow the correction of astigmatism which is expected to be the major aberration with the disc amplifiers. This concept was successfully demonstrated at the VULCAN laser in the Rutherford Appleton Laboratory.

The bimorph mirror is placed in the relay image plane of the laser rods and represents the object plane for the transport telescopes of the double pass section in the main amplifier. The maximum achievable deformation of this mirror is about 6 λ. This allows the mirror to correct the aberrations that arise in the pre-amplifier and, in the near future, to pre-correct for aberrations in the main amplifier. Behind a leaky mirror at the end of the pre-amplifier a Shack-Hartmann wave front sensor is installed. With this wave front sensor and an automatic control program, a closed loop operation for the pre amplifier is realized.After the calibration of the close-loop adaptive mirror setup, we successfully demonstrated the optimization of the pre-amplifier. The laser was fired two times with a delay of five minutes between each shot to introduce thermal aberrations into the amplifier. During the second shot the wave front was measured and inverse surface of the adaptive mirror was calculated. Figure 1 shows the optical path difference over the entire surface for the adaptively controlled amplifier and for the free running system. The correction system proofed to be capable of improving the Strehl ratio by a factor of three. Here, as expected for the rod amplifier, the major part of the thermal aberrations is in the defocus term. To measure beam properties in the double pass amplifier, a middle-of-chain sensor is installed behind the retro reflecting mirror and in addition an end-of-chain sensor will be installed at the exit of the amplifier. A telescope corrected for spherical aberrations is used for down collimating the beam in both sensors in a way. The reduced beam is guided to a near and far field measurement and a Shack-Hartman sensor. For pre-correction of aberrations of the disc amplifier with the actively controlled adaptive mirror this Shack-Hartmann sensor can be used to close the control loop. The expected aberrations are in the magnitude of a few waves and appear mostly in the astigmatism term. With the actively controlled adaptive mirror and the static deformable mirror it should be possible to increase the repetition rate dramatically and concurrently increase the brightness.

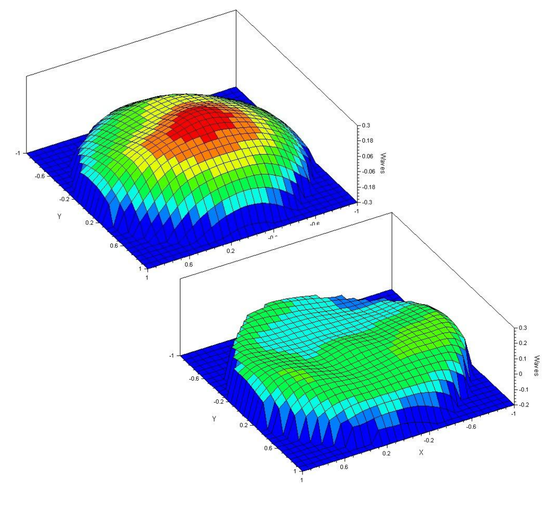

Figure 1: Wave front of a fs-pulse amplified with the pre-amplifier without (top) and with (bottom) the closed loop adaptive correction.

References

[1] H.-M. Heuck, C. Häfner, P. Wiewior, E. Gaul, S. Borneis, T. Kühl, and U. Wittrock, *Waverfront measurement and adaptive optics at the phelix laser*, Proceedings of the 4th International Workshop on Adaptive Optics for Industry and Medicine, 2003.