Correcting Pulse-Front Errors in the OMEGA EP Pulse Compressor

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Abstract:

In the Omega EP laser, the pulse must be stretched in time, amplified, and subsequently compressed in a grating compressor in order to obtain high peak power. A model was used to characterize the temporally resolved near-field and far-field beam distributions for several different compressor configurations that included grating alignment errors and grating surface figure errors. The spatio-temporal effect of correcting the compressor output wavefront by use of a deformable mirror (DM) is presented and a trade-off between best spatial and temporal performance is elucidated.

1. Introduction

1.1 Pulse Compression

In order for a short laser pulse to be amplified, it must first be stretched because it may otherwise cause damage to the optics required for amplifying it. After being stretched through time, the pulse must be recompressed. To do this, a pulse compressor consisting of four diffraction gratings is required which will provide for a stretched pulse to be propagated through. In going through the compressor, the wavelengths of the pulse are separated before being focused together. However, since the diffraction gratings required for the pulse compressors need to be quite large, three gratings are placed in series to form each complete diffraction grating. Errors may be caused if the gratings are out of alignment or if there is any curvature on the grating tiles. Misalignment and surface figure errors broaden the pulse and degrade the far-field focal spot. Some error is anticipated because it may not be possible to perfectly align the diffraction tiles.

1.2 Deformable Mirror

Once built, the OMEGA EP laser will be the most powerful laser in the world. The laser will use a femto-second pulse which will be split and amplified before being focused on a target to aid in the creation of fusion reactions with the release of energy. Fusion is being explored as a solution to providing an alternate source of energy. However, the laser pulse may have errors in the wavefront that may affect the efficiency of the laser. The deformable mirror (DM) is useful in correcting any errors in the wavefront by using a series of pistons to adjust itself to compensate for the wavefront error.

2. Methodology

2.1 FRED

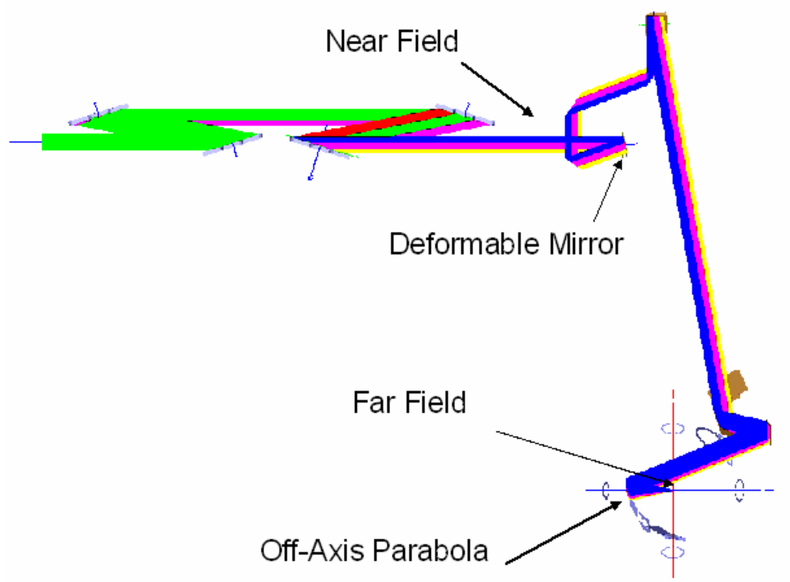

Figure 1 – **Modeling in FRED** – Beams are propagated through the pulse compressor to the deformable mirror and on to the off-axis parabola. The encircled energy and FWHM of the compressor are found at analysis planes in the near field and far field.

FRED is an advanced optical engineering software program capable of simulating the propagation of light through virtually any optical/mechanical system. In this case, FRED was used in order to trace waves at different frequencies as they propagated through the pulse compressor to the deformable mirror and the off-axis parabola (OAP) to the target chamber (see Fig. 1). The OAP is used to focus the beam. The diffraction gratings were modeled in FRED to conform to a set of design parameters such that the grating pairs were a certain distance apart from one another.

A 30 by 30 beam grid was traced through the compressor, originating from an optical source. Data collection took place at two separate analysis surfaces; one just before the beams hit the DM and the second at the focus of the OAP. These two planes have been designated the near field and far field, respectively. This allowed for observation of the spatial and temporal movement of the pulse in both fields.

Through the use of FRED, error could be applied to the diffraction gratings so that its effect on the pulse could be observed, and numeric feedback on the pulse performance could be calculated. The primary evaluated data were the temporal full width at half maximum (FWHM) and the percent of the pulse energy focused inside a circle of diameter 20 μm (known as the encircled energy). This diameter corresponds to laser rays deviating by 9.58 μrad from the ideal direction.

2.2 MATLAB

Once an error was created in FRED, the data from the near-field and far-field raytraces was used in MATLAB to create graphs of the FWHM and the spatially integrated pulse through time. This was helpful in observing the effect of error on the pulse compression model.

3. Results

In order to properly consider the effect of error upon the grating tiles of the pulse compressor, a "perfect" compressor model was configured in FRED in order to meet up to the proper specifications. Data was collected from the "perfect" raytrace that could be compared to later raytraces in which error was applied on the tiles. The results of the calculated total encircled energy and the FWHM were compared to the desired values. The desired value of total encircled energy is ≥80%; that of the FWHM is ≤1 picosecond (ps). The FWHM of the "perfect" compressor was 523 fs; its total encircled energy was 100% (see Fig. 2).

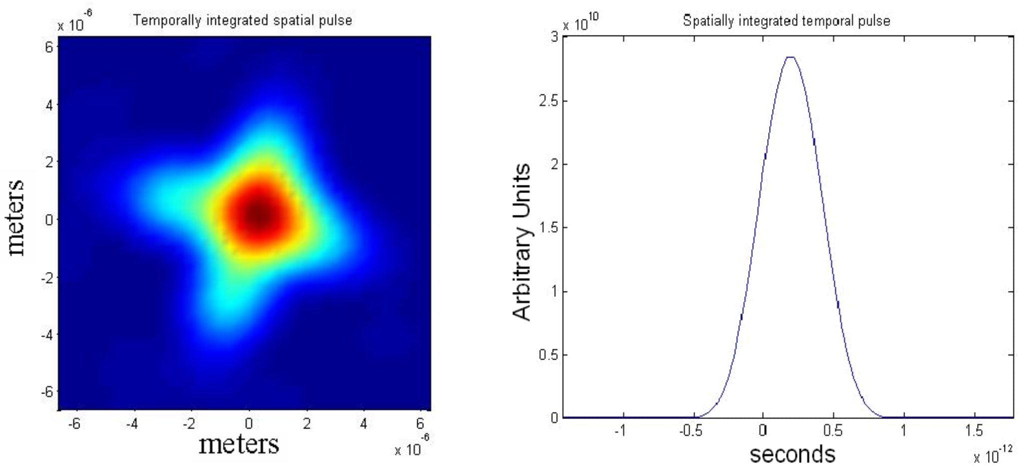

Figure 2 – **"Perfect" Compressor** – The encircled energy of the pulse of the "perfect" compressor may be viewed in the temporally integrated spatial pulse (left). The spatially integrated temporal pulse (right) shows the FWHM of the pulse.

3.1 Tip, Tilt, and In-plane Rotation

The first types of error which were considered when examining the pulse compressor model were those caused by tip, tilt, and in-plane rotation. Tip refers to a

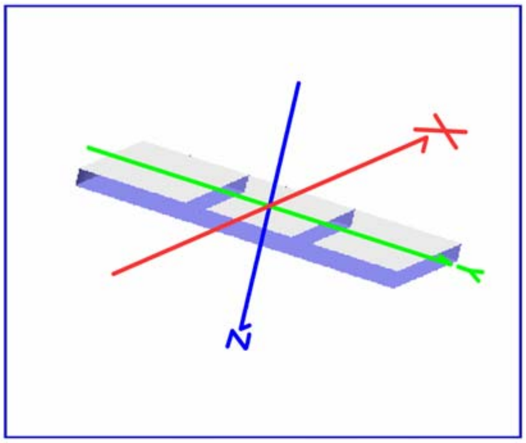

Figure 3 – **Orientation of a Diffraction Grating with three tiles.**

rotation across the horizontal axis. Tilt is the rotation about the vertical axis, and in-plane rotation is rotation about the axis normal to the diffraction grating (see Fig. 3). There already existed pre-determined grating alignment tolerances. For tip, the alignment tolerance was 33 μrad; for tilt the alignment tolerance was 10 μrad and for in-plane rotation, the alignment tolerance was 61 μrad. These errors were applied to each grating plane as well as each of the tiles in the diffraction grating planes. The tiles of the diffraction grating had different tolerances. The tiling tolerance for tip was 0.14 μrad, that of tilt was 0.33 μrad, and that of in-plane rotation was 0.15 μrad.

A "worst-case scenario" model of the pulse compressor was created that applied tip, tilt, and in-plane rotation to the diffraction gratings of the model. The effect of this error on the far field of the laser's focus was that the FWHM was 1.089 ps. This is a very good result, especially when compared to the FWHM of the "perfect" compressor, which was 523 fs. The total encircled energy of the pulse was 27%.

3.2 Tile Shifts

The second type of error that was applied to the compressor model was tile shifts in which the tiles making up the diffraction gratings were moved out of alignment along the horizontal, vertical, or normal axis. The tolerance for tile shifting along any of the x, y, and z axes (see Fig. 3) was 36 nm. In one raytrace which applied the "worst-case" scenario described in 3.1 to the three tiles making up the diffraction gratings as well as the tile shifts, the error observed was less than that for the "worst-case" scenario when applied to the entire diffraction grating.

3.3 Power on the tiles

Surface error also must be taken into consideration. There is no guarantee that the surface of the diffraction grating tiles will not have some sort of curvature or error on them that will cause error in the pulse front. Quarter-wave concave parabolic curvature (at 1.053 micron wavelength) was applied to each of the three tiles making up each complete diffraction grating to observe the effect of concave and convex curvature on the gratings. Figure 4(a) shows the results of a raytrace that applied the quarter-wave curvature on each of the three tiles in each diffraction grating. The FWHM was found to be 674 fs while the encircled energy was 39.42% in the far field.

It was anticipated that it would perhaps be easier to correct for wavefront error if the curvature errors on the tiles were arranged so that they formed a continuous curve rather than three separate curves. Thus, a raytrace was performed that applied the quarter-wave curvature to each of the diffraction gratings that were altered in FRED so that one large diffraction grating took the place of the three separate tiles. The FWHM of this raytrace was 1.99 ps and the encircled energy was 7.13% in the far field [see Fig. 5(a)]. Both this wave front and the one involving curvature on the three-tiled diffraction grating were applied to the deformable mirror to observe its effect on correcting their error.

One unique observation made in the far field of the single-tiled diffraction grating model with 1.053 micron concave power applied to it was that an astigmatism appeared, creating two separate but distinct foci. This explains the low encircled energy that was found in this raytrace; the data for the encircled energy was taken at a point between the two foci. It was anticipated that the astigmatism would be corrected for by the DM.

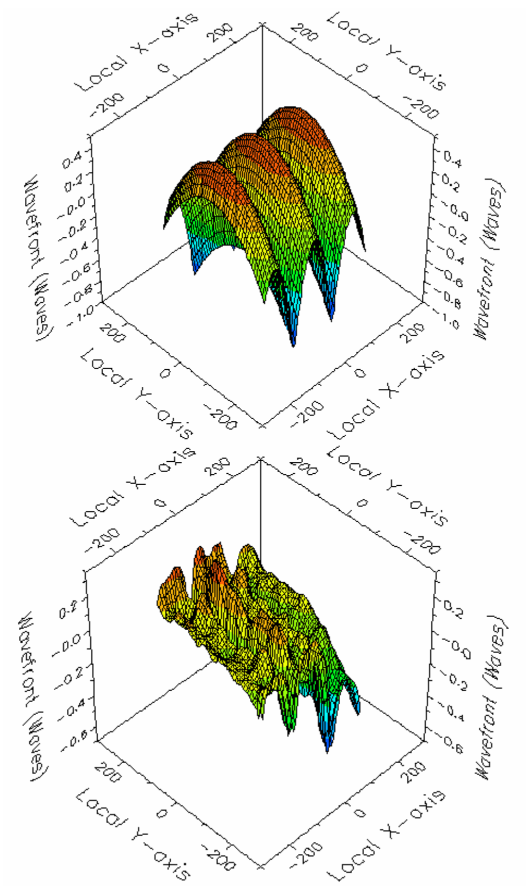

Figure 4 – **The DM corrects for the broadening of the pulse –** The upper image is the wavefront of the pulse when quarter-wave error is applied to the diffraction gratings. The lower wavefront shows the corrections of the DM in narrowing the pulse.

The wavefronts of both scenarios of power applied on the tiles of the diffraction grating were corrected by the deformable mirror [see Figs. 4(b) and 5(b)]. The DM corrects for the concave surface error on the three-tiled diffraction grating model from 39.42% to 75.13% encircled energy in the far-field. However, this still does not meet the desired value of 80% encircled energy. When the wavefront of the single-tiled diffraction grating scenario was applied to the DM, the results were much more promising (see also Fig. 6). The encircled energy that resulted from the raytrace once the corrections of the DM were applied to the compressor model was 87.07%, as opposed to its original 7.13%. This also corrected for the astigmatism that had occurred in the far field. This is significant because if curvature appears on the tiles, then they may be arranged so that they form a continuous curve rather than three separate curves. The DM is able to correct a continuous curve to a greater extent than three separate curves because it is easier for the pistons to adjust to the single curve. The alternative of pulling the DM in different directions diminishes its effectiveness.

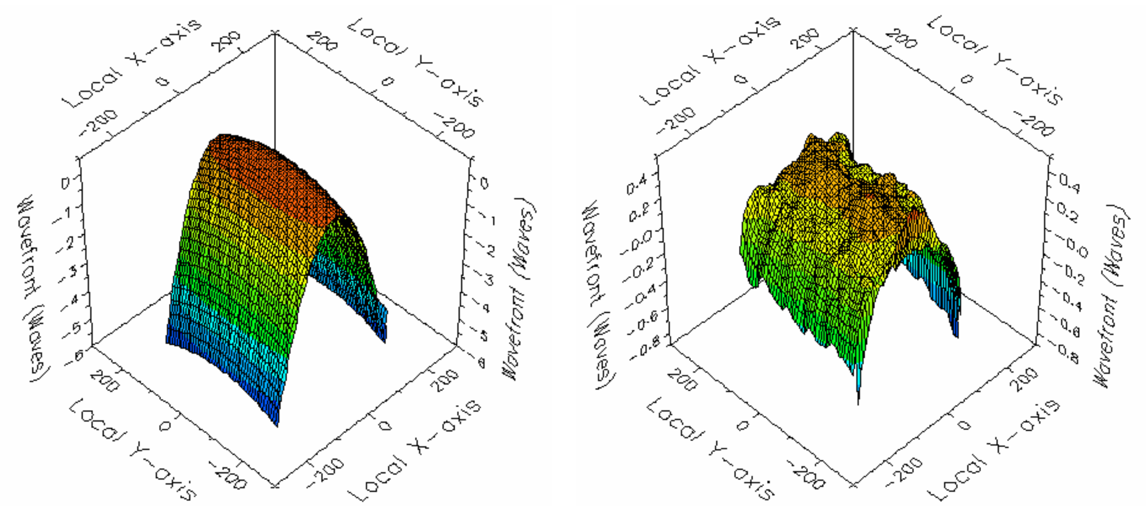

Figure 5 – **The DM corrects better when the power error on the diffraction grating is continuous** – The wavefront of the corrected pulse (right) is narrower and smoother than that of the corrected pulse in Fig. 4. The DM is better equipped to correct for a smooth, continuous error (left).

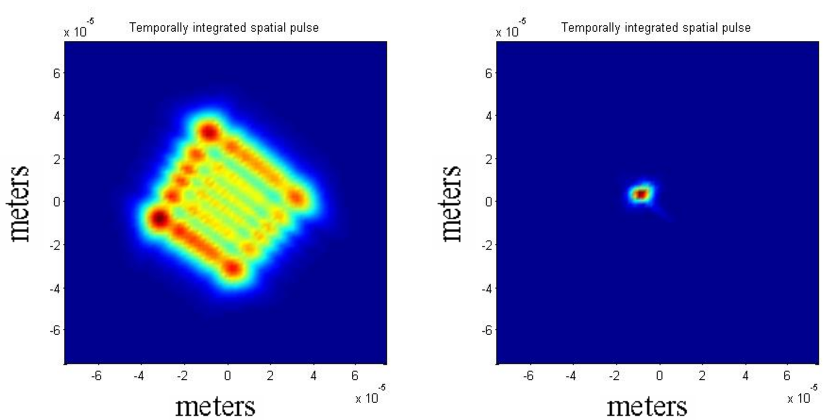

Figure 6 – **The DM is able to correct the encircled energy of the continuous curvature error to within the desired value** – The smearing evident on the uncorrected far field (left) is nearly eliminated when the DM is applied to the wavefront.

Though the DM was able to correct for the encircled energy of the two curvature scenarios, the temporal FWHM still was not corrected. Though both FWHM's were within the short-term desired value of 10 ps, eventually scientists will want the FWHM to be within 1 ps. The fact that the DM was incapable of presenting a solution to correcting temporal error in the pulse shows that there exists a trade-off between best spatial and temporal performance.

4. Conclusion/Further Work

Though errors may exist in the pulse compressor, the deformable mirror is able to correct for spatial error in the wavefront. The DM corrects for the concave surface error on the three tiles of the grating to 75% encircled energy at 9.58 μrad while it corrects for the concave parabolic surface error in the single tiled grating to 87%. However, though encircled energy is improved in the single tiled grating, there exists a larger FWHM of 1.93 ps as compared to 671 fs. This shows that a trade-off between best spatial and best temporal performance exists between the two compressor configurations. Thus, though the requirement of 80% encircled energy is met by the corrections found in the single tiled grating raytrace, the FWHM may yet be optimized.

Further work may show improved results. The off-axis-parabola alignment has yet to be optimized; doing so may improve the encircled energy and FWHM of the pulse. In addition, corrections from the DM may be applied to further raytrace scenarios and elucidate the trade-off between spatial and temporal performance and help produce a median between the two.

5. Acknowledgements

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6. References

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