Synthetic aperture compression scheme for multi-petawatt high energy laser

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Abstract. An original synthetic aperture compressor scheme is proposed for multi-kilojoule petawatt beam. This scheme uses two compressor stages with multi-dielectric gratings allowing suppressing the mosaic of gratings. The main technical issues are detailed.

1. INTRODUCTION

An additional line in petawatt range [1] is now under construction in the LIL facility, the prototype of the LMJ (Laser MegaJoule in France) [2]. This laser will permit to study new regimes of high intensity physics. In such high power lasers (7.2 PW – 3.6 kJ beam), the CPA (Chirped Pulse Amplification) technique is used. To keep the fluence on the compressor under damage threshold, meter range gratings should be used. Indeed, the damage threshold of the new multi-dielectric (MLD) gratings is less than 3 J/cm\(^2\) in right section for an incident angle of 72°. Hence, for the LIL square beam (40 × 40 cm\(^2\)), to compress 3.6 kJ, 1.8 m gratings are needed for a classical compression scheme. To achieve this grating size, an alternative, studied by many groups, is mosaic grating consisting of smaller, coherently added gratings [3, 4, 5]. In this paper, we propose a new synthetic aperture compression scheme. This system uses only one segmented mirror and allows suppressing the use of mosaic gratings. The objectives are to simplify the alignment processes and to limit the ghost beams.

2. BASELINES OF THE MIXED COMPRESSION SCHEME

2.1 Principles

The pulse compression is achieved in two stages (figure 1). First, a compressor in air reduces the pulse duration from few nanoseconds to few hundred picoseconds in a double pass configuration (or equivalent). The relative long duration of the first stage output permits to decrease the incident angle on gratings and so to use smallest gratings. Then a single pass compressor under vacuum is used to obtain 500fs. The second part of the compression is designed for a small compression factor to limit transverse chromatism (dependence of the transverse spatial coordinate versus wavelength) and to reduce the volume under vacuum. Moreover the gratings are spatially translated to avoid coupling between two neighboring gratings. This specification allows us to consider this compressor as 4 independent compressors. Finally, a segmented mirror is inserted between the two compressors to compensate for the spatial phase shift and delay induced by the 4 compressors on the beam.
The three main advantages of this new compression scheme are: use of 1 segmented element instead of 4, placed in air atmosphere and 3 degrees of freedom instead of 4 (mirror compared to grating).

![Figure 1](image)

**Figure 1.** Double stage compressor separated by a segmented mirror. The first stage is equivalent to double pass compressor with monolithic gratings. The second stage is designed to be equivalent to 4 independent compressors.

### 2.2 Technical issues

As explained, the vacuum compressor is reduced to a small compression factor and allows compressing the pulse duration from few hundred picoseconds to few hundred femtoseconds. Therefore, the first compressor is designed to compress the stretched pulse coming from the amplifier section (few ns to few hundred ps) without transverse chromatism.

Thanks to the higher damage threshold in nanosecond regime, the incident angle on the grating may be reduced, resulting in less than the diffracted angle. With an incident angle around 60°, the beam size on the grating is reduced by a factor of two allowing the use of monolithic component [6]. This compressor is used in a configuration equivalent to a double pass (no transverse chromatism) and so we have no mosaic gratings anymore in the complete compressor.

The vacuum compressor is designed to minimize the distance between the gratings. This characteristic limits transverse chromatism. It means that the contribution of the spectral repartition is negligible compared to the beam diameter. Then the gratings are placed to avoid coupling of energy between two gratings next to each other and suppressing pre-pulses. So each grating of the mosaic can be considered as independent. The compressor becomes equivalent to 4 independent compressors with classical alignment tolerances. At this stage we have estimated the losses induced by this configuration (spectral losses and travelling wave) on the focal spot intensity. For the MPWHE-LIL (Multi-PW High Energy LIL) configuration (N = 1780 t/mm, i = 77.2°, 2 m between gratings, 38 cm beam, 450 mm grating), the peak intensity decrease is only 5%. The main effect is on the short time contrast ratio reduced to $10^{-9}$, 10 ps before the main peak, the long pulse contrast is not affected.

So coherent addition of gratings is no more required, we just have to phase the output beams from these 4 compressors. This can be easily made using a segmented mirror. This segmented mirror will be inserted in air before the vacuum compressor to limit constraints on mechanical systems. Interferometric precisions are required on this mirror to phase the beams in piston with 50 nm precision and tilt with 1 μrad precision. A second piston in the micrometer range is required to synchronize temporally the 4 compressors. To limit damage on the segmented mirror, a spatial beam shaping is realized in the front end to minimize the energy on the edges of the components.

The final parameters which can decrease the intensity on target are the B-integral in the vacuum chamber window and the spectral phase term. To limit the non-linear effects, the thickness of the window is limited to 30 mm. The high stretching factor in the Offner system (front end) allows limiting the cumulated B-integral in the power chain and reducing the effect of the B in the compressor. Concerning the spectral phase term the stretcher parameters (incident angle, groove density) are adjusted to cancel on target the second and third orders. The residual orders ($4^{th}$, ...) are negligible.
3. CONCLUSION

A new compression scheme for high energy PW laser is proposed. This scheme allows suppressing the use of mosaic gratings. Numerical simulations for the MPWHE-LIL gives a global efficiency of more than 95% in intensity compare to the monolithic segmented mosaic compressor. This decrease is due to the spectral losses and transverse chromatism in the second stage and is given for a perfect alignment of the mosaic elements. Moreover interferometric alignment processes are strongly simplified: only one segmented mirror with 3 degrees of freedom has to be aligned compare to 4 mosaic gratings with 4 degrees of freedom. The two compressor stages use the classical compressor alignment techniques and a wavefront sensor is used to adjust the pistons and tilts of the 4 parts of the beam.

Acknowledgements

This work is performed under the auspices of the Conseil Régional d’Aquitaine and the “Institut des Lasers et Plasmas” (ILP). We thank S. Nuaillés and S. Mousset for fruitful discussions.

References