Performance of a high-resolution deformable mirror for wavefront correction on the LIL/LMJ and PETAL baselines

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Abstract. The performance of a high-resolution deformable mirror (“HRDM”) is analyzed for wavefront correction on the CEA high-power laser baselines in France: the Laser Mégajoule (LMJ), the Laser Integration Line (LIL) and the Petawatt Aquitaine Laser (PETAL). This study is achieved using monochromatic numerical simulations with the CEA “MIRÔ” laser propagation code. When compared to the LMJ deformable mirror used alone, the HRDM located at the L-turn is shown to give equivalent performance at filtering pinholes whereas the HRDM located at injection is less efficient. The use of an HRDM improves the impulse response of the LIL/LMJ main amplifier section. As a consequence, on the PETAL 1ω focal spot, it gives a reduction of factor 2.7 of the radius at 80% of encircled energy and an increase up to 40% of the peak intensity. Finally, maximum mechanical amplitude of 10 nm is numerically evaluated for sinusoidal phase technological defects in the case of the HRDM located at the L-turn.

1. Introduction

The Laser Mégajoule (LMJ) project [1], in France, is part of the CEA-DAM nuclear weapon simulation program. It is dedicated to high energy physics experiments including thermo-nuclear ignition and burn by inertial confinement. The laser system is composed of 240 neodymium glass laser lines arranged in bundles of 8 beams. It is designed to deliver pulses up to 1.8 MJ energy at 351 nm-wavelength (3ω) on target, after frequency conversion. Peak power is up to 550 TW depending on pulse shape and pulse duration which can be tuned between 0.3 ns and 25 ns.

The Laser Integration Line (LIL), the prototype of LMJ, is a 4 beam facility. Each beam delivers between 1 kJ and 9.5 kJ energy with a pulse duration ranging from 0.3 ns to 25 ns at 351 nm on target. The LIL was commissioned in 2004 [2] and is currently used to test technological improvements and for plasma experiments.

The Petawatt Aquitaine Laser (PETAL) is an additional line in the LIL facility. It is designed to deliver 500 fs pulses with a 3.5 kJ-beam energy and a 7.2 PW-peak power. It will enable the study of new regimes of the high intensity physics. This laser line uses a chirped pulse amplification (CPA) technique at 1.053 μm (1ω) and a synthetic aperture compression scheme [3]. The line is under construction. Wavefront correction on PETAL is one current challenge to obtain the laser performances at target chamber center including requested focal spot size without any spatial pedestal, peak power and eventually peak intensity.
In this paper, the performance of a high-resolution deformable mirror (HRDM) is evaluated in comparison with a LMJ deformable mirror for wavefront correction on the LIL/LMJ and PETAL baselines. This study is achieved by using the CEA “MIRÓ” laser propagation code. First, the principle and architecture of the considered deformable mirror systems are described as well as the calculation process with the MIRÓ code. Then the performance obtained with the HRDM is presented in terms of the laser spot dimension in the spatial filter pinholes, the residual phase at the main amplifier output and the dimensions of the focal spot at 1ω (PETAL) and at 3ω (LIL/LMJ). Finally, an amplitude specification on the HRDM technological defects is given for the HRDM located in the L-turn and for sinusoidal phase defects.

2. Wavefront correction configurations and calculation method

2.1 Principle and architecture of deformable mirror systems

The main amplifier section (MAS) of a LIL/LMJ single beamline and of the PETAL beamline is shown on figure 1. In order to minimise the spot size, the design includes control loops which are devoted to aberration compensation. Aberrations are either static (due to optical component manufacturing and positioning) or dynamic during system shots (due to the thermal stress inside the large flash-lamp-pumped amplifier slabs).

![Figure 1. The four-pass amplifying architecture, for a single LIL/LMJ beamline and for the PETAL beamline.](image)

The LMJ deformable mirror “M1” is located in the rear end of the MAS where the beam size is about 400 × 400 mm². The design of this mirror was optimized with 39 mechanical actuators. It has been tested and gave the expected results on the LIL facility [1,4].

The HRDM has 18 × 18 actuators. It is located at injection or at the L-turn : its size is about 40 mm or 80 mm, which is respectively about ten to five times smaller than the LMJ deformable mirror. We assume that an additional compensation of aberration is obtained by adjusting the position of a spatial filter lens, therefore the HRDM can be used alone. Thus five configurations of deformable mirror systems are examined : M1 alone, HRDM at injection, HRDM at L-turn (“M2”), HRDM at injection combined to M1 and HRDM at L-turn combined to M1.

The case of a deformable mirror located at the rear end of the MAS, that would have the same spatial resolution as the HRDM, has not been studied yet.

2.2 Calculation method using the MIRÓ propagation code

The phase correction to apply to the deformable mirror (M1 alone or HRDM alone) is obtained by minimising the residual phase at the MAS output. This optimisation is achieved using three-loop optical propagation calculations with the CEA MIRÓ laser propagation code [5]. In the case of a combined use of the M1 and the HRDM, a first three-loop wavefront correction calculation with the
M1 gives a phase correction that is used in a second three-loop wavefront correction calculation with HRDM.

Then for each of the five wavefront solution configurations, a monochromatic MIRÓ calculation which takes into account phase corrections applied on mirrors gives the laser performance.

3. Performance of HRDM on LIL/LMJ and PETAL baselines

3.1 Laser spot performance in the spatial filters

Considering the dimension of spatial filter focal spots, the maximum amplitude required for the HRDM actuators are evaluated in all cases and are compatible with the current range of previous fabricated HRDM.

Laser spot angular radii at 99% of energy in the pinholes planes of the spatial filters are calculated in order to be compared to the pinholes dimensions. These radii are equal to 20 μrad to 50 μrad for the HRDM used alone at L-turn and for the HRDM at L-turn or injection combined to the M1. When the HRDM is used alone at injection, the spot radii are all less then 70 μrad except in the first pinhole where it is equal to 140 μrad, that is 7 times the diameter obtained with the LMJ M1 mirror. Indeed, when the HRDM is used alone at injection, phase pre-compensation before the first pinhole is very high. Thus, considering the 60 μrad LMJ first pinhole nominal dimension, HRDM used alone at injection is not an acceptable wavefront correction solution.

It results that using the HRDM at injection is an acceptable wavefront correction solution only if it is coupled to the M1. The HRDM in the L-turn, alone or combined to M1, gives laser spot performance in the spatial filters equivalent to the M1 alone.

3.2 Residual phase at the main amplifier output

The use of the HRDM (with or without the M1) improves the impulse response of the LMJ laser amplifier section when compared to the M1 used alone. The beam wavefront peak-to-valley amplitude is reduced of 20% (figure 2) and the beam residual wavefront slopes are reduced of 25% for spatial periods greater than 10 mm in the main amplifier section.

3.3 Dimensions of the focal spot at 1ω(PETAL) and at 3ω(LIL/LMJ)

A simplified PETAL baseline is modeled at 1ω with MIRÓ by using a perfect thin focusing lens with a focusing distance of 3.5 m. The calculation is monochromatic and B-integral effects on the focal spot are not studied. The use of the HRDM at L-turn (with or without the M1) in comparison to the M1 used alone, reduces of a factor 2.7 the 1ω focal spot radius at 80% of encircled energy, down to 17 μm (figure 3) and increases up to 40 % the focal spot peak intensity.

![Figure 2](image1.png)

**Figure 2.** Comparison of 1ω residual wavefronts at the MAS output for wavefront corrections with the HRDM at L-turn (right) and with the LMJ deformable mirror (left).

![Figure 3](image2.png)

**Figure 3.** Comparison of 1ω focal spot encircled energies for wavefront corrections with the HRDM at L-turn and with the LMJ M1 deformable mirror.
MIRÓ simulations of the LMJ baseline are achieved for a 5 ns square pulse. Nominal filtering parameters are applied: 100 µrad angular radius at each pinhole except on the first pinhole where it is reduced to 60 µrad to avoid parasitic retro-reflections towards the front end. The injected energy is adjusted in order to obtain 18 kJ at the main amplifier output (1ω). It results that when the HRDM is used instead of the M1, a 12 % decrease of the 3ω focal spot diameter is obtained in the first transverse direction with a 4% decrease in the other direction, corresponding to the pump-induced aberration asymmetry.

4. HRDM specifications on technological defects
Technological defects due, for example, to inter-actuators effects, are modeled by two-dimensional sinusoidal phase defects at the HRDM surface. The case of a L-turn located HRDM with defect periods from 1 mm to 4 mm is considered through MIRÓ monochromatic propagation simulations. It results that for a peak-to-valley mechanical amplitude of the defects less than 10 nm, no critical amplitude modulation or energy loss is observed at the output of the MAS and the 1ω focal spot energy and peak intensity are stable up to 0.5%.

5. Conclusion
Wavefront correction performances of the HRDM on the LIL/LMJ and PETAL baselines, is compared to the LIL/LMJ M1 deformable mirror performances with the CEA MIRÓ laser propagation code. The HRDM located at the L-turn gives equivalent performances at filtering pinholes whereas the HRDM located at injection is less efficient. The HRDM improves the impulse response of the LIL/LMJ main amplifier section for spatial periods greater than 10 mm. As a consequence, on the PETAL 1ω focal spot, the HRDM reduces of a factor 2.7 the diameter at 80% of encircled energy and increases the peak intensity up to 40%. Also a maximum mechanical amplitude of 10 nm is numerically evaluated for phase sinusoidal technological defects in the case of an HRDM located at the L-turn.

On the PETAL baseline, the next wavefront correction tasks are the following ones: broad spectrum beam simulations of the PETAL main amplifier section including a compensation system for longitudinal chromatism, optimisation of HRDM actuator number, experimental validation with a LIL/LMJ M1 deformable mirror then with an HRDM in the L-turn (M2), coupled with a second deformable mirror located before the compressor output.

6. References
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