Overview of LMJ alignment to target chamber center and very first results

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Abstract: The laser Megajoule (LMJ) is a high energy laser facility (176 UV beam lines) designed for High Energy Density Physics. The end of the year 2014 was devoted to the progressive commissioning of the LMJ to achieve the first experimental campaign with 8 beams. This paper describes the alignment system developed in order to focus the laser beams and point the plasma diagnostics on the target. Alignment performances have been validated at very low power (1J front end shots) on an active target supporting a CCD sensor. Additional high power pointing shots have been performed to complete the characterization. We have demonstrated beam to target positioning accuracy < 52µm rms which is the LMJ requirement.

1. INTRODUCTION

The Laser MégaJoule (or LMJ), is a high power laser facility being constructed at the CEA Cesta site near Bordeaux (France) to study high energy density physics [1]. For the most demanding experiences the alignment requirements are 50 µm rms for the laser quad (groups of 4 beams) and 15µm rms for the target [2]. Plasma diagnostics are located all around the target chamber to measure and follow the physical phenomena occurring during an experiment. Some of these diagnostics need to be aligned up to better than 10% of their optical field to minimize field loss due to misalignment. In order to shorten the chain of dimensions and to reduce the number of sensors, the laser beams and the plasma diagnostics are aligned with a single sensor named the Common Reference.

2. LMJ ALIGNMENT SYSTEMS AROUND THE TARGET BAY

A simplified diagram of one LMJ beam line is shown Figure 1, together with the main components involved in laser, target and Plasma diagnostics alignment. A front end and a preamplifier module (PAM) generate a 39mm x 38mm beam at 1\(\omega\) (\(\lambda=1053\)nm). This initial pulse is injected in the main amplifier where it is amplified to more than 15 kJ @ 3ns. Then the beams propagate in the experience bay where a series of 6 mirrors directs the beams into the Final Optic Assemblies (FOA). The FOA is composed with two KDP crystals (tripling the frequency) sandwiched between a 3\(\omega\) focusing grating and a 1\(\omega\) grating [3]. A continuous phase plate (CPP) is placed at the input of the FOA to produce a top hat focal spot. The whole FOA can be moved to place the focal spot at the desired aim point [4]. FOA alignment principle is based on a double autocollimation at 3\(\omega\) and at 1\(\omega\) on the CPP [2]. 3\(\omega\) autocollimation is measured on the Common Reference whereas 1\(\omega\) autocollimation is measured by the Alignment sensor (AS) located at the end of the amplification section just after the last spatial filter hole. Six tele-microscopes are positioned around the chamber allowing the target alignment. The tele-microscopes operate in pairs and are placed face to face relatively to the target chamber center. This system called SOPAC works with green light (532 nm) [5] [6]. The origin of the shot coordinate system is given by the Common Reference. Plasma diagnostic aim point is materialized by the intersection of two focusing green laser pointers (532nm) attached to their end. In the common reference plane, the distance between the two spots gives the plasma diagnostic focalization whereas the mean position of the spots provides the pointing information.
3. RESULTS OBTAINED DURING FIRST BUNDLE COMMISSIONING

The end of the year 2014 was devoted to the progressive commissioning of the LMJ to achieve the first experimental campaign with 8 beams [7]. Concerning alignment, the commissioning was performed in 4 steps:

- Laser beam alignment on the common reference
- Target alignment with the SOPAC
- Beam to target alignment at low energy (1J rod shot) on the Nanojoule Active target (NAT) which is a target equipped with a CCD sensor
- Quad to target alignment via high energy pointing shots

3.1 Laser beam alignment on the common reference

As mentioned earlier the laser beams are aligned via a double autocollimation process on the FOA continuous phase plates. The alignment sequence starts with the 3ω autocollimation on the common reference. Each phase plate has two actuators with sub µrad accuracy which are used to superimpose the 4 FOA spots on the common reference. The whole FOA structure is moved with two rotations (pointing) and one translation (focus) to locate the FOA focal spot at the desired point on the common reference. The loop convergence tolerance is 1.4 µrad which correspond to 11 µm on the target. Once the FOA is aligned, we can move to the 1ω autocollimation. Adjustment is done using the TM6 (the last transport mirror, as shown in Figure 1) tilt actuators. The loop convergence tolerance is 2.8 µrad which correspond to 22 µm on the target. At this point the laser beams should be aligned on the common reference. This can be checked by firing rod shots on the common reference to get the beam spot locations. Measurements have shown pointing errors exceeding 100 µm (see black square points in Figure 2). Fortunately these errors are constant with time. They can therefore be taken into account via a simple offset correction during the 3ω autocollimation process. After offset corrections, one can see on Figure 2 that beams pointing error is 39µm rms which is below the required 50 µm rms.
3.2 Target alignment with the SOPAC
The SOPAC is made of 6 identical viewers (or tele-microscopes) placed face to face around the target chamber. They define 3 lines of sight. Four viewers are placed orthogonally at the chamber equator while the last two viewers are placed near the poles (16°). Each tele-microscope is equipped with 4 episcopic light sources and one less intense source for the shadow-viewing mode. Shadow viewing is the nominal mode for cryogenic target alignment since it substantially reduces the light flux reaching the target. Each tele-microscope has a 40 x 60 mm field of view. It has been optimized to have a point spread function limited by the diffraction and to exhibit less than 2µm rms total distortion in a \( \phi \) 26 mm field. In site measurements have also shown that they were very stable (<1 µm/ hour) [6].

The LMJ target can be aligned in two operation modes:
- The first operation mode is manual. It is based on a specific GUI, with which an operator try to superimpose real-time target images with dedicated alignment reticles (see Figure 3). Alignment accuracy is strongly dependents on target geometry and target contour quality. Target orientation tuning is also difficult for the operator. This mode is therefore mainly used to pre-aligned the target and possibly to check target position before the shot.
- The second alignment mode is semi-automatic. It is based on image processing and mathematical alignment algorithms. Spheres have been added around the target to facilitate the target alignment process. The SOPAC precisely locates the spheres in each of the six tele-microscope image plan via image processing. Thanks to target metrology we know the position of target interest points relative to the 4 spheres and the sphere positions relative to each other. This target model is projected by the SOPAC on the 6 image plans. An alignment measurement consists then in minimizing the distance between the model and the experimental sphere positions. The system is strongly overdetermined since we have 2x4x6 = 48 equations for 6 degrees of freedom. The alignment performances of this method are impressive : loop tolerance performance < 2µm and 10 µrad per axe, converge in typically 2 iterations (less than 5 minutes), reconstruction error between the target model (4 spheres) and the SOPAC measurements is typically < 10 µm rms. This gives an idea of the coherence of the different data.

Figure 3 : image of a target on 3 SOPAC viewers. Alignment reticles used for manual alignment are drawn in white. The 4 spheres added around the target are used for semi-automatic alignment.

3.3 Test of beam to target alignment on the nanojoule active target
A specific target has been designed to measure directly shape and position of the focal spots on the target. This target is called NAT (Nanojoule Active Target) and is composed of a CCD sensor surrounded by small spheres. Their positions are accurately measured relative to the CCD pixel matrix. NAT is held by the target positioner and is aligned with the same process than a real target. It is a reusable target and sees all the alignment defects except those induced by high energy shots. NAT is also useful to validate plasma diagnostics alignment by locating the two green pointers focal spot on the CCD matrix. An example of measurements is shown on Figure 4. Measurements performed on the NAT have shown that de beam to target requirements (50µm rms for the quad + 15 µm for the target i.e. 52 µm rms) were fulfilled on low energy shots.
3.4 Test of beam to target alignment via pointing shots
The last step concerning alignment commissioning is to check the alignment performances on power shots. This is performed on dedicated pointing shots. Pointing target consists of a thin gold plate on which are arranged CH patterns. The center of the target is given by the middle of the hypotenuse of three small CH discs (see Figure 5). X-Ray emission is recorded on a time resolved hard X-ray imager with a spatial and temporal resolution of respectively 30 µm and 110 ps [8][9]. Six pointing targets have been shot during the first LMJ experimental campaign. All of them have been done with SSD beam smoothing and phase plates producing a 940µm focal spots. Various laser energies (from 1 kJ to 10 kJ), pulse durations (from 0.7 ns to 3 ns) and configurations (upper quad, lower quad and both quad) were used. Figure 5 shows two images recorded during pointing shots. Alignment errors are given in the target plan. Due to the beam to target angle of incidence a correction must be applied to get the alignment error in the plan perpendicular to the quad direction. After correction, the quad to target alignment error measured on the 6 shots is 48µm rms. This meets the 52 µm required for the LMJ.

![Figure 4: Nanojoule Active Target and pointing measurement examples.](image)

![Figure 5: pointing target and pointing shots images recorded on the time resolved X-ray imager.](image)

References
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