ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-WEPV036

THE LMJ TARGET CHAMBER DIAGNOSTIC MODULE

R. Clot, CEA, Le Barp, France

Abstract

The Laser MegaJoule (LMJ), the French 176-beam laser facility, is located at the CEA CESTA Laboratory near Bordeaux (France). It is designed to deliver about 1.4 MJ of energy on targets, for high energy density physics experiments, including fusion experiments. The first bundle of 8-beams was commissioned in October 2014. By the end of 2021, ten bundles of 8-beams are expected to be fully operational.

Due to the energy levels achieved, the optical components located at the end of the bundles are highly subject to damage stresses. This is particularly the case with vacuum windows whose integrity is critical.

To measure these damages, identify the growth laws, and prevent their degradation (through blockers), the Target Chamber Diagnostic Module (called by its french acronym MDCC) was integrated into the LMJ installation in 2019. This diagnostic, which also measures the windows transmission rate, as well as the spatial energy distribution at the end of the bundles, has been designed to operate automatically at night, between two experiments.

This presentation describes this three years feedback of MDCC. It also presents the areas for improvement which have been identified to optimize its efficiency and reduce its timeline.

INTRODUCTION

The laser Megajoule (LMJ) facility, developed by the "Commissariat à l'Energie Atomique et aux Energies Alternatives" (CEA), is designed to provide the experimental capabilities to study High Energy Density Physics (HEDP). The LMJ is a keystone of the Simulation Program, which combines improvement of physics models, high performance numerical simulation, and experimental validation, in order to guarantee the safety and the reliability of French deterrent weapons. Once fully operationnal, the LMJ will deliver a total energy of 1.4 MJ of 0.35 µm (3ω) light and a maximum power of 400 TW.

The LMJ is sized to accommodate 176 beams grouped into 22 bundles of 8 beams. These will be located in the four laser bays arranged on both sides of the central target bay of 60-meter diameter and 40-meter height. The target chamber and the associated equipment are located in the center of the target bay.

Due to the energy levels achieved, the optical components located at the end of the bundles are highly subject to damage stresses. This is particularly the case with vacuum windows whose integrity is critical as it is a safety component which constitutes the vacuum limit of the chamber where the experiments take place. It's also an expensive component that we need to take care of.

To measure the damages they suffer, identify the growth laws, and prevent their degradation, the Target Chamber Diagnostic Module (called by its French acronym MDCC) was integrated into the LMJ facility at the end of 2019. This diagnostic inqtrument, which also measures the windows transmission rate, as well as the spatial energy distribution at the end of the bundles, has been designed to operate automatically by night, between two experiments.

This paper reminds the LMJ facility principle before presenting the MDCC and its functionalities with a focus on the measurement of optical component damaging. It also presents the feedback of the measurement sequence timeline and the work achieved to reduce it and make it fit in the facility timeline.

LMJ OPERATING REMINDER

The LMJ 176 beams (37 x 35.6 cm² each) are grouped into 22 bundles of 8 beams. In the switchyards, each individual bundle is divided into two quads of 4 beams, the basic independent unit for experiments, which are directed to the upper and lower hemispheres of the target chamber.

Basically, an LMJ laser beam line is composed of three parts: the front-end, the amplifying section, the switchyard and the final optics assembly.

The front end delivers the initial laser pulse (up to 500mJ). It provides the desired temporal pulse shape and spatial energy profile.

The initial pulse leaving the front end is amplified four times through two amplifiers, in order to obtain the energy required for the experiments (up to 15 kJ at 1ω per beam). Positioned between the two amplifiers, focusing lenses, associated to a diaphragm (spatial filter pinhole), take out the parasitic (noise) beams that may arise. Beyond the two amplifiers is a reflecting mirror (M1), making the four passes possible through angular multiplexing, as shown on Fig. 1. The surface of this mirror is deformable (being controlled by electro-mechanical actuators), allowing beam wavefront distortions to be controlled.

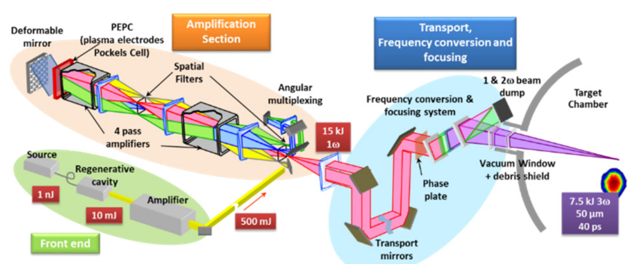

Figure 1: Laser beamline schematic diagram.

The 8 beams coming from the amplification section are divided into two quads. Each quad is transported over more than 40 meters into the target bay and is directed to the upper or the lower hemisphere of the target chamber using six transport mirrors per beam. Each quad arrives into a frequency conversion and focusing system (SCF). Inside the SCF, the beams frequency is changed from infrared (1,053

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-WEPV036

nm) to ultraviolet (351 nm). The frequency conversion is realized by two KDP crystals, with a global efficiency of about 60%. The beams are focused on target using a 3ω focusing grating. This specific component allows spectral separation (to ensure only 351 nm wavelength reaches the target).

MDCC MEASUREMENTS

The MDCC achieves three different measurements on LMJ facility.

The first one is the damaging of the end of bundle optical components: the vacuum windows and the 3ω gratings. The vacuum windows being the most important optical component, they make the damaging measurement critical for LMJ facility security.

The second measurement is the vacuum windows transmission rate. It consists in an intensity comparison of a monitored ultraviolet LED signal send through the vacuum window, and the returned signal (reflected) measured by the MDCC.

The third measurement is the energy distribution at the end of the bundles, which is measured by the MDCC on the vacuum window on a 1J shot to the target chamber.

MDCC PRESENTATION

The MDCC is made up of two subsystems: an Optical Block and a Motion Block (Fig. 2).

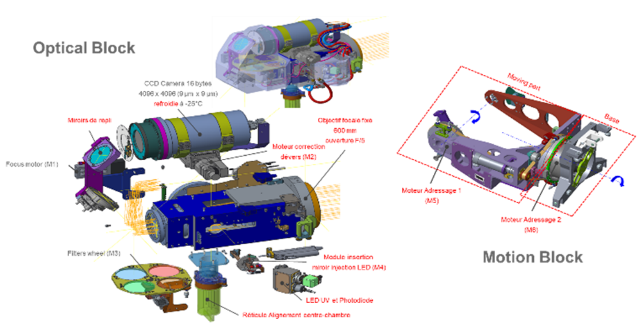

Figure 2: MDCC presentation.

The Optical Block is assigned to the acquisition part of measurement. It's especially made up of a large lens and a CCD camera which receive and acquire the signals. Transmission between them is handled by two redirection mirrors which enable the camera focus thanks to a motor. Three other motors are used on the Optical Block to correct the camera camber, to move a wheel to filter wavelengths, and to insert a mirror dedicated to a UV LED redirection for the transmission rate measurement.

The Motion Block is assigned to the diagnostic positioning. It carries the Optical Block and enables to address the various optical components of the installation thanks to two motors and two rotation angles.

DAMAGING MEASUREMENT PROCESS

The acquisition of damages on vacuum windows is realized shot to shot at night with the MDCC while teams are resting (Fig. 3).

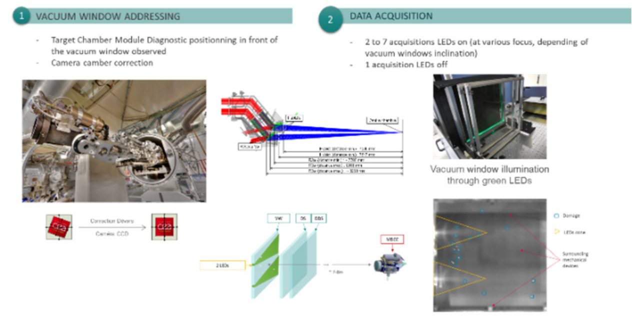

Figure 3: Damaging measurement process.

In the first part of the measurement, the MDCC positions itself in front of the vacuum window observed, 7 to 8 meters away. The camera camber, dependent of the component tracked, is corrected at the same time to center the window on the camera.

Two green LEDs on the side of the vacuum window are used to light the surface and optimize the damage tracking. Each damage becomes a bright spot visible on acquisitions. The illustration down center shows the LEDs cone in yellow and the damages surrounded by blue squares.

Several acquisitions are made at various camera focus to take in account the different vacuum window inclination and the camera depth of field.

A final acquisition, with LEDs off, is made to substract a noise image to the useful ones and also enhance acquisition analysis.

DAMAGING MEASUREMENT STAKES

The vacuum window damaging measurement is the most critical and has 3 determining stakes for LMJ facility (Fig. 4).

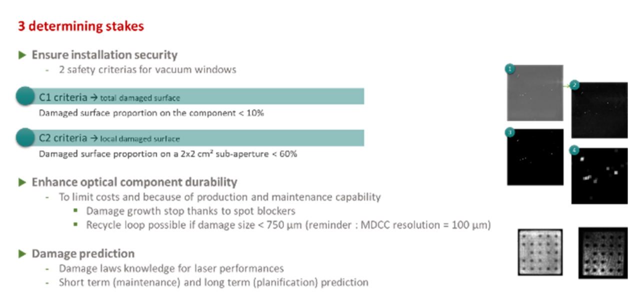

Figure 4: Damaging measurements stakes.

Thanks to MDCC, we're able to detect damages of a 50 micrometers size. This size corresponds to the triggering of damages and the beginning of their growth. To characterize them we track 2 safety criteria thanks to a software analysis with one being the most restrictive. By keeping C2 criteria under 60% for any 2x2cm² sub-aperture, we ensure the LMJ installation security.

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-WEPV036

A second stake of the damage measurement is to enhance our optical components durability. Our goal is to stop the growth of damages from 400 µm as we are unable to repair damages bigger than 750 µm.

The challenge is therefore to be able to monitor damage growth in noisy images before damage size reaches 5 pixels.

We also have to set efficient algorithms to detect and track damages.

To prevent the growth of the damages and keep them under the limit which allows their repair, we developed a new functionality on the LMJ installation. It enables to set spot blockers on the energy spatial distribution at the start of the laser bundles, and also prevents spreading energy on the most damaged surfaces of the vacuum windows. The pictures down right show a spot blockers grid at the start and at the end of a bundle.

The third stake of the damage measurement is the prediction capability. We need to identify the damage laws to improve laser performances, optical components maintenance at short term, and installation planification at longer term.

Our strategy is also to protect our end of bundle optical components is based on a complete scheme including acquisition, damage detection, damages growth brake and recycling loop of the components.

The first steps are already in use, whereas the first recycled components will be back on the installation around 2025.

SEQUENCE TIMELINE

MDCC has been designed to operate automatically by night, without needing any operator intervention. This is very important for the LMJ installation as experiments are prepared from the early morning for the shot to happen in the evening. The damage measurement at night is also critical to give the green light to the experiment of the next day.

After MDCC integration at the end of 2018, the sequence duration put in the front that by extrapolation it was well too long and totally incompatible with installation timeline.

So we launched a research for solutions to shorten the sequence and make it fit the 4 hour time slot allocated in the targeted installation timeline.

TIMELINE IMPROVEMENTS

Thanks to an efficient team work, 12 improvements have been identified to reduce the damaging measurement sequence timeline. They have been classified in 4 themes whether they relate to the camera, the MDCC mechanics, the measurement principles or the command control.

Two of them have been dropped as they were either too complex to implement or too restrictive on performances.

The other ten have been considered in view of their gain on the timeline and our ability to implement them quickly or in the long-term (Fig. 5).

THEME	IMPROVEMENT	IMPLEMENTATION COMPLEXITY 1	TIME SAVER FROM MDCC ORIGINAL CONFIGURATION (22CL) 2	PERFORMANCES IMPACT
CAMERA	Upgrade of acquisition card electronics	Average	4h30	-
	Camera model change (CCD to CMOS)	High	6h	-
MECHANICALS	Compensation of vacuum window tilt through POCC	Very high	8h	Very good
	Compensation of vacuum window tilt through MDCC	High	8h	Very good
	Addressing motor speed enhancement	Very low	35mn	Minor or none
MEASUREMENT	Optimisation of useful acquisition number	Low	- 6mn	Very good
	Reduction of noise acquisitions number	Low	4h10	Minor
	Decrease of acquisitions resolution	Very low	6h	Very bad
COMMAND CONTROL	Deletion of sequence configuration bypassing	Very low	10 mn	-
	Deletion of double results production	Very low	3h20	-
	Enhancement of results production	Low	1h45	-
	Parallelization of configuration and results production	Average	3h20	-

[1] Cost/Time compromise
[2] Improvements combination reduce timesaver compared to sum of ndividual improvement timesavers

Figure 5: Sequence timeline improvements.

IMPROVEMENTS IMPLEMENTATION PLAN

To reduce the sequence timeline according to the LMJ installation needs, we built an implementation plan of the selected improvements. We planned each other into one of 3 phases forecasted between 2020 and 2024 (Fig. 6).

Phase 0 2020 Summer

THEME	IMPROVEMENT	IMPLEMENTATION STATE
COMMAND CONTROL	Deletion of sequence configuration bypassing	Achieved in 2020
	Deletion of double results production	Achieved in 2020

Phase 1 2021 Summer

THEME	IMPROVEMENT	IMPLEMENTATION STATE
CAMERA	Upgrade of acquisition card electronics	Achieved in 2021
MESURE	Optimisation of useful acquisition number	Achieved in 2021
	Reduction of noise acquisitions number	Achieved in 2021
COMMAND CONTROL	Enhancement of results production	Achieved in 2021

Phase 2 2024 Summer

THEME	IMPROVEMENT	IMPLEMENTATION PLANNING
CAMERA	Camera model change (CCD to CMOS)	2024-2025
MECHANICALS	Addressing motor speed enhancement	2022
	Compensation of vacuum window tilt through MDCC	2024
COMMAND CONTROL	Parallelization of configuration and results production	2024

Figure 6: Improvements implementation plan.

The first one has been achieved in 2020 and the second mid-2021. The results confirm the expectations we made as we already reduced the sequence timeline by more than 50% as foreseen.

Without surprise, the mechanicals improvements and the camera change will be the latest to be implemented, as they lead to an important work of preparation and maintenance.

EVOLUTION OF SEQUENCE TIMELINE

The following diagram (Fig. 7) presents the damaging sequence timeline evolution thanks to the implementation plan previously described.

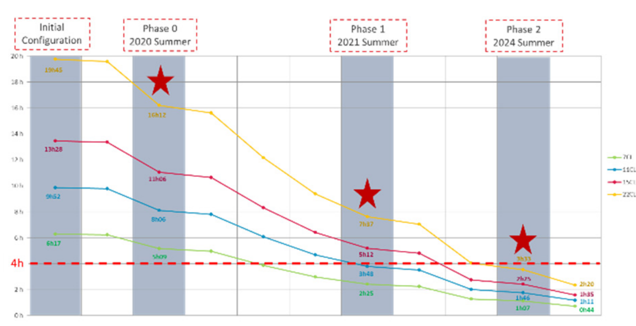

Figure 7: Sequence timeline evolution.

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-WEPV036

It shows the way the sequence timeline shortens through the 3 phases displayed in the previous slide.

Each colored line matches a configuration of LMJ, that is to say the number of laser bundles used for the main milestones of the installation.

Thanks to Phase 1, we're now already able to run the damaging measurement sequence in less than 4 hours for 11 laser bundles, which is our next milestone in 2022.

Phase 2 will be a prequisite for the next ones when we will use 15 and 22 laser bundles, with an expectation of hardly 2 hours and 20 minutes for LMJ nominal configuration.

It will mean MDCC came a long way if we consider where is started in term of sequence timeline.

SUMMARY

To sum up, there are six things to remember:

1. MDCC is a recent and autonomous laser diagnostic which achieves three measurements.
2. The vacuum windows damaging one is the most critical for LMJ installation as it's the greenlight for the next experiment.
3. MDCC also enables to ensure installation security and enhance optical components durability.
4. The first sequences led to a warning on the duration of the damaging measurement sequence.
5. To reduce it we identified various improvements that we started to implement, with the main ones to come.
6. The evolution of sequence timeline is promising to fulfil the installation needs and our expectations.