ISBN: 978-3-95450-238-7 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2023-TUMBCM023

# DEVELOPMENT AND NEW PERSPECTIVES ON THE LMJ POWER CONDITIONING MODULES

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*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 2023, 15 bundles of 8-beams are expected to be fully operational.

In this paper, we will present:

- The LMJ Power Conditioning Modules
- The unexpected security shutdown of the PCM during experiments
- The software solution against the security shutdown.

## INTRODUCTION

The laser Megajoule (LMJ) facility, developed by the "Commissariat à l'Energie Atomique et aux Energies Alternatives" (CEA) [1], 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 nuclear weapons. When completed, 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 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.

The first bundle of eight beams has been commissioned at the end of 2014. The second bundle has been commissioned at the end of 2016 following the same commissioning process. Eleven additional bundles are now operational since the end of 2022, and the last fusion experiment using 80 operational beams took place in spring 2022.

The PETAL project consists in the addition of one short-pulse (0.5 to 10 ps) ultra-high-power (1 up to 7 PW), high-energy beam (1 up to 3.5 kJ) to the LMJ facility. PETAL offers a combination of a very high intensity petawatt beam, synchronized with the nanosecond beams of the LMJ [2].

The first phase of nuclear commissioning of LMJ has been achieved to take into account high-energy particles created by PETAL, and neutron production from DD fusion reaction [3]. A subsequent phase will take into account DT targets.

This paper describes the LMJ Power Conditioning Modules (PCM), the issue of security shutdown when there were more than 10 bundles during the LMJ-PETAL shots. And it will describe data tools and software patch to solve the problem.

## LMJ CONTROL SYSTEM

The LMJ facility has a Control System which is divided into 4 layers as shown in Fig. 1.

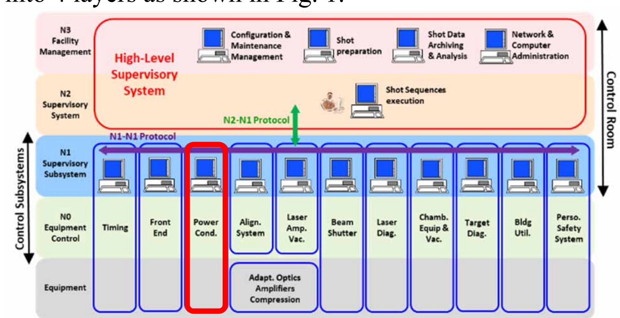


Figure 1: LMJ Control System architecture.

All control system software developed for the supervisory layers use a common framework based on the commercial SCADA Software PANORAMA E2.

In this framework the facility is represented as a hierarchy of objects called "Resources". Resources represent devices (motors, instruments, diagnostics…) or high level functions (alignment, laser diagnostics). Resources are linked together through different kinds of relationships (composition, dependency, and incompatibility) and the resources life-cycle is described through states-charts. Control points, alarms, states and functions can be attached to any resource.

Dedicated mechanisms manage the resource reservation and propagate properties and states changes into the tree of resources through relationships. There are about 200 000 resources in order to describe the entire LMJ.

## PCM FOR LASER AMPLIFICATION

The laser pulse amplification is obtained by feeding it with photons from Neodym dopped glass slab. Flash lamps powered by PCM stimulate the amplifying slab. The power pulse is provided by the PCM capacitors charged to 22 kV and this power is transfererd to the flash lamps on the synchonisation triggering order. Because of material security specifications, at the end of the 22 kV charge, the PCM capacitors return to ground voltage after 15 seconds, by the security shutdown if the triggering order is not received.

19th Int. Conf. Accel. Large Exp. Phys. Control Syst. ICALEPCS2023, Cape Town, South Africa JACoW Publishing
ISBN: 978-3-95450-238-7 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2023-TUMBCM023

## PCM HARDWARE

For each LMJ bundle (Fig. 2), there are 2 PCM sections, Cavity and Transport. Figure 3 shows in the details of a LMJ module. In Cavity section, there are 7 LMJ modules and 9 in the Transport section.

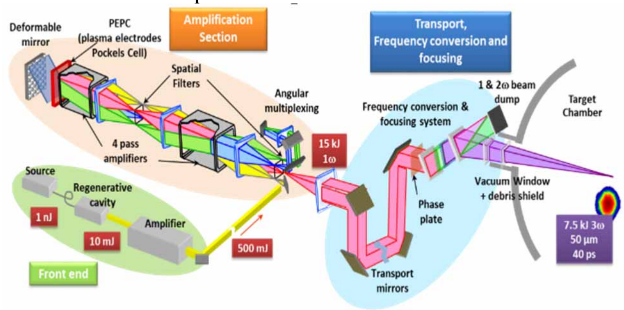


Figure 2: Architecture of one LMJ beamline.

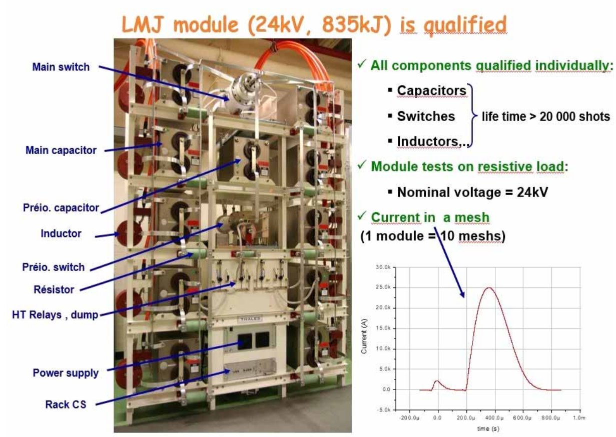


Figure 3: Picture of LMJ module.

For all of the LMJ, there are 44 Layer 0 bays for equipment communications (see next paragraph for control system description), 352 modules, 3520 capacitors of 290µF / 24 kV, 200 kms of coaxial cables. Each module has 10 meshes, and each mesh gives electrical power to 2 flash lamps of the laser amplifier. The capacitors can stay under high voltage for 15 seconds then the security shutdown is done by the dump. This delay defines the LMJ shot window.

## PCM CONTROL SYSTEM

You can see in the Fig. 4 the interfaces between the PCM Control System, PCM CS, et others CS.

The PCM for a LMJ shot needs to receive shot parameters from facility configuration software, called GCI and from sequence administration system, called SVP. These parameters are : the high voltage setpoint, the PCM modules available from GCI and, from SVP, the active bundles, the PCM modules used and the timeline guide for configuration and the beginning of HV charge.

The PCM CS allows us to do the commissioning of new bundle and system maintenance services by doing equipment's tests ( Fig. 5 ), and system sequences (Fig. 6 ).

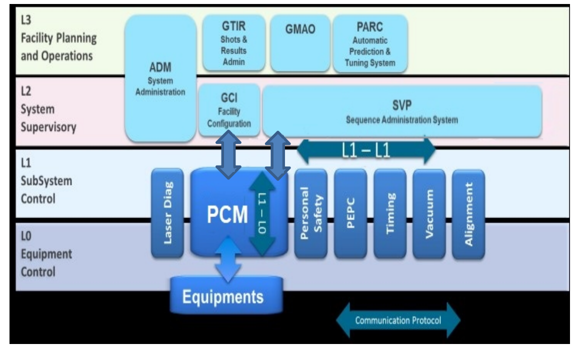


Figure 4: The LMJ Control System Architecture.

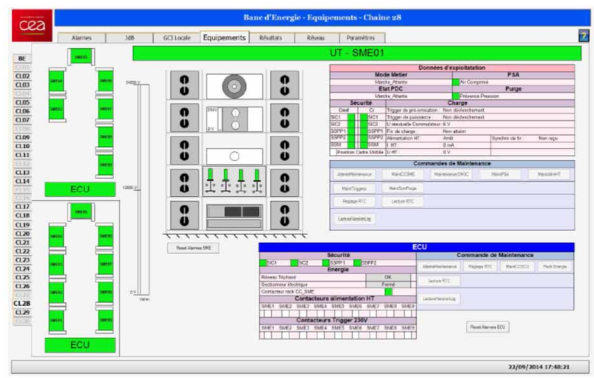

Figure 5: Test equipment's HMI.

The main HMI ( Fig. 6 ) is used to follow a LMJ shot sequence.

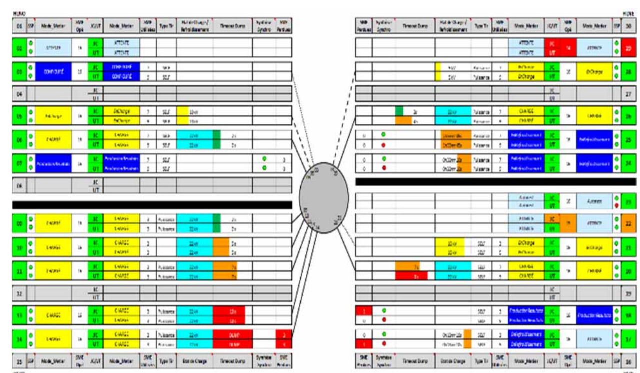

Figure 6: Multi-bundles state HMI.On the main HMI (Fig. 6 ) for each bundle, the technical operator can check: the PCM state, the personal safety system authorization [4], the sequence state, the shot kind (rod shot, power shot, lamp test), the available modules, the HV charging status, the delay before secure dump and if the synchonisation triggering order arrived.

After a shot, we have a results HMI to verify the work of the PCM ( Fig. 7 ) and a HDF5 results file, with all the parameters, timing and results values (current, voltage, synchronisation, …) for all the PCM modules.

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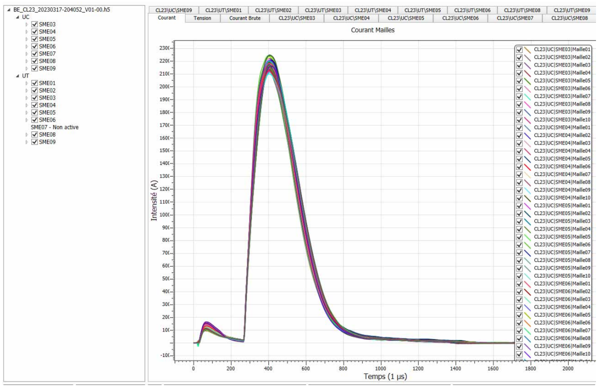


Figure 7: Results HMI.

## EVOLUTION OF PCM CS IN 2022-23

Since 2013 to 2022, the PCM CS worked fine with the same software, which was reliable and allowed LMJ shot without surprise. With this initial conception, the delay time between the shot order from SVP and the beginning of charge of the 1st module was a function of the number of bundles, around 2 seconds by bundle. And it works fine until 9 bundles and allows to make synchronous shot between LMJ and PETAL laser.

While a 10 LMJ bundles shot with PETAL laser in 2022, we have noticed around 10 seconds of extra delay in regards to the habit from the beginning of the PCM charge. It wasn't planned and made the PETAL shot to dump because Petal didn't receive the LMJ synchonisation triggering order in his shot window. Because of the capacitors security specifications, the PETAL shot window is only 12 seconds.

To identify the trouble, we had to add traces with timestamp in the log files for each event made by the PCM CS. So we could find which step of the sequence made the communication instability.

After the first studies, we found out that it cames from the software architecture. Because of the initial PCM CS team was retired, the actual team had to study the "how it works" between all the CS modules and it took around 2 months. The PCM CS was made for 22 bundles but built on copy/paste from 1st bundle. With the old conception made in 2012, there were 28 parameters reading per half-bundle in the same time from the layer 0 to GCI parameters on a local server. Those 28 parameters are identicals for all request so there are 1 232 parameters for 10 bundles. The excessive request number to GCI has caused an unlogged network traffic jam that results in shot window overrun and has made the shot failed with security shutdown.

To solve this traffic jam trouble, the 28 parameters are loaded in local on the layer 1 and read by each half bundle before to start the shot sequence. To follow the PCM CS behaviour, we have added logs for each step of the sequence.

The logs instrumentation of the layer 1 and 0 allows us today to follow the sequence timing and her stability. The new time line description is shown on Fig. 8. We have this description for each module of the shot, viewable in the HDF5 results files.

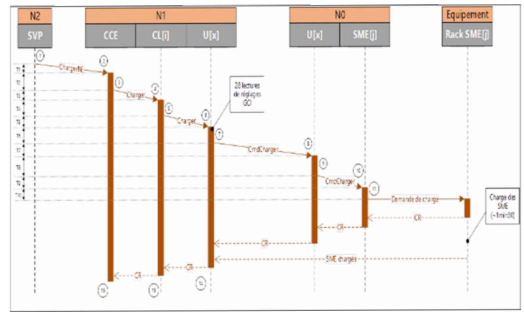


Figure 8: Time line of a shot sequence.

With this software evolution in January 2023, we didn't have any more trouble with a new unknown extra delay even with 12 bundles, Fig. 9.

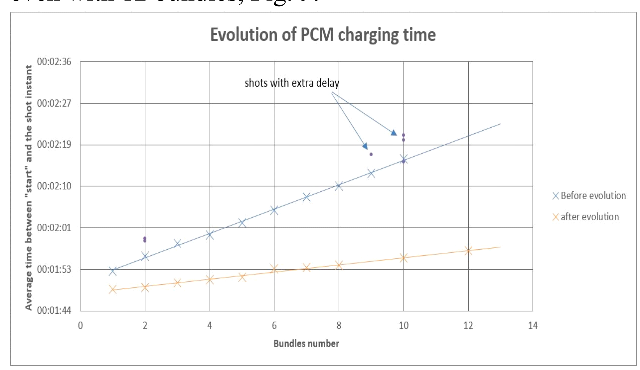


Figure 9: Evolution of PCM charging time.

## FUTURE EVOLUTION OF PCM CS

The next important evolution for the PCM CS will be to introduce a new sub-sequence in the global LMJ sequence [5] to test all layer 0 and PCM equipements. This sequence will be like a shot sequence with a 3 KV setpoint instead of 22kV and the capacitors will discharge to the ground. This sequence will test HV power supplies, low level communication, HV relays, dump and synchonisation triggering order. This new sequence will be located just before the power shot for two reasons. First, we need to get the authorization from the safety personal system [4] to insure that nonody is inside the bays.. The second reason deals with the HV power supplies of PCM. They are by default turned off except just before the powershot and we have to be

confident in their wake-up. This validation sequence will produce report to the LMJ sequence driver. Then, he will decide if he can continue or not to go until the shot.

## CONCLUSION

Since this evolution, regarding the regularity of the shot sequence, we are convinced that we have solve this problem.

It's also important to keep the memory of the project genesis : The first team to work on the PCM CS was retired in 2018-19 and in 2022, it stays the 3rd team generation which had to do reverse engineering to rediscover the "how it works" of the PCM software.

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