

# THE LMJ SYSTEM SEQUENCES ADAPTABILITY (FRENCH LASER MEGAJOULE)

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## Abstract

The French Atomic and Alternative Energies Commission (CEA : Commissariat à l’Energie Atomique et aux Energies Alternatives) is currently building the Laser MegaJoule facility. In 2014, the first 8 beams and the target area were commissioned and the first physics campaign (a set of several shots) was achieved. On the LMJ, each shot requires more or less the same operations except for the settings that change from shot to shot. The supervisory controls provide five semi-automated sequence programs to repeat and schedule actions on devices. Three of them are now regularly used to drive the LMJ. Sequence programs need to have different qualities such as flexibility, contextual adaptability, reliability and repeatability. Currently, the calibration shots sequence drives 328 actions towards local control systems. However, this sequence is already dimensioned to drive 22 bundles, which will lead to manage almost 5300 actions. The presentation introduces the organization of the control system used by sequence programs, the sequence adjustments files, the GRAFCETs of sequences, the GUIs, the software and different tools used to control the facility.

## LASER MEGAJOULE SHOT OVERVIEW

The LMJ facility will count 176 laser beams. It is dimensioned to deliver 1.4 MJ shot of UV laser at 351 nm to a 10mm target. The LMJ is designed to study high density plasma physics. It’s also a part of the French Simulation Program that forms the basis of the safety and reliability of French nuclear weapons.

The LMJ facility is divided in 4 laser bays. In its center, takes place the target bay. A shot is composed of laser pulses which are amplified in the laser bays and focused on a target in the target bay.

A timing shot that lasts 1s, consists in switching on the laser amplifiers lamps, creating, shaping and pre-amplifying the laser pulses, sending it through the amplification section to fill up, converting laser infrared pulses into laser UV pulses. Then, the energy heats the target and the diagnostics record the experiment radiations data. [1]

Shot sequence manages shot preparation steps, timing shot and post shot step.

First comes facility preparation step. It does not include time critical actions.

The preamplifiers perform several triggers to ensure delivered energy repeatability. If needed, inserters carrying diagnostics move at that time.

Then we have the Alignment step. Each laser beam must hit the millimeter target after hundreds meters propagation. Different areas get their own alignment: Amplification sections, Transport Sections, Frequency converter Sections and Target Chamber.

Once alignment is finished, a whole test without Power conditioning is performed: the validation shot or rod shot. It checks that all the required equipment is activated without wasting the target. This equipment is configured and triggered, laser beam measures are analyzed by automatic data processing.

When the validation shot has passed, power shot repeats the validation shot, adding the power amplifiers charge leading to timing shot.

After the shot, amplifier flash lamps test is performed while other devices are secured. Results are stored in a shot database. This is post shot step.

## CONTROL SYSTEM

### Data Model: Key Words

The main concept of the data model is called a “resource”. A resource represents an equipment (motors, instrumentations, diagnostics...) or a high level function (alignment, amplification section, power conditioning bundle). LMJ counts 200 000 resources.

A resource owns a name and attributes:

- Reserved : to forbid unexpected use,
- Context: resource membership of a perimeter. A perimeter is a group of resources existing for the same purpose such as sequence.
- Operational State : Running, Standby or Stop

A resource can be attached to other objects:

- Functions : what a resource can do,
- Control points : resource information,
- Alarms: asynchronous resource events.

### Architecture

The LMJ control system architecture is built on a 4 layers architecture as shown in Fig. 1:

- Level 3 system supervisory provides facility planning and operation functions which are dedicated to the shot director
- Level 2 consists of the supervisory system (SVP) which provides GUI to the shot director. As system sequences are SVP programs, system sequences

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drive subsystems through SVP interfaces with supervisory subsystems.

- Level 1: supervisory subsystems that allow operators to drive facility subsystems (capacitor banks, preamplifier, alignment control system...)
- Level 0: equipment controls (PCs or PLCs).

All the command control software developed for the supervisory layers uses a common framework based on the industrial PANORAMA E<sup>2</sup> SCADA from Codra society. This framework includes resource management, sequence management and configuration management.[2] [3]

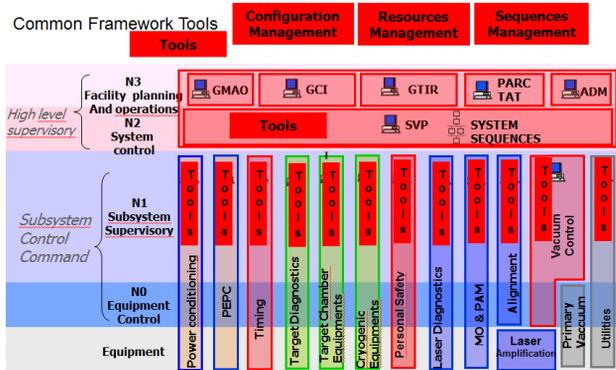


Figure 1: LMJ control system architecture.

**Resource Manager**

The resource manager provides the ability to link resources with different kind of relationships in order to describe the whole structure of the facility. A resource may be composed of other resources or a resource may use other resources. Such links make perimeter definition easier. For example, working with an 8 beams bundle (resource called Bxx), required to add Bxx resource to the perimeterF ; then the distributed resources manager analyses links and automatically inserts to the perimeter resources that compose Bxx... and so on with every resource that is found and filled in this perimeter.

**Configuration Manager**

The configuration database contains resources and functions default settings. The configuration manager duplicates for each perimeter the configuration database restricted to the sequence perimeter, adding settings from the sequence adjustment file.

**Sequence Manager**

Sequences are driven by a GRAFCET. In each step of the GRAFCET, actions are implemented in VB Script. For instance, an action may be a call to another sequence (subsequence) or function. The sequence engine executes the GRAFCET diagrams and the scripts included into the sequence.

The sequence is suspended if an alarm is encountered on a resource that belongs to the sequence perimeter. During suspension, the shot director has the ability to solve the problem or to abandon the default resource, before going on. He can also choose to abandon the sequence itself.

Sequencer debug mode allows executing the sequence GRAFCET step by step, monitoring its execution, debugging VB scripts and inspecting SCADA object properties.

**GRAFCET**

The shot sequence main GRAFCET splits into several steps. The two first steps consist of the Sequence Program Initialization: shot database initialization, Resources Lock (reservation), GUI's are raised to the shot director in order to check sequence adjustments. Next five steps have been described in the shot overview: facility preparation, alignment, validation shot, power shot and facility securing. Last step is always executed. It drives actions to ensure facility safe state mode before exit the main sequence.

Transitions take place between steps. Moving from one step to another requires shot director authorization. Transitions are also implemented to authorize restarting a main step.

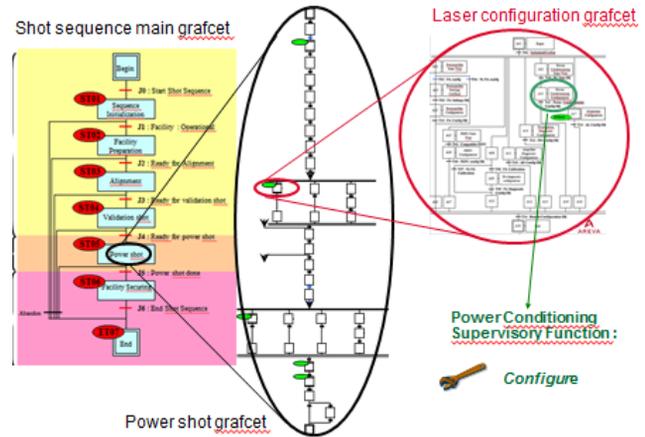


Figure 2: Subsequence calls.

**Programming Rules**

For readability, one development rule consists in implementing only one action per step.

In shot sequence example as shown in Fig. 2, step 5 manages the power shot and it counts a lot of actions. To respect the above-mentioned rule, the step 5 VB script is a call to the Power Shot subsequence.

In the same way, in the power shot subsequence one step is a call to a laser configuration subsequence because it counts many actions too.

In the laser configuration subsequence, one step is the Power Conditioning configuration function call. This

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function is run by the Power Conditioning supervisory controls.

### GRAF CET Behavior

When a resource state changes to the default state, the resource generates an alarm. If this default resource belongs to sequence perimeter, the sequence manager suspends the main GRAFCET.

Sequence programmer implements suspension behavior concerning subsequences and functions in each GRAFCET program. Most of the time, function suspension is time consuming. Only functions that operate iterative actions are worth being suspended. In system sequence, suspension usually propagates to subsequence and does not to functions.

### System Sequences

At that time, 5 system sequences are available:

- Shot sequence: it drives a power conditioning amplified shot sequence on the target.
- Calibration sequence: it drives a power conditioning amplified shot sequence without any target. Calorimeters are inserted through the beams to calibrate laser energy.
- Laser bay non amplified shots sequence is dedicated to numerous repetitions of non-amplified shots in laser bay.
- Target bay non amplified shots sequence is dedicated to numerous repetitions of non-amplified shots in the target bay.
- Target bay equipment calibration sequence is dedicated to inserters positioning calibration.

	Calibration sequence	Shot sequence	Laser Bay non amplified shots sequence	Target Bay non amplified shots sequence	Target Bay equipment calibration sequence	Total
Number of Grafquets	21	31	14	27	13	106
Number of Functions	68	107	43	86	14	318
Number of Actions	267	400	162	325	77	1231

Figure 3: Sequences size.

The shot sequence is the most complex sequence as it almost uses all the facility resources. The 31 GRAFCET of the shot sequence lead to 107 function calls. Figure 3 shows a main difference between the number of function calls (107) and the number of actions (400). Functions may be considered as equipment actions. Actually, GRAFCET management actions, control point check actions and GUI display actions represent a predominant part of the sequence programs.

Calibrating the LMJ and making all kind of shots should need 18 system sequences. Sequence design and adjustment policy are combined to reduce the number of sequences, and thus to reduce maintenance costs. For instance, Calibration sequence can be adjusted to be used for laser energy calibration in amplification section or in focusing section.

## ADJUSTMENT

Sequence main goal is function executing. From one shot to another, function settings are different.

### Sequence Model File

To define what kind of settings is expected by a sequence, each sequence owns a sequence model file. The sequence model file includes identification, supervisory list, main resource classes, excluded resource classes, resource class priorities and settings names ordered by supervisory subsystems, by sequence main steps and by function classes.

### Sequence Adjustment File

Before the beginning of the shot sequence, the shot database manager combines the sequence model file to shot requirements. With PARC help, the Automatic Settings Prediction System [4], the shot database manager builds the sequence adjustment file. This file gives settings values to each function which resource belongs to the perimeter.

Adjustment files contain instances instead of classes. It is shaped like sequence model file:

- Program identification.
- Supervisory list adjusts SVP to address settings to subsystems.
- Main resources list.
- Excluded resource.
- Resource priorities
- Settings value ordered by supervisory, by sequence main step and by function.

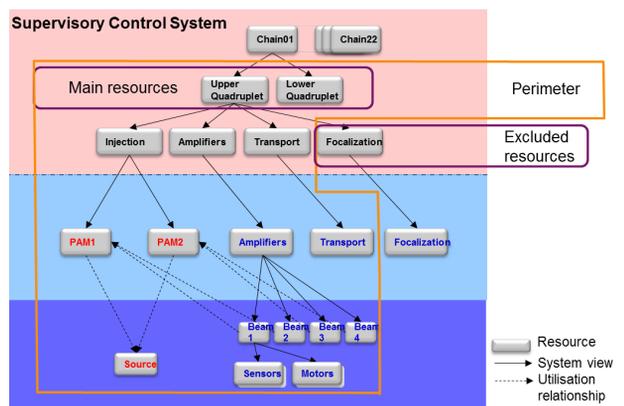


Figure 4: Resource tree and perimeter concept.

Most of the time, main resources are the 4 beams bundles, named “quadruplet”. The facility has got 44 quadruplets. For each quadruplet resource class in the model file, the shot database manager can determine which quadruplets resources are required.

For instance, considering upper and lower quadruplets from the chain number 01 as main resources, sequence perimeter is built thanks to these 2 resources. Resource managers follow resource links to add resources to the perimeter automatically. Resources that are not required appear in the excluded resources list. And resource managers automatically adapt the perimeter as shown in Fig. 4.

*Function Adjustment*

The last items of sequence adjustment file are settings value with a specific filing. It is explained by subsystem settings reading upon sequence main steps.

For example, considering that one subsystem has a “configure” function that has to be adjusted by a “shot type” setting. Considering also that the adjustment file defines values for both 4 and 5 main steps. In step 4, it is equal to “Validation”. In step 5, it is equal to “Power”.

Before starting the sequence, SVP sequence manager performs « sequence injection ». It consists in perimeter creation and setting distribution to subsystems by splitting the adjustment file, it ends by a sequence GRAFCET “start”. Perimeter creation is executed by resource managers. Settings loading is executed by configuration managers that create contextual configurations restricted to the perimeter. At the end of the injection, a “shot type” setting value is set to a default value.

When GRAFCET main step 4 is reached, the sequence manager notifies the current step to subsystems sequence managers. Next subsystems update their “shot type” settings to “Validation”. When step 5 is reached, the sequence manager notifies the subsystems sequence managers again and the “shot type” setting changes to “Power”.

**SHOT SEQUENCE GUI**

Sequence GUI development is part of sequence program development. All system sequence GUIs have the same layout. Figure 5 presents the Shot sequence GUI. After Injection, the shot director drives shots using this window.

GUI philosophy is to control actions in progress. It means to be able to control each running actions state. Colors indicate actions state: red is error, green is done and correct, yellow is in progress, white is inactive. Progress bars indicate the remaining time when actions last more than a few seconds.

The GUI splits into 7 areas. On top, the first area indicates file adjustment name, sequence name, general information about main GRAFCET state and progress. Under the first area takes place the main step bar. It indicates complete main steps and the running one.

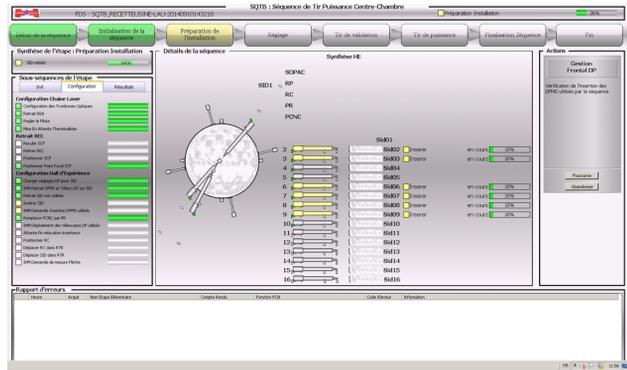


Figure 5: Shot sequence GUI.

On the top left, the third area details progress information of the running main step. On the left, fourth area presents all the actions that occur during the main step execution. In the middle, the fifth area details one action. For instance in figure 5, GUI displays progress information and the state of all the started « insert » function as they result from the same “insert” function class. In this case, the sequence manager provides the ability to call all these functions at once.

In area 4, « Insert Inserters » action state is a synthesis of the 6 run inserters function states. If one indicates an error then synthesis is in error. Else, if all of them are complete and correct, synthesis is complete and correct. Else, if one is running, synthesis is running. Else, if all are inactive, synthesis is inactive. This synthesis construction highlights potential difficulties: errors and remaining actions.

On the right, area 6 is dedicated to shot director authorizations to carry on with sequence. On the bottom, area 7 shows errors that occur during one main step.

**SUMMARY**

Adjustment file eases resources addition to sequence perimeter and GUI synthesis philosophy does not depend on resource number. Consequently, system sequences are ready for the next LMJ bundles commissioning to come.

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