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THE LASER MEGAJOULE FULL AUTOMATED SEQUENCES

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Abstract

The LMJ (Laser MegaJoule), a 176-beam laser facility developed by the French Nuclear Science directorate CEA (Commissariat à l'Energie Atomique et aux Energies Alternative), is located at the *CEA CESTA (Centre d'Etude Scientifique et Technique d'Aquitaine) site near Bordeaux. The LMJ facility is part of the French Simulation Program. It is designed to deliver about 1.4 MJ of energy on targets, for high energy density physics experiments, including fusion experiments. Since 2022, the LMJ facility aims at carrying out experiments with 13 bundles of 8 laser beams and 20 target diagnostics. In order to achieve daily shots including all the preparatory steps, the LMJ performs night activities from now on and the presence of technical operators is not required. These sequences perform vacuum windows inspection and beam alignment. They take into account all the prerequisites for their good performances and are scheduled automatically one after the other. They deal with material security and unexpected equipment alarms. They endeavour to required tasks success and give a detailed report of the night events to the shot director. This paper gives a presentation of the two sequences with solutions in order to answer the technical specifications and the last enhancements.

LASER MEGAJOULE SHOT DAY

The LMJ [1] facility will count 176 laser beams. It is dimensioned to deliver 1.4 MJ shot of UV laser at 351 nm to a 10 mm 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 deterrent weapons.

The LMJ facility splits in 4 laser bays. In its center, takes place the target bay (Fig. 1). A shot is composed of laser pulses which are amplified in the laser bays and focused on a target in the target chamber through the vacuum windows. As prerequisites to shots, two actions are performed:

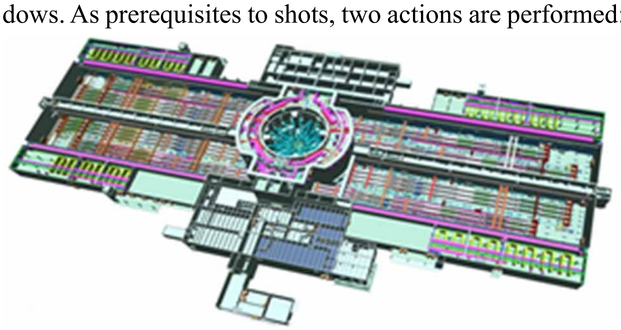

Figure 1: LMJ view.

- the alignment of laser beams and Target Diagnostics
- the vacuum windows damage inspection

Both these actions require positioning specific devices in the center of the target chamber. Two different positioners have to be inserted but not at the same moment [2].

At 8:30 PM, first of all, the vacuum windows inspection sequence is started. It is called SQMH (SeQuence Machine H). It lasts 4 hours. Right after, a second sequence is launched. It deals with beams alignment first part and it is called SQME (SeQuence Machine E). It lasts 9 hours, nevertheless it waits the end of SQMH, to start night alignment main part. From 9 PM to 6 AM, these sequences remains without any operator control.

Operators come back handling sequences at 6 AM. SQMH is finished. SQME is paused and displays night results. At that time, operator could play again part of the SQME if necessary.

Then SQME ends, in order operators to align Target diagnostics and beam transport section. They also carry out KDP configuration (Wavelength conversion) and CSO (Wavefront correction).

Next, target is aligned. And shot sequence starts with validation shot without power conditioning followed by power shot. Post shot steps handle power conditioning lamp test and results recovery (Fig. 2). And at 8:30 PM, a new shot day starts.

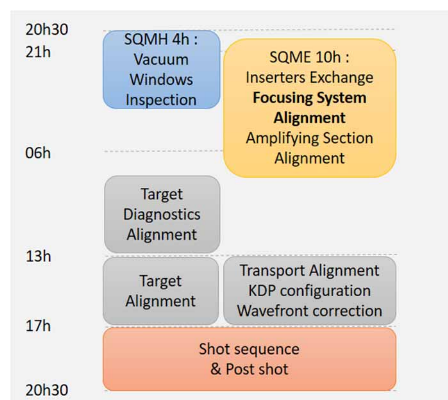

Figure 2: Shot day timeline.

Critical path is built of functions which require to position a device in the center of the target chamber. SQMH need to insert MDCC (Center Chamber Diagnostic Module) held by POCC (Center Chamber Object Positioner), whereas SQME inserts RC (Common Reference) fit at the end of PR (Reference Positioner). Changing inserters without operator increases collision risk, it is shown thereafter how it is reduced and controlled.

CONTROL SYSTEM KEYS

Control System Architecture

The LMJ control system architecture is built on a 4 layers architecture (Fig. 3):

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- Level 3 system supervisory provides facility planning and operation functions which are dedicated to the shot director
- Level 2: SVP consists of the supervisory system (SVP) which provides GUI (Graphical User Interface) to the shot director. System sequences such as SQME and SQMH are SVP programs. System sequences drive subsystems through SVP interfaces with supervisory subsystems.
- Level 1: supervisory subsystems that allow operators to drive facility subsystems (target chamber equipment, capacitor banks, preamplifier, alignment control system…)
- Level 0: equipment controls (PCs or PLCs).

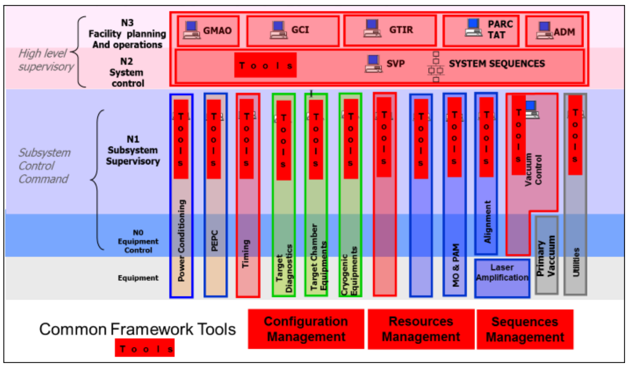

Figure 3: LMJ control system architecture.

Common Framework Tools

All the command control softwares developed for the supervisory layers use a common framework based on the commercial SCADA software Panorama. This framework includes resource management and sequence management.

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 (resource called Bxx), needs to add Bxx resource to the perimeter ; then the distributed resources managers 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. The resource manager also provides reservation service. Reserved resource is locked for a specific perimeter. Other perimeters have to wait unlocking first to reserve. Resource manager only allows reserved resource to carry out function, in other words using the associated device.

Sequence Manager

Sequence manager is mainly composed of sequence engine and sequence display. The sequence engine executes the GRAFCET diagrams and the scripts included into the sequence [3]. Sequences are driven by a GRAFCET. In each step of the GRAFCET, actions to do are implemented in VB Script. For each action, a call to another sequence (subsequence) or function is made. VB Script allows to implement sequence engine request such “stop GRAFCET” or “suspend GRAFCET”.

FULL AUTOMATED SEQUENCES

SQMH Vacuum Windows Sequence

To control default growth on chamber optics, the SQMH sequence takes pictures of vacuum windows one after the other (Fig. 4).

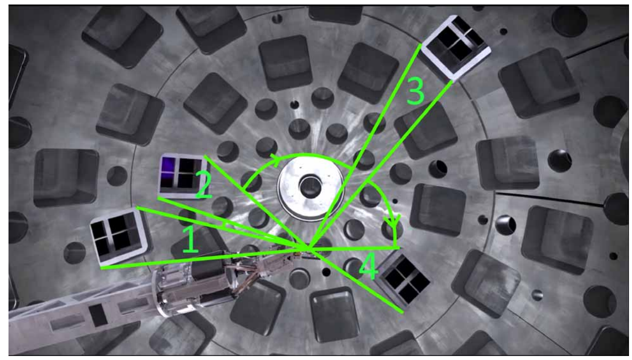

Figure 4: Vacuum windows pointing.

SQMH launch is initiated by the shot director and the sequence is carried out without his control until the end. A display is available for checking and when step by step testing (Fig. 5).

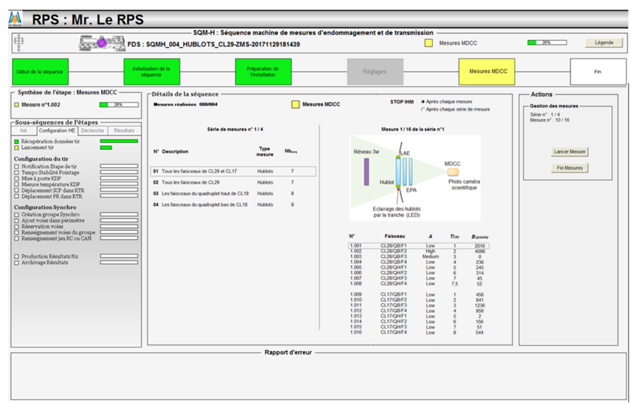

Figure 5: SQMH GUI.

First, an assigned sequence perimeter is created, it is filled with resources as POCC and MDCC. These resources are locked for this sequence.

Out of the chamber FOA take place (Final Optics Assembly from Conversion and Focusing System LMJ called SCF) behind the windows. The SCF position must be the same for each vacuum windows inspection to get constant lighting. SQMH moves SCF if necessary in this purpose (Fig. 6).

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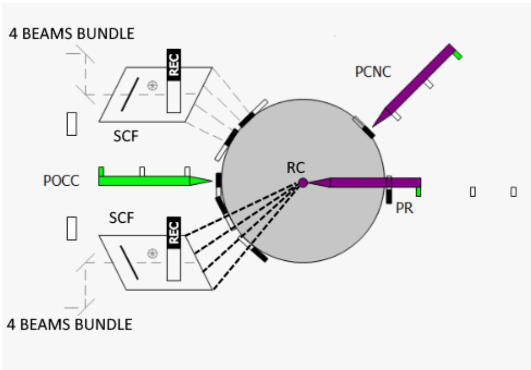

Figure 6: Disposition of SCF, REC and Target Chamber.

When devices are ready, SQMH loops to position MDCC towards every windows, take picture and stores it. To finish, SQMH starts an asynchronous data analysis of stored results. It lets the sequence exit and stop releasing POCC and MDCC resources at the same time (Fig. 7).

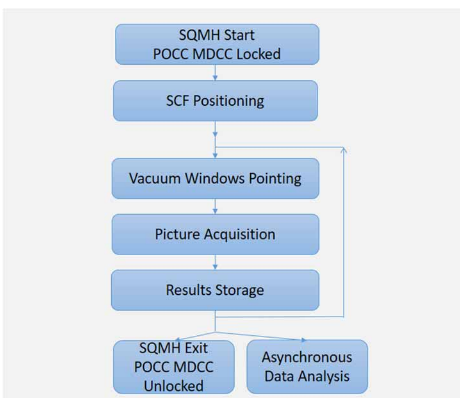

Figure 7: SQMH overview.

SQME Alignment Sequence

SQME achieves several goals. The main one is SCF alignment, that implies inserters exchange, positioning system availability check, initialization and RC positioning. Secondary goals are SA alignment (Amplifying Section), ST alignment (Beams Transport Section) KDP configuration (Potassium Dihydrogen Phosphate Optics for wavelength conversion), wavefront correction and PAM (Pre Amplifier Module) Tuning.

SQME is launched by shot director after SQMH in order to ensure SQMH reserves POCC resource first.

Operator GUI is displayed to shot director (Fig. 8). It presents actions that could be carried out by the sequence. The shot director can adjust perimeter, actions and SA SCF Alignment start times. After this step, the sequence is left unchecked by operators throughout the night.

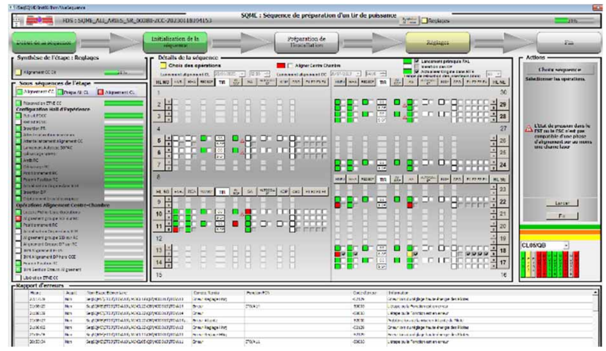

Figure 8: SQME GUI.

For each quadruplet (4 beams bundle), a new subsequence is started. It reserves SA resources and SCF resources which are not held by SQMH. During part of the night, both SQMH and SQME are working. SQME fits PAM High Energy Setup that will be called back during the shot sequence. In parallel, SCF are positioned coarsely all at once. If they cross the beams, REC (Conversion Energy Radiometers) are removed.

In the same time, inserters reservation is started. Target positioner and RC positioner are reserved but POCC reservation is in standby waiting for POCC release from SQMH. Reservation mechanism is waiting for the end of SQMH. It guarantees not replacing POCC when used by SQMH on the one hand and SQME will start as soon as SQMH is finished on the other hand.

When SQMH unlocks POCC, CC reservation is done (Chamber Center is composed of POCC, PR, PCNC (Non Cryogenic Target Positioner), RC and SOPAC(Optical Positioning and Target Alignment)). And POCC is replaced by PR. Two initializations ensue: RC and SOPAC. It makes them available for shot frame origin update. At the same moment a timer waits for SCF Alignment start time that shot director has previously set. SQME handles such a function for stability purpose. Alignment should be performed as late as possible. When time has come, SQME updates shot frame origin.

After, SQME checks that REC SCF positioning has been carried out successfully (it should always be done during SQMH), then SCF alignment is started. It consists in following an instructions list that contains RC position point and adjustments of each SCF that use this RC position point. Then the next RC position point and adjustments of the linked SCF come, and so on. SQME is therefore sequencing RC positioning and SCF alignment until the end of the list.

Each 4 beams quadruplet subsequence waits for its SCF alignment and SA Alignment to carry on with Transport Alignment. Then comes KDP configuration and wavefront correction. These three last actions are often not selected for afternoon rescheduling (Fig. 9).

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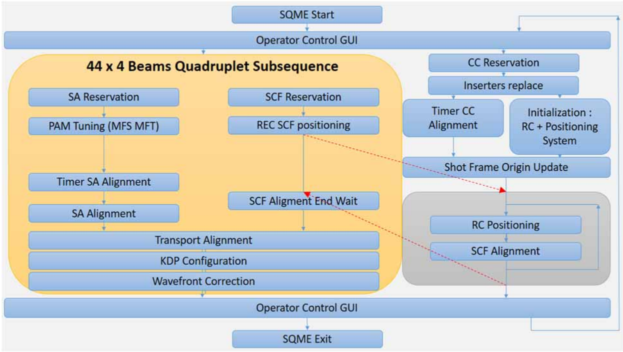

Figure 9: SQME Grafcet.

SQME ends by displaying Operator Control GUI. It shows results and allows partial relaunch. At 6 AM, the operator takes up his workstation. He checks the results. He needs to find out if sequence has behaved as expected. To do so, the operator has two GUI.

The first one is the Control GUI (Fig. 8) that indicates if completed alignment function are successful or not, or if it is still running. There is an indicator for each function that the operator can call from this GUI.

The Second is SQME Alignment GUI (Fig. 10). It indicates all the results of the functions carried out by SQME. It uses coloured indicators with end date in order to understand the night scheduling. Rectangle indicators display error in red, success in green and not carried out function in white. When a function concerns a 4 beam bundle, the identification number of this bundle is coloured with the same code as it is used for rectangles.

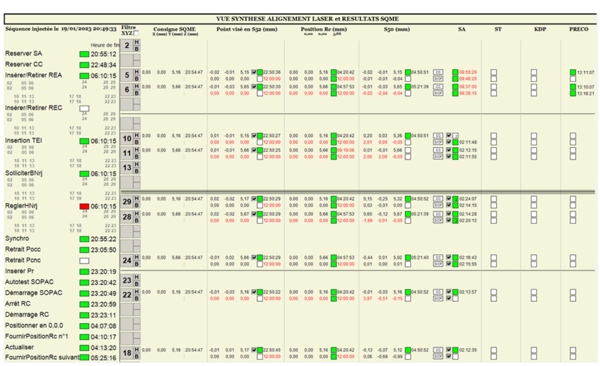

Figure 10: SQME Alignment GUI.

This GUI also indicates alignment and positioning control points. One type of control point indicates if a 4 beam section is currently aligned or not. A second type deals with the time when it became "aligned". The date disappears with alignment break. It turns red if it lasted too long. A third type gives the point coordinates where RC should have been positioned for SCF alignment, the coordinates where RC was at the end of the SCF alignment, the coordinates where SCF was coarsely positioned and the current coordinates of SCF. Coordinates of SCF means the coordinates of the point that the SCF is pointing at (It should correspond to RC position). These four coordinates are compared with each other. Red color is used to draw the operator's eye to a gap that is too wide.

At the very end of SQME shot director can exit the sequence unlocking resources by the way.

ENHANCEMENTS

Reservation Check

Locking resources ensure that two sequences are not carrying out tasks at the same time on the same device. But as SQME reserves resources when operator are absent, sequence could wait resource release all night doing nothing in case it is locked. To solve this issue, before operator choice GUI appears, a lock is processed on SQME resources without waiting option. The output gives the list of already locked resources if any and displays it to operator. As POCC and MDCC should always be reserved during this test, SQME controls reservation perimeter. If the latter belongs to SVP supervision, it is considered right because it is expected. If reservation is complete then unlocking is performed right after.

SQMH Error Resilience

Some devices can raise alarms. In LMJ control command it sometimes leads to suspend the main grafcet. This suspension can spread to subsequence. Thus SQMH do not exit and SQME can not perform its job. When alarm disappears, a call to Grafcet engine is done to resume the sequence and quit. When the alarm persists, it should be handled to be allowed to resume. As it is too complex to anticipate such various alarms, the chosen solution consists in calling Grafcet engine to stop the grafcet which automatically unlock resources and suppress the perimeter. Of course, in order not to break normal windows check, the call run condition is that SQMH acquisition subsequence is either "not running" or "in error".

Inserter Anticollision Control

During the night, POCC must be remove from the chamber whereas the PR must be inserted. Moving the PCNC in the chamber center is a potential collision risk. To ensure the sequence will not lead to collision, each grafcet step that generates inserter move, should it be backward or forward, controls insertion control points in the same step. Before moving, positions of the three previous inserters are checked. They must be defined, compatible with the move and the OPC (Open Platform Communications) control points must be present with good quality.

Reservation participates to anticollision too. SQME reserves the three inserters avoiding other sequence or command control to drive them.

Positioning System Availability

RC and SOPAC initializations used to be operator prerequisite of SQME and SQMH beginning. As these devices issues fully block SQME, they have been made reliable, automated and integrated to sequence. First, it was only carried out before SCF alignment. Now, SQME is enhanced by detecting a wrong RC positioning which is the RC SOPAC initialization trigger. If the previous SCF alignment failed, it means both previous RC positioning and

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previous SCF alignment should be relaunched, and that is what SQME does.

CONCLUSION

LMJ sequences are built to inspect vacuum windows and perform laser beam alignment throughout the night without operator. Collision risks are controlled by reservation mechanism and control point checks. GUI are designed to set sequence parameters and to display its overview. This system saves 9 hours per day for achieving daily shots. The main issue is when unexpected events stop the sequence before its end. Sequence enhancements solve these issues Sequences endeavour to automatically restart faulty function. They also force to carry on the hanged grafcet. These undriven sequence always manage to complete on not broken down equipment context.

Anticollision handled by sequences will be improve next years by taking account of Target Diagnostic inserter positions, the latter is currently checked by operators through perquisite list. In the same thematic, SQME will integrate Target Diagnostics Alignment as well.

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