MASTER

UCRL - 76341
PREPRINT

Conf-751125-15

LAWRENCE LIVERMORE LABORATORY
*University of California/Livermore, California*

# Control and Data Management for a Large Fusion Laser

J. W. Davis and F. W. Holloway

November 11, 1975

This paper was prepared for submission to the
Sixth Symposium on Engineering Problems of Fusion Research
on November 17-21, 1975.

San Diego, CA

# CONTROL AND DATA MANAGEMENT FOR A LARGE FUSION LASER*

J. W. Davis and F. W. Holloway
Lawrence Livermore Laboratory
P. O. Box 808
Livermore, California 94550

## Summary

SHIVA is a powerful (10-kJ 25 TW) neodymium glass laser system to be used (in 1977) for target irradiation in fusion research. SHIVA is also a development project in that it is pushing the state of the art in laser and optical technology. The present design calls for 20 parallel laser amplification chains whose light output is pointed and focused at a small (100 μ) target within a chamber from semi-equally spaced three-dimensional directions. It is probable that SHIVA will be upgraded to as many as 42 chains in the next few years. Each chain of SHIVA contains 7 high energy laser amplifiers and perhaps 20 other major optical components, many of which send and receive control and measurement information. Again future expansion may add additional elements. Each chain has also associated 10 gimbal or translation motions for beam assignment from the oscillator onto the target.

Over 50 power supplies must be set, and their set-points checked before a shot; these supplies charge 1100 capacitor banks up to a stored energy in excess of 20 megajoules. The integrity of each bank-lamp circuit must be checked before and after a shot, and this information presented to the system operators.

SHIVA will be evolutionary and many of its aspects will require data acquisition and supervisory control whereby the designers operate SHIVA to study its performance. At other points open loop control, where the designers direct an operational control to do a series of tests for statistical or variable parameter information, will be required. Eventually for manpower reasons and repeatability of performance during production operation it is desired to go as far toward automatic control as possible. Since SHIVA itself is a development project and when operational will be used for research, a high degree of modularity is required. For target research this modularity will tend to be along the lines of number of laser chains and amounts and direction of light energy from each chain. For laser development and checkout modularity will tend to be along the lines of single elements in a single chain. This paper presents some of the fundamental considerations and implementation plans behind the architecture of the control and data management of the SHIVA laser system.

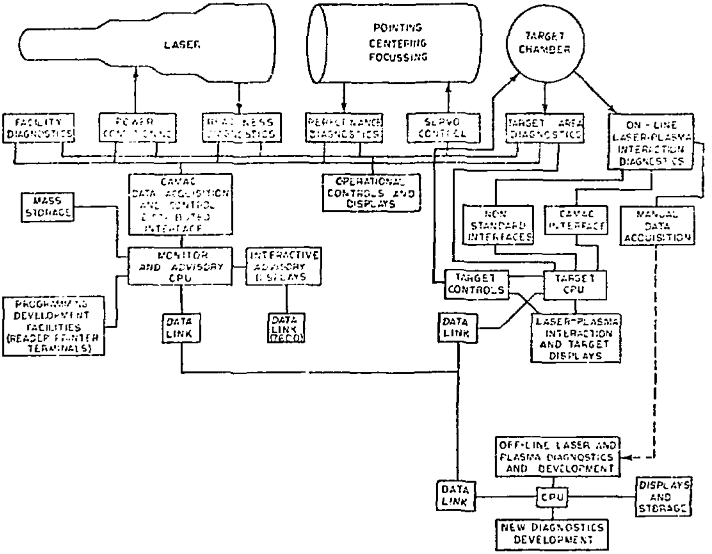

Figure 1. SHIVA Block Diagram

---

*Work performed under the auspices of the U.S. Energy Research & Development Administration under contract No. W-7405-Eng-48.

## Functional Requirements

Data management and machine control are philosophically separate but closely related topics in the design of this large irradiation facility. The general data management problem is to provide hardware, software and data taking procedures and structures such that data from different data takers may be efficiently collected, archived, recalled and correlated. The general machine control problem is to implement a control structure, again a mixture of hardware, programming and procedures - during the construction, debugging and use of the facility without compromising its evolution from a laser under test to an operational irradiation facility, and to do this while insuring reliability and cost effectiveness.

Figure 1 is intended to convey a broad brush overview of the SHIVA system from the viewpoint of data management and machine control. The salient features are primary and backup control systems, multiple data linked central processing units (CPU's), and a major *effort towards standardized (therefore shareable)* hardware and software.

The functional requirements are: (1) the *collecting, checking, formatting and quick look* display of the diagnostic data of the facility, (2) the assistance of the control room staff in monitoring pre-shot and post-shot facility status, (3) the storage and retrieval of shot records, (4) the provision for a programmed alternative to certain manual laser control paths, (5) the maintenance of a data base and (6) the supervisory control of the *pointing* and alignment system.

| TIME | EVENT | | COMMAND | MONITOR | DISPLAY |
|---|---|---|---|---|---|
| 60 secs | EOA 600 | [illegible] | 1 binary | 1 binary | [illegible] |
| 50 secs | EOA [illegible] | Select energy | 1 binary | 1 binary | Execution |
| 40 secs | [illegible] | [illegible] | 1 [illegible] command | 1 binary | Execution |
| 30 secs | [illegible] | Pulsed laser [illegible] | [illegible] | 40 [illegible] signals<br>40 binary [illegible] | Execution |
| 20 secs | [illegible] | 7 axis [illegible] target | 1 binary [illegible]<br>1 camera command | | |
| 15 secs | EOA [illegible] | [illegible] | 1 binary | 20 binary & acknowledge | Execution |
| 15 secs | [illegible] | [illegible] | 1 binary | 20 binary Acknowledge | [illegible] CRT Execution |
| 15 secs | [illegible] | [illegible] | 1 binary | 20 binary Acknowledge | [illegible] CRT Execution |
| 15 secs | [illegible] | [illegible] | 1 binary to [illegible] | 4 [illegible] | Execution |
| 15 secs | [illegible] | [illegible] | [illegible]<br>[illegible]<br>[illegible] redundant<br>[illegible] voltage [illegible] | | |

Table 1
SHIVA Event List

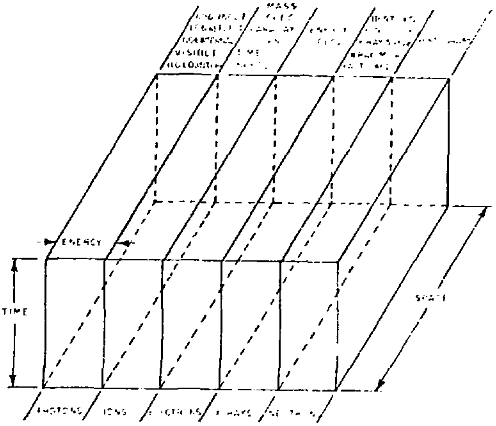

Figure 2. Laser-Plasma Diagnostics Space

Table 1 is an excerpt from a long list generated during the task of defining control system requirements: it is organized in time line form since SHIVA is not a continuous process but an event-by-event procedure. Shown are the responsibility nodes (e.g., EOA600, electro optics alignment call to freeze all gimbal motions), and what is necessary in the way of commands to be sent, performance to be monitored and data to be displayed for the satisfaction of this node. The sum collection of all these entries is the control structure of SHIVA.

Figure 2 is a conceptual "diagnostics space" for SHIVA laser-plasma interaction; there are numerous entries in each general area, particularly in "photons" (time integrated mono-energetic spatially resolved) and "x-rays" (time integrated, spatially integrated energy resolved). The total number of bits of information contained in this space, even with conservative estimates for the information density of photographic diagnostics, may easily exceed $10^9$ bits per shot.

*The on-line acquisition of this amount of data in* near-real time is, in all probability, neither possible nor desirable; consequently data management in the SHIVA system will employ a variety of local temporary storage techniques and will record large amounts of image data directly on film, however the elimination of film (where resolution requirements permit) by direct electrical readout of cameras (through digitally controlled vidicons and charge-coupled-device arrays) will be pursued as the above-mentioned techniques move from their current development status into production. A fundamental consideration in these efforts is that even a small section of an interesting piece of film may *contain* $10^3 \times 10^3 \times 50$ *elements of information.* The pattern recognition, digitization and data reduction problems are clearly awesome and will ultimately be the area of endeavor which claims the most resources. CAMAC data acquisition modules and methods are currently in use on our JANUS and CYCLOPS laser systems, and are being installed on ARGUS - a regular evolution *of these techniques will be used on SHIVA.*

## Design

### Data Management

Data processing machinery is required to acquire the tremendous volume of diagnostic data required, subsequently process the raw measurements into diagnostic units (for example millivolts to Joules) and to archive the results into a historical performance record for later retrieval and correlation. Our philosophy is to encourage multiple processors, recognizing that some (for example the laser-target interaction CPU) will for most shots have to be functional and on line while others (for example the alignment system) will be deliberately frozen just before a shot and others (the central monitor) may, by the system design, be non-functional for some longer time before and after a shot without jeopardizing its success.

"Mini" CPU's of moderate complexity will be used since it is planned that the facilities of the massive LLL central computer complex will be generally used for large scale number crunching, sophisticated displays and correlation of intershot parameters. Standards have been established for the make and model of the CPU's, the applications software language (FORTRAN) and the interfacing hardware (CAMAC). Distributed computation is encouraged to reduce dependence on a CPU and to lower data transfer rates to and from CPU's. Converting the analog signal from a process transducer (e.g., millivolts from a calorimeter) to a digital signal as close to the transducer as possible - or using a digital transducer - is a great advantage, since digital transmission has a greater noise immunity and even more importantly allows convenient local control and storage thereby reducing the dependence of the whole system on a single central controller.

An example of this approach is the calorimeter interface. The calorimeter output signal is a slowly varying low voltage, which must be sampled approximately once every two seconds for thirty seconds before a shot and ninety seconds afterward to permit accurate reconstruction for processing to yield a measure of deposited energy. For one or two laser chains the calorimeter signals can be directly connected to the control room, but for twenty chains with multiple calorimeters this becomes considerably less desirable. Analog multiplexing places considerable dependence upon the multiplexer hardware and increases the bandwidth requirements. Also if more calorimeters are added the bandwidth requirements rise directly and affect expandability, a primary system guideline. The interface of present choice multiplexes between 16 calorimeter outputs, does an analog to digital conversion, and stores the results in 16 digital registers, each register corresponding to an analog input. A complete 16 input scan and conversion cycle can be done in less than half a second. Since the storage is local, bandwidth requirements back to the CPU are considerably relaxed and in fact if local memory is used in the CAMAC crate the CPU need not access the data until completely after the shot.

Local (at the crate) storage and manipulation of diagnostic data is the position toward which data management is moving as rapidly as the equipment and techniques permit.

### Machine Control

To inaugurate a facility under computer control without the option of manual control demands an early large commitment in programming since computer programs must be developed to perform "hardwired" control when the facility is installed and be flexible enough to expand toward automated control methods without hindering operations. There is, however, a very real advantage to computer control in being able to archive from the beginning all steps taken in the operation of the facility and being able to use one CPU or one section of a CPU to model the process operation for simulation exercises. We have chosen what might be called a "transitional" control scheme characterized by the following features. All possible detailed diagnostics are taken by the CPU from the first. Summary diagnostics and essential control are hardwired (although in many cases hardware multiplexed) and under operator supervision. As the facility and its operation become "productionized" the manual control systems--designed from the beginning to do so--are decoupled and replaced by redundant CPU control, retaining the manual fallback operation option. In the above "manual" implies hardwired.

As an example redundant control panels are provided in the central control room to permit manual entry of power supply set points (which set laser power levels). The manual entry panels are so designed that they may be functionally deleted and replaced by a CAMAC interface module when programmed automatic setting of the supplies is desired. Moreover the digital delay generators used for time-staged firing of the capacitor banks are manually set but monitored by interface modules for later verification of proper sequencing.

A final example shown in Figure 3 is perhaps the clearest example of the intended interrelationship between the manual hardwired and CPU-related aspects of the control philosophy.

The figure shows a set of series-connected single-pole switches connected by one twisted pair to a hard-

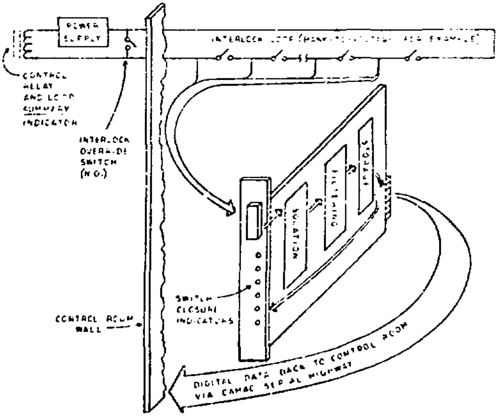

Figure 3. Switch Monitor Interface Module

wired permissive interlock in the control room. In one application, each switch is associated with one capacitor bank. In another application, the lamp integrity check, it is associated with one pair of lamps. In the first instance, switch closure indicates that the bank is charged. In the second instance, it indicates that lamp integrity has been verified. The number of loops for the whole laser could vary between the extreme cases of one switch per loop (1100 loops) or one loop of 1100 switches. A compromise solution is clearly desirable. In fact, each loop will represent the number of circuits in a laser amplifier module. The hardwired loop then provides the positive protection desired by stopping the shot immediately if a bank breaks down or fails to charge due to a blown fuse. This is essentially a yes/no (or 1-bit) transfer at maximum information rate. The detailed information as to the identity of the particular offender in the string is obtained at the slower serial data transfer rate when the switch closure monitor interface modules are queried by the computer program. This detailed information is then available for tabular display to the system operators.

Figure 4 is a simplified view of the data-transfer paths in the CAMAC interfacing system. This modular international interfacing standard is in wide use throughout (and beyond) the national laboratory community. Note that each crate can contain over twenty separate interface modules. The parallel-branch highway can service seven crates but is limited to the control room. The control room "crates" house the serial highway drivers (ten serial highways per crate), which can communicate, at a maximum bit rate of 5 MHz, with a maximum of 62 crates, each serial highway using only two twisted pairs. An inherent disadvantage of serial communication--a slower transfer rate than that obtained with parallel communication--is overcome when, as in the present case, the system is designed to transfer the fast "go/no go" information along the fastest pathway and the detailed maintenance information along another, slower one. The outstanding advantage of the serial system is that it drastically reduces the number of long-run cables, allowing the economical use of more sophisticated signal-conditioning methods (noise immunity, ground isolation) on each wire pair penetrating the control room.

## System Integration

SHIVA is a large system, involving a year simply in the construction phase. Total system debug time can be reduced to the extent that significantly large functional modules are brought up and checked out off line. The examples cited above were chosen to show the functional modularity of a large part of the data acquisition and control hardware. It is further intended that techniques such as structured programming be used to benefit the functional modularity (and therefore the phased and orderly checkout) of the software.

The CAMAC system of interfacing is particularly adapted to our intended approach of module-by-module facility integration since, for example, CAMAC subsystem controllers, which in normal operation communicate with the central processor, are themselves plug-in functional modules and may be replaced with plug-in manual control modules for set-up, debugging and troubleshooting.

Finally, the mode of system integration will be to debug and initially operate the facility under computer assisted manual control with maximum automation of detailed diagnostics data, phasing into redundant programmed control as it is warranted by developing system characterization.

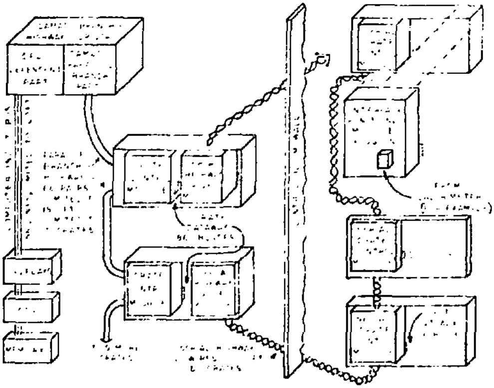

Figure 4. CAMAC Data Transfer Paths