Design and Fabrication of a Handheld Optically Coupled Water Flow Calibrator

Robert Balonek

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Robert M. Balonek

Byron-Bergen High School
Bergen NY

Advisor: David Lonobile
Mgr., Controls Eng.

Laboratory for Laser Energetics
University of Rochester
250 East River Road
Rochester, NY 14625-1299

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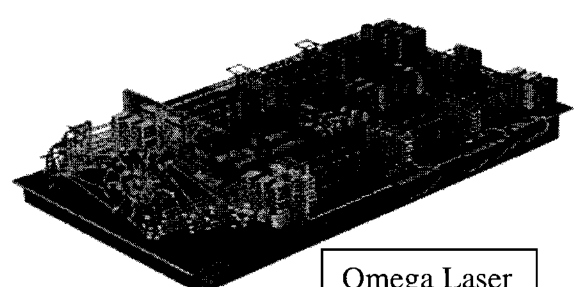
Abstract:

Hundreds of fiber optic coupled flow detectors are planned for use on the OMEGA EP laser system [1] to measure the flow of coolant water through the laser amplifier flashlamps. A handheld device capable of sending precise optical frequencies was created, which will allow the flow detectors to be tested and calibrated to within +/- 1 gallon per hour. The handheld device, known as the Flow Detector Calibrator (FDC), can measure the voltage output of the flow detector to an accuracy of +/-1%, and can determine if a flow detector is transmitting its optical 10 kHz stimulus frequency. The FDC will be utilized as a test fixture initially for incoming inspection of production quantities of Omega EP flow detectors and subsequently will support in debugging and maintenance operations within the laser bay.

Introduction

The Laboratory for Laser Energetics in Rochester, NY is home to the Omega laser, the world's largest laser (Fig 1, Ref. 2). Omega has sixty individual 12-inch diameter beams that each deliver 500 joules of 351 nanometer ultraviolet laser energy. The combined 30 kilojoules of laser energy is focused onto a single fuel target. The resulting extreme pressure and temperature creates a momentary fusion reaction. The



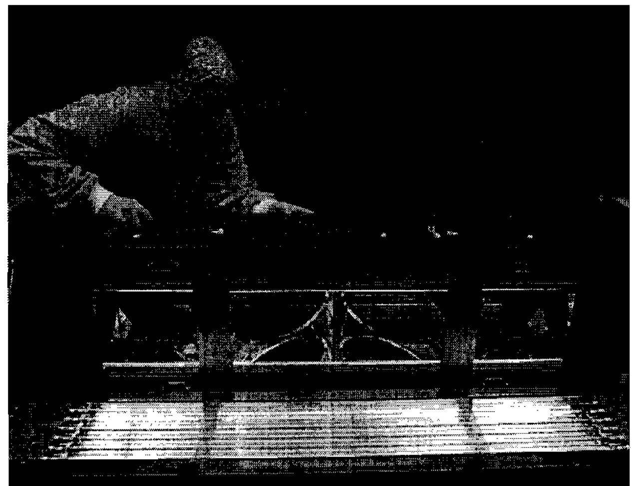
Omega Laser
Figure 1.

Omega laser system enables scientists to study fusion as a potentially clean renewable source of future energy. Construction of a new laser system Omega EP (Extended Performance) is currently underway that will complement the research capabilities of the laboratory.

Background:

In order to get the maximum possible energy on target it is necessary to amplify the laser beam. Each of the 60 beams is comprised of a sequence of laser amplification stages with increasing beam diameter. Each arnplifier stage contains a neodymium center that is the active laser element that the beam propagates through (see Fig. 2). The neodymium core is stimulated by xenon flashlamps that convert stored electrical energy into photons. These are similar in function to a camera flash but thousands of times more powerful. Prior to the laser event the flashlamps discharge 14,000 volt capacitor banks. The resulting 10,000 ampere current pulse "pumps" the neodymium core with intense white light. Subsequently the laser propagates through the neodymium core and is amplified by the energy it extracts. The process of electron energy conversion to photon energy creates intense thermal heat inside the flashlamp due to the large amounts of infrared light that is emitted. The excess thermal energy has to be removed so that the flash lamps do not overheat, fatigue, and crack. If the flash lamps crack during

Figure 2. OMEGA disk amplifier with flash lamps at the bottom



Amplifier's Flash Lamps

discharge of the 10000 ampere current pulse, they will explode and damage the delicate interior of the amplifier.

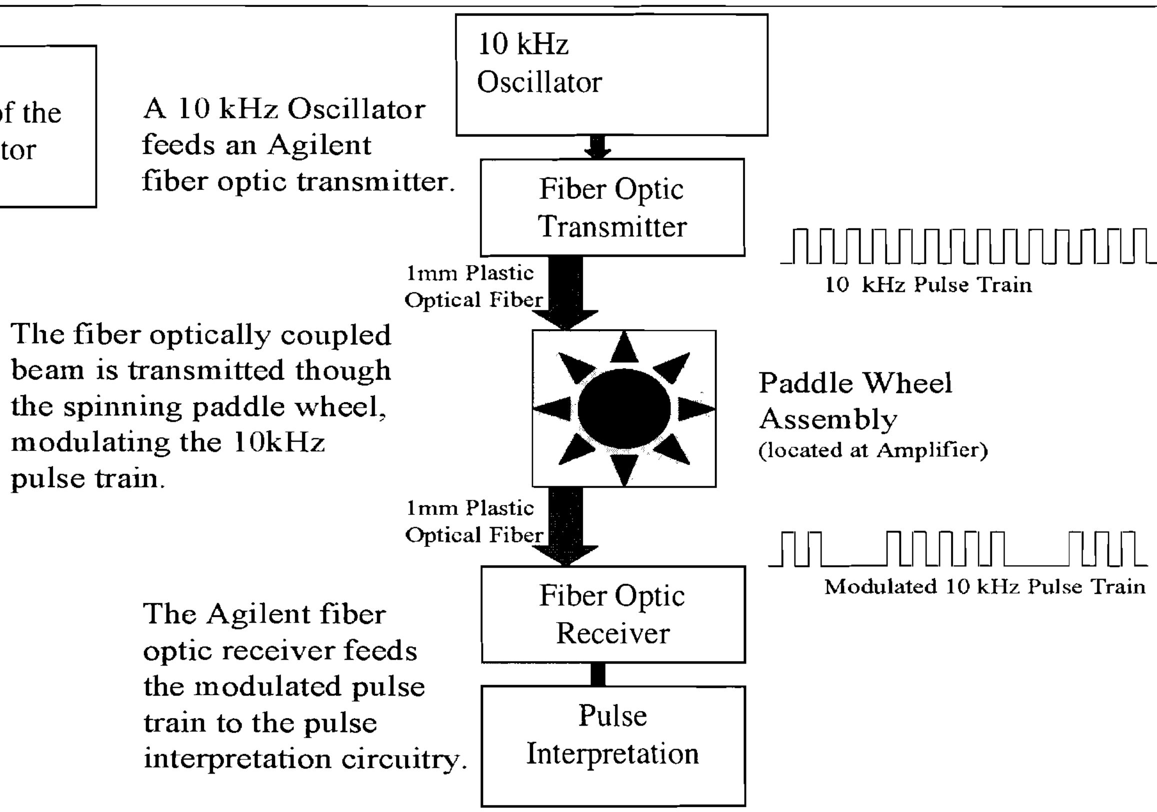
To cool the flashlamps each tube is encased in a fused silica sheath. Through the sheath de-ionized water is pumped at a constant flow rate. Pumping water over the flash lamps allows the heat to be transported away from the tubes. Cooler flash lamps last longer, and will have less of a chance for catastrophic failure. Regulating the water flow results in maintaining the flashlamps at a preferred operating temperature regime.

Flow detector theory of operation

De-ionized water is set to flow through the flashlamps at a rate between 4-60 gallons per hour (GPH). The flow rate is monitored by the Flow Detector Module (FDM) that then sends a signal to the Amplifier Facilities Controller (AFC) [3]. The AFC will then alert the control room if too much flow is detected or too little flow is detected. The FDM is constantly monitoring flow in the amplifiers through optical fibers. Optical fibers are required to isolate the flow monitoring instrumentation from proximity to the potentially hazardous high voltage present in the flashlamps. The optical fibers enable the flow detection system to be completely isolated electrically from the flash lamps.

In operation the FDM sends a 10kHz optical pulse train through a source fiber to a remote paddle wheel. Water flowing through the paddle wheel causes it to spin at a rate proportional to the flow. As the paddle wheel spins it physically “chops” or cuts the 10kHz frequency source (refer to Fig 3). The chopped frequency is then sent back to the FDM over a signal fiber where it is analyzed by a frequency to voltage converter circuit and transmitted to the AFC as gallons per hour information.

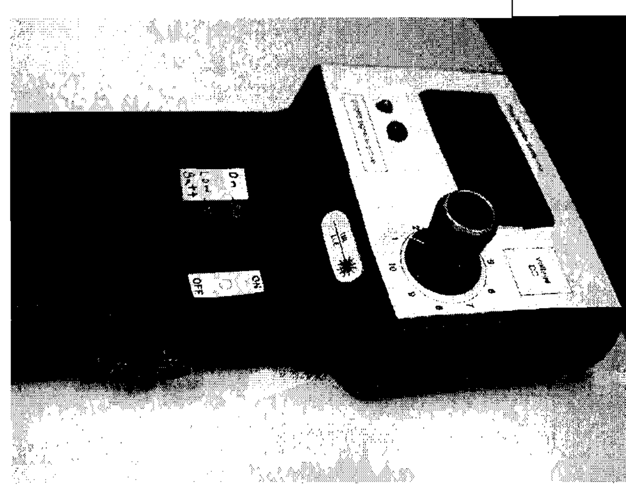
Figure 3. Operation of the Flow Detector Module



Flow Detector Calibrator

In operation each FDM employs circuits that must be setup properly to achieve accurate measurements. Prior to installation, circuitry must be adjusted to correct for unit-to-unit component tolerance differences. In this manner FDM's are matched to a calibration standard that insures interchangeability of modules and consistent characterization of water flow conditions in the laser amplifiers.

Figure 4. Hand-Held portable FDC



A unit has been built that can accurately calibrate EP's Flow Detector Modules. This unit is a hand-held portable calibrator (Fig. 4). It can optically calibrate the Flow Detector Modules by sending precise optical signals. It can send ten different signals to the FDM, each signal representing a different gallon per hour reading. The FDC can represent flow from 4-60 GPH. This unit incorporates an on-board voltmeter that can measure the voltage that comes from the FDM so that calibration can take place in both the lab environment and bench top inspection. The voltage is displayed using a LCD monitor to +/- 1% accuracy. The unit incorporates a low battery indicator, using a single comparator circuit, which will alert the user to a low battery situation so that calibration accuracy will not be lost. The FDC also incorporates a feature to insure the FDM is operating properly. The FDC has two LED's that will light up indicating that the FDM is sending a 10kHz isolating signal. This will help diagnose if the systems problem resides in the optical fibers or paddle wheel assembly.

Break Down of the FDC

The FDC will become a valuable asset in the Omega Laser system in many ways. The main goal of this unit is to qualify incoming units. When Flow Detector Modules are built they need to be calibrated. The FDC will allow all new incoming units to be calibrated to a standardized set point. With all new units calibrated to the same standard, the Laboratory can be assured that all units are operating properly. The portability of this unit allows easy real-time inspections of the laser system without large complicated equipment. Its portability will allow technicians to quickly find and localize any problems that could be coming from the FDM's.

Troubleshooting Capabilities

The FDC has a simulation feature to allow the diagnosis of troublesome FDM's. The FDC has the ability to send out ten different frequencies. Each frequency has a correlating GPH reading (Table 1).

Position	GPH	Frequency Hz
1	< 8	4
2	8	30
3	16	50
4	19	60
5	26	80
6	29	90
7	47	150
8	56	180
9	60	195
10	> 60	202

Table 1. Flow rates and corresponding frequencies used by the flow detector calibrator.

The frequency output on the FDC is selected using a ten-position rotary switch. When coupled with the paddle wheel input and output optical fibers the FDC simulates water flow to the FDM. With the capability to simulate water flow, the FDM's can be calibrated before and after installation without having to have water flowing in the system. A graph of water flow vs. frequency was plotted. The frequency and GPH readings were found to have almost a linear relationship. The FDC samples ten points on this line. With ten spaced out samples on this line an accurate calibration of the FDM is ensured. To further the calibration accuracy, the frequency output from the FDC is stable to +/- 2 Hz. The addition of an on-board voltmeter accurate to +/- 1% allows the operator to sample the voltage output pins on the FDM. This further increased the useful range of the FDC since not only can it simulate water flow but it can also accurately measure voltage readings from the FDM's without the further complications of additional equipment.

Internal Operation of the FDC

Many possibilities for different components and configurations were investigated for optimal performance of the FDC. Many options were considered for the oscillating circuit. One option was a quartz crystal that would oscillate and be controlled using voltage. The instability of voltage control led to the next choice. The inverter IC chip 74hc14 is the best choice for this circuit. It has a stability rating based on external components. The ability to control oscillations externally is why the 74HC14 inverter IC was chosen for the FDC.

An internal rechargeable battery was considered during development. Based on tests and experiments a separate charging station was ruled out due to cumbersomeness and lack of rack space in operating environments. With an external charging station ruled out internal charging was then investigated. Two options exist for an internal charging station: a charging process controlled by a IC or constant charge via a walwart transformer. The IC controlled charging would provide stability and safety to charging of the internal battery. It is a good choice for a unit that is going to be constantly used. Due to the nature of the FDC as a calibrator and troubleshooter, the FDC may only be used on a month to month basis. Without constant use the IC would terminate charging on a full battery and not start charging until either being disconnected from the battery or a flip of a reset switch. Without the ability to charge constantly the IC was discarded for it could not keep the FDC ready for use at a moment's notice. The walwart transformer provides a constant current to the battery keeping it at a top charge indefinitely. The trade off in this situation is the long recharge time of at least 8 hours. This was considered acceptable for the ability to keep the FDC on the ready at a moment's notice for long periods of time. A Nickel Metal Hydride battery was chosen as the best choice, with its ability to take a top charge indefinitely and up to 1,000 total charges.

With a rechargeable system in place, a choice had to be made between 1.5, 3 and 5 volt logic. Initial tests proved that 1.5 volt logic was too low to provide sufficient power to the screen. Three volt logic was a optimal choice due to low current draw but made oscillations vary as much as 5%. Five volt logic was chosen because it was able to keep oscillations within a 2% variation. To keep the oscillations stable a higher current draw was considered acceptable.

With a voltage chosen for operation of the circuit, a way of qualifying that voltage was necessary. An internal low battery indicator was devised. This comparator circuit continually verifies the voltage of the circuit. When the voltage falls below a certain threshold (where oscillations fall out of the accepted +/- 2 Hz range) an orange indicator light alerts the operator to this problem. The low battery indicator insures that the FDC is working within an acceptable voltage range.

Each component in the FDC has been carefully chosen for current draw, stability and performance characteristics. With each part chosen for a specific task, the FDC is optimized internally for peak performance.

Calibrating the Calibrator

Since the FDC plays a fundamental role in calibrating instruments at the Laboratory for Laser Energetics, each FDC must be hand tested before leaving assembly. I found that a burn-in of three days allows the assembler to accurately determine if the oscillations are stable. Each resistor and capacitor must also be hand chosen due to tolerances on each. Due to lack of time I was not able to test the long-term stability of the FDC. I recommend checking the FDC every six months to ensure optimal performance of the internal circuitry.

Conclusion:

A calibration unit has been built that will accurately calibrate Flow Detector modules. With a calibration standard that can be put into practice, accurate water flow can be determined. A constant volumetric water flow through the system that can now be accurately measured will increase the life of the flash lamps. Increasing the life of the flash lamps will save the amplifiers from undue stress caused by opening and closing the doors. This will decrease downtime, and increase the number of productive shots on the new Extended Performance laser.

References:

1. http://omegaep.lle.rochester.edu/110_overview/

2. http://www.lle.rochester.edu/05_omega/05_omega.html

3. David Lonobile; *Amplifier Facilities Controller Requirements Definition*

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3-D Characterization of Deuterium Ice-Layer Imperfections in Cryogenic Inertial Confinement Fusion Targets

Bruce Brewington