Optical Time-Domain Reflectometry for the Transport Spatial Filter on the OMEGA Extended Performance Laser

Troy Thomas
Webster Thomas High School
Advisor: Dr. Brian Kruschwitz

Laboratory for Laser Energetics
University of Rochester
High School Summer Research Program
2011

Abstract

An optical time-domain reflectometer (OTDR) is a diagnostic that measures light that has been reflected back towards the laser's origin. The transport spatial filter (TSF) OTDR is a device that measures these reflections in the latter half of the laser system, especially to monitor retroreflections from the target. A MATLAB computer program has been created that imports and analyzes OTDR data files. These data files contain information on the voltage of the return signal at specific times, the time scale used, and the shot type. The time that the light takes to return to the OTDR from specific optics has been determined through the use of ray trace charts. These charts have been used to trace the beam's path to the optic and back to the TSF OTDR. These times are used to create labels on the graph for the most important optics. The program then plots the data on a graph of voltage vs time. This graph allows easy interpretation of the data, allowing the user to diagnose any optic malfunctions or unexpected return signals.

Purpose

Optical time-domain reflectometry is used in the OMEGA EP (extended performance) system to identify and locate optics which have deformations or impurities, or optics that have another source of retroreflected light. To do this, it measures the reflected energy coming from each optic in the system. A small amount of energy is expected to come from each optic, but if a substantial amount is reflected, it may indicate that the optic is damaged. This excess energy can have various negative consequences. It can damage small optics in the beginning of the system that are only able to handle small amounts of energy. Some types of experiments also need a certain amount of energy, so if some is lost to reflection by damaged optics, the experiments can give flawed results. The OTDR measures the energy that is reflected back by optics. It can also identify which optic is damaged by measuring the time that the energy took to reach the diagnostic. This is important because if we can identify which optic is damaged in a quick and precise manner, we can minimize the time it takes to replace the optic, and minimize the time the system is down.

The OMEGA EP laser can provide a plethora of shot types, not only by itself, but in tandem with the OMEGA laser. There are two OTDR diagnostics set up in the OMEGA EP laser system. The OTDR unit of interest for this work, the transport spatial filter (TSF) OTDR, is set up in the middle of the laser system, which allows it to diagnose problems with optics in the latter half of the system. In particular, the TSF OTDR was created to monitor the energy that is reflected back into the system by targets that passes by the safeguards installed in the OMEGA EP system. Until now, the TSF OTDR was aquiring shot measurements, but there was no way to read or use the data. If we could create a way to read and understand the data, it would be easier to monitor target retroreflections, identify failing optics, and keep the system running smoothly.

OMEGA EP Laser System

The OMEGA EP laser system was created to expand the range of experiments that can be carried out at LLE. It has its own target bay for independent experiments. The laser system uses a multi-pass architecture, which means the beam passes through optics multiple times in order to be amplified to higher energy levels. Figure 1 shows the path that the laser takes on its way to the target.

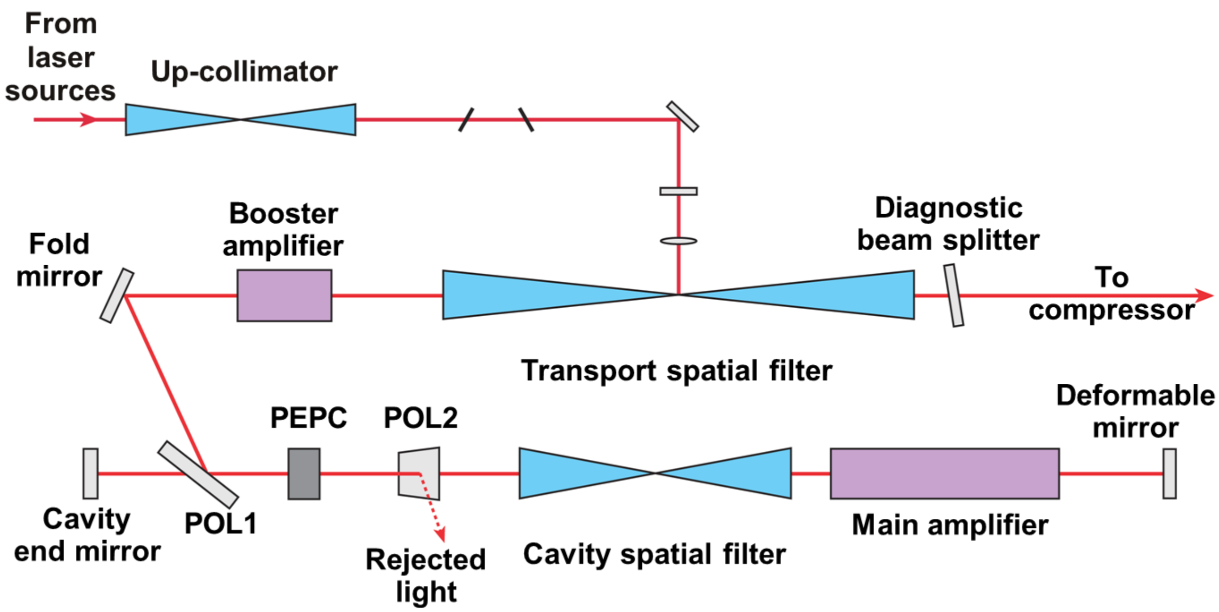

Figure 1 – OMEGA Extended Performance beam path. The OTDR records the signal at the center of the transport spatial filter, which includes retroreflections from all of the optical surfaces in the figure (except the injection path at the top of the figure from the laser sources), from the optical surfaces later in the system, and from the target.

The transport and cavity spatial filters (TSF and CSF) reduce modulation in the spatial beam profile, and allow the beam size and quality to remain intact over the long propagation distance required. The spatial filters focus the beam through a pinhole, then recollimate. However, there is more than one pinhole in each filter, in order to enable multiple passes. The CSF has 4 pinholes, because the beam normally passes through four times, and the TSF has two, corresponding to the first and fourth passes through the CSF. This means that the beam goes from the TSF first pinhole to the CSF first pinhole, and exits going through the CSF fourth pinhole to the TSF second pinhole. The OTDR measures the optical signal in the vicinity of the TSF pinholes, including retroreflections from all subsequent surfaces in the system.

The Plasma-Electrode Pockels Cell (PEPC) allows for the multi-pass architecture, by acting as an optical switch in conjunction with the cavity polarizer (seen in Figure 1 as POL1).

When turned on, the PEPC rotates the polarization of the laser. Then, when the beam comes back to the cavity polarizer, the polarizer can either pass through or reflect the beam, depending on the polarization. This complicates the OTDR analysis because each optic can provide multiple features on the OTDR, due to different paths to the optic, and different paths back through the system. In order to combat this, ray trace charts are used to determine all the possible ways and times that the beam can reflect off each optic. This allows for a more accurate diagnosis of the source of retroreflected energy.

Another important role of the PEPC is to isolate the laser system from light retroreflected from a target. Infrared light that is retroreflected from the target can propagate back through the beamline and become further amplified, which can create enormous fluences on the small optics in the front end of the system. This can greatly damage these smaller and more vulnerable optics. To protect the system, the PEPC is switched again when a target-retroreflected pulse would arrive back in the beamline. A short-pulse polarizer (POL2 in Figure 1) reflects this light, with its polarization rotated by the PEPC, into a beam dump where it can do no damage. However, due to imperfections in the PEPC switch and polarizers, a small amount of light is let through and reamplified. Most of this light is diverted into a beam dump in the TSF, but some can propagate back to the laser sources where it can damage optics if its energy is sufficiently high. The TSF OTDR is connected to the beam dump inside of the TSF in order to monitor the light reflected from target that leaks through the PEPC isolation system.

Optical Time Domain Reflectometry

There are two OTDR's built into the OMEGA EP laser system. Both were installed when OMEGA EP was created. The first is in the source of the laser system, so it is most effective for the optics in the beginning of the system. This has been running for most of the laser’s existence with a program that analyzes the data. The other OTDR is the TSF-OTDR, which is located at the TSF beam dump, previously described. Before now, it had never been utilized.

An OTDR is made up of an optical detector positioned to look forward into the system and detect light that reflects backwards. The optical detector, specifically a photodiode receptor, receives optical power and converts it into an electrical signal. The optical detector is connected to an oscilloscope, which records the electrical signal as a function of time to produce a voltage “waveform”. By synchronizing the waveform with a reference time for the laser pulse, and calculating the time delay between the reference time and the reflected features, we can infer the path that the retroreflected pulse must have taken to reach the OTDR detector. In this way, the OTDR is like a radar system, which measures an object’s distance by emitting radio waves and measuring the time required for reflections to return.

Development of Time Reference

In order to use the data acquired from the OTDR, we needed to create a time reference, in which to base the program off. This allows us to determine which optic has a defect. In order to determine a zero time, a lab procedure for the TSF OTDR time calibration was developed.

In the lab procedure, we used the deformable mirror (DM) to point the beam into the third pinhole instead of the second pinhole in the CSF. This caused it to reflect off the polarizer back into the TSF beam dump. This means that the OTDR will have one big voltage spike corresponding to the propagation of the beam to the DM and back. Then we turned the power down to ten percent throttle, and gradually turned the throttle up until an accurate reading could be determined. Then we misaligned the DM so that we could be sure the spike was caused by the DM. Then we returned the DM to its original position.

With this information, the program could analyze OTDR data with an accurate time reference. Figure 2 shows the result of the experiment. The large spike around 600 ns is the reflected energy from the DM.

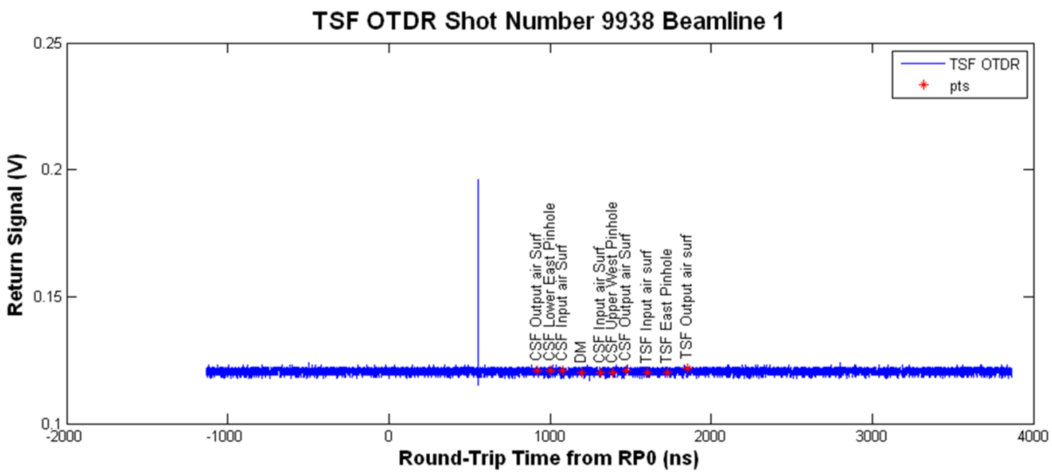

Figure 2 – Result of the time reference experiment on OMEGA EP Beamline 1. The voltage spike is a result of retroreflected light from the deformable mirror.

Software Development

A program was written in MATLAB which imports and analyzes the TSF OTDR information. MATLAB is an environment whose main objective is numerical computing and one that allows for matrix processing. It was chosen for this project due to its versatile matrix functions. The OTDR information includes long lists of times and voltages.

The user provides the shot number, and which beam line was diagnosed. Figure 3 shows the user input interfaces, which allow the user to feed information into the program. The program goes into the LLE database and searches for the corresponding shot. If the computer cannot find the shot, the user can manually select the file. Once the file is imported, the program displays a voltage versus time graph of the information (such as Figure 2). There are labels that allow the user to identify which optic corresponds to which voltage peak.

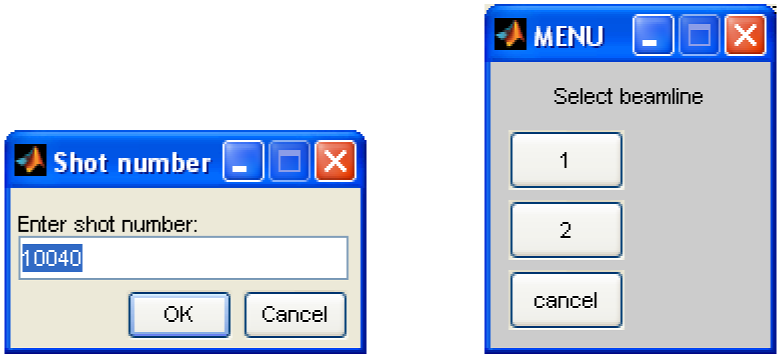

Figure 3 – User input interfaces for TSF-OTDR MATLAB program implementation

The program allows for easy user interpretation of the data, and allows the user to easily identify any optic malfunctions.

Software Implementation

The program is activated and runs for each OMEGA EP shot. The program then displays the graph and information with the other diagnostics. This helps make sure that there are no problems with the OMEGA EP laser system. When there is a defect, it is easy to identify.

Future Work

Future work includes calibrating the voltage along with the time. This way we could determine the energy of the retroreflected pulse, in addition to the location of its source. If it were calibrated, it would also be much easier to view and understand.

The OMEGA laser system could also implement this technology. It would be much more difficult to implement, because there are sixty beams instead of four, but it would be worth the investment, because it would cut down the amount of time required to identify and rectify defects in the optics of the system. In this way, the program and the OTDR technology could eventually help the OMEGA system as well as the OMEGA EP system.

Conclusion

The OTDR software provides a significant benefit to the OMEGA EP laser system, by helping to monitor target retroreflections and identify optic malfunctions. To do this, it records the energy that is reflected back through the laser system towards the source. By recording this and analyzing this data, we can monitor target retroreflection and identify damaged optics, allowing for efficient replacement. This minimizes the time it takes to identify and repair problems, allowing for more experiments and shots.

Acknowledgements

I would like to thank Dr. Brian Kruschwitz for advising me on the project and supervising me in this research. I would also like to thank Dr. Jack Kelly for stepping in for a short time during Dr. Kruschwitz's absence. Finally, I would like to thank Dr. R. Stephen Craxton for supervising the LLE High School Research Program, and for allowing me the opportunity to do this research.