PROCESS CONTROL MONITORING OF LASER CUTTING

R. D. Huber and G. H. Thomas
Lawrence Livermore National Laboratory
Livermore, CA 94550

INTRODUCTION

Process control monitoring can lead to increased efficiency and tremendous cost savings when compared to post-processing inspection. In-process monitoring can evaluate the quality of a process and can be used to detect the completion of a process. Process control monitoring can help reduce waste if the process can be stopped or corrected as soon as a problem is detected. Performing in-process inspection can eliminate the need for post-process inspection, thereby leading to large savings in time and money.

A state-of-the-art laser cutting system has been developed at the Lawrence Livermore National Laboratory. This system provides an extremely short pulse of laser energy, on the order of tens of femtosecond, focused to a beam size of less than 1 mm. The short duration of the pulse allows for removal of material from the part being cut without leading to an increase in the temperature of the part. This means that the cutting process has very little effect on the part immediately away from the cut thereby limiting the effect on the microstructure of the part. The small beam size means that the kerf of the cut can be very small, thus minimizing the loss of material. This is a major benefit when working with expensive materials or parts, and also may facilitate in the production of near net shape parts by limiting the amount of machining required before or after the cutting process.

Figure 1 is a block diagram showing some important items in the cutting chamber. The cutting beam enters through a port and is brought to a final focus at the part using the focusing lens. A debris shield is placed between the focusing lens and the part. The debris shield acts to protect the focusing optics from becoming coated during the cutting process and can be rotated and then replaced when the surface has become coated.

Process monitoring of the cutting process can yield important information concerning the cutting process including efficiency of cutting and cut-through. The

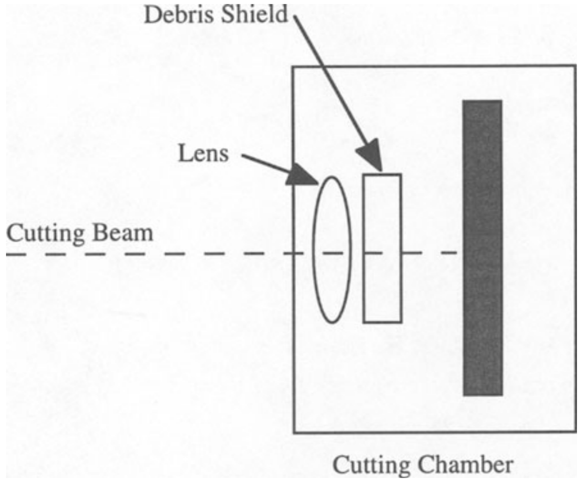

Figure 1. Laser cutting chamber.

efficiency of the cutting can be affected by several factors. One factor affecting cutting efficiency is laser energy. A decrease in the energy of the cutting pulse will lead to a reduction in the amount of material being removed. A reduction in the energy hitting the part can result from a decrease in the energy being emitted from the cutting laser system, or from the debris shield being coating. The cutting efficiency is also affected by the depth of the cut. When the cutting process first starts, the cutting beam encounters a flat surface, and the interaction area is small. As the cut progresses through the material, the focusing of the beam leads to a larger effective interaction area, and thus less material is removed per pulse. Reduction in cutting efficiency leads to a reduction of material being removed from the part, and thus a decrease in the amplitude of any stress waves generated in the part. By monitoring the cutting, a control system could use information to determine if the debris shield should be rotated to a clean area, or replaced. Determining when cut-through occurs can lead to savings in time, and also save on the lifetimes of the flash lamps and other components in the laser system.

When the laser cutting system is fully operational, laser cutting of parts will take place in an evacuated chamber on parts that may be moving. For this reason, a non-contact, optical technique has numerous advantages over contact techniques for this application since contact techniques may restrict the motion of a part. An interferometer-based system used to detect the ultrasound generated by the cutting process in the part being cut has been selected as the process monitoring technique. The laser beam used for detection can be sent through a window in the vacuum chamber, and since the technique is non-contact, the part is free to move inside the chamber. If the cutting takes place over a large area of a part, cut-through may occur at different times for different locations. Using an interferometer, the process-monitoring sensing location always moves with respect to the cutting location, thus aiding in signal analysis.

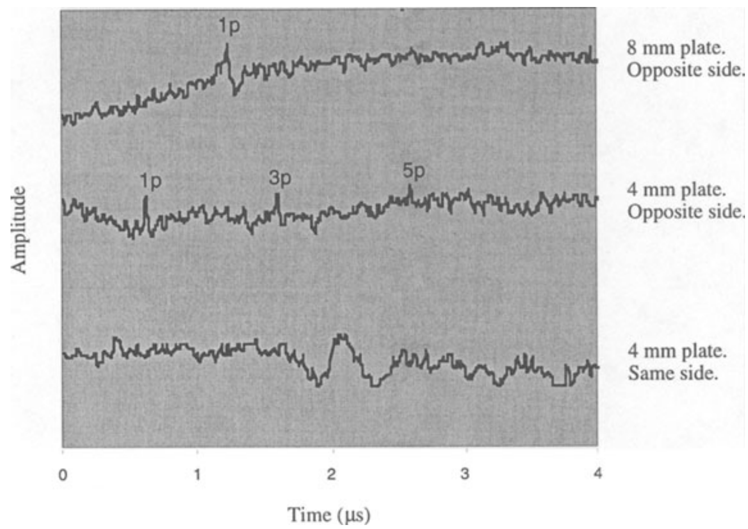

Figure 2. Signals detected from laser cutting on plates.

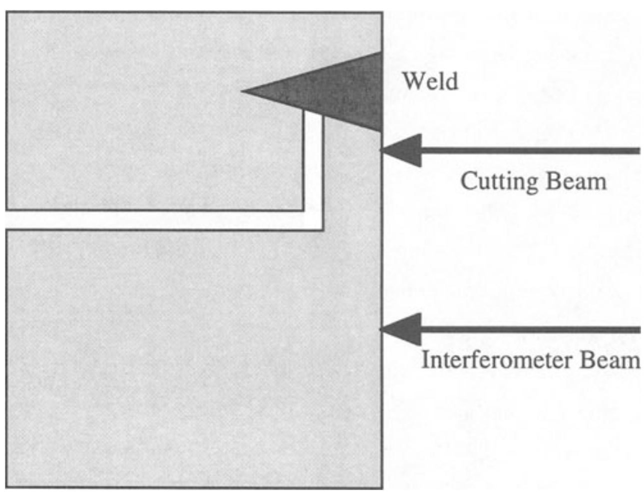

Figure 3. Welded part with step.

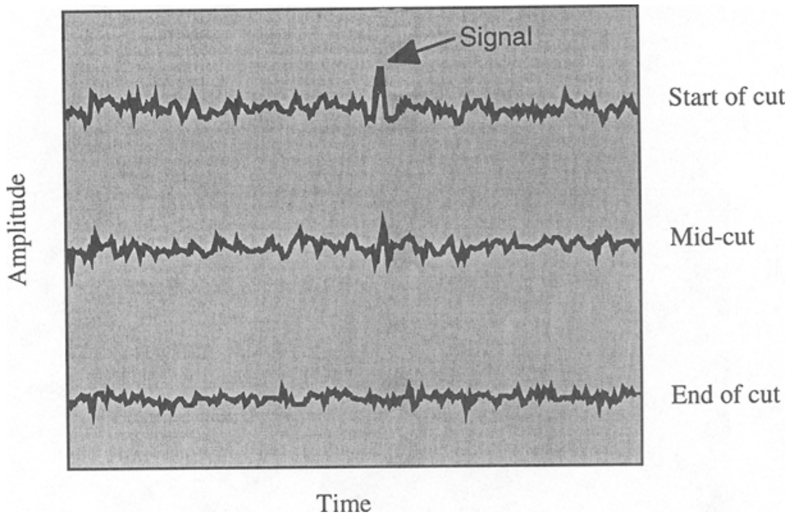

Figure 4. Signals detected from welded part with step.

EXPERIMENT

An initial feasibility study was run to check if the ultrasound generated by the cutting process could be detected using a laser-based interferometer. For these tests, a Michelson interferometer was used to detect the ultrasound generated stainless steel plates of thickness 4 and 8 mm by the cutting process. The parts were cut in air for these tests. For the first test, the cutting beam was directed towards one side of the 8 mm thick plate, and the interferometer beam was directed towards the opposite side. The next test had a similar set-up, but used the 4 mm sample. The third test in this feasibility study had the Michelson probe beam directed towards the same side of the 4 mm thick stainless steel sample as the cutting beam. This test was performed to give data for both same side and opposite side cutting and detection. Figure 2 contains the waveforms for these tests on stainless steel. For the through transmission tests, the signals correspond to longitudinal waves traveling through the part. For the thinner sample, three arrivals are seen, corresponding to a longitudinal wave and its multiple reflections, whereas for the thicker sample, only the initial longitudinal arrival is clear. For the same side case, the signals correspond to surface waves. The wasveforms are all single-shot signals.

After successfully detecting ultrasound from the cutting process, tests were set-up to look at a part being cut inside the cutting chamber. The part used for these tests was composed of two pieces welded together at a step, Figure 3. The part was cut adjacent to the weld through the step. The interferometer probe beam was directed towards the same side of the part as the cutting beam, but displaced from the cut by approximately 150 mm.

The detection occurred on the piece of the part which contained the outer part of the step. Therefore, when cut-through at the step occurred, there would be no sound transmission path in the part to the detection beam since the cutting beam would hit only the other piece of the part after cut-through. Figure 4 shows three waveforms corresponding to the start of the cut, part-way through the cut, and cut-through of the part. There is a clear signal at the start of the cut, and this signal decreases in amplitude as the cut progresses through the part.

CONCLUSIONS AND FUTURE WORK

Non-contact laser-based interferometric detection of ultrasound generated during a laser cutting process offers a means of process control monitoring. Signals in various parts were successfully detected using a Michelson interferometer. Enhancement of the signal-to-noise is required to determine the exact point of cut-through. The use of a Fabry-Perot interferometer for poorly reflecting surfaces, implementation of signal processing techniques to enhace the signal-to-noise ratio of detected signals, and integration of the interferometric detection into a process control monitoring system are planned.

ACKNOWLEDGMENTS

Work performed under auspices of the U. S. Department of Energy by the Lawrence Livermore National Laboratory under contract no. W-7405-ENG-48.