

PROCESS INSIGHT ABOUT LOM SYSTEMS

Chen Chi
Helisys, Inc.

ABSTRACT

A Laminated Object Manufacturing (LOM) machine offers much freedom in terms of system parameters: laser cutting speed, laser power setting, roller speed, roller temperature, and so on. Because of this freedom, users can choose any number, within certain limitations, to create well-constructed objects. Obviously, each user has a different definition for the quality of an object. Therefore this freedom has induced some confusion. Most commonly, each customer has his own preferred parameter data sets. These sets may not be the same but they are good sets. We need to devise a method as a guideline for system parameters to ensure a consistency in the construction of objects.

We have been studying actual laser power at different cutting speeds, actual cutting curves and bonding curves for different materials, actual temperature distribution, etc. These results have helped us find a proper way to set system parameters so that any user can run LOM machines without difficulty and confusion. The research methodology and results are elaborated in this paper.

INTRODUCTION

LOM is a patented rapid prototyping technique that allows the fabrication of 3-dimensional objects by sequentially laminating sheet materials and cutting the corresponding cross sections with a CO₂ laser beam. Because it is a high tech machine, it gives users the flexibility to manipulate the machine in such a way that good objects of any kind can be built. The flexibility comes from parameters in the LOMSlice program that can be changed. It is also assumed that users are knowledgeable about LOM machines. Without proper knowledge, it is hard to manipulate a LOM machine.

Helisys realizes that the flexibility sometimes derives complexity, hardship, confusion, and frustration. In order to eliminate those negative points, we have conducted research in various fields and seek improvements to continue offering customers a competitive edge. This paper only reports results related to the paper bonding process and laser cutting, two critical factors in the construction of quality objects. It is assumed that a LOM-2030E machine is used in this study.

LASER CUTTING

The system parameter menu in the LOMSlice software provides all the parameters for the motors, heater, laser, etc. In the menu, there are two parameters controlling the laser cutting: cutting speed and laser power setting [%]. Material type is another factor that affects object building process as well. For example, LPH042 and LPH080 are two commercially available paper types. For different paper types, different cutting behaviors should be observed.

Because of the complexity of the laser cutting process, it is difficult to derive a theoretical curve to represent the relationship between laser cutting speed and laser power. Therefore, an empirical result is presented.

Before beginning data collection, a machine is always checked to make sure it is in an optimal condition: the laser beam delivery system is aligned and the laser output power is at its maximum. Because the laser power setting represents the percentage of maximum laser power, it has a meaning only if we know actual laser power. In general, using the same laser power setting on different LOM machines does not guarantee that the same laser cut quality can be achieved. One laser used on various machines may put out different maximum power.

A Molecron laser power meter was used to measure actual laser power. It was placed right after the first mirror of a laser beam delivery system. The LOM machine has been designed in such a way that its actual laser power is a function of laser cutting speed and laser power setting. Different power readings should be displayed on a power meter at different cutting speeds. By changing the laser power setting and cutting speed in a LOMSlice program, maximum laser power readings on the meter were recorded. In order to make sure that a laser beam moves at the speed specified, a longer linear traveling distance of 30 inches was used. With recorded data, a series of curves have been drawn as shown on Fig. 1 which is called **laser power curve**. It is apparent that a laser can put out more power at faster speeds than slower speeds. But at higher cutting speeds, the maximum power a laser can put out is less than that at slower speeds. The same experiments have been conducted on other LOM-2030E machines. Curves similar to Fig. 1 are observed. Fig. 1 tells us laser power characteristics, but we need another curve to determine if a paper can be cut.

To determine proper cutting speed and laser power, we must define what a good cut is. One definition is that a laser beam should cut through all the required layers and a quarter inch deep into an additional layer. I found that it is difficult to visually determine the depth of the cut on the additional layer. Therefore we decided not to worry about the cut quality on additional layer. Instead, we tried to find out minimum laser power at which a laser beam can cut through all the required layers. The worst situation is that there are some strings on one side attaching paper to the other side. Many types of commercially available paper were used to find out the minimum power required to cut those papers. Data has been collected for a single layer cut, a double layer cut, and a triple layer cut (only for LPH042 paper). Only the data for LPH042 and LPH080 are reported here. Data for LPH042 is drawn on Figure 2 which is called **paper cutting curve**. It shows in the figure that any data point falling between curve A and B will cut a single layer; any

data point falling between curve B and C will cut double layers. The region defined by two adjacent curves apparently has a large area where many choices can be made. Because of this, each user may have a different pair of laser power setting and cutting speed. However, most parameter pairs will produce an overcut. In order to verify its validity, we have collected data for cutting parameters from people actually running LOM machines. This data has been plotted on Fig. 3. It is self-explanatory. Fig. 4 is for LPH080 paper.

Now we have two different figures: laser power curve and paper cutting curve. Each time a LOM machine operator wants to figure out values for laser power setting and cutting speed, he can follow the procedures as described below:

1. Select a paper type. Ex. LPH042.
2. Select a laser cutting speed. Ex. 15 (in/s).
3. From the paper cutting curve, select an actual laser power such that the corresponding point is between curve A and Curve B. Ex. 35 (w).
4. On the laser power curve, he can look for a curve corresponding to the cutting speed just selected, 15 (in/s). The right curve should be curve (C). From this curve, he can find a laser power setting associated with actual laser power, 35 (W). Therefore the laser power setting should be around 28 %.
5. Enter the pair data (15, 28) into the system parameter menu.

Here we have shown a logical procedure to find proper parameter sets for cutting objects. This procedure should not create controversy even though many different parameter pairs can be chosen.

The work shown so far assumes that a laser can put out maximum power and a beam delivery system has been cleaned and aligned properly. In the case that a LOM machine is not in optimal condition, one should do the following:

1. Use a laser power meter to measure maximum laser power at the HOME position.
2. User should know the power reading in an optimized LOM machine. Ex. 60 (w).
3. If a reading is 50 w, compute difference, i.e., 10w.
4. Follow the normal procedures described above. In step 3, the actual power becomes 45(= 35 + 10) (w).
5. Complete steps 4 and 5 of normal procedures. The laser power setting should be 34%.

Of course, a power reading can not be too low. If it is too low, a LOM machine can not cut objects. The lowest acceptable power depends on the cutting speed.

PAPER BONDING

The paper bonding process implemented in a LOM machine is a function of heated roller speed, roller temperature, roller pressure to paper, and paper itself. It is also affected by a platform's temperature and surrounding temperature and humidity. Because these factors are not directly controlled by a LOM machine, they are not considered in this study. This process starts by rolling a heated roller across a sheet of paper coated with a thin layer of thermoplastic adhesive on its bottom side. Due to the pressure of the roller to the paper and its rolling speed, a certain amount of heat will be transferred to the paper and adhesive beneath it. This amount of heat and roller pressure determines how well sheets of paper bond together.

It is assumed that a LOM machine is properly aligned and also the temperature distribution on a heated roller is uniform. To avoid temperature fluctuations, a temperature controller is used to indirectly control roller temperature. Because of this indirect temperature control, the actual temperature on a roller is not the same temperature as displayed on the controller. In order to study the actual bonding process, actual temperature distribution on a roller should be measured. An Omega temperature indicator and a J type thermocouple were used to measure temperature. The roller was about equally divided and marked so that there were 10 points of interest at which a J type probe touches. At each point the maximum reading was recorded. By changing the controller's temperature setting, a series of actual temperature distribution curves was recorded. The results are shown on fig. 5 which is called **roller temperature curve**. We notice on this figure that actual temperature is about two times higher than that of the controller's temperature. The actual temperature is evenly distributed.

Now we need to find out how much heat is transferred to the other side of paper. This transferred heat is a function of roller speed, roller pressure, and paper material. A LOMSlice program can be used to change roller speed and pressure. A pressure sensor was used to study how the actual pressure affects paper bonding process. We found out that this sensor is not reliable enough to provide some good data, but we noticed that the effect from pressure is not very pronounced. After we find a good sensor, we will report more quantitative information. A base of 10" x 10" was made first. A piece of paper of the same size was laid on top of the base. A J type probe was placed underneath the paper. By entering different values into the LOMSlice program, the maximum temperature reading was recorded. Temperature increase was computed and used to represent the amount of heat transferred to the adhesive. The roller speed range used was from 1 to 15 (in/s). The actual temperature range on the roller was from 423 to 731 (F), which are average temperatures computed from Fig. 5. The results are shown in Fig. 6 which is called **paper bonding curve**. Each curve represents temperature increase of the adhesive at different roller temperature. This curve can tell us actual temperature of the adhesive which should be equal to base temperature plus temperature increase at a specified speed. Once we know the temperature of the adhesive, we know if the adhesive should work. In this study we found the service temperature range of adhesive on the paper is about from 150 to 250 F. If it is outside of this range, paper will not be bonded well. The paper bonding curve for LPH080 is shown on Fig. 7.

For the bonding, two different figures, paper bonding curve and roller temperature curve, should be consulted to find proper roller speed and controller temperature. Additionally a pressure curve should be considered. Because of the explanation given in the previous paragraph, the results reported in this paper should still apply if the data for retract entered into a LOMSlice program is less than 0.015 in. The paper bonding curve is paper type specific. The roller temperature curve is machine specific. Each time a LOM machine operator can use the following procedures to find out proper roller speed and controller temperature:

1. In the beginning, measure platform temperature. Ex. 78 F.
2. Select a roller speed. Ex. 5 in/s.
3. Select a proper temperature increase from Fig. 6 so that the actual temperature at the adhesive is greater than 150 F but less than 250 F. Ex. 118 F.
Then actual temperature should be 196 F which is in the service temperature range. The point of (5 in/s, 118 F) is on curve A. The actual temperature of roller is about 731 F.
4. With Fig. 5, controller's temperature should be about 350 F.
5. Enter roller speed, 5 in/s, and controller temperature, 350 F, into the system parameter menu. Then a LOM machine should build an object with good bonding.

SUMMARY

This paper has shown a logical way to figure proper values for paper bonding parameters and laser cutting parameters. This eliminates any trial-and-error in determining system parameters. The methods reported in this paper save time in preprocessing and serve as a guideline to eliminate confusion and frustration. However, one may need many data curves; different materials will have different bonding curves and cutting curves. Therefore, a program is forming to implement suggested procedures. This program is about 40% complete. The completed portion has been tested in Helisys. The test result is good. After this program is completed and fully tested, it will be a part of LOMSlice program. Eventually the LOMSlice program will have some intelligence and the option to be a turn key system.

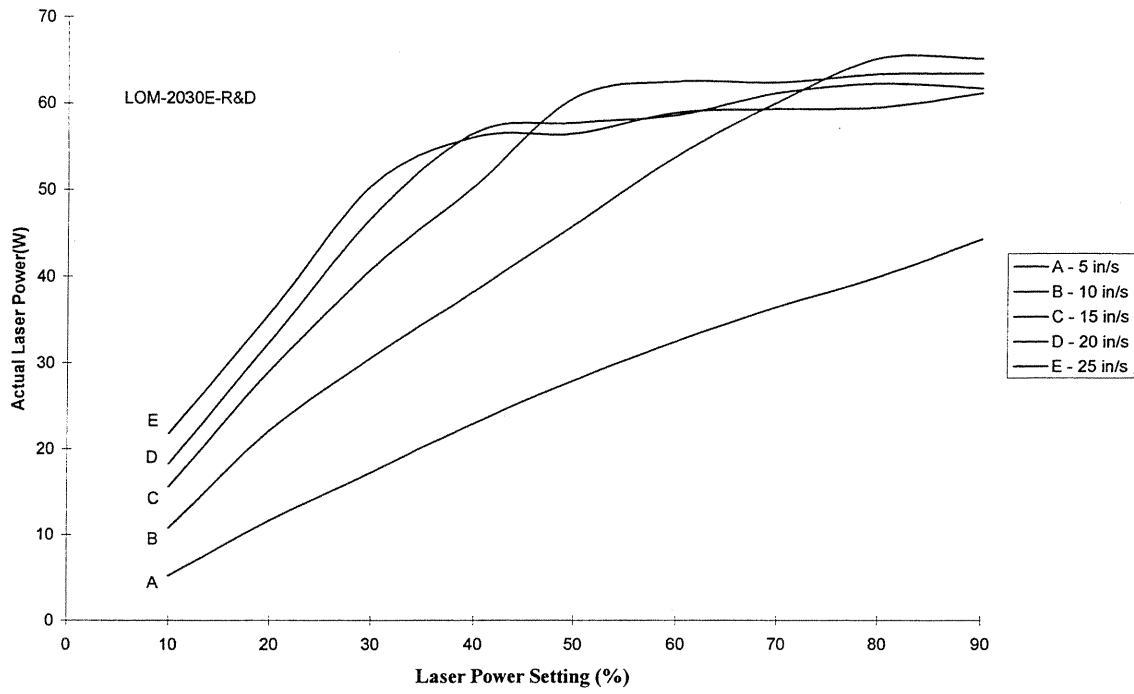


Figure 1. Laser Power Curve

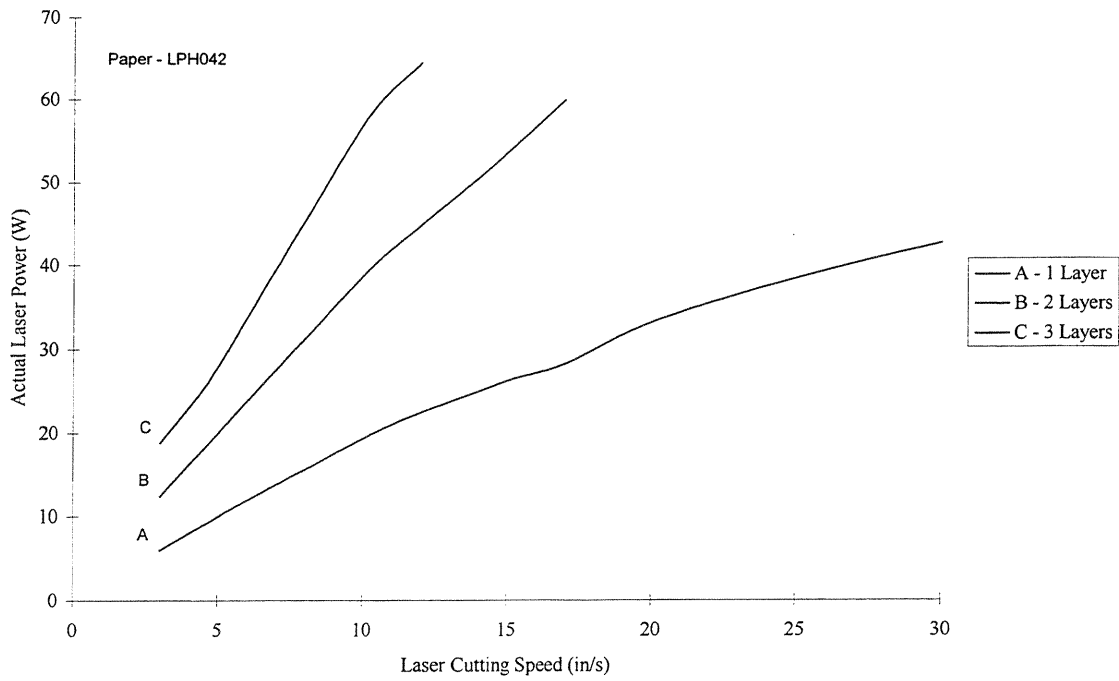


Figure 2. Paper Cutting Curve

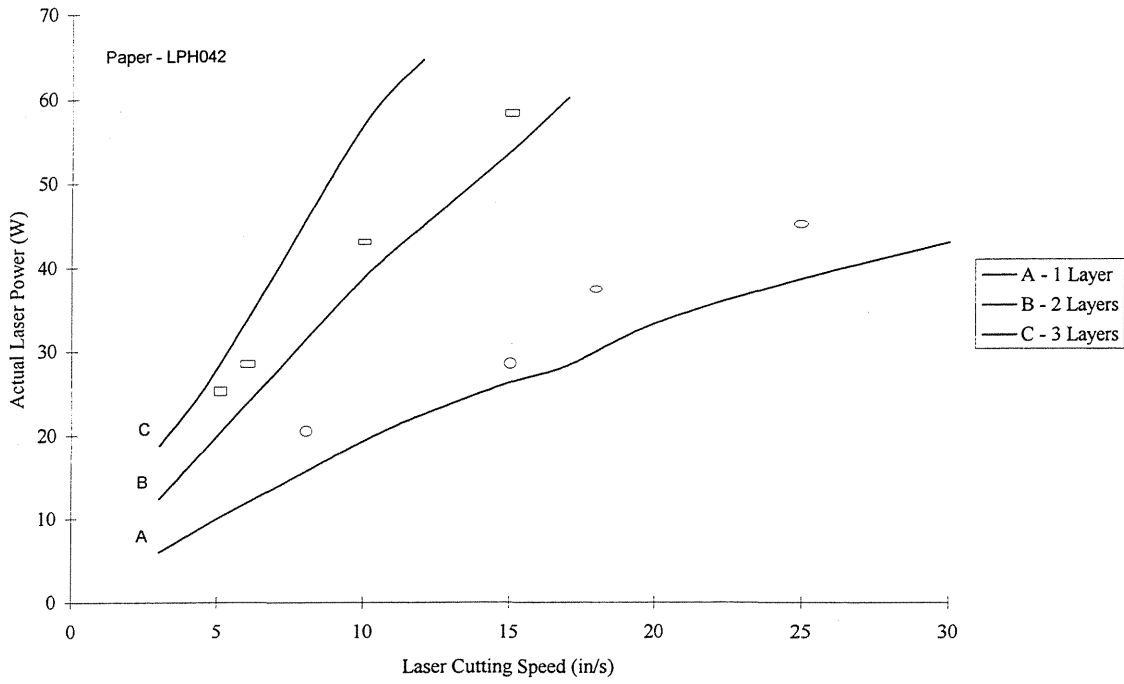


Figure 3. Collected Data Verifying Curve

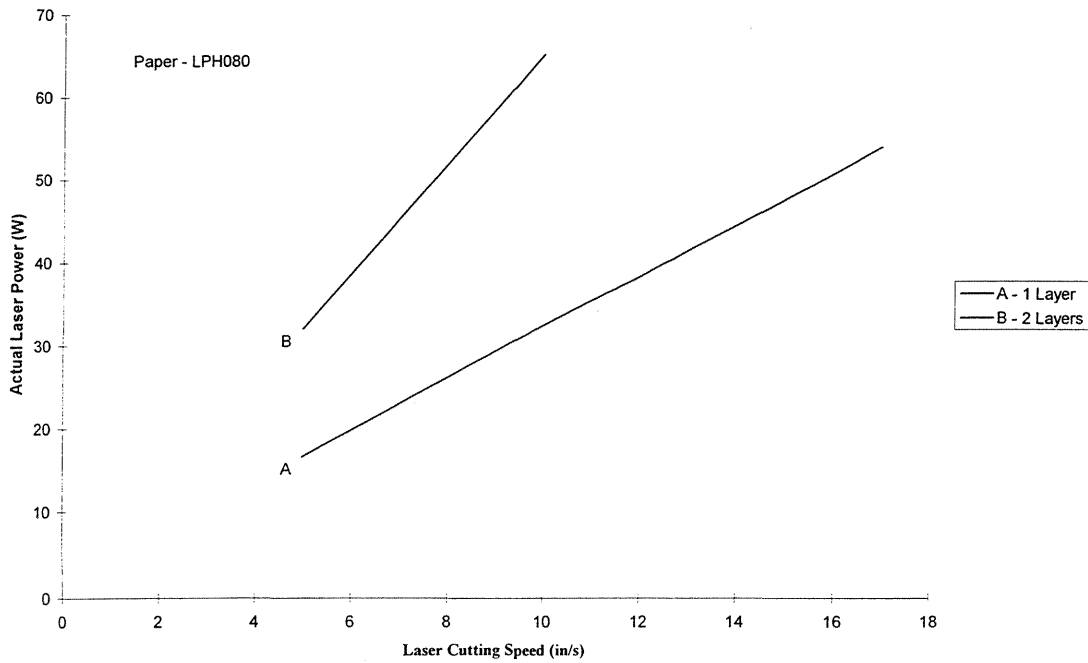


Figure 4. Paper Cutting Curve

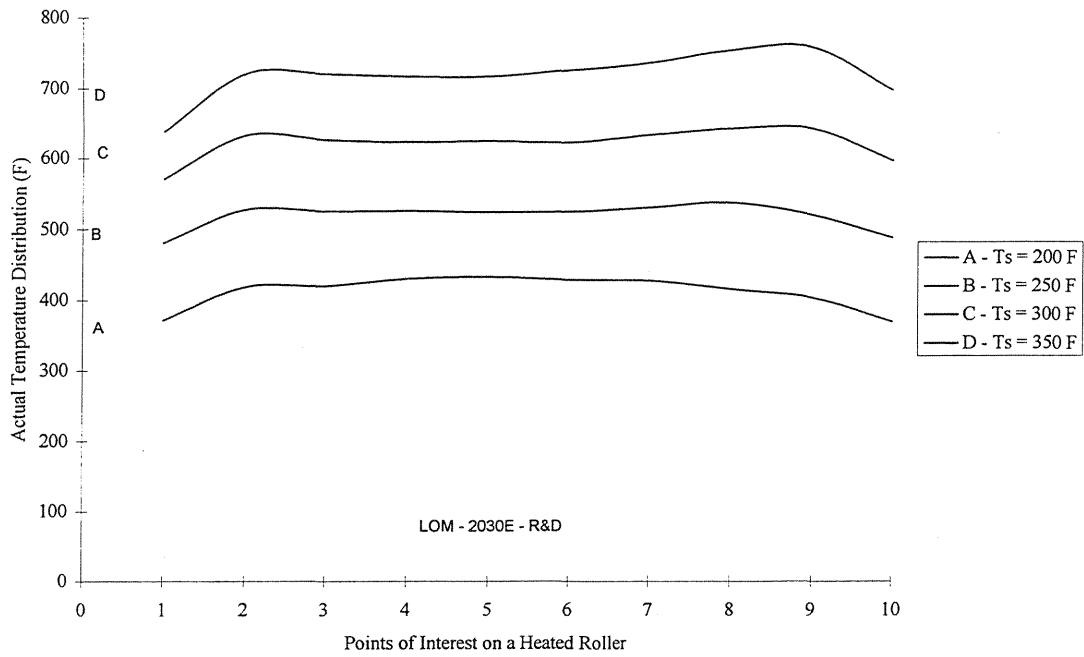


Figure 5. Roller Temperature Curve

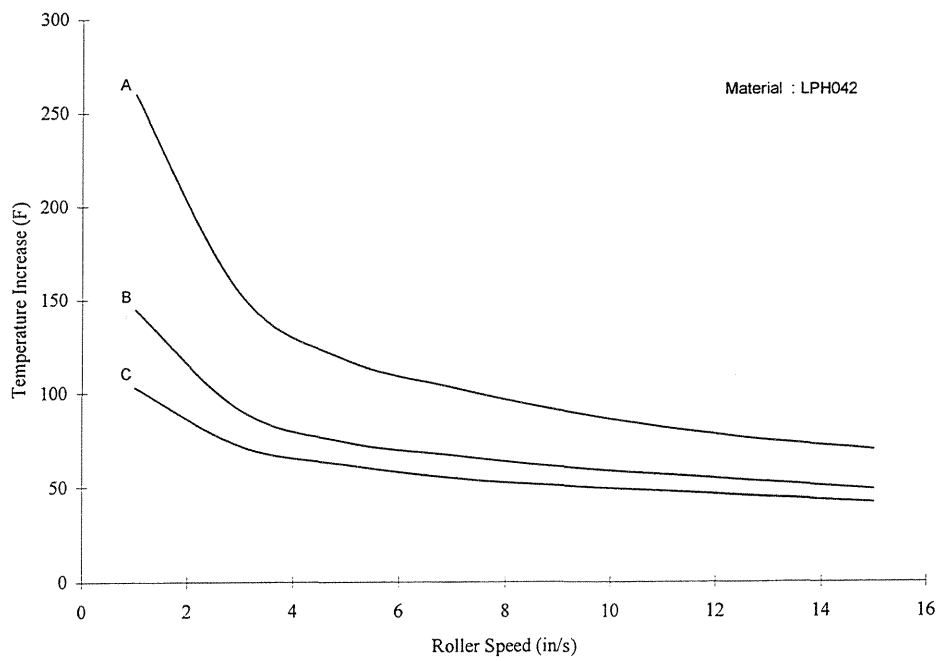


Figure 6. Paper Bonding Curve