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Mathematical Model for Machining Time of a YAG-Rod Laser Cutting Machine

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Authors' contributions

This work was carried out in collaboration between all authors. Author SAJ designed the study, wrote the protocol and performed experimental work. Author KJA designed and monitored experimental procedure. Author MOO supervised the validation of results and author ARA interpreted results. All authors read and approved the final manuscript.

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ABSTRACT

The Laser cutting machine cuts a given profile with precision and accuracy that cannot be compared with other CNC cutting machines. This is made possible because the laser cutting beam forms a thin kerf of about 0.15 mm during the cutting process. The heat affected zone (HAZ) on the material is also minimal. One of the commonly asked questions by our clients is, "how long would it take to cut this profile." The inability of the cutting software to predict the machining or cutting time becomes a challenge for the operator. In this paper, a model was developed relating speed and profile length to machining time. The actual machining time of five different profiles were obtained from the HG LCY 300 laser cutting machine and compared with the calculated machining time obtained using the model. By comparison, the slight differences between the actual and the

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calculated machining time are just in milli-seconds; suggesting that the model is valid and can be employed by laser cutting machine operators to predict the machining time for job profiles ahead of the cutting operation.

Keywords: Laser cutting; profile length; machining time; cutting software; model.

1. INTRODUCTION

Over the past decade, laser cutting has developed into a state-of-the-art technology. It is estimated that more than 25,000 cutting systems are used for the high-power cutting of metals and non-metals worldwide [1]. Laser cutting machines are used in workshops for cutting materials, especially, mild steel which is predominantly used in the laser cutting industry [2].

A high intensity beam of infrared light is generated by a laser cavity; this beam is focused onto the surface of the work piece by means of a lens, the focused beam heats the material and establishes a highly localized melt (generally smaller than 0.5 mm in diameter) throughout the depth of the sheet. The molten material is ejected from the area by pressurized gas jet acting coaxially with the laser beam. With certain materials, this gas jet can accelerate the cutting process by performing some chemical as well as physical functions (for instance, the oxidation process initiated by cutting carbon or mild steel in a jet of pure oxygen generates its own heat and this substantially improves the efficiency of the process). The localized melt is extended across the surface of the sheet thus generating a cut [3].

The cutting speed and *assist gas* control the cutting process while laser pulse width, frequency and discharged current control the beam quality. CNC 2000 software coordinates the beam together with all process parameters. By contour cutting 2-D thin sheet parts the use of machines with X-Y coordinate is effective and real when CNC control unit is used. It is often a multi-axis mechanical system which permits linear movement. The CNC is claimed to be superior to other machines conventionally used in the manufacture of machine tools. It is up to 10 times faster, compensates for overrun errors, adapts the programmed laser power to the processing speed, and controls the *assist gas* pressure and other laser parameters. CNC laser-cutting machine offers an optimal solution to cutting all kinds of sheet materials economically [4].

The assist or cutting gas helps in cooling the work piece, clearing the fines off the cutting path and raising the exothermic reaction of the cutting process. The type of gas chosen depends on the reactive nature of the material being cut: molten thermoplastics do not chemically react with nitrogen or oxygen and so compressed air can be used as the cutting gas. CO₂, on the other hand, is usually a cheaper production route and is therefore favoured for general engineering purposes because it is not reactive with a wide range of materials ranging from metals and polymers to wood. Molten stainless steel reacts with oxygen but not with nitrogen and so nitrogen is used in this case; on the other hand, molten titanium reacts with oxygen or nitrogen and so argon, which is chemically inert, is used as the cutting gas [3].

Laser is a beam with high brightness, high power and very good direction. Thus, laser cutting excels in applications requiring high productivity, high edge quality and minimum waste, due to the fast and precise cutting process [5,6].

The laser machines used in workshops are of CLASS 4 type; the light this laser system produces, whose wave length is close to that of infrared light, is invisible, therefore, more attention needs to be paid to safety protection when using it in the work place [7-9].

Laser cutting machine cuts a given profile with precision and accuracy that cannot be compared with other CNC cutting machines; this is made possible because the laser cutting beam forms a thin kerf of about 0.15 mm during the cutting process. The heat affected zone (HAZ) on the material is also minimal because of the thin kerf and the *assist gas* used [10-12]. The laser cutting technology has actually made industrial cutting of mild, silicon and carbon steel plates easy since the profile can be drawn on CAD software and imported to the laser cutting machine for implementation.

The inclusion of machining time in the cutting software of the laser cutting machine would make its features complete and excellent. In this work, we developed a model for calculating the

machining time of the laser cutting machine using the HG LCY 300 model. This became necessary because of the need to establish or predict machining/cutting time even before the cutting process begins, based on our customers' demand in order to improve the value of the machine.

2. METHODOLOGY

The resolution of stepper motors used for the worktable was first determined by cutting out a circle of radius 20 mm on a 2 mm thick mild steel plate and taking the machining or cutting time at different speeds. A relation was then established to convert the profile length to number of revolutions using the stepper motor's resolution obtained. The machining time was then obtained as a variable that depends on the cutting speed, profile length and stepper motor's resolution. The last step was validation of the model. The profile samples were drawn on CAD software and imported to the laser machine; the cutting process was observed on the monitor, the cutting time was also monitored and recorded as actual machining time when cutting was completed. Five different sample profiles were cut at selected speeds and their actual machining times were recorded; the calculated machining times were also obtained using the model. The results obtained for actual and calculated machining times were tabulated and compared to see the extent to which the model is valid.

3. RESOLUTION OF THE STEPPER MOTOR

There are two stepper motors attached to the worktable, the movement of the table in both x

and y axes are carried out by each of these motors [9] and can move 500 mm in both directions. The cutting speed is selected on the parameter settings of the CNC 2000 software, the effect of which is seen on the table. If a cutting speed is selected to cut a particular profile on work pieces of different thickness, the machining time will be the same. For instance, if the beam parameters are set to cut a 2 mm mild steel plate at 40 rev/min, a 3 mm mild steel plate can also be cut at 40 rev/min if the parameters are raised higher. The resolution of the stepper motor (R), which is constant is what makes this achievable.

To get the resolution R of the stepper motor, the following data was taken while cutting out a circular profile of radius 20 mm from a 2 mm mild steel plate: Profile length = $\pi D = 125.66$ mm



Fig. 1. Profile sample

Table 1. Machining time for cutting profile sample

Speed (Rev/min)	Actual machining time (s)
60	126
120	63
180	42
240	31

3.1 Relating Machining Time to Profile Length and Number of Revolution

126 s \longrightarrow 125.66 mm at 60 rev/min \longrightarrow 1 s \longrightarrow 0.9973 mm

Also,

60 rev \longrightarrow 1 min \longrightarrow 1 rev \longrightarrow 1 s

Therefore;

1 rev \longrightarrow 1 s \longrightarrow 0.9973 mm

This is the resolution R of the stepper motor.

3.2 Converting Profile Length to Number of Revolution

Since the profile length is determinable, there is the need to convert it from linear value to number of revolutions made in cutting the profile. Using the deduction made from the resolution of the stepper motor, we can conclude that,

$$\begin{array}{l} 1 \text{ rev} \longrightarrow 0.9973 \text{ mm} \\ X \text{ rev} \longrightarrow \text{profile length in mm} \end{array}$$

Therefore;

$$X \text{ rev} = \frac{\text{profile length}}{0.9973} \quad (1)$$

where X is the number of revolutions made by the stepper motor for a given profile length.

3.3 Model for Calculating Machining Time

Linear speed is given as the rate of change of distance moved with time, i.e.

$$\text{Speed} = \frac{\text{Distance}}{\text{Time}} \quad (2)$$

But in the case of HG LCY 300, the cutting speed is given in revolution per minute, (rev/min), i.e.

$$\text{Cutting Speed} = \frac{\text{Number of revolution}}{\text{Time (min)}} \quad (3)$$

Therefore, machining time (T) in second is,

$$T = \frac{\text{Number of revolution} \times 60}{\text{Cutting Speed}} \quad (4)$$

Substituting equation (1) for number of revolution in (4), we have,

$$T = \frac{\text{Profile length} \times 60}{\text{Cutting Speed} \times 0.9973} \quad (5)$$

Equation (5) is the model for calculating machining time in seconds for a given profile length.

4. VALIDATION OF THE MODEL

The model was used to calculate the machining time for profiles 1 to 5 shown in Fig. 2. The results obtained were compared to the actual machining time recorded in the process of cutting; these actual cutting/machining times are usually displayed by the computer system. The results are shown in Table 2.

Comparing the results, it was observed that there is a slight difference, in the order of milliseconds, between the actual and calculated machining time. This is probably due to the fact that the laser cutting machine is not designed to recognize machining time in decimal values. It actually displays the time in whole number. Therefore, rounding off the calculated machining time to the nearest whole number makes it exactly the same as the actual machining time. Since there is only a slight difference between the actual and calculated machining time, the model is validated.

Table 2. Results for actual and calculated machining time for prof. 1 to 5

Profile number	Speed (rev/min)	Actual machining time (T_A)	Calculated machining time (T_C)
1	50	70.0	70.46
	100	35.0	35.23
	150	23.0	23.49
	200	17.0	17.62
2	60	25.0	25.20
	100	15.0	15.12
	150	9.0	10.08
	200	7.0	7.56
3	60	40.0	40.11
	120	20.0	20.05
	150	15.0	16.04
	200	12.0	12.03
4	60	72.0	71.61
	80	54.0	53.71
	120	36.0	35.81
	200	22.0	21.48
5	60	126.0	125.00
	120	63.0	63.00
	180	42.0	42.00
	240	31.0	31.50

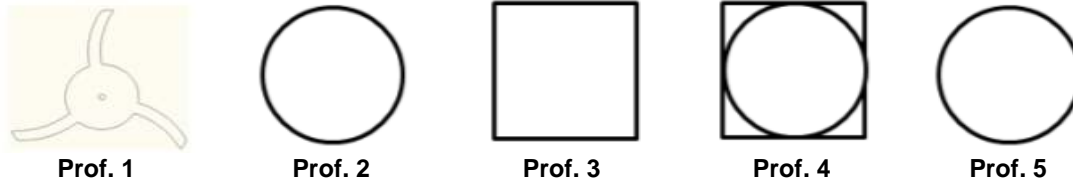


Fig. 2. Test profiles

Profile 1 has a perimeter of 58.56 mm; Profile 2 has a radius of 4 mm with a perimeter of 25.13 mm; Profile 3 is a square of side 40 mm; Profile 4 has a circle of radius 5 mm inscribed in a square of side 10 mm, with a total perimeter of 71.42 mm; Profile 5 has a radius of 20 mm with a perimeter of 125.66 mm

5. CONCLUSION AND RECOMMENDATION

The objective of the work was achieved, and the model was validated using the five test profiles. The slight differences seen between the actual and calculated machining times are attributed to the inability of the machine to display decimal values.

The value of the machine would further be enhanced with this work if properly implemented. As a form of recommendation, the CNC 2000 software of the HG LCY 300 should be upgraded by adopting this validated model in its program design.

Furthermore, work is presently on-going on the application of this approach to predicting the machining time of CNC lathe and milling machines in machining operations.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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