Volume 2, Issue 2, March-April 2012
Available Online at www.gpublication.com/jcer
ISSN No.: 2250 - 2637

Journal of
Current Engineering Research

RESEARCH PAPER

Transforming Linear Laser Cutting machine Into Laser Lathing – An Empirical Investigation & Evaluation of Roundness Quality

S.R. Subramonian*, A.Z. Khalim, Hussein, N. I. S, R. Izamshah, M. Amran and M. Hadzley
Department of Manufacturing Process, Universiti Teknikal Malaysia Melaka, Durian Tunggal, Melaka
Malaysia
sivarao@utem.edu.my

Abstract

Lasers are widely used in industries as cutting tools due to ultra-flexibility cutting capabilities in obtaining high quality end product while posing advantage of quick set up, non-mechanical contact mechanics, and small region of heat affected zone. This paper presents the laser lathing performance of 2D CO2 flatbed laser cutting machine by investigating the roundness quality. A specially designed mechanism was developed to clamp and spin a steel rod of 10mm diameter cylindrical workpiece on X to Y sacrificial table. Three significant cutting parameters were controlled in this experiment namely; cutting speed, spinning speed and depth of cut. The experiments were carried out based on DOE full factorial matrix design. The results were realistic, promising and efficient as compared to manual lathes within the same range of workpiece properties and dimension.

Keywords

3D laser machining, laser cutting, laser turning, CO2 laser machining, 2D flatbed laser

INTRODUCTION

Lasers are widely known for rapid and precise cutting as compared to mechanical cutting. The ability of machining intricate profiles with small region of heat affected zone has placed laser machines in high volume production lines. One great advantage possessed by laser cutting is non-contact machining which provides wide range of applications for super hard, flexible, non-metallic materials, etc..High quality end product produced by laser eliminates the secondary process in manufacturing of precision parts. Accuracy and tolerance are very important especially dealing with automotive industry which deals with critical burr-free components. Tolerances produced by lasers are much tighter and lasers can easily produce parts at micro level which is almost impossible by conventional lathes. In engineering, geometric dimensioning and tolerancing (GD&T) is very important because it is a system for defining and communicating engineering tolerances. Roundness is one of the GD&T systems. Measuring of roundness is a biggest challenge in metrology department. Roundness is related to a circle or cylinder part which is measured by precision tools such as micrometer, verniercaliper, and also automated modern CNC roundness tester. Nowadays in modern industry, machining process demands low cost products with closed specification. To achieve the specification needs, characteristic such as cutting parameter, machining time, machining cost play vital role which requires one to look into them seriously.

REVIEW OF PREVIOUS WORK

The important issue in three-dimensional laser shaping is improving the dimensional accuracy along the optical axis without decreasing the materials removing rate. The concept of performing three-dimensional laser shaping has been performed using Nd-Yag by [1]. A fully automated 3D laser micromachining based on the main concept of geometrical flexibility integrating two UV laser sources, excimer and diode pumped solid state laser (DPSS) in ns pulse regime with six degrees of freedom to machine complex parts [2]. A new 'machine tool' for advanced material processing conceptualizing two converging laser beams was introduced to build optical system around a beam splitter that generates two beams from the same laser head [3]. Three-dimensional (3D) laser machining was done using two laser beams to improve the material removal rate and energy efficiency of laser machining [4]. Laser machining of 3D micro part based on layer by layer pealing concept carried out by controlling three main parameters namely power, repetition rate and speed of laser process [5]. Three-dimensional laser machining has been carried out on composite materials using two intersecting laser beams to create grooves on a workpiece where, the volume of material is removed when the two grooves converge [6]. Three-dimensional laser machining allows implementation of turning, milling, and threading, and grooving were investigated where, issues of material removal rate, surface quality, and process control of laser was discussed [7]. A three-dimensional laser machining concept was developed and investigated kinematically in applications of gear making, threading, turning, and milling in completing a die set [8]. Three dimensional laser concepts were focused mainly in laser machining and laser welding by incorporating one or two laser beams simultaneously at industrial level along with their advantages and limitations [9]. The relationship of processes parameters of pulsed Nd:YAG laser-turning operation for production of micro-groove on cylindrical workpiece was investigated by considering air pressure, lamp current, pulse frequency, pulsed width and cutting speed as correspondence controllable parameters [10]. A square micro-groove on cylindrical surface was performed based on five level central composite design techniques by feed-forward artificial neural network (ANN) in process modelling of laser turning [11]. A new concept of laser machining using two intersecting beams was optimized to investigate the phenomena involved in laser 'blind' cutting [12].A method of removing stock using two laser beams has been investigated where, the first laser beam produced first kerf and second laser beams intersects with the first beam axis to produce second kerf [13]. CO_2 laser machining of three-dimensional auto-body panel was investigated to evaluate the cut quality with respect to kerf width, surface roughness, and heat affected zone (HAZ) [14]. A new approach of 3D laser cutting by 2 kW laser mounted directly to the arm of the robot was studied. This set-up enables a simple, off the shelf solution without having to have complicated beam delivery system for applications that require laser power levels of 2 kW [15]. The process features of three-dimensional laser machining was presented with industrial robots, specifying the principal reasons for using lasers and describing the system components with respective practical applications [16]. The ablation using femtosecond needs more concentration for micromachining as the advantages of efficient ultra-thin layer peeling without undesirable thermal effects for both opaque and transparent materials. The femtosecond laser turning is highly recommended for excellent surface finish requirements. [17]. Aninnovative technique of CO2 laser machining to create 3D cavities of a mould was conducted. The removal of a single layer is achieved using multiple overlapping straight grooves where the groove profile has been predicted by theoretical models before the work was carried out [18].The integration of interference phenomenon into femtosecond laser micromachining of circular interference pattern was demonstrated by overlapping infrared femtosecond laser pulses [19]. The characteristics of laser beam including cutting obliquity and cutting direction on 3D laser cutting quality was critically investigated. In this experiment, the range of upward 3D cutting was slightly wider than 2D, and the range of downward 3D cutting was sharply narrower than 2D cutting [20]. A novel ultra-short pulse laser lathe system for bulk micromachining of axisymmetric features with three-dimensional cylindrical geometry was studied. One hundred twenty femtosecond pulses from 800-nm Ti:sapphire laser were utilized to machine hexanitrostilbene (HNS) rods into diameters of less than 200 micrometres and the results indicate that surface roughness is dependent upon rotation speed and feed rate [21].

TRANSFORMING 2D FLATBED LASER INTO LASER LATHING

This investigation relates to transform a 2D CO_2 flatbed laser cutting machine which is currently capable of cutting flat workpiece into lathing of circular parts. The first stage idea is to apply the same conventional lathe machine conception onto existing 2D laser machine. Similar to the traditional lathe concept, it has a motor and chuck. The tail stock was design to support longer workpiece if they are required to be lathed in future. The function of the rail on the table is to create a path for the tailstock when dealing with a shorter workpiece. The rail and tailstock are not permanently fixed but can be utilized if necessary to help in better accuracy of laser processing. There are two rails on the right and left side to guide the movement of headstocks and tailstocks. The speed of a motor which has been mounted on a face plate is controlled by a specially designed motor speed controller from 0-1500 RPM. Laser head moves along the Y-axis for cutting process. Stand of distance (SOD) is the distance of laser nozzle to workpiece which plays an important role in laser processing. This laser machine has the laser head moving on Y axis and the table moves on X axis. Thus, to ensure which axis gives tighter tolerance during machining, preliminary experiments were carried out by placing motor at two different axis positions of sacrificial laser table. Figure 1 shows Y-axis position of a spinning mechanism / motor. This orientation focuses on the quality evaluation by laser head movement.

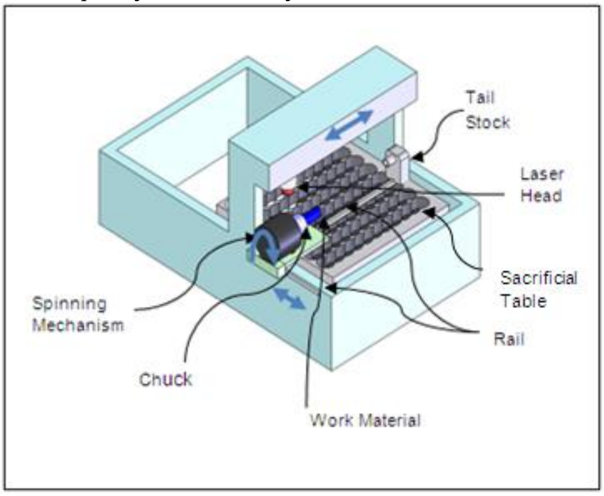


Figure 1: Y axis -Head Movement

The second motor orientation was designed to move the table while the laser head is kept stationary. Figure 2 shows the said motor orientation.

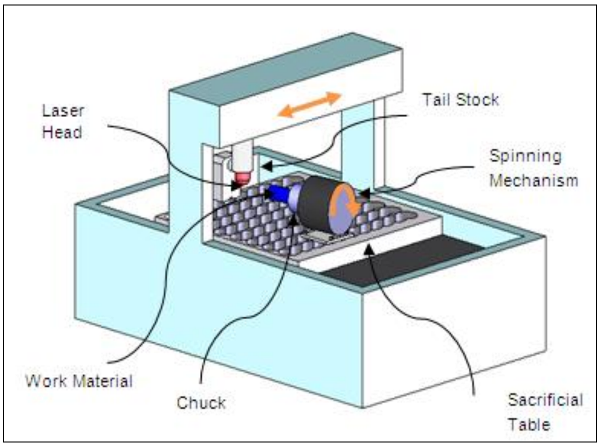
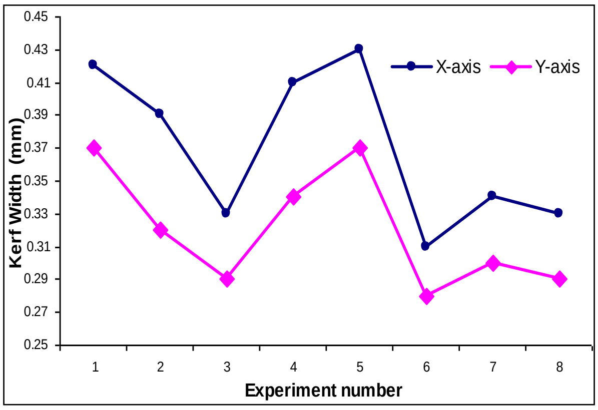


Figure 2: X axis – Table Movement

This preliminary investigation is expected to result a significant difference in determining whether the head or table movement is more precise on 4' x 8' CO_2 laser cutting machine to decide on how should the circular workpiece positioned during lathing process. Thus, the comparison of cut quality by considering kerf width as response can be easily investigated to decide on which



orientation should the motor be mounted. Based on the preliminary investigation of X to Y axis cutting quality, kerf width in Y axis was found to be better than X axis. Figure 3 shows the results of preliminary investigations The Y axis orientation was found to be providing tighter tolerance as compared to X axis. Thus, the motor is fixed on Y axis for the rest of lathing experimentation in completing the work. Both head stock and tailstock are designed to be user friendly enables easy installation and removal in case the machine is to be turned back into flat cutting of metal sheets.

Figure 3: The kerf width analysis of X to Y axis cutting quality to decide motor orientation

EXPERIMENTAL SETUP

In order to transform 2D cutting into 3D, a work spinner of single phase motor was embedded with a 3 jaw chuck to hold the circular workpiece. The motor was mounted on the table where the only the laser head will lathe while the table controls depth of cut for each pass. The motor and chuck assembly was set to aligned almost perfect vertically and horizontally to prevent collision between laser head and workpiece during lathing. Besides setting the alignments to prevent geometrical errors and materials accidents, setting of process parameters also play crucial role in obtaining good research output. The parameters are clustered into three categories; constant parameters, controllable machine parameters and controllable motor parameters. Motor speeds were varied between 1000 and 1500 rpm throughout this research. Table I shows the constant parameters used in this experiment.

Table I: Constant parameters of laser

Laser Processing	***Value***
Power	1800
Frequency	1800
Duty cycle	85
Gas pressure	0.5
Laser mode	Continous wave
Stand off distance	1 mm
Nozzle type	Cylindrical
Beam diameter	0.5 mm
Gas jet selection	O_2
Focus lens type	Cylindrical
Focal distance	0
Nozzle diameter	1.2 mm

EXPERIMENTATION AND RESULT

i) Laser Lathing

Experiments were conducted by varying the significant parameters as in table of design matrix. Table II shows the controllable parameters and actual coded values used for these entire experiments.

Table II: The variable parameter control and actual coded values

Factors	***Level***	
	Low	***High***
Laser cutting Speed (mm/min)	510	680
Work spinning speed (rpm)	1000	1500
Dept of Cut (mm)	1	1.5

Figure 4 clearly shows how a motor is placed on the sacrificial table with the workpiece clamped by a chuck and being lathed by the moving laser head. Thus, the non-contact cutting mechanism is taken advantage to perform lathing.

Figure 4: Laser lathing at 1000 rpm

For the first cutting, the rotation of workpiece rod was set to 1000 rpm with 680 mm/min laser speed. The observation shows that the obtained lathed surface was rough and requires fine tuning of interaction between laser speed and work spinning. As to further investigate, the next lathing was carried out at 1500 rpm with the laser head speed of 510 mm/min. Figure 5 shows the cutting phenomenon of the latter set cutting condition. The observed results between first and second set of cutting was totally different where, the surface finish of higher spinning speed with reduced laser cutting speed shows better results as compared to earlier. Table 3 shows the matrix of coded values and the lathing results of eight performed experiments.

Figure 5: Laser lathing with workpiece spinning of 1500 rpm

ii) Conventional lathe

To compare of mechanical lathing with laser lathing, same raw materials were also performed by traditional mechanical lathes. This is to compare the other benefits of traditional lathes (if any) on working with circular stocks. Table III shows the machining conditions set on mechanical lathes for rough cut which was obtained from machining handbook [22].

Table III: Machining condition of conventional lathe

Factors	***Cutting Speed (m/min)***	***Spindle Speed (rpm)***	***Feed (mm)***
Level	27	650	0.25-0.5

The experimental results of both the manual lathe and laser lathe were obtained successfully. They were compared in terms of percentage for the quality evaluation of roundness. The comparative values of both the lathing techniques are presented in Table IV.

Table IV: Comparison of roundness between laser lathe and conventional lathe

Exp.No.	***Roundness (µm)***		***Percentage Error (%)***
	Laser lathe	***Conventional Lathe***	
1	57	61	6.56
2	57	89	35.96
3	52	61	14.75
4	57	83	31.33
5	72	97	25.77
6	57	87	34.48
7	71	83	14.46
8	66	89	25.84

Table IV shows the percentage error of roundness between laser lathe and conventional lathe. The highest percentage error is 35.96% and the lowest percentage error is 6.56%. Figure 6 shows the illustration about the comparison between laser lathe and conventional lathe. From the illustration, it is found that laser lathe shows better quality of roundness as compared to the conventional lathe. This proves that the transforming 2D laser cutting machine into lathing is very much possible and positive within the range of experimental values. Table V shows the complete machining conditions set for the laser lathing. Their respective snap shots of the lathed workpiece for each experiment are shown in Figure 6. It provides the full picture of finishing quality that can be gained by simple transformation of readily available 2D flatbed laser cutting machine.

Table V: Machining conditions for all experiments

Exp. No.	***Cutting Speed (m/min)***	***Motor Spinning (RPM)***	***Depth of Cut (mm)***
1	5100	1000	1
2	510	1000	1.5
3	510	1500	1
4	680	1000	1
5	680	1500	1.5
6	680	1500	1
7	680	1000	1.5
8	510	1500	1.5

Experiment No. 1

Experiment No. 2

Experiment No. 3

Experiment No. 4

Experiment No. 5

Experiment No. 6

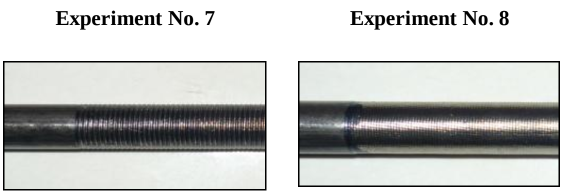


Figure 6: The respective snapshots for each experiment

Figure 7 shows the comparative analysis of the manual and laser lathing. It is clear that laser lathing has produced better roundness values as compared to manual lathing. Thus, it is confirm that, laser lathing can be performed by flatbed laser cutting machine if the workpiece can be made into rotational towards laser axis.

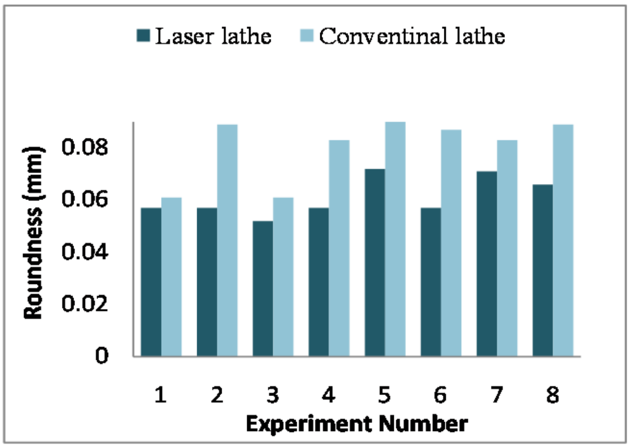


Figure 7: Comparative analysis of manual & laser lathing

ANALYSIS OF MACHINING PARAMETERS

From the main effects plot of laser lathe in Figure 8, the cutting speed and depth of cut shows a significant effect on roundness. On the other hand, the spinning speed was found not to be highly significant as the slope indicates very minimal correlation with the response.

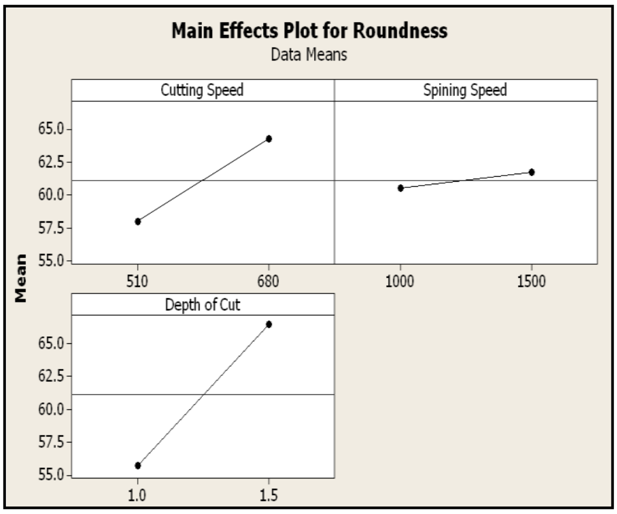


Figure 8: Main effects plot of roundness laser lathe

As per the main effects are concerned, the optimal conditions for best attained roundness value, the laser cutting speed should be set at low level (510 mm/min) while the depth of cut must also be set at low (1.0 mm).Figure 9 show that, there are significant interaction between cutting speed and depth of cut and interaction effect between spinning speed and depth of cut. For cutting speed and spinning speed, there is least significant interaction. The effect on roundness by machining parameters during laser lathe has been analysed and can be witnessed that roundness is very much affected by laser cutting speed and work spinning speed. The observation found that, when the cutting speed and spinning speed decrease, the value of roundness tends to decrease. The roundness will be increase when the cutting speed and spinning speed increase. Thus, the roundness quality is directly proportional to the said controllable parameters within the range of experimental parameters.

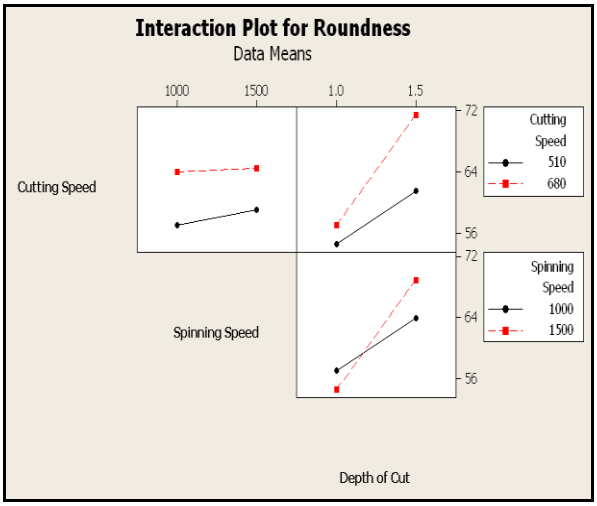


Figure 9: The interaction plot of roundness laser lathe

Figure 10 shows the surface plot for roundness over the controllable parameters of laser cutting speed and work spinning speed. The observation found that, the lower level setting provides better quality of roundness.

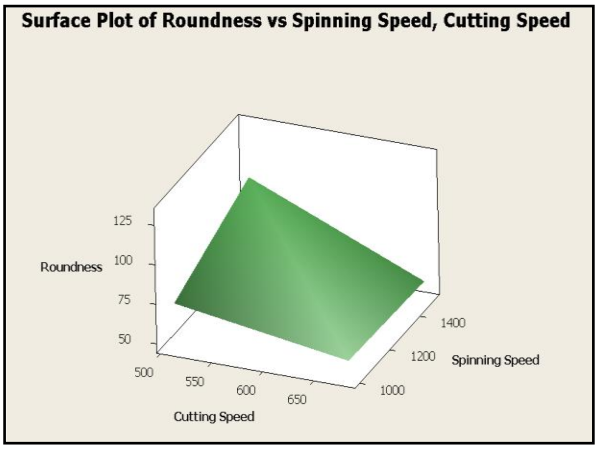


Figure 10: The effect of cutting speed and spinning speed on roundness laser lathe

Figure 11 shows the effect of cutting speed and depth of cut on roundness value of the lathed part. The surface plot shows that, the roundness decrease when the cutting speeds and depth of cut decrease. The roundness tends to increase when the cutting speed and depth of cut increase. The surface plot effect between spinning speed and depth of cut in Figure 12 shows that, increasing the spinning speed and decrease the depth of cut results in best quality of roundness value. The roundness remains increase when the spinning speed and depth of cut increase.

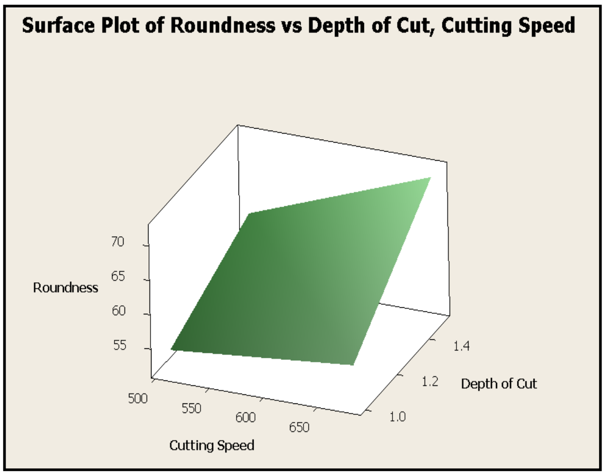


Figure 11: The effect of cutting speed and depth of cut on roundness laser lathe

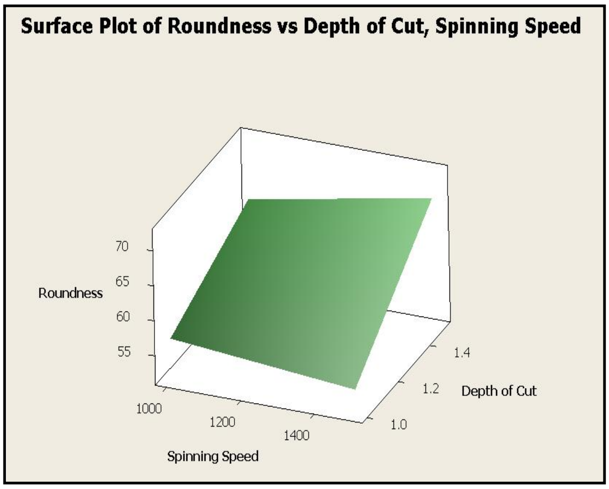


Figure 12: The effect of spinning speed and depth of cut on roundness laser lathe

.

CONCLUSION

From the research work carried out, it is clear that the flatbed laser cutting machining is able to be transformed into laser lathing by selecting appropriate mechanical features and fittings. As for the cutting, it is found that SOD setting becomes challenge when the surface of a rod is too tiny for the laser head to auto detect in preventing part collision. Even the profiling is done and codes are generated by CAD-Man PL technology, yet it has to be manually jogged to prevent unexpected collision of laser head and work which may lead to expensive repair cost. As for the work quality, decrease of laser cutting speed with the combination of decrease spinning speed and depth of cut gives better correlation. Yet, this is to be further confirmed by carrying out extensive quantitative experimentation employing full DOE matrix with low, medium and high level settings of controllable parameters. As to conclude thus work, it can be strongly claimed that laser lathing by transforming 2D into 3D is the cheaper solution to perform lathing as it is proven this method provides better results as compared to manual lathing. Thus, even super hard materials can be explored in near future to observe its performance capability towards stretching into robustness.

ACKNOWLEDGEMENT

The author would like to thank to the Higher Education Ministry to fund this project via Fundamental Research Grant Scheme (FRGS/2010/FKP/TK02/3–F0084). Nevertheless, the authors are indebted to thank top level management of UTeM and Faculty of Manufacturing Engineering for their continuous support and encouragement. The authors would also render their sincere thanks to LVD Laser technical support personnel Mr.Vegiayan Ramiah for his expertise and advice provided in transforming 2D into 3D laser. Last but not least, thanks to Puan Nurlisa Loke Abdullah who has very much guided us in improving the readability of this paper.

REFERENCES

[1] Liu J.S., Li L.J., Jin X.Z. (1999); Accuracy control of three-dimensional Nd:YAG laser shaping by ablation. Optics & Laser Technology 31, pp. 419-423.

[2] Molpeceres C., Lauzurica S., Garcı´a-Ballesteros J.J., Morales M., Ocan˜a J.L. (2007); Advanced 3D micromachining techniques using UV laser sources, Microelectronic Engineering 84, pp. 1337–1340.

[3] Chryssolouris, G.; Bredt, J.; Kordas, S. (1985); Laser Turning For Difficult To Machine Materials. American Society of Mechanical Engineers, Production Engineering Division (Publication) PED 17, pp. 9-17.

[4] Chryssolouris, George; Sheng, Paul; Anastasia, Nicholas (1991); Development of three-dimensional laser machining techniques. SAE (Society of Automotive Engineers) Transactions 100, pp. 916-924.

[5] Young, H.-T. Lin, F.-F.Hong, S.-B. (2008); Novel approach to fabrication of 3D micro-structures by laser machining, Key Engineering Materials 364-366 I, pp. 19-24.

[6] Chryssolouris, G., Sheng, P., Choi, W.C. (1990); Three-dimensional laser machining of composite materials, Journal of Engineering Materials and Technology, Transactions of the ASME 112 (4), pp. 387-392.

[7] Chryssolouris, G., Sheng, P. (1991) Recent developments in three-dimensional laser machining, LIA (Laser Institute of America) 71, pp. 281-293.

[8] Chryssolouris, G., Anastasia, N., Sheng, P. (1991) Three-dimensional laser machining for flexible manufacturing, American Society of Mechanical Engineers, Production Engineering Division (Publication) PED 50, pp. 163-178.

[9] Tsoukantas, G., Salonitis, K., Stavropoulos, P., Chryssolouris, G. (2002) An overview of 3D

laser materials' processing concepts, Proceedings of SPIE - The International Society for Optical Engineering 5131, pp. 224-228.

[10] Dhupal D., Doloi B., Bhattacharyya B. (2008); Pulsed Nd:YAG laser turning of micro-groove on aluminum oxide ceramic (Al2O3), International Journal of Machine Tools & Manufacture 48, pp. 236–248.

[11] Dhupal D., Doloi B., Bhattacharyya B. (2009); Modeling and optimizationonNd:YAG laser turned micro-grooving of cylindrical ceramic material, Optics and Lasers in Engineering 47, pp. 917–925.

[12] Chryssolouris, G., Bredt, J., Kordas, S., Wilson, E. (1988); Theoretical aspects of a laser machine tool, Journal of engineering for industry 110 (1), pp. 65-70.

[13] Chryssolouris, George M. (2005), Stock removal by laser cutting. PatentStorm [Online]. Available at http://www.freepatentsonline.com/4625093.html (Accessed: December 2009).

[14] Li-fang Mei, Gen-yu Chen, Ming-jun Zhang, Xu-fei Liu, and Zujian Wang. (2009); Study on three-dimensional laser cutting technology in auto-body panel. Proc. SPIE, Vol. 7515, 75150O.

[15] Deile, Jochen; LaManna, Greg; Fritz, Michael; Fischer, Axel. (2006); A new approach to 3D laser cutting, 25th International Congress on Applications of Laser and Electro-Optics.

[16] Lange, F.J.; Ruhland, G. (1989); Three-dimensional laser machining with industrial robots. Werkstatt und Betrieb122, pp. 39-44.

[17] Atsushi Yokotani, Kosuke Kawahara, YasunobuKurogi et al (2002) Development of laser turning using femtosecond laser ablation. Proc. SPIE, 4426, pp. 90

[18] Romoli ,L. Tantussi, G. Dini, G. (2007); Layered Laser Vaporization of PMMA Manufacturing 3D Mould Cavities. Annals of the CIRP Vol. 56, pp. 209-212.

[19] Liang W.L., Ngoi B.K.A., Lim L.E.N., Venkatakrishnan K., Hee C.W. (2003); Micromachining of circular ring microstructure by femtosecond laser pulses, Optics & Laser Technology 35, pp. 285 – 290.

[20] Zhang, Yong-Qiang; Wu, Yan-Hua; Chen, Wu-Zhu; Zhang, Xu-Dong; Yan, Qi (2006); Effect of laser beam attitude on 3D laser cutting quality. Chinese Journal of Lasers 33, pp. 124-127.

[21] Jeremy A. Palmer and Eric J. Welle (2007) An Ultra-Short Pulse Laser Lathe For Axisymmetric Micromachining of Explosives. Proc. SPIE, Vol. 6460, 64601.

[22] Steve F Krar., Arthur R. Grill., Peter Smid., 2006. Technology of Machine Tools,6th ed., New York: McGraw Hill.