Proceedings of
2009 IEEE International Symposium on Assembly and Manufacturing
17-20 November 2009, Suwon, Korea

An experimental study for rising manufacturing time and accuracy on SLS process

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Abstract— **Rapid manufacturing and high accuracy are very important factor in the Selective Laser Sintering (SLS) process, one of Solid Freeform Fabrication (SFF) system due to the life cycle of a product getting shorter. This paper addressed development of an industrial SFF system which employs the new laser scan path algorithm for more elaborate and speedy system for fabricating objects compared to existing SLS process. New laser scan path algorithm called Digital Mirror System (DMS). It contains variable beam expander for getting various laser beam spot size instead of the existing fixed beam expander. Also, experiments were performed to evaluate the effect of a new laser scanning path and fabrication parameters on sintering process and to fabricate the various 3D object using polymer power.**

Index Terms— **Selective Laser Sintering, Digital Mirror System, Laser scan path**

I. Introduction

RECENTLY, the multi-functional Solid Freeform Fabrication (SFF) systems are actively being implemented into the real manufacturing process, which are used not only for fabrication a solid freeform 3D CAD files but also for scanning a 3D object rapidly and precisely. Bae on the original form of used material and the hardening method, the various RP systems, such as SLA (Stereo Lithographic), 3DP (3 Dimensional Printing), SLS (Selective Laser Sintering), FDM (Fused Deposition Modeling), LOM (Laminated Object Manufacturing), SDM (Shape Deposition Manufacturing), MJM (Multi-Jet Modeling), JM (Jetting Modeling), have been introdeced to the market [1].

Among them, SLS is an additive manufacturing process that produces parts directly from the CAD model by melting or by sintering layers of a powder together with the use of a laser beam [2]. Also, SLS provides high accuracy and has characteristics being process without support structures. With SLS process, prototypes have been produced with various uses of thermoplastics, metal composite and ceramic composite powder [3].

SLS system is consisted of various element technologies such as a position control and a speed control of roller, nitrogen atmosphere furtherance for the powdered sintering of the build room and the feed room for powder epitaxy and a temperauture control, a scan path generation of laser and control. The powder material for laser sintering is necessary to produce prototypes in Solid Freeform Fabrication based on SLS process. With this powder, polymer of metal molecule in powder room is sintering using CO_2 laser after spreading evenly using roller to reporduce and mold SFF [2].

Currently, fast manufacture and modification have close relation with the market competitive power of products as shortening the product development period in SFF. However, SFF system based on existing SLS process is unable to precisely and rapidly fabricates many sides-models, because the laser beam spot size is fixed when scanning laser on many sides. Therefore, in this study a method will be introduced to fabricate models having more detailed and quicker comparing to existing study. Specially, the small beam spot size is used for shape of microscopic part, and the large beam spot size is employed for wide hatching part, by having ability to change the laser beam spot size (Digital Mirror System).

But when the application of DMS (Digital Mirror System) to existing SFF system for a shortening of total processing time, sintering characteristics are very important factor by heat energy; laser power, sintering temperature, scan speed etc. This is due to sintering rate changes by heat energy distribution corresponding to time. The change of the sintering rate occupies curling present state by shrinkage, warpage occurrence, laser and scan delays. The shrink, flexure, and distortion act to big controversial point in efficiency of whole system as well as exert influence on accuracy of the manufactured products. Therefore, the scan path generation method that can reduce the total processing time and heat equilibriums is important problem in SFF system [2, 4-5].

Digital mirror system (DMS) is the method that scans the laser to various spot sizes according to various areas to solve theses problem. The optimal spot size for area is select. This optimization method can reduce total processing time and is kept heat equilibrium for laser scan time and proves processing accuracy and efficiency.

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This paper addresses an industrial SFF system by using the SLS process which applied DMS system to enable rising manufacturing time and accuracy of 3D shape. Especially, the DMS system was developed by applying variable beam expander. To evaluate applicability of the DMS system, experiments were conducted with optimal fabricating parameters.

II. INTRODUCE OF INDUSTRIAL SFF SYSTEM

A. Existing system

As illustrated in Figure. 1, an SFF system developed is composed of a laminating module that supplies and transfers the powder, a heating module to preheat the powder, a nitrogen supply module to create a nitrogen atmosphere, the laser module that supplies the laser to a large area, laser unit, and a control module to control the entire system.

In the existing study, three-axis dynamic focusing systems are consisted of a laser Engine, a scanner, a fixed beam expander, a reflection mirror. The dynamic focusing lens consisted of object lens, concave lens, and galvano-mirror prevents spot size distortion phenomenon when scanning laser beam in great area. For this purpose, the focal length of lens can be variable. Also, in order to obtain the desired spot size, 0.5mm, which allows to sintering, the system was constructed so that the fixed spot size is available at some position utilizing the beam expander.

When scanning laser in the existing system, occasion of scanning the center part is no problem, but the additional part of three dimension shapes is processed as being examined to escape part area in occasion of scanning boundary part. Due to these reasons, the existing system has shortcoming that shape accuracy for microscopic part becomes low. Also, boundary part must be again processed to overcome the accuracy problem. Figure 2 shows the laser part of existing system and Figure 3 shows that manufactured 3D model by using the existing system. From the Figure 3, we see that precision of microscopic part is low [6].

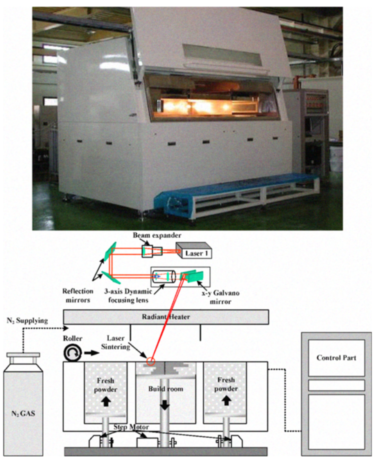


Fig. 1 Industrial SFF system and Schematic representation

B. Digital Mirror System (DMS)

The developed digital mirror system can change the laser beam spot size to be suitable to great area sintering in the existing study. Specially, instead of the zoom beam expander to obtain the equal beam spot size in existing system, the variable beam expander being able to adjust a laser beam spot size was been installed, which controls the magnification by built-in two motors. A motor moves lens to control magnification and another motor creates the balance beam. The variable beam expander can adjust the source beam in 2 x to 8 x automatically. The accuracy and the processing speed are finally improved for the three dimension model through the hatching part of cross section sinters using large spot size, and the outer boundary part sinters using small spot size. Table I and Figure 4 shows the specification and system of the variable beam expander which is applied to the Digital Mirror System, respectively.

To apply DMS to the industrial SFF system using SLS process, a new scan path generation algorithm is needed due to the necessity of changing the spot size of the laser beam. Therefore, area division algorithm was developed which is classified into 3 algorithms according to the complexity about the sliced section.

Especially, area division algorithm reduces unnecessary scan paths as compared to the existing simple zigzag laser scan algorithm. So it can improve the scan efficiency by minimizing the laser's transfer section. Division area scan algorithm which is displayed in Figure 5 can create a new arranged scan path. This happens by rearranging the scan path on each scan area centering around the area which is divided into region1, 2, 3, and 4. By storing the scan area again in order of region1→ region 2→ region 3→ region 4 [6].

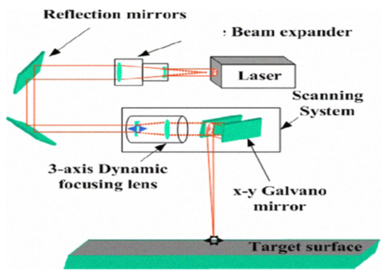


Fig. 2 Laser part for existing SFF system

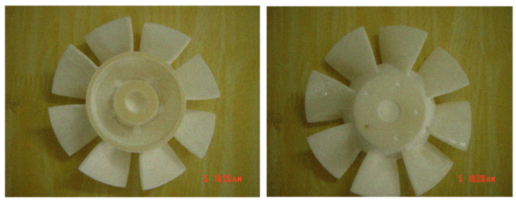


Fig. 3 Fabricated 3D model by using the existing SFF system

TABLE I

SPECIFICATION OF VARIABLE BEAM EXPANDER

Item	*Expansion Range*	*Input Aperture*	*Output Aperture*	*Expansion change Time*
Spec.	2~8	10mm	30mm	~10 seconds

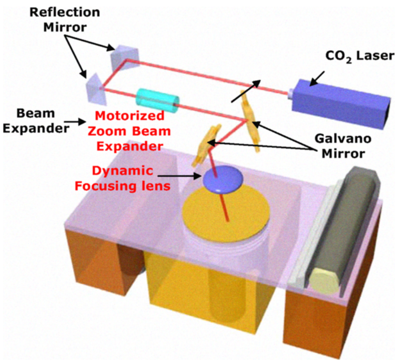


Fig. 4 Laser part for Digital Mirror System

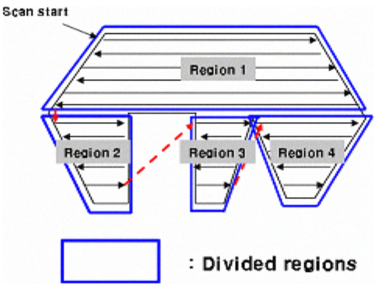


Fig. 5 Scan path for divided regions

C. *Digital Mirro System application*

A laser scan program was developed by applying interrelation of the sintering rate according as the laser irradiating time. Application of DMS is divided into 3 levels by area division scan path algorithm. First, the smallest part is classified by comparing the size and task of comparing the complexity to make them in order was taken. The area divided by these 3 levels will be scanned by different beam spot size, spacing, and speed at each area. These procedures shorten the processing time, and increase the accuracy and process efficiency through equilibrating the heat between each area.

We fabricated an actual model using the newly developed program. To evaluate the performance of DMS, the total processing time when applying basic algorithm; 1, DMS (fixed scan speed); 2, and DMS (variable scan speed); 3 was compared. Fabrication shape was a key model. The thickness of the key model was 5mm and layer thickness was 100um. Table II shows each experimental conditions and results of the compared total processing time. Thus, when fabricating key model that has 5mm of thickness, more than 2 times of processing time was saved than the basic algorithm and 4 seconds were gained per 1 layer. Figure 6 shows the model which is fabricated by conditions of Table II. From the left side, there are basic algorithm, DMS (fixed scan speed) and DMS (variableness scan speed).

And to verify the strength, specimens manufactured through the DMS. Table III shows the experiment parameters for each specimen in the tensile test. Default means that basic algorithm. Tensile test was then performed to measure the strength of each specimen, and their results are shown in Figure 7. Every specimen had strength of more than 0.5kN, which was higher than the minimum required strength.

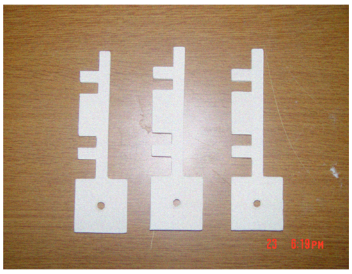


Fig. 6 Fabricated key model according to algorithm

TABLE II

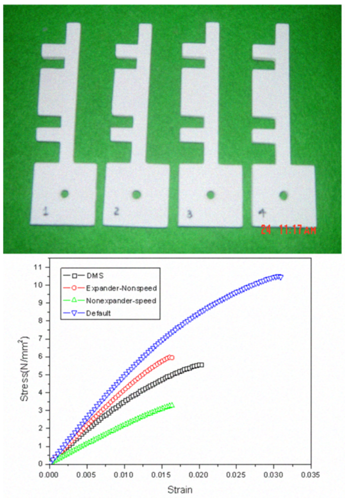
DMS APPLICATION PROCESS DATA

	1	2	3
Spacing(mm) / (spot size)	0.3/(0.5)	0.3/(0.3) 0.3/(0.6) 0.6/(0.8)	0.3/(0.3) 0.3/(0.6) 0.6/(0.8)
Speed(m/s)	5	5	6, 5, 4
Total Processing Time(ms)	390198	211881	189063

TABLE III

EXPERIMENT PARAMETERS FOR EACH SPECIMEN

	Default	None-expander and speed	Expander-fixed speed	DMS
Spacing(mm)/ (spot size)	0.3/(0.5)	0.3/(0.5)	0.3/(0.3) 0.3/(0.6) 0.6/(0.8)	0.3/(0.3) 0.3/(0.6) 0.6/(0.8)
Speed(m/s)	5	6, 5, 4	5	6, 5, 4



(a) (b)

Fig. 7 Result of tensile test, (a) Fabricated key model for tensile test, (b) Ultimate stress according to the algorithm

With the preceding described result, pan model was fabricated to estimate the performance of DMS. The fabricated model was a pan which was same model from the existing study. The condition of fabricating is shown on Table IV and the fabricated model is shown on Figure 8. From the Figure 8, accuracy of microscopic part is higher than existing study. Also, more complex model fabricated using the DMS. Fabrication condition was same Table IV and model was a mission cover which was 70% of a real CAD model as Figure 9.

To examine dimension error, we fabricated scale bar model (Figure 10). Table V presents the results of dimension errors between a 3D CAD model and a fabricated scale bar model. The experimental results demonstrated that the dimension error rate was less than 1mm for each measurement point.

TABLE IV

FABRICATED CONDITION

	Specialty	Mid	Hatching
Temp.	176℃		
Scan speed	6m/s	5m/s	4m/s
Spot size	0.3mm	0.5mm	0.8mm
Scan space	0.3mm		
Laser power	18W		
Layer thickness	100㎛		

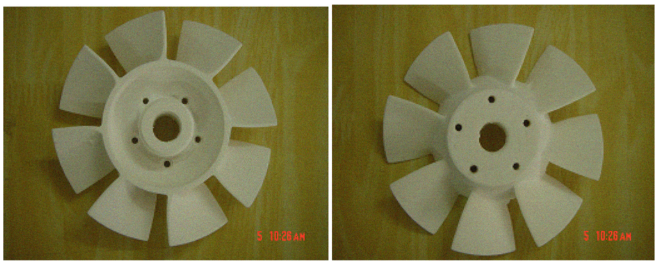


Fig. 8 Fabricated model mission cover using the DMS

Fig. 9 Fabricated model mission cover using the DMS

III. CONCLUSIONS

The In this study, it was confirmed that by applying the Digital Mirror System, which is newly suggested to the industrial SFF system using SLS process, the optimum process parameter can be achieved. The following conclusion was gained.

1) The experimental setup was made to conduct the study the concept of Digital Mirror System.

2) To improve the efficiency of laser scan in SFF system, the method to generate scan path was developed by employing three algorithms.

3) The DMS system specimens were stronger than the desired mechanical strength of 0.5kN.

3) The efficiency to manufacture complex model was also improved by optimizing heat equilibrium and decreasing the area and processing time by applying area division scan path to DMS.

4) Through fabrication and experimentation on each algorithm of the DMS developed, dimension error was very low compare with 3D CAD model.

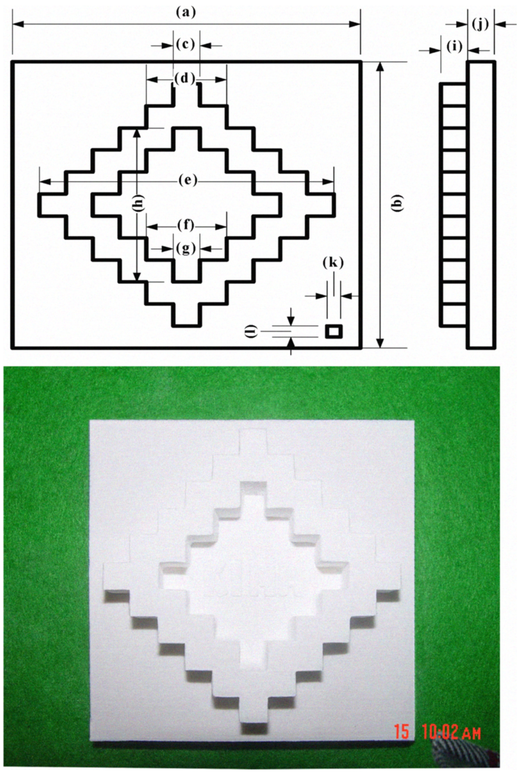


Fig. 10 Fabricated mission cover model using DMS

TABLE V

COMPARISON OF ACTUAL PART AND FABRICATED PART WITH DMS

	a	b	c	d	e	f
3D model	96	96	7.2	21.6	79.2	21.6
Fabricated model	95.8	95.7	7.39	21.85	79.21	21.16
Dimension Error	0.2	0.3	-0.19	-0.25	-0.01	-0.44
	g	h	i	j	k	L
3D model	7.2	50.4	12	12	3.6	3.6
Fabricated model	7.18	50.5	12.4	12.1	3.66	3.71
Dimension Error	-0.18	-0.1	-0.4	-0.1	0.06	-0.11

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