Stereolithography System Using Multiple Spot Exposure

Yoji MARUTANI, Takayuki KAMITANI
Faculty of Engineering
OSAKA SANGYO UNIVERSITY
3-1-1 Nakagaito, Daito City
OSAKA, 574 JAPAN

ABSTRACT

A new method of making 3-D objects is proposed. A discharge lamp is used as a UV light source, and to make the fabrication time shorter, multiple spots exposure using optical fibers is employed. The light is distributed to some optical fibers. The output side of each fiber is arrayed linearly and the emitted lights are focused on the surface of the photosensitive resin. As the fiber array is raster-scanned, the light transmission of each fiber is controlled by the optical shutter independently according to the pixel data at the corresponding position to be irradiated. Small-sized stereo-lithography systems can be realized economically by this method.

1. INTRODUCTION

The rapid prototyping is a method to make 3-D models by mutual bonding of raw material on the basis of digital data. Stereolithography is one of the methods using a UV laser and photopolymer resin, and is now applied to the fabrication of industrial models, medical models from CT or MR images[3], etc.. However the cost and size of present stereolithography systems have issues because of the UV laser. Presently commercially available systems are very expensive. As rapid prototyping(R/P) become popular, small and inexpensive systems are requested.

When stereolithography was first proposed, a discharge lamp was used as a UV light source[1]. However it did not put to practical use because of its low accuracy and energy efficiency. Commercial high-precision systems were realized using UV lasers[2]. But they have been very expensive and bulky.

Although some R/P systems, such as FDM and LOM are relatively inexpensive. They can not gives more stable reaction process and transparent, complicated models than stereolithograpy.

Here, we propose the new method to realize smaller and more inexpensive stereolithography systems[4]. In the system, a discharge lamp is used as a UV light source, and to make the fabrication time shorter, multiple exposure spots are employed. Using this method, the small-sized stereo-lithography system can be realized economically. In this paper, the principle of the method, hardware and software of the experimental system and some results of experiences are mentioned.

2. PRINCIPLE OF OPERATION

Fig.1 shows the configuration of the system. The UV light from the discharge lamp is introduced to the quartz optical fibers. The fibers are arranged at the optical head and consists the emitting unit. Images of their output ends are formed on the surface of the resin. The light emission of each fiber is controlled by the electromagnetic shutter independently. The shutter is consisted of the electric solenoid and the thin metal blade. The optical head is moved by the signal from the computer. As it moves, the data of sectional pattern are applied to each shutter of the fiber.

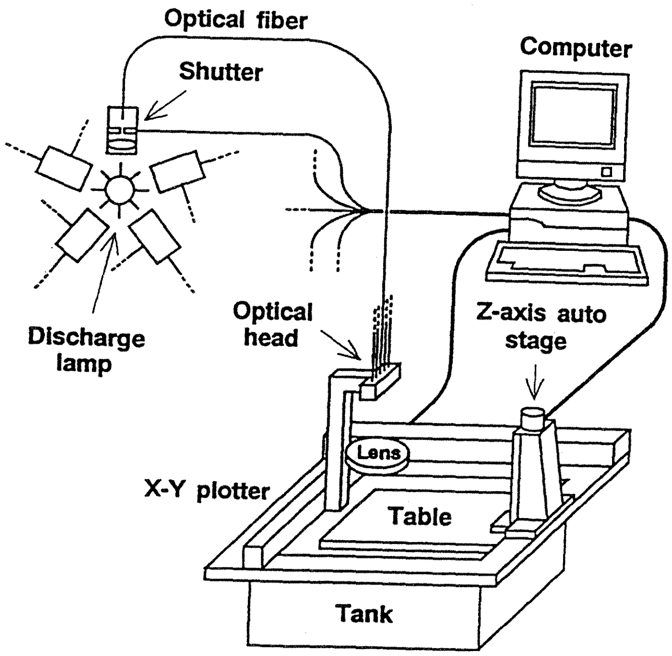


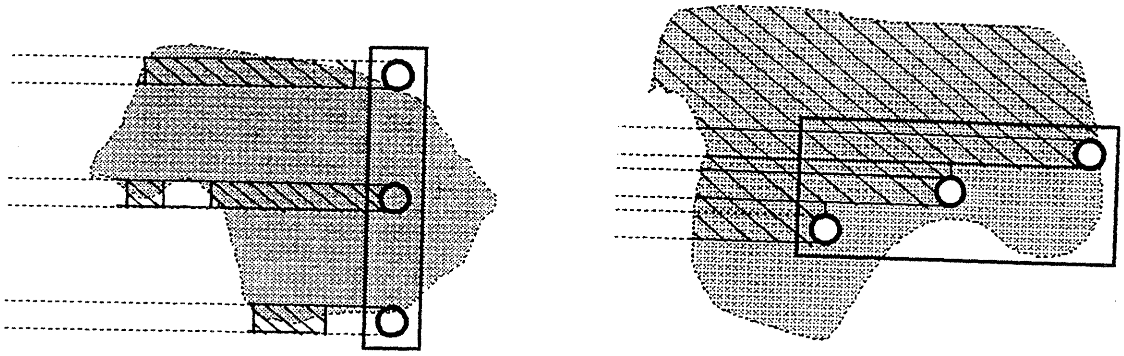
Fig.1 Schematic diagram of the system.

In general, two methods to make 2-D pattern exist : masking method and spot-scanning method. Masking method needs active optical mask. But no such masks are available on the market. So we adopted spot-scanning using optical fibers as flexible optical paths. To make use of light effectively, the multiple fiber system is employed.

In the computer, 3-D CAD data are sliced mathematically and sectional patterns, then these patterns are converted to the pixel image by painting process and stored in the buffer memory one by one. As the optical head moves, the light pattern at the head is controlled by the shutters according to the sectional image in the memory. The pixel data of corresponding position of each optical fiber are read out from the memory and given to the optical shutters.

After exposing whole the surface, the table goes down by the thickness of one layer. The new liquid resin layer covers the solidified layer, and next exposure is done using next sectional image. The thickness is same as that of slicing of the CAD data and is less than the depth of solidification. So the solidified layers unite each other firmly.

One of the difficulties of the system is the existence of gaps between fibers. The gaps cause the non-solidified part and prevent making models perfectly. Filling up of them is done by the software and/or hardware technology. The gaps between each fiber at the optical head are considerably broad because of the clad and the guard sheath of the optical fiber. So the trace of the optical head also has very broad gaps. In this system, to fill the broad gap between the traces, two methods are adopted. In one method, as shown in Fig.2(a), after scanning in X axis, the head moves by one pixel in the Y axis. Next scan runs between the last traces. If the gap is more than one pixel, this scanning are repeated until the gap are buried. In another method, as shown in Fig.2(b), the fiber array is set oblique to the scanning direction. On scanning, close exposure between each trace is established. By adjusting the angle of the head, the pitch of the traces can be changed freely.



(a)array with gaps **(b)array without gap**

Fig.2 Scanning path.

The finest width or diameter of solidified part is determined by the diameter of the light spot imaged on their surface. To make fine structure, the image of the fiber end should be as small as possible.

3. EFFICIENCY OF LIGHT COLLECTION

The light from a discharge lamp is dispersive, so it is impossible to concentrate it at a spot. Fig.3 shows the optics of the system. A lens is used to collect and concentrate the dispersing light. Let the focal length of the lens be f, the diameter of it be D, radiance of the light source be B, and magnification of the image be m. Then the irradiance E of the image is generally expressed as follows,

$$E = \pi B(D/f)^2/4(1+m)^2 \tag{1}$$

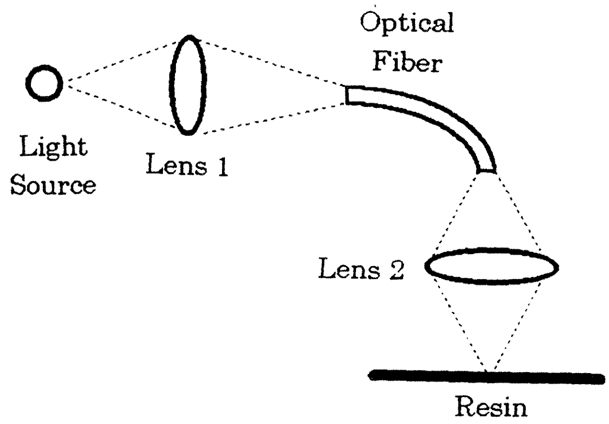


Fig.3 Optics of the light source.

At the input end of the optical fiber, the dispersive light from the lamp is collected to the core of the optical fiber. The optical fiber can accept only limited light which has restricted angle of incidence. Let the maximum incident angle be θ_{m}. To transfer all the light passing through the lens aperture to the optical fiber, the distance b between the lens 1 and the fiber end should be

$$b = (D/2)/\tan\theta_m \qquad (2)$$

As the magnification m is $m=b/a=(b/f)-1$, using eq.(1),

$$E = \pi B\tan^2\theta_m \qquad (3)$$

The radiant energy Φ transmitted by the optical fiber is the product of E and the area of the core S.

$$\Phi = \pi SB\tan^2\theta_m \qquad (4)$$

To improve Φ, it is necessary to select the optical fiber having large θ_m and S. The distance between the lamp and the lens 1 is calculated so as to make the image of the light source on the fiber end. The length of the optical system is $a+b$. To minimize this, condition $b=2f$ is necessary, because $a+b=bf/(b-f)+b$.

At the output of the optical fiber, according to eq.(1), f/D and m should be small to maximize the light quantity on the resin. f/D can be make smaller by selecting the lens, and m can be small by adjusting the optical system.

4. EXPERIMENTS

In the experimental system, a X-Y plotter was used and the optical head was attached instead of its pen. A 150W Hg-Xe discharge lamp(HAMAMATSU Co. L2482) as the UV light source and five quartz optical fibers with core diameter 0.4mm were used. The resin was ADEKA HS-673. The system was controlled by a personal computer through serial and parallel interface.

To measure the resolution and the solidification rate, the resin was exposed by single fiber. As illustrated in Fig.4, thin glass plate is set afloat on the surface of the resin. The transmission rate of the plate is about 92% with UV and visible light. Fig.5 shows the relation between the irradiation time versus the diameter and depth of solidified part. With visible light, the exposure time is improved.

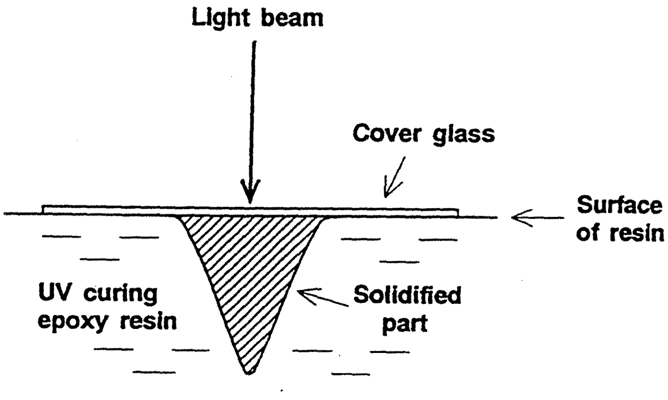


Fig.4 Illustration of the shape of solidified resin.

In a example of commercial system using a 100 mW UV laser, a layer 0.08 mm in diameter and 0.2 mm in thickness is solidified at scanning speed of 770 mm/sec. the volume production rate is 9.7 mm^3/sec. From Fig.5, our system produces 0.58 mm^3 in 2 sec. So about 34 fibers are equivalent to the ability of 100 mW UV laser.

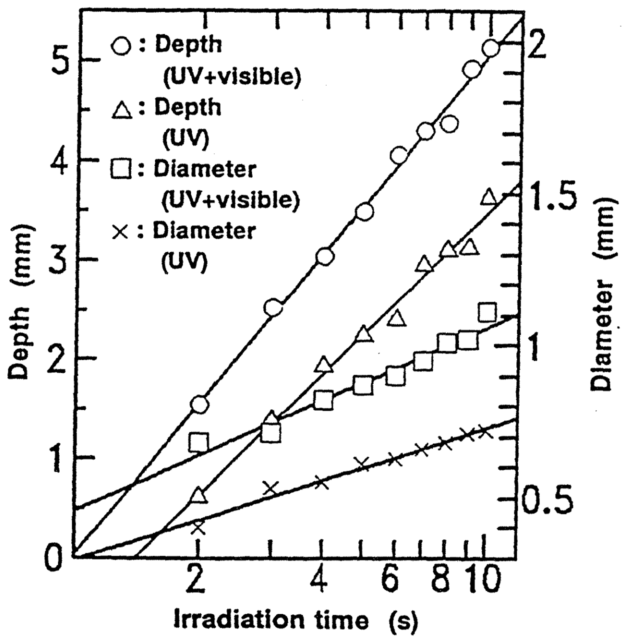


Fig.5 Relationship between the size of the solidified resin and irradiation time.

Fig.6 shows examples of 3-D objects made by the system. Five spots with 0.5 mm diameter were used, and gaps between spots were 4 mm. The exposure time in each spot was 2 sec.

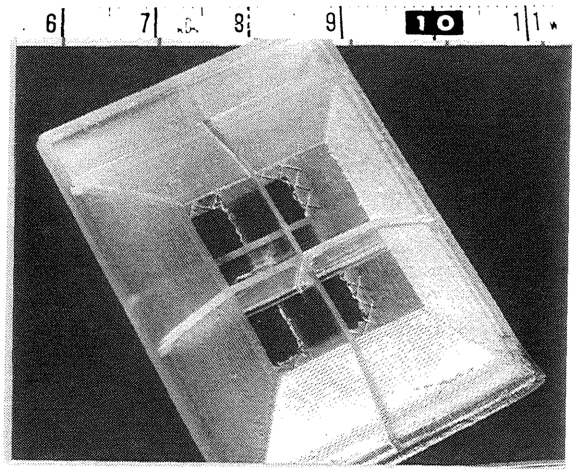


Fig.6 An example of 3-D object.

5. CONCLUSION

By using a discharge UV lamp economical and small-sized stereolithography system can be realized, and the multiple spot exposure method leads to high fabrication speed. The resolution of this system is determined by the spot size of optical fiber. Generally the incoherent light can not be concentrated without energy loss. The finer the spot size, the less the total optical power. So the proposed method may be suited to the rough models.

REFERENCES

[1] Kodama,H:"Automatic Method for Fabricating a three-dimensional Plastic Model with Photo-hardening polymer",Rev. Sci. Instrum., Vol.52, No.11, pp1770-1773('81)

[2] Nakai,T.,Marutani,Y.:"Shaping 3-D Objects Using a UV Laser and Photopolymer", Conf. on Laser and Electro-Optics '86, ME-2('86 San Francisco)

[3] Nakai,T.,Marutani,Y.:"Applications of UV Laser Fabrication to Organ Models Interpolated from Computed Tomography and Magnetic Resonance Images", Applied Optics, Vol.31, No.25, pp5375-5379('92)

[4] Kamitani,T.,Numata,Y.,Marutani,Y.:"Rapid Prototyping System Using an Optical Fiber Array" ,Record of the 1995 Kansai-Section Joint Convention of Institutes of Electrical Engineering, Japan, G12-49.