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UTILIZATION OF RAPID PROTOTYPING SYSTEM FOR LAMP SHADES DESIGN

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ABSTRACT: Manufacturing of objects with complicated curve surface had limitation in terms of both designing aspect and modeling aspect. 3-Dimensional modeler solved the limitation of designing stage. Now, rapid prototyping system is solving the limitation of modeling stage as the system can complete modeling of objects with highly complicated curve as long as data of the objects is described electronically.

The characteristic of curved surface is clearly reflected when the surface is for lamp shades because normal vector of the surface has close relationship with reflection and luminance of the point. This paper presents utilization of rapid prototyping system to lamp shade design.

We proposed 2 works named 'Refracting Mobius Loop' (hereafter RML) and 'Reflecting Paraboloid Shell' (hereafter RPS). RML is constructed by ruled surface generated from double helix on a sphere. As normal vector of each point change gradually on RML surface, luminance on RML should change gradually as well. RPS is constructed by set of paraboloid curved lines sharing focus point. If point light source is located at the focus point and the surface have specular reflection characteristic, the light reflected by RPS should be parallel.

We designed both RML and RPS by 3D renderer POV-Ray to evaluate from viewpoint of visual aspect. Then, set of commands for 3D modeler Rhinoceros was automatically generated from POV-Ray scene file to construct STL format data. Finally we got actual products developed by rapid prototyping system. We also applied specular reflection paint to RPS surface to secure mirror-like (specular reflection) surface.

After development of products, we conducted luminous performance test. We measured luminance distribution on RML and illuminance level of the point under RPS to examine luminous performance. In case of RML, luminance made by reflection and transmission of the surface change gradually as designed. In case of RPS, though flow of reflected light was not perfectly parallel because of designing, modeling and applying problems, illuminance level was increased by RPS reflection.

Keywords: Lamp Shades, Rapid Prototyping System, 3D-Modeler

1. INTRODUCTION

Modeling objects with highly complicated curve surfaces involves limitations both in designing and modeling stages. In the designing stage, the major challenge is how to express objects to be designed in the two-dimensional surface: the more complicated the curved surface is, the more complicated the shape of the curved surface projected on the two-dimensional surface becomes. The advent of the 3D modeler automated the projection process, thereby removing restrictions in the designing stage and making it possible to freely design highly complicated curve surfaces. What emerged next was a rapid prototyping system, which has seen major progress and come into wider use in recent years. Thanks to its capability to manufacture the 3D modeler's output as it is, this system has eliminated limitations involved in the modeling stage.

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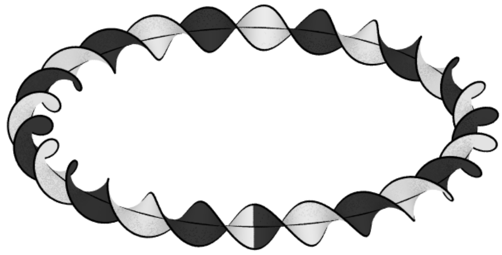

Figure 1: Multiplex Mobius loop

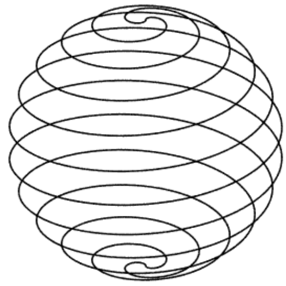

Figure 2: Double helix developed on spherical surface

2. DESIGN AND EXAMINATION OF RML

2.1 Design of RML

We decided to realize the shape which is not similar to existing lamp shade shape to make good use of advantage of rapid prototyping system. And we also decided to exclude convex and concave corner to realize gradual and continuous luminance distribution on the lamp shade. Paying attention to common close relationship between Mobius loop and lamp shades, which are connecting front side and back side harmoniously, we decided to adopt Mobius loop as basic principle of the designing of lamp shade.

At first, basic Mobius loop was twisted repeatedly to realize multiplex Mobius loop (See Figure 1). Then reference line (center line) of Mobius loop was transformed to double helix developed on spherical surface (See Figure 2). Finally, we got highly complicated ruled surface.

Detailed parameters of the reference line (hereafter 'frame') and generating line (hereafter 'generator') are decided by following steps.

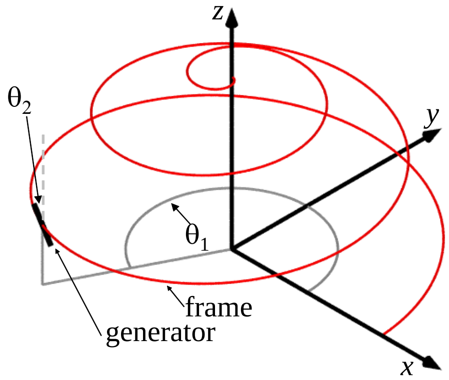

Figure 3: Parameters for generator and frame

To set interval angle constant, the position of the frame (same as the center of the generator) is expressed as follow;

$$x = r \cos(\theta_1 / (4n)) \cos \theta_1$$
$$y = r \cos(\theta_1 / (4n)) \sin \theta_1$$
$$z = r \sin(\theta_1 / (4n))$$

where r (radius) = 300 (mm) , n (number of rotation) = 3 and θ_1 is from -2.7π to 6π.
The span of generator changes depending of θ_1. And the angle between z-axis and generator, θ_2 (See Figure 3), is set to $n \times \theta_1$, where n is number of twist of generator in a rotation (in this case, n is 6). At last, we got the final shape of lamp shade (See Figure 4). And we also actually manufactured the lamp shade by rapid prototyping system. However, the size of the shape was reduced to one-third approximately due to limitation of rapid prototyping system.

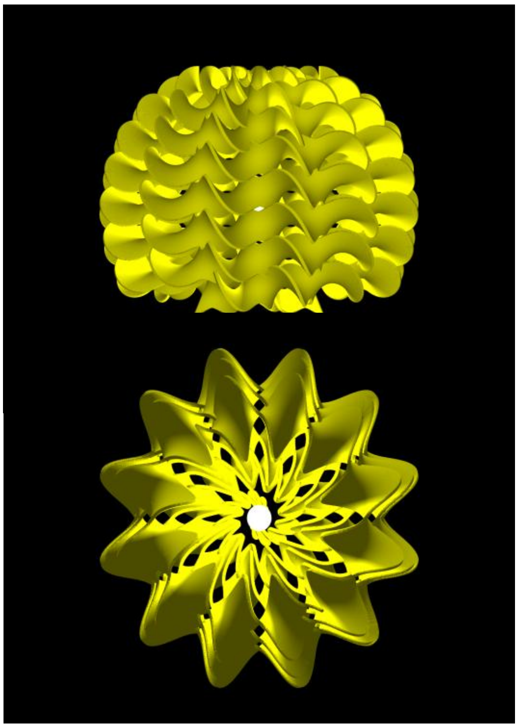

Figure 4: The final shape of lamp

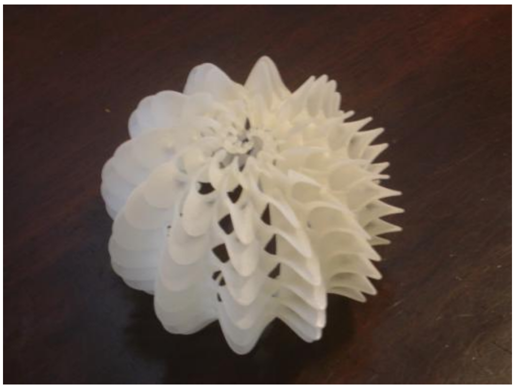

Figure 5: Manufactured lamp shade

Figure 6: Compact krypton lamp on stand (left) and RML on the lamp(right)

2.2 Examination of RML

To check luminous performance of RML lamp shade, we conducted lighting test by putting RML on compact krypton lamp (See Figure 6). We measured luminance distribution of lamp shade surface and surrounding area.
Luminance distribution was measured by Luminocam (KOZO KEIKAKU ENG. INC.) making use of multi-exposure digital images. At first we used 60W lamp but we could not observe clear luminance distribution due to too strong light emission and inter-reflection. Then we replaced the lamp with 25W lamp.

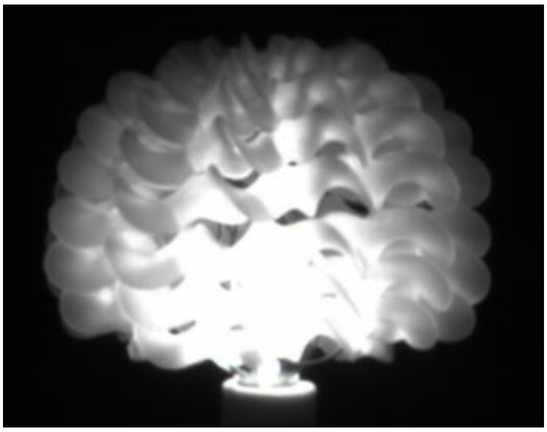

Figure 7: Photo image of RML with 25W compact krypton lamp

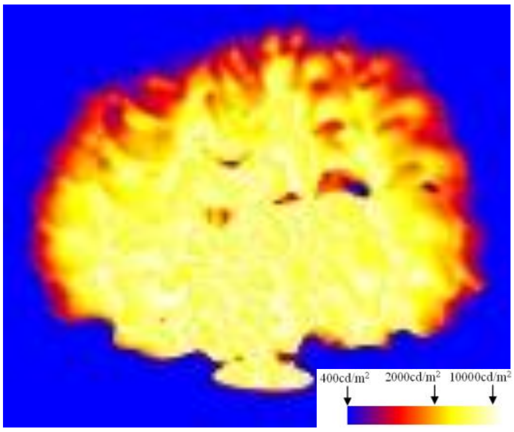

Figure 8: Luminance distribution of RML with 25W compact krypton lamp

Figure 7 shows photo image of RML with 25W compact krypton lamp and Figure 8 shows luminance distribution of RML. Except the area where the lamp and RMP surface are overlapping, gradual and continuous luminous distribution was observed. However, the change of luminance value was not much significant as shown in Figure 8.

To obtain clearer luminance distribution, we should have used weaker lamp or larger shade. Accurate reflectance and transmittance of the material of RML are required to conduct precise simulation in future.

3. DESIGN AND EXAMINATION OF RPS

3.1 Design of RPS

The parabola curves specularly reflects a flow of parallel light and gathers it to the focal

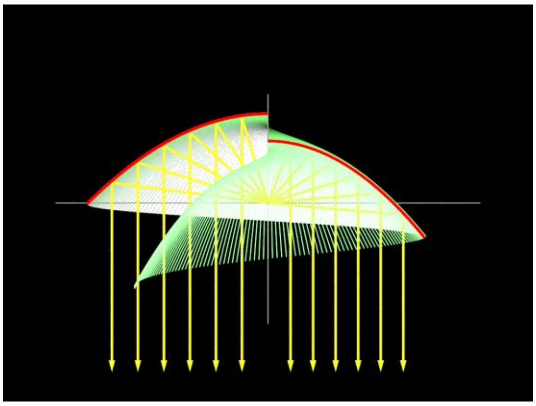

Figure 9: Combined parabola curves sharing the same focal point and reflected parallel light flow

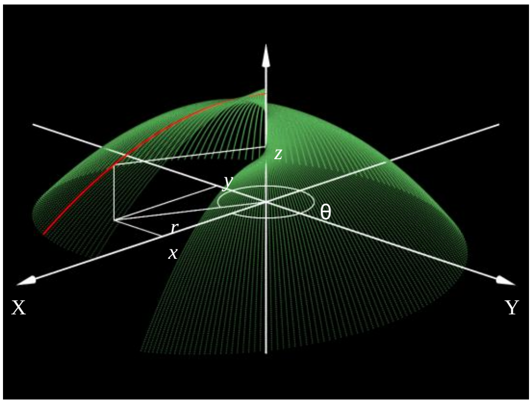

Figure 10: Parameters for RPS

point. Conversely, when light is emitted from the focal point, the parabola can produce a parallel light flow. In architectural spaces, parallel light flow is important to prevent glare and undesirable reflection. Louvers attached to lighting fixtures, for example, serve this anti-glare/reflection purpose by adjusting the flow of light. Using a louver, however, is not an aesthetically elegant solution. Nor is it an energy-efficient means. Yet, using a simple surface comprising a rotating parabola designed to achieve a parallel light flow will result in a dull shape like a parabolic antenna.

To address these challenges, we combined parabola curves sharing the same focal point to produce a lamp shade that can adjust the flow of light with its dynamic shape (See Figure 9). Generally, if x, y, z, r and θ are set as in Figure 10 and the parabola is expressed with $Z=-\frac{r^2}{4p}+p$ (where, $r=\sqrt{x^2+y^2}$), the focal point will be the origin regardless of the value of *p*. In this case, if the values of *p* and the maximum of *r* are fixed, a resultant shape will be like a parabolic antenna. However, if *p* and *r* are the functions of θ, complicated curve surface appears. In this study, a surface was determined by assuming that *p* and *r* are linear functions of θ, as shown in the following equations;

$$p=45\times\frac{\theta}{2\pi}+30,\quad r=(150-110)\times\frac{\theta}{2\pi}+110$$

(Unit: *mm*)

To produce a sample for the reflection test of the curved surface, we used a rapid prototyping system EDEN250 (Altech Co., Ltd) and modeled a sample to the scale of 54.68% of the original design. After removing support material, specular paint was sprayed over the curved surface for three times and fixed with lacquer. Figure 11 shows the RPS after the application of the paint. As shown in the figure, lower specularity was visually observed in areas where the support material remained.

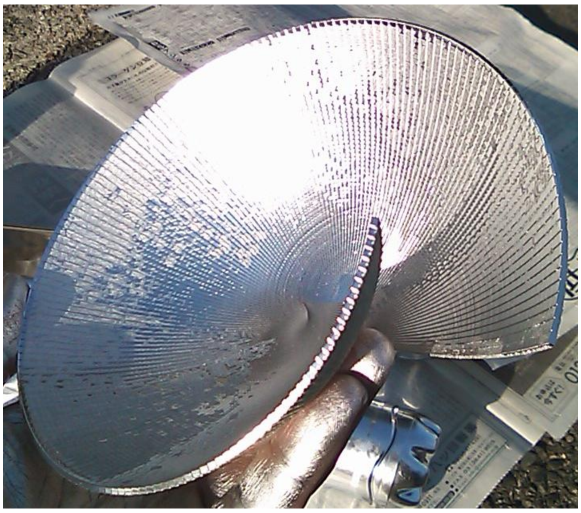

Figure 11: RPS after the application of the paint

3.2 Examination of RPS

3.2.1 Comparison and analysis of results with and without the RPS

As shown in Figure 12, a lamp stand was attached diagonally to a tripod placed in the darkroom. A light source (25W compact krypton lamp) was set at 1,500 (*mm*) high from the floor level, with an illuminance meter placed on the floor just beneath the light source. Vertical illuminance of the floor surface was measured for three times with the light source off and found to be 0.00 (*lx*) at all times. This indicated that there was no effect of external light that could distort test results as noise.

As the next step, compact krypton lamp was turned on and illuminance of the floor surface was measured. The results were 14.57 (*lx*), 14.71 (*lx*), and 14.65 (*lx*), respectively, averaging 14.64 (*lx*).

Figure 12: Lamp stand for luminous performance test

When reflecting light with the RPS, it was found impossible to place the light source accurately at the focal point, because the lamp was too large for that purpose. We therefore moved the RPS to measure illuminance and obtained the maximum illuminance of 107.77 (*lx*). This indicates that use of the RPS increased the illuminance of the floor surface by up to a little over seven times.

3.2.2 Comparison of results between the RPS and a hemispherical lampshade with a perfect diffuse reflection surface

In Section 3.2.1, because the flow of light moving upward above the light source was not considered when the RPS was not used, the increase in illuminance that occurred when the RPS was used included an increment not attributable to the shape or normal reflection performance of the RPS. To address this challenge, we virtually placed above the light source a hemispherical lampshade of the size similar to the RPS with a perfect diffuse reflection inner surface and measured illuminance for the purpose of comparison.

We assumed that the average radius of RPS is 73.5 (*mm*) and the light source is placed in the center of a hemispherical surface with this length of radius. Assuming that the lamp used in Section 3.2.1 is a point light source, if direct illuminance at 1,500 (*mm*) away from the light source is 14.64 (*lx*), direct illuminance at 73.5 (*mm*) from the light source will be 6097.46 (*lx*), in accordance with the inverse-square law of illuminance. And assuming that reflectance of the inside of the hemispherical surface is 1.0, luminous emittance of the hemispherical surface attributable to the reflected light will be equal to illuminance. Where the diffuse reflection surface based on the Lambert's law is concerned, luminance = luminous emittance/π. Therefore, luminance of the hemispherical surface will be 1940.88 (cd/m^2). In this case, the solid angle of the hemispherical lampshade at where the illuminance meter is placed will be 0.0075 from the following equation; Horizontal projected area on the hemispherical surface ($=\pi \times 73.5(mm)^2$) / Square of distance ($=1500(mm)^2$). Based on this positional relationship, the configuration factor can be regarded as the same as the solid angle and the illuminance of the light reflected by the hemispherical lampshade at the position of the illuminance meter will be determined by the following equation; configuration factor × Luminance of reflected light, which is 1940.88 (cd/m^2) × 0.0075=14.64 (*lx*).

These results suggest that, when use of the RPS increased illuminance by 93.13 (*lx*) from 14.64 (*lx*) to 107.77 (*lx*) in Section 3.2.1, the increment of 14.64 (*lx*) equal to direct illuminance could have been obtained even if the lampshade had not been of the shape and properties of the one we used. The rest of the increment, however, can be regarded as attributable to the design unique to the RPS.

3.2.3 Problems

In the examination, challenges remained in achieving parallel light, such as a decline in specular reflection performance resulting from the residual support material for rapid prototyping system, the size of the filament of the compact krypton lamp, and the size of the lamp itself. In the future, by completely removing the support material, using a LED light source, and taking whatever other steps believed necessary, we plan to ensure even more accurate identification of the RPS' properties.

4. CONCLUSION

We proposed 2 shapes for lamp shades, RML and RPS. Not only designing but we manufactured actual products making use of rapid prototyping system. We also applied specular reflection paint to RPS surface to secure mirror-like surface.

After development of products, we conducted luminous performance test. And we examine luminous performance of each lamp shade.

For further development, we have to study more about luminous performance of materials for both modeling and painting. And also we have to study more about modeling products which are strong enough against heat damage.

NOTE

'Refracting Mobius Loop' was selected at the 2rd Digital Modeling Contest by Japan Society for Graphic Science.

'Reflecting Paraboloid Shell' won an excellent prize at the 3rd Digital Modeling Contest by Japan Society for Graphic Science.

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