Design of Circular-shape No-loss Bent Lightpipe with a Novel Transform of Elliptical Form

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ABSTRACT

We provide a novel scheme in designing no-loss bent light-pipe with the help of a transformation of elliptical form on equiangular spiral.

Keywords: Polarization, Light Pipe, Optical Design

1. INTRODUCTION

A light-pipe is an optical element guides light from one place to another with expected performance. Typical applications that are widely used include illumination engines in projectors [1], backlight systems for liquid crystal panels [2], automobile dashboards [3], and headlights [4]. The major, noticeable difference between these light pipes is their shape that manages the performance of light after guided by the pipes. Among a variety of operation of lightpipe, bending a lightpipe is inevitable for many practical applications and it introduces loss (leakage) to the system. How to reduce the bending loss even prevent the loss of leakage while bended in bent light pipes has been one of the important issues in this field. Recently, as illustrated in one paper [5]: No-loss bent light pipe with a shape related to the ***equiangular spiral*** cracks the crux of preventing the bending loss.

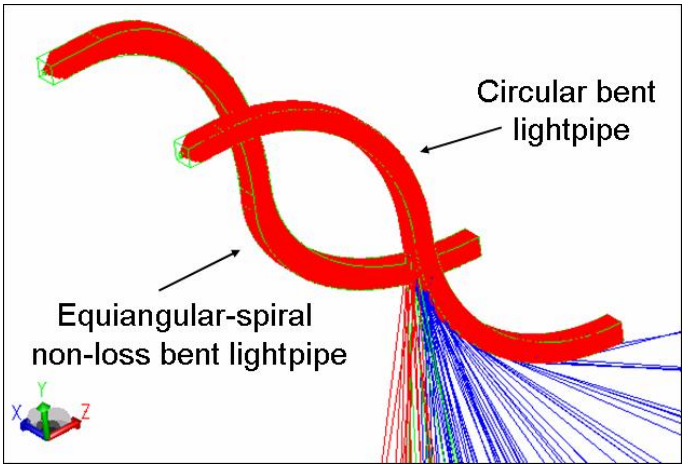

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Fig. 1 Illustration of circular bent light-pipe and equiangular-spiral no-loss bent light in which leakage of ray from circular bent light-pipe could be seen.

It is worthwhile to design more different shapes of the bent light pipe based on the idea of equiangular spiral, if possible. It is because that it may bring us the benefits of preserving source energy, minimizing bend losses, and also to enable the bent light pipe to guide the lights with no limitation on acceptance angle. The major purpose of this paper is to show that there is a novel transform which can help us in creating such a no-loss bent light-pipe.

2. BASIC STRUCTURE OF AN EQUIANGULAR SPIRAL

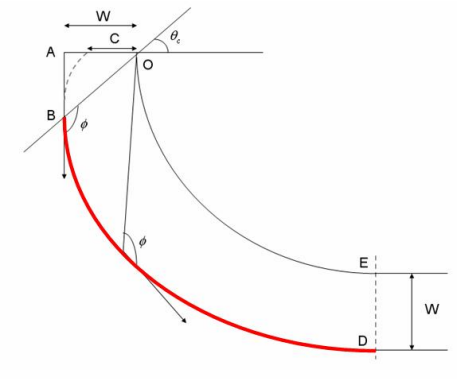

Fig. 2. Proposed no-loss bent light pipe with a multiple factor of m=1.

Let us first make a short review on equiangular spiral. One can construct the model of such a bent light pipe by referring to Fig.2 similarly that shown in Ref. [5]. For a given width of the light pipe W, there is a value of C, we use C_0, such that C_0 follows:

$$C_0 \exp(-\theta_c \cot \phi) = W \sec(\theta_c) \quad (1)$$

The C_0 is the minimum length parameter for the outer equiangular facet can be connected and tangential to the straight facet AB without shift as shown in Fig. 2. Since the length parameter C has the minimum value C_0, we can rewrite the Eq. (1) to be $C = m C_0$, where m is a multiple factor. If $C = C_0$, i.e., m=1, the profile is as that shown in Fig. 2.

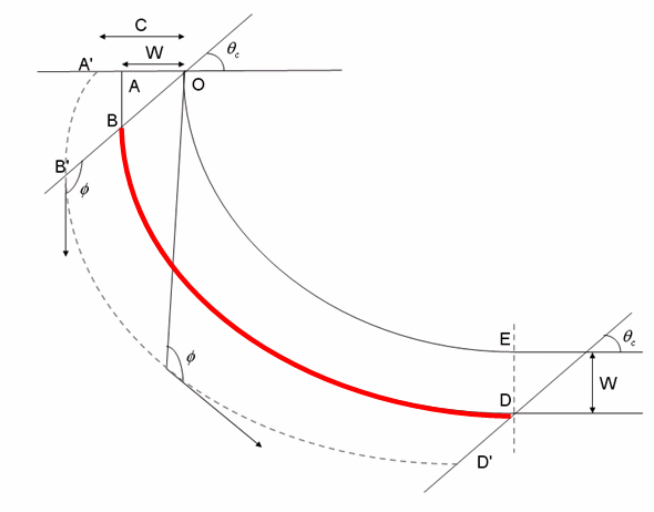

Fig. 3. Proposed no-loss bent light pipe with a multiple factor of m=2.5.

When m is no more equal to 1, i.e., C = m C_0, the actual outer facet curve satisfies equation (1) will be curve B'D' as shown in Fig. 3 where m=2.5. Then we could shift the B'D' curve along the direction of an inclined angle of θ_c with the horizontal plane. To move B' to the position B, D' will be shifted to the position D for this kind of connection in order to satisfy the required width of light pipe W. As that illustrated in Ref. [5], we could choose the inner curve to compliment the condition we mentioned to ensure the size of the entrance port is the same with the existence port.

3. TRANSFOROM BASED ON AN ELLIPTICAL FORM

The shape of the entrance port and the existence port in Ref. [5] is rectangle which means we can only allow four kind of connection between two light pipes, i.e., (1) 0 degree, (2) 90.0 degree, (3) 180.0 degrees, and (4) 270.0 degree which also means that the light pipes are connected in the same direction or in the opposite direction or perpendicular to each other. In other words, the bending is a two-dimensional bending only.

Here we would like to design a no-loss bent light pipe with the circular shape of the entrance port and the existence port. For this shape of ports of light pipe, we can take all kinds of angle to connect two light pipes without the limitation of angle like pipes of ports with rectangular shape. In other words, the bending here is a three-dimensional bending.

The basic idea is simple, i.e., for the intention of circular shape port of pipe, the scarf of the figure of the pipe should be ellipse. Based on this idea, we could build the bent light pipe with surface equation which follows:

$$X(\theta,\phi)=\frac{W_x}{2}+\frac{W_x}{2}\cdot sin(\phi) \qquad (2)$$

$$Y(\theta,\phi)=\frac{1}{2}\cdot[(b+b')-(f_y(\theta)+f_y'(\theta)) +((b-b')+(f_y(\theta)-f_y'(\theta)))\cdot\cos(\phi)] \qquad (3)$$

$$Z(\theta,\phi)=\frac{1}{2}\cdot[(a+a')-(f_z(\theta)+f_z'(\theta)) +((a-a')+(f_z(\theta)-f_z'(\theta)))\cdot\cos(\phi)] \qquad (4)$$

where a = C exp (θ_c tan θ_c) cos θ_c, a' = C' exp (θ_c' tan θ_c') cos θ_c', b = C exp (θ_c tan θ_c) sin θ_c, b' = C' exp (θ_c' tan θ_c') sin θ_c', f_y = C exp ((β +θ_c) tan θ_c) sin (β +θ_c), f_y' = C' exp ((β +θ_c') tan θ_c') sin (β +θ_c'), f_z = C exp ((β +θ_c) tan θ_c) cos (β +θ_c), f_z' = C' exp ((β +θ_c') tan θ_c') sin (β +θ_c'), θ is the inclined angle with the horizontal plane, ϕ is the inclined angle with the Z-axis on X-Z plane. One typical form is shown in Fig. 4.

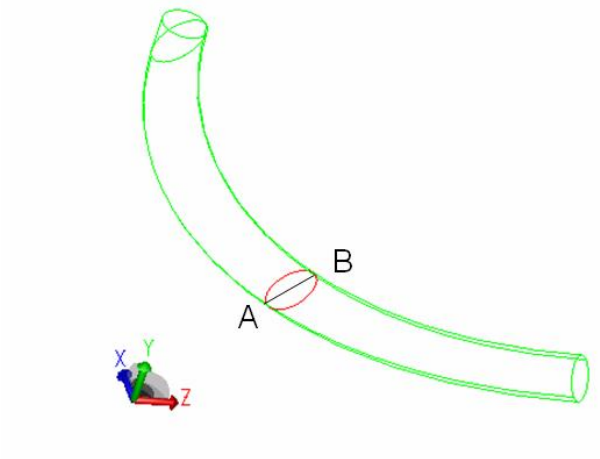

Fig. 4 circular-shape no-loss bent light-pipe

4. THE DIFFERENCES BETWEEN EQUIANGULAR AND ELLIPTICAL-FORM TRANSFORMED SPIRALS

To see the difference between the rectangular no-loss bent light-pipe that developed in Ref. [5] and the circular-shape one proposed here, one could use a cross-section to compare these two kinds of light-pipe. In Fig.5 we show some differences between light pipe with rectangular port and light pipe with circular port by a direct comparison of geometrical forms. Referring to Fig.5 (a), the green lines are curves with ϕ = 0, ϕ =π; the blue lines are the curves with ϕ =5π/3, and ϕ =4π/3 in pipe of circular port; the red lines are curves with the same width of pipe of rectangular port. It is obviously there is no possibility that the red curves can be equal to the blue curves. In Fig.5 (b), the blue curves and the green curves are mentioned already. Although they look similar in Fig.5 (b), but in Fig.5 (c) we can tell they are still different.

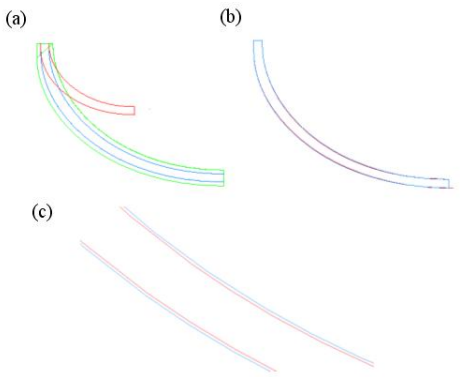

Fig. 5 (a) cross-section comparison between rectangular port and circular port; (b) comparison after shifting the curves; (c) enlarging a port of (b).

5. NUMERICAL EXPLORATIONS

In this section, we provide several numerical examples. The simulation package is TracePro (version 3.2.5), which is commercially available. To prevent confusion; the return beam rays from the final exit surface are not shown in the simulation result means the output facet is set as a perfectly absorbed surface. We set the index of refraction with a wavelength of 0.5461 μm to be 1.4935 and the Lambertian-like source emits 50000 rays with an angular distribution of –90.0 degrees to 90.0 degrees.

One can find that there is no loss of leakage of rays for all six examples. Different incident angles with 60 and 120 degrees are provided to demonstrate the advantage of circular shape no-loss bent light-pipe in comparing the rectangular equiangular spiral.

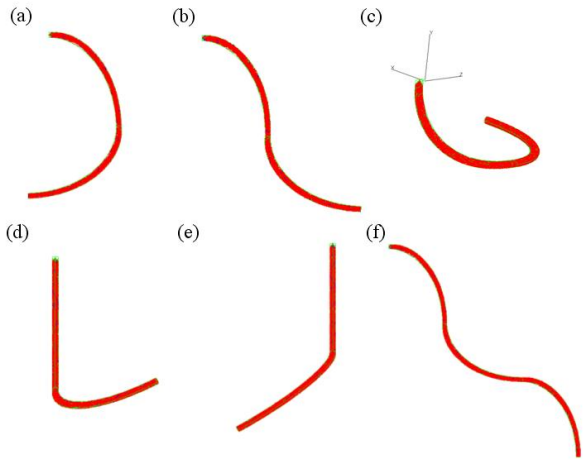

Fig. 6. Circular-shape no-loss bent light pipes: Two no-loss bent light pipes are connected (a) in opposite directions, (b) in the same direction, (c) perpendicular to each other, (d) inclined angle 60.0 degrees, (e) inclined angle 120.0 degrees with the longitudinal direction of pipe, and (f) three no-loss bent light pipes are connected in opposite directions

6. CONCLUSIONS

It is worthwhile to note that the ray guiding in the equiangular spiral, of rectangular port can be lossless, but the connection of two pipes has limitation. In short, the pipe of rectangular port limits the bending in 2-dimension while lights propagating. On the other hand, the pipe of circular port banishes the limitation of pipe connection which means we can connect two light pipes with any angles between the longitudes of one of light pipe. Hence, the lights guided in the light pipe of circular port can be bent in a 3-dimensional way.

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