COUPLING COEFFICIENT PARAMETRIC FOR POWER TRANSIENT FUNCTION

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ABSTRACT

Fiber coupler are passive devices in which there is no control over phenomena, with a wide range of parametric changes occurring during fusion due to the fact that the coupled fiber are affected by heating. A simulation of power propagation is developed to describe the effect of power flow to coupled fibers which continuously propagates from one fiber into the second fiber. In order to explain these phenomena, characteristics of power speed and power acceleration are examined. In this research, power splitting into the second fiber junction that moving along fabrication will be developed by deriving the coupling power depending on times. The model is examined using single mode fiber with linearly change of refractive index. This simulation results shown the power speed and acceleration are accumulated by time evolution.

Keywords: *Single mode fiber, Power propagation, Coupling power*

INTRODUCTION

Development and fabrication of single-mode fiber (SMF) coupler widely expand both for a tunable filter or optical waveguide switch in a sense that the coupling fiber can be used for multipurpose in telecommunication. Waveguide fiber fabricated is to control and to apply power propagation from one fiber to another by splitting it at a junction. However, the coupling fiber fabrication has complicated problem since the power is affected by geometry of the fiber [1,2]. Optical fiber fusion coupling is the process by which a permanent, low loss, high strength, welded joint is formed between two optical fibers. The ultimate goal for this is to create a junction with no optical power loss yet with mechanical strength and long term reliability [3,4]. The optical loss and reflectance of fusion coupling are typically much lower than alternative optical fiber connecting technologies. In order to investigate the fiber coupling in terms of the reliability, the power propagation is a dominant effect to evaluate it during fabrication. Power transient on SMF, where the coupling power depends in time is simply derived and substituted from function of position where the initial velocity of moving fiber are known. The coupling power is then a function of time for the first and second derivative will be depicted.

COUPLING POWER DIRECTION MODEL

We begin with wave propagation in cylindrical waveguide for medium is assumed isotropic, linear, non-conducting, non-magnetic but inhomogeneous. The wave equation is as follows [7]

$$\nabla^2 \mathbf{E} + \nabla\{(1/\varepsilon_r)\nabla(\varepsilon_r)\,.\,\mathbf{E}\} - \mu_o\varepsilon_o\,\partial^2\mathbf{E}/\partial t^2 = 0$$

The wave equation of electric field vector $\boldsymbol{E}$, where $n=\sqrt{\varepsilon_r}$, is similar for magnetic field $\boldsymbol{H}$, where it changes to scalar Ψ as

$$\nabla^2\Psi = \varepsilon_o\mu_o\, n^2\, \partial^2\Psi/\partial t^2 \qquad (1)$$

Based on electromagnetic theory, we determine the electric and magnetic field of guided waves that satisfy Maxwell's Equations and obey the boundary conditions imposed by the cylindrical dielectric core and cladding of the fiber. Each component of the electric and magnetic field must satisfy the Helmholtz Equation given by a scalar component,

$$\nabla^2\Psi + n^2k^2\psi = 0 \qquad (2)$$

Since the refractive index is cylindrically symmetric, Helmholtz Equation can be written as,

$$\frac{d^2\psi}{dr^2} + \frac{1}{r}\frac{d\psi}{dr} + \frac{1}{r^2}\frac{d^2\psi}{d\phi^2} + n^2k^2\psi = 0 \qquad (3)$$

Solving this equation for an ideal step-index fiber under the weakly guiding approximation [6], gives a set of solutions,

$$\Psi(r,\varphi,z,t) = R(r)\, e^{il\varphi}\, e^{i(\omega t - \beta z)} \qquad (4)$$

where $R(r) = \begin{cases} A\,J_l\,(ur/a) & \begin{cases} \cos(l\,\varphi)\,;\, r<a \\ \sin(l\,\varphi)\,;\, r<a \end{cases} \\ B\,K_l\,(wr/a) & \begin{cases} \cos(l\,\varphi)\,;\, r>a \\ \sin(l\,\varphi)\,;\, r>a \end{cases} \end{cases}$

A and *B* are constant, J_l *and* K_l are Bessel and Hankel functions (the second kind of modified Bessel function), where the solution depends upon normalized lateral phase constant (*u*), and normalized lateral attenuation constant, (*w*) for modes *l* (0,1,2,…). The Bessel functions $J_l\ (ur/a)$ are oscillatory in nature, and hence there exists *m* allowed solutions (corresponding to *m* roots of J_1) for each value of *l*. Thus, the propagation phase constant β is characterized by two integers, *l* and *m*. *k* is the wave number. The value of β_m is calculated from the normalized propagation constant b, which is equal to $(\beta^2_{lm} - \beta_2)/(\beta_1 - \beta_2)$. Thus the total power can be written as [7],

$$P_{total} = C\pi a^2 (V^2/u^2)\left[\frac{K_{l-1}(w)K_{l+1}(w)}{K_l^2(w)}\right]$$

where

$$\left.\begin{aligned} u^2 &\equiv (k^2 n_1^2 - \beta_{lm}^2)a^2 \\ w^2 &\equiv (\beta_{lm}^2 - k^2 n_2^2)a^2; \quad \beta_1 = kn_1 \;;\; \beta_2 = kn_2 \\ V &= (u^2 + w^2)^{1/2} = (2\pi a/\lambda)(n_1^2 - n_2^2)^{1/2} \end{aligned}\right\} \quad (5)$$

Total power is equal to initial power, $P_{total} = P_o$. When power splits at Y junction of coupled fiber there exists two propagation power which is respectively coupling and transmission power shown below,

$$P_{total} = P_o \sin^2 \kappa z + \cos^2 \kappa z \quad (6)$$

Since other power will be loss, then it can be written,

$$\sum P = \text{Constant},$$

$$\sum \frac{dP}{dt} = 0 \quad \text{and}$$

$$\sum \frac{dP}{dt} \neq 0 \quad (7)$$

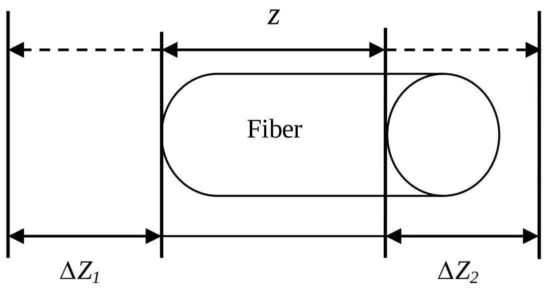

Fig. 1. The fiber length (Z) after moving to other length (ΔZ).

Consider z is length of fiber, and the moving fiber is similar to both sides, which is $\Delta Z_1 = \Delta Z_2$ and $\Delta Z = \Delta Z_1 + \Delta Z_2$.

Total z is $Z_{total} = Z + \Delta Z$ at the coupling region and proportional to $v + \Delta v$. the coupling power can be calculated from time dependence,

$$P_{coupling} = P_o \sin^2 (\kappa z) \quad (8)$$

Where κ is coupling coefficient and z is propagation direction.

The power speed at coupling length can be simply derived from equation (8) and results $10^{-4} P_o \sin 2 \times 10^{-4} t$ where $z = 10^{-4} t$ at $z \leq C_L$ and the time is from 0 to 60 second. Z keeps moving even the coupling ratio preset is achieved about 75second. This implicitly describes that the fiber coupler keeps moving within 15second although the fiber set up has been completely reached at the present value. This is due to the effect of heating while the coupling power remain to propagate with different geometry in radius and length.

The power acceleration, P_{ac} can be shown as follows,

$$P_{ac} = \frac{d}{dt}\left(\frac{dP}{dt}\right) \tag{9}$$

Where the power propagates in cylindrical coordinate, speed of power is faster than the acceleration of power before forming the coupling length, $\left|\frac{dP}{dt}\right| \rangle \left|\frac{d^2P}{dt^2}\right|$ and the power after reaching complete the coupling ratio, $\left|\frac{dP}{dt}\right| \langle \left|\frac{d^2P}{dt^2}\right|$. This effect is due to mechanical process where the fiber are strongly heated and change their properties. Along the length of path, the moving fibers for coupling is about 100μm/second while the refractive índices changes are by factor 10^{-3} from higher to lower indexe even the moving fiber after reaching complete coupling ratio $z \geq C_L$.

POWER AND COUPLING COEFFICIENT

Power speed and acceleration at coupling length are influenced by fiber movement. Speed of power changed for geometrical and mechanical fabrication of fiber coupling. The refractive index is low due to heating to achieve the preset of coupling ratio.

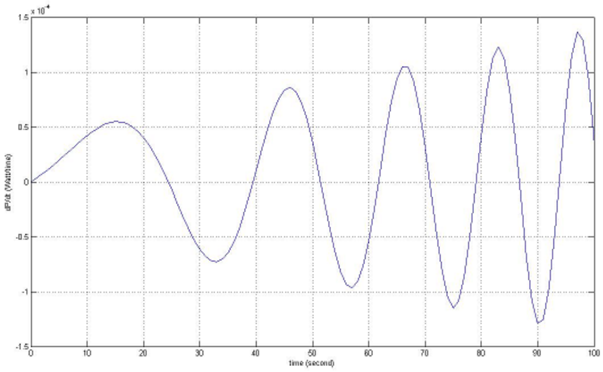

Fig. 2. Power speed at coupling length.

From the Fig. 2, describe the initial coupling power propagates along fiber two. At early condition, power speed is zero and increase significantly from 40 second. As the coupling length stretches, power speed increase partially to the second fiber until 75 second shown experimentally and continues to 100 second computationally. This effect is caused by the difference of refractive index starting at 40 second to both cores and cladding.

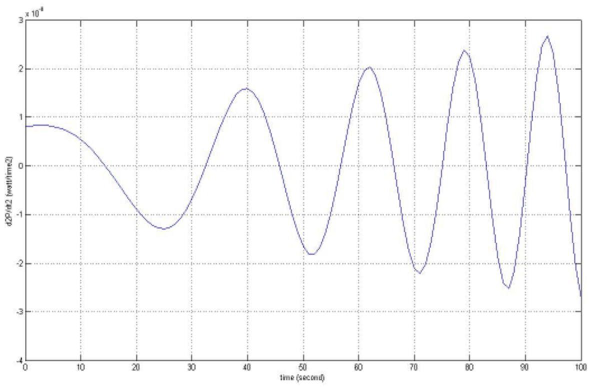

Fig. 3. Power acceleration at coupling length.

Unlike the power speed, the power acceleration starts nearly at 1 watt/s. at 40 second, the power acceleration reaches the peak earlier and keeps continuously going up by time. The refractive index starts lower than

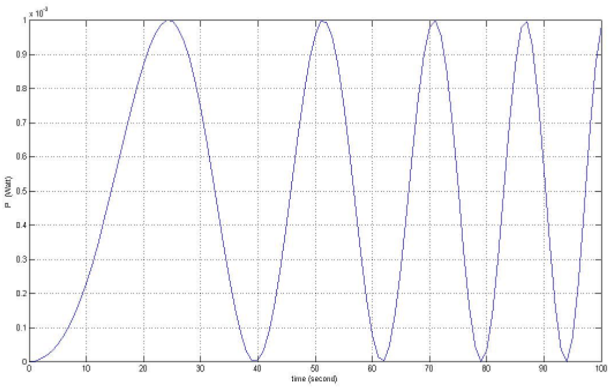

Fig. 4. Power transient along fiber

Assume there are no power losses during propagation along fiber, and then power propagation to second fiber can be shown in Fig. 4. Power periodically oscillates faster along the time and starting from 40second. The peak continuously constant but the oscillation effect is more frequent as a result of coupling coefficient increase.

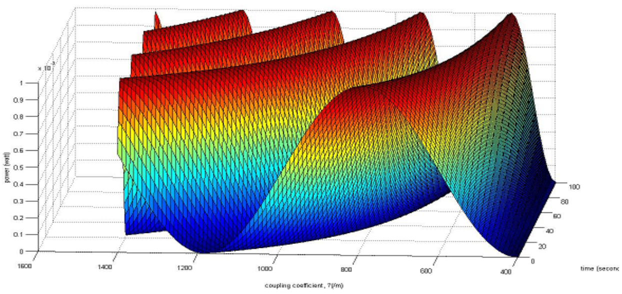

Fig. 5(a) Power versus Coupling Coefficient

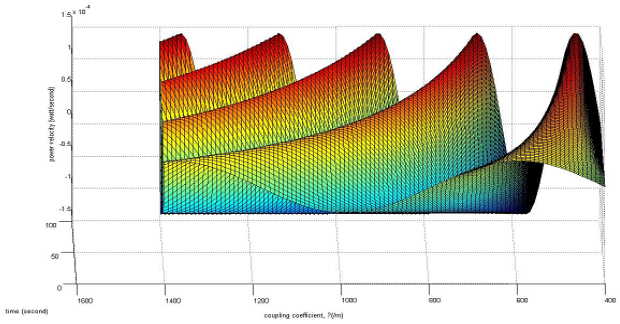

Fig. 4(b). Power Velocity versus Coupling Coefficient

When coupling power is a function of the time, the coupling coefficient experimentally from 800 to 1200/mm leads to control power flux sinusoidal as shown in figure 5(a). The more coupling coefficient is achieved, the more frequent power propagates periodically together with a lower refractive index at coupling length. This is expected that the power is proportional to the lower refractive indices changes.

Figure 5(b) shown that when the time is long, the coupling coefficient will increase as linearly as the refractive indices. The increasing time can produce the high coupling coefficient as far as power speed concerns.

CONCLUSION

The power speed and power acceleration at coupling length have been successfully described and predicted to the experimental results with a transient condition when coupling length slightly more during fiber coupling. The calculation shows some of the coupling power is affected by small amount of fiber movement along coupling length by factor 10^{-4}m/s. This condition can be used for various coupling length as long as the refractive indices differences are not large.

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