Microbend in an SMS Fiber Structure

Fitri Rahmah[1], Sekartedjo[1], Agus Muhamad Hatta[1]

***Abstract* – We present a numerical and experimental model of microbend in an SMS fiber structure. We obtain the numerical model by using several boundary conditions in SMS fiber structure. These conditions divided into transmission of light in a straight multimode fiber and in a bend multimode fiber. The microbend in multimode fiber affects the radius of curvature of the fiber. Thus, causes radiation several modes and then re-distribution of guided modes. The guided modes itself will vary in MMI and bring out different output power. The numerical result compare well with the experimental result from variation of the radius of curvature of the fiber (R) and the arc length.**

***Index Terms* – microbend, SMS, MMI.**

Introduction

The demonstration of singlemode-multimode-singlemode (SMS) fiber optic as sensor has been developed for many years. For sensing element, self-imaging formation and multimode interference (MMI) are the key parameters in the SMS fiber sensor [1]-[3]. Self-imaging is a waveguide phenomenon in which the input light profile is reproduced in a periodic interval along the propagation of light [4]. The field input of singlemode lead-in in SMS fiber structure will be the same with the output of singlemode lead-out if the length of multimode fiber is the same as the re-imaging length. When perturbation such a microbend is applied in the SMS fiber structure, it causes re-distribution of light along the fiber, then changes its intensity or loss. Loss caused by microbend is due to the coupling of the highest guided mode to the radiated modes [5]. The total of guided mode caused by microbend depends on the radius of curvature of the fiber. The formula for the effective number of guided modes is presented by a curved fiber formula [6]. A model about microbend in SMS fiber structure has not developed yet, but a formulation of transmission of light in straight SMS fiber structure has been presented by Kumar [7]. In this paper, we formulate the microbend SMS by using the light transmission formula in straight SMS fiber structure [7] and taking into account the effective number of guided modes due to the microbending as in [6].

Method

In our model as in Figure 1, there are several boundary conditions when the microbend is applied to the SMS fiber structure. By using a modal propagation analysis [7], the field profile (ψ) at the boundary can be written as in the equation (1)

$$\Psi_k = \Psi_{k+1} = \sum A_m \Psi_{km} e^{-i\beta mLk} \qquad k = 1,2 \qquad (1)$$

Where A_m is the amplitude of the mth mode of the multimode fiber, βm is the propagation constants of the mth symmetric mode, and L is the length of the multimode fiber section.

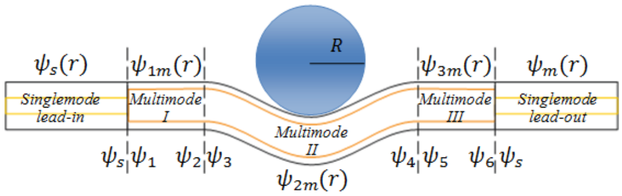

Figure 1. The boundary conditions along SMS fiber structure due to microbend

At the first splice between singlemode lead-in and multimode section I, the power will couple to various modes in the multimode fiber. In order to obtain the amplitude of the mode (A_m), we can calculate the overlap integral between field profile in boundary condition respectively as in

$$A_m = \frac{\int_0^\infty \psi_s \psi_m r dr}{\int_0^\infty |\psi_m|^2 r dr} \qquad (2)$$

In the section II, the presence of microbend with a radius R affect the fiber radius of curvature and the total number of guided modes [6] as in

$$\mathrm{m_b} = \mathrm{m}\left\{1 - \frac{\alpha+2}{2\alpha\Delta}\left[\frac{2a}{R} + \left(\frac{3}{2n_1 kR}\right)^{2/3}\right]\right\} \qquad (3)$$

Where m_b is the total of guided mode caused by microbend, α is the refractive index profile, Δ is the refractive index difference, and R is the radius of curvature of the fiber. The changes of the total number of guided modes will affect the propagation constants (β_{mb}) as in the equation (4). These values are used to compute a new field profile as in the equation (1).

$$\beta_{mb} = kn_1\left[1 - \frac{2(2m_b+1)\alpha_{m_b}}{k^2 n_1^2}\right]^{1/2} ; m_b = 0,1,2,\ldots \quad (4)$$

At the last splice, the power between multimode section III and singlemode lead-out fiber will couple from various modes of the multimode fiber to the lead-out singlemode fiber. The output power can be calculated by using equation (5).

$$P_{(dBm)} = 10 \log_{10} \frac{\left|\int_0^\infty \psi_s \psi_6(z=L3) r dr\right|^2}{\int_0^\infty |\psi_6|^2 r dr \int_0^\infty |\psi_s|^2 r dr} \qquad (5)$$

Result

In Figure 2, it is shown the numerical result of our model. One can see in Figure 2, the output power varies with the radius of curvature (R) and the arc length in the unit of circumference ($2\pi R$). Microbend leads to change the number of R and the arc length. Thus, causes radiation several modes and then re-distribution of guided modes. The guided modes itself will vary in MMI and bring out different output power. It is also presented the experimental result of the transmission of SMS fiber structure due to microbend. The experimental result show a different

[1]Fitri Rahmah, Sekartedjo, Agus Muhamad Hatta are with Department of Engineering Physics, Faculty of Industrial Technology, Institut Teknologi Sepuluh Nopember, Surabaya. Email: fitri.rahmah09@mhs.ep.its.ac.id; sekartedjo1@gmail.com; amhatta@ep.its.ac.id.

output power as a function of radius of curvature of the fiber (R) and the arc length.

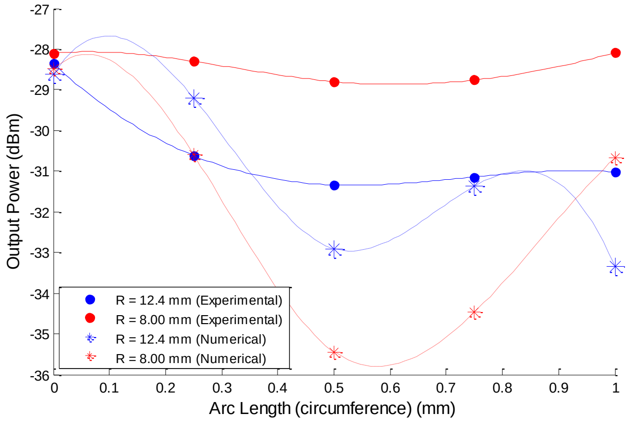

Figure 2. Variation of normalized output power as a function of radius of curvature (R) and arc length in SMS fiber structure

The linkage between numerical and experimental results can be tested by using the principle of correlation and covariance. Correlation is a relationship between data, which is can be measured by a value called the correlation coefficient. Covariance show the association between the two variables. The numerical and experimental results for radius of microbender 12.4 mm show a strong correlation at 0.9916 and also give a positive covariance value. It also happen in radius of microbender 8.00 mm, where the results of numerical and experimental testing show a strong correlation value at 0.9830 and the value of covariance is positive. The positive covariance value indicates that the variables vary in the same direction. The numerical and experimental results show a satisfactory agreement. Future work will consider the use of this structure for sensing element.

CONCLUSION

We have developed a numerical model for microbend in SMS fiber structure. The model resolved using the boundary condition of the transmission in the straight SMS fiber and the transmission in the bend SMS fiber. The transmission in the bend SMS fiber causes radiation several modes and makes different output power. A comparison to the numerical model are done experimentally and show a good agreement.

REFERENCES

[1] Mehta, et al.," Multimode interference-based fiber optic displacement sensor," *IEEE Journal & Magazines of Photonics Technology Letters*, vol. 15, pp. 1129 – 1131, 2003.

[2] Q. Wang and G. Farrell, "All-fibre multimode-interference-based refractometer sensor: proposal and design,"*Optics Letters*, vol. 31, pp. 317 – 319, 2006.

[3] E. Li, X.Wang, and C. Zhang, "Fiber-optic temperature sensor based on interference of selective higher-order modes,"*Applied Physics Letters*, vol. 89, 091119, 2006.

[4] L. B. Soldano and E. C. M. Pennings, "Optical multi-mode interference devices based on self-imaging: principles and applications," *IEEE Journal of Lightwave Technology*, vol. 13, pp. 615 – 627, 1995.

[5] Nicholas Lagakos, et al., "Microbend Fiber Optic Sensor," *Applied Optics*, vol. 26, pp. 2171 – 2180, 1987.

[6] D. Gloge, "Bendding loss in multimode fibers with graded and ungraded core index," *Applied Optics*, vol. 11, pp. 2506 – 2513, 1972.

[7] Arun Kumar et al.," Transmission characteristics of SMS fiber optic," *Optics Communications*, vol. 219, pp. 215 – 219, 2003.