Spatial Mode Dispersion Control in a Coupled MCF using High Density Cabling Parameters

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Abstract: Spatial-mode dispersion (SMD) of a coupled multi-core fiber is controlled with cabling parameters for the first time. An SMD coefficient of 1.5 ps/√km is achieved by optimizing the bundle pitch and tension in the cable. © 2020 Author(s).

1. Introduction

Multi-core fiber (MCF) is one of the attractive transmission media for increasing the transmission capacity in a limited cabling space. MCF can be categorized as non-coupled or coupled type. Non-coupled MCF is designed so that signals transmitted through each core are not degraded by inter-core crosstalk. This requires a relatively larger core pitch. Coupled MCF is designed to compose a super-mode by controlling the coupling condition of neighboring cores. Thus, the coupled MCF intrinsically realizes higher spatial density [1, 2] although it needs multiple-input multiple-output (MIMO) equalizer. One of important issue with coupled MCF is the management of spatial mode dispersion (SMD) since it closely relates with the MIMO complexity and limitation in transmission distance. SMD coefficient in a loose tube cable was experimentally investigated [3], and the lowest SDM coefficient of 2.5 ps/√km was observed in an installed loose tube cable link [4]. However, it has been reported that SMD closely depends on bending and twisting conditions [5, 6]. Thus, it is important to clarify the influence of cabling structure on SMD and control whose property by optimizing the cabling parameters.

In this paper, we investigate the controllability of SMD coefficient in a high density optical cable using rollable optical fiber ribbon [7, 8]. We experimentally reveal that bending and twisting conditions in an optical cable can be controlled by means of bundle pitch and tension of a rollable optical fiber ribbon. We successfully control the SMD property in a high density cable and obtained a coefficient of 1.5 ps/√km based on our proposed cable design.

2. Cabling parameters for controlling SMD

Figure 1 shows our discussion model for controlling the bending and twisting conditions in a high density optical cable using a rollable optical fiber ribbon. Figure 1(a) shows cross sectional image of a 200-fiber cable. This cable is composed of fifty 4-fiber rollable optical fiber ribbons, strength members, rip cords and a polyethylene sheath. The cable has ten fiber-units containing five rollable optical fiber ribbons, and each unit is stranded. The outer diameter is 11.5 mm. The fiber density is 1.9 fiber/mm^2. Figure 1(b) shows a longitudinal image of a fiber-unit, and which is bundled with tape as shown with red line.

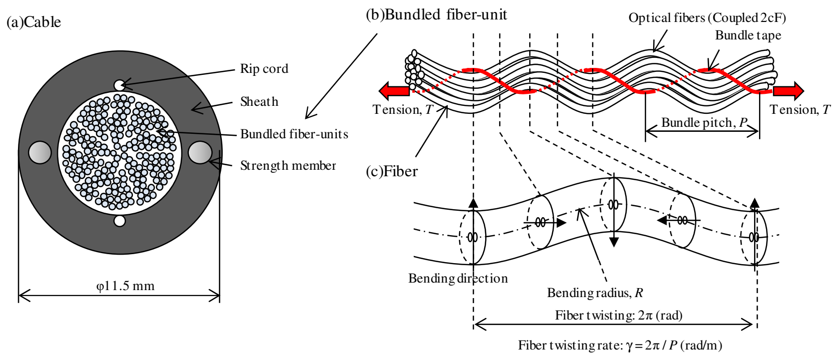

Fig. 1 Cabling parameters for controlling fiber bending and twisting.

By winding the bundle tape around the fiber-unit with bundle pitch P and tension T, the bundled optical fiber in the fiber-unit is simultaneously deformed into a helical shape as shown Fig. 1(c) schematically. This deformation enables to vary the bending radius R and twisting pitch γ. It has been pointed out that an SMD coefficient of coupled MCF varies with R and γ [2].As a result, it is expected that we can control the SMD coefficient in a high density optical cable by optimizing P and T.

3. Experiments and discussion

We used a coupled 2 core fiber (2cF) composed of two step index type cores whose core pitch was about 20 µm. Figure 2 shows the measured R applied to the optical fiber in the bundled fiber-unit. R value can be calculated as $R = \{r^2 + (P/2\pi)^2\} / r$ [9]. Here, $r = (D - d) / 2$ denotes a helical radius, d and D are fiber-unit diameter and outer diameter of deformed fiber-unit, respectively as shown Fig. 2(b). D was directly measured with a micro gauge. Horizontal axis shows relative value which is normalized with a value at which we used in a conventional high density cable. Green, red and blue symbols show the results obtained when P was set at 30, 60, and 100 mm, respectively. Here, P = 30, 60, and 100 mm respectively corresponds to $\gamma$of 20π, 33.3π, and 66.7π. The photo in Fig. 2(a) shows the measured sample of the fiber unit with P = 30 mm and a relative T at 1.

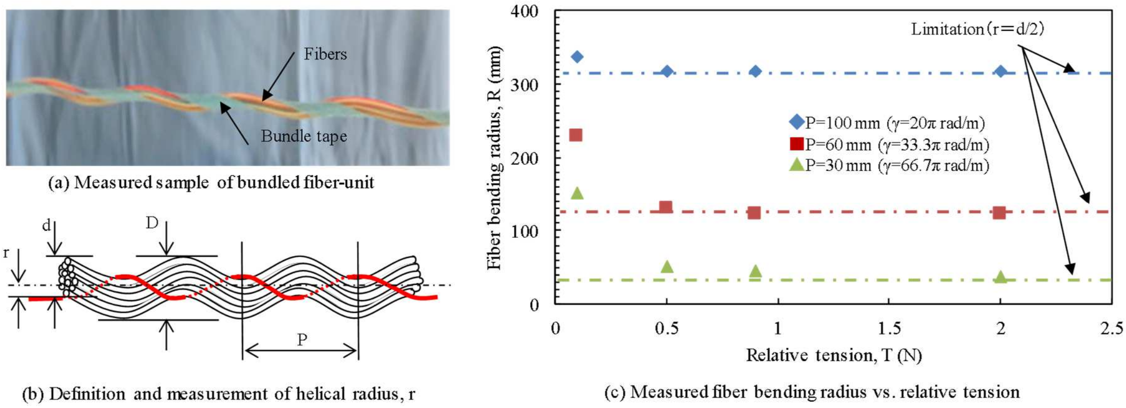

Fig. 2 Relationship between bundled fibre-unit parameters (P and T) and fiber bending radius R.

Figure 2 shows that R tends to decrease and saturate to a particular level shown with dash-dotted lines when sufficient tension is applied. This is because the bundle tape is straightened at a larger tension and r value convergence to a half of the fiber-unit diameter d. d = 1.5 mm in our experiments. As a result, Fig. 2 confirms that R and γin our fiber-unit can be controlled with P and T.

We then fabricated a four 1.2 km long 200-fiber cables. Coupled 2cFs and conventional single-core fiber (ScF) are installed in each cable. 2cFs are installed in different fiber-units in the cable. Here, cable A is a typical high-density cable. We set P at 60 mm as constant, and set the relative T at <0.3, 0.5, 1 and 2 for cable A, B, C and D, respectively. In order to confirm the fiber deformation in the fabricated cable, we measured 3D-fiber-position using X-ray computed tomography (CT) images obtained at a cable cross-section [10]. In order to fix the fibers position during the CT measurement, we injected epoxy resin into the cable core of a 300 mm long sample. Once the resin had hardened, we measured thousands of cross-sectional CT images. Figure 3(a) shows the measured example of the cross sectional absorption coefficient image along the sample. Figure 3(b) shows the measured locus of an optical fiber in the cable C. Left and right, in Fig. 3(b) show the results measured in the orthogonal axis. Solid and dashed lines corresponds to measured and fitting results, respectively. Figure 3 confirms that helical deformation was well maintained in the cabled fiber-unit, and whose measured P value of 60.2 mm agrees well with the designed one.

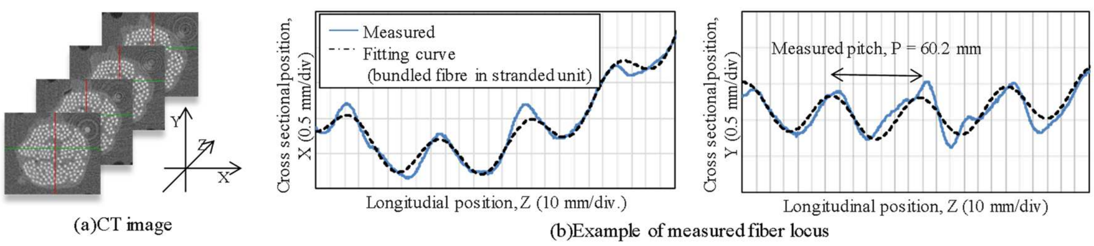

Fig. 3 Measured example of (a) CT image, and (b) fiber locus in the cable C (P = 60 mm at a relative T of 1).

We then examined the optical property of fabricated cables. Figure 4 (a) shows cabling loss increase (filled and open circles) and SMD coefficient (triangles) measured at 1550 nm. Here, the cabling loss increase corresponds to the loss difference between cabled and uncabled optical fibers. It can be seen from Fig. 4 that the loss of both 2cFs and ScFs are degraded in the cable D. We consider that the larger tension than the conventional high density optical cable resulting in an increase in macro and/or micro bending loss. Figure 4 also confirms that cables A, B and C have no significant loss increase. The optical loss of coupled 2cFs assembled into cable C was 0.23 dB/km at 1550 nm, and 0.22 dB/km at 1625 nm on average. For comparison, that of ScFs was 0.19 dB/km at 1550, and 0.22 dB/km at 1625nm. Thus, it can be considered for the cabling loss increase of 2cF that we can expect similar dependency on P and T with that in the conventional ScF. As for the SMD coefficient, we used the conventional fixed analyzer method which is used for measuring polarization mode dispersion [11]. We derived the Fourier transformed data using the measured interference spectrum. Figure. 4 (b) shows example Fourier transformed data obtained with the cable C. Red and black lines show the measured and Gaussian fitted results, respectively. It can be seen from Fig. 4 (a) that SMD coefficients tend to decrease as increasing the T. Average value of SMD coefficients measured with cables A, B, C and D shown with solid lines are 5.3, 3.2, 2.5 and 2.2 ps/√km, respectively. Thus, it is confirmed that cable C can reduce the SMD coefficient 47 % against the cable A while keeping the feasible cabling loss increase property.

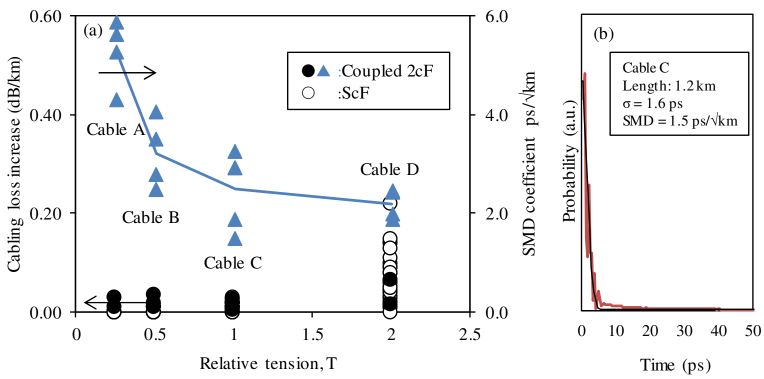

Fig. 4 Cabling loss increase and SMD coefficient as a function of relative tension measured at 1550 nm.

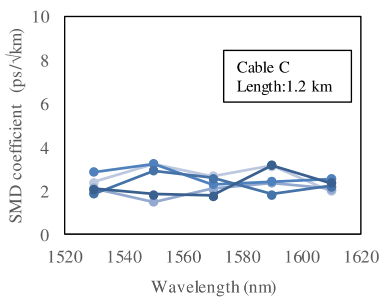

Fig. 5 Wavelength dependence of SMD coefficients measured with cable C

Figure 5 shows the wavelength dependence of SMD coefficient of cable C. Each plot show the result obtained with different 2cF in the cable C. It is confirmed that SMD coefficients of five cabled 2cFs are successfully controlled in the wide wavelength range of 1530-1610 nm. We also observed that there was no degradation in Q factor and mode dependent loss values between back to back and a 1.2 km long cable transmission by conducting a 1.25 Gb/s QPSK 4 × 4 MIMO transmission experiment using cable C. These results reveal that the SMD coefficient of a coupled MCF can be controlled in terms of high density cabling parameters such as bundle pitch and tension.

4. Conclusion

We revealed that SMD coefficient of coupled MCF can be controlled using the high density cable parameters such as bundle pitch and tension for the first time. We achieved the lowest SMD coefficient of 1.5 ps/√km in our knowledge while keeping the negligible cabling loss increase by optimizing the pitch and tension values in the cable. We believe that SMD characteristic controlled optical cable greatly supports to make progress on space division multiplexing based long-haul and large capacity transmission.

5. References

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