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# Laser Speckles from Multimode Fiber under Scrambling

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**Abstract.** When a laser beam transmits through a multi-mode fiber, speckles show in the output beam. In this work, we study the laser speckle under static and dynamic scrambling by the histogram and line profile of far-field pattern. The results show that static scrambling has little effect on the intensity distribution. The dynamic scrambling reduces the speckles without changing the line profile. Two possible explanations are proposed.

**Keywords.** scrambling, laser, multi-mode fiber.

## 1. Introduction

Nowdays laser is widely used in modern astronomy (Arrue 2005). Unlike the incoherent light, the laser transmitted by fiber shows speckles in the far field because of interference between guided modes (Goodman 2006), worsing the beam uniformity. In order to reduce the speckle phenomenon, many works have been done such as using dispersing element to create a variation in optical length (Lehmberg 1987), dividing the laser pulse into a series delay lines (Michaloski 2001), and using acousto-optic modulator to change the polarization state and angel of divergence (Kotov (2001). The most used method is vibrating the fiber in high frequency in order to provide mode coupling and phase modulation (Kajenski (1992). Unfortunately, the number of guided modes in multi-mode fiber is very large, so there is no simple mathematical model describing the laser speckle generation. In this work, we show the experiment results about the laser speckles under static and low frequency dynamic scrambling.

## 2. Experimental

In our experiment, the laser beam is from a THORLABS LP635 pigtail fiber laser diode, and a SIGMA 10X object lens couples the laser beam into a 3 m long, 300 $\mu$m core diameter, plastic fiber after collimating. The incident beam locates at the center of the fiber with 50 $\mu$m spot size. Looking through a beam splitter, CCD1(HV1351UC, $1024 \times 1280$ pixels) monitors the input end of the fiber. A second CCD, (CCD2, similar to CCD1) records the far field pattern 6 mm away from the output end of the fiber. The experiment setup is shown in Fig. 1. Under dynamic scrambling, the fiber is vertically vibrated with an amplitude of 5 mm, and in the static case, the minimum bending radius of fiber is 12 mm. The line profile through the beam center and the intensity histogram of the whole beam are used to describe the beam.

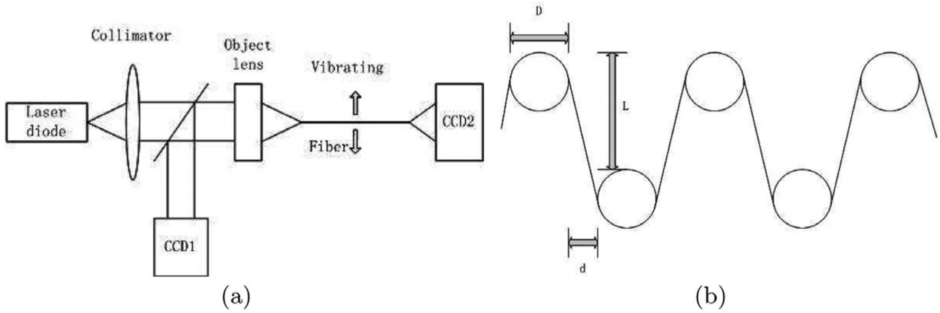


**Figure 1.** (a) Experiment setup, (b) Static srambler: D = 24.8 mm, d = 71.7 mm, L variable.

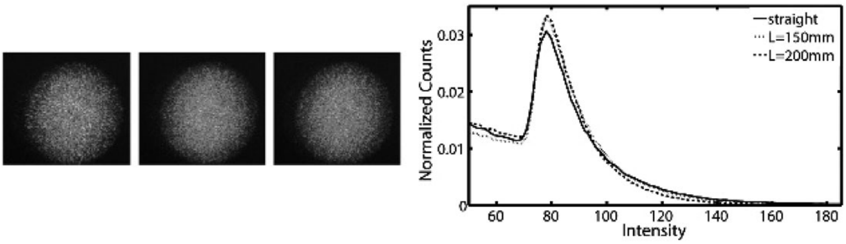


**Figure 2.** Far-field pattern under static scrambling, from left to right, L = 150 mm, L = 200 mm and the normalized intensity distribution

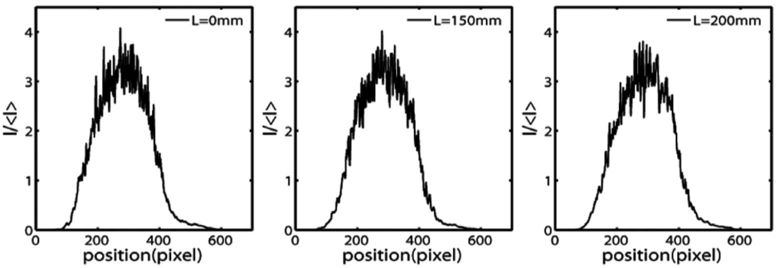


**Figure 3.** Line profile under static scrambling

## 3. Results and Discussion

*Static scrambling*. According to Todd (1992), under incoherent light condition, the bend of fiber provides the mode coupling, inducing the exchange of power between different modes, resulting the variation of the intensity profiles across the fiber cross-section. Our results (Fig. 2) show that under static scrambling, the counts of intensity undergo minor changes, and the line profile (Fig. 3) hardly changes under static scrambling. One explanation might be that the static scrambling affects the distribution and intensity of speckles, but it has little effect on the distribution of guided modes. Another explanation might be that the distribution of guided modes changed but the changes of speckles offset it.

*Dynamic scrambling*. The frequency of the driving signal changes from 5 Hz to 30 Hz while the amplitude remains constant. Figure 4 shows the far-field pattern when the uniformity is much better comparing with static scrambling. As the pattern recorded on CCD is an integration of the intensity in time domain, it can be expected that under vibrating, the counts of intensity in low and high regions decrease and in the middle parts they increase due to the drift of speckles, as shown in Fig.5(a). One unique phenomenon is

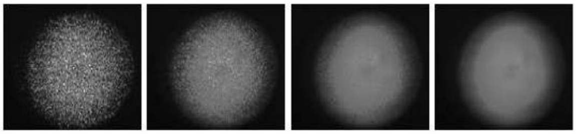

**Figure 4.** Far-field pattern in different frequency vibrating, from left to right: 0, 5, 10, 30 Hz

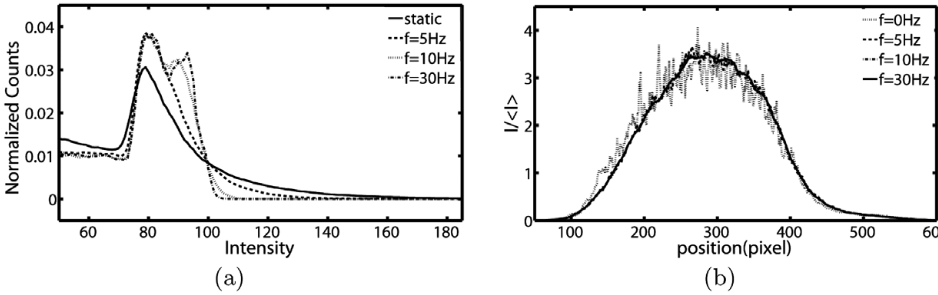


**Figure 5.** (a) Normalized intensity distribution. (b) Line profile under vibrating

that when the frequency increases, low intensity part (below 90) hardly changes, but the high region (100-120) decreases and a minor peak forms in 90-100 region, indicating that power exchange only happened beyond some level. Meanwhile, the line profile still hardly changes (Fig. 5(b)). For Figure 5, one possible explanation is that scrambling changes the distribution of guided modes and intensity distribution of speckle simultaneously, and the variations of them offset each other, inducing the line profile varying little.

*Off-axis and defocus*. We also analyzed the far-field pattern under the off-axis and defocus condition. The results show the same tendency as the central incidence, only the scrambling effects are a little bit stronger.

## 4. Conclusion

From our experiments, we found that the line profile hardly changes under scrambling. In the vibrating case, there was a power exchange but only happened at the intensity beyond some level. It is still hard to tell if the changes of intensity distribution is due to the mode coupling or the speckle changing. Further works need to be done to explore the relation between mode coupling and speckle changes.

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