External Optical Feedback Induced Noise in DFB Fiber Laser Sensor System

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Abstract—External optical feedback effects due to reflection, Rayleigh backscattering and coherent Rayleigh backscattering in fiber distributed feedback (DFB) fiber laser sensor system have been investigated. If the feedback intensity exceeds critical amount, excess noise would be induced in the demodulator. The maximum tolerable intensity back-reflection coefficient \( R_B \) and backscattering coefficient \( S_B \) into a fiber DFB laser with lead fiber length from 1 m to 37.5 km before the onset of instabilities are shown. \( R_B \) is found to decrease with increasing lead fiber length while \( S_B \) was relatively invariable with varying fiber length. The coherent Rayleigh backscattering (CRBS) would induce neglectable noise with a lead fiber exceeding 13.5 km. To eliminate these noises, one or two isolators should be incorporated in the system.

Index Terms—Coherent Rayleigh backscattering, external optical feedback, Rayleigh backscattering, reflection.

1. Introduction

Fiber distributed-feedback (DFB) lasers used as sensors became more and more attractive due to their small volume, single-mode operation, and multiplexing convenience. Remote pumping and demodulation of such lasers require long lead fibers to connect the pump and lasers and demodulator. Consequently, the fiber laser will experience Rayleigh backscattering (RB) from lead fiber. If Michelson interferometer is used to demodulate the laser signal, reflections and RB of reflected light from the two mirrors are involved. In this article, these three kinds of optical feedbacks effects are discussed below.

2. Experiments

2.1 Experiments Setup

Fig. 1 shows the schematic of a fiber sensor system. A fiber laser which is used as a sensor is pumped by 980 nm LD through a 980 nm/1550 nm wavelength-division multiplexing coupler (WDM) coupler and the 1550 nm light propagates through a 10/90 coupler into the lead fiber which varies from 1 m to 37.5 km. After intervening in Michelson interferometer which is configured by two Faraday rotator mirrors (FRMs) with an OPD of 5 m, the laser signal is detected and processed by demodulator.

Here our discussion was focused on remote demodulation, i.e., long-lead fiber is only placed between fiber laser and demodulator.

The branch 2 and 4 are used for monitoring the backward and forward power by optical spectrum analyzer (OSA) and optical power meter (OPM). The fiber laser is operated on 1535 nm, \( -13 \) dBm, and the isolator has isolation of 56 dB. The noise level of demodulation system is \( 10^{-6} \) pm/Hz\(^{1/2} \) as shown in Fig. 4 (a).

Fig. 2 shows the main components of external feedback light in a long-lead-fiber sensing system. Suppose that \( I_0 \) is the input light, then the feedback contains \( I_{bs(o)} \) is Rayleigh backscattering components of \( I_0 \) and \( I_{s1} \) are the return part of the reflection components by Michelson interferometer, \( I_{s2} \) is another part of the reflection components to detector, and \( I_{bs(s1)} \) is Rayleigh backscattering components of the return part. Theoretically, all these feedback components can be eliminated by isolators, but there are still cases that isolators are not the best way. Thus, three cases related to isolators have been investigated.
2.2 Back-Reflection (Case 1: No Isolators are Incorporated in Lead Fiber)

In this case, back-reflection is the main factor to be concerned. We have found that the critical back-reflection power above which excess noise occurs is decreased with the increasing lead fiber length up to 1 km, that is to say, the critical reflection coefficient $R_c$ is decreased while the lead fiber length increase as shown in Fig. 3.

Fig. 3. The relationship between critical reflection coefficient and lead fiber length.

The result is coincident with the theoretical analysis\(^1\), where the feedback parameter $C$ is written for DFB laser as

$$C \propto LR$$  \hspace{1cm} (1)

where $L$ is a lead fiber length, $R$ is the reflection coefficient. When $C<1$, the DFB fiber laser is unstable. So $R_c$ is proportional to $1/L$ if $C>1$ is maintained.

2.3 Rayleigh Backscattering (Case 2: One Isolator is Placed in Position b)

In this case, only RB\(^2\) from the long lead fiber return the fiber laser source. We have investigated the critical condition with lead fiber length from 3 km to 13.5 km, results reveal that the fiber laser is stable only when backscattering intensity is below $-55$ dBm, which is close to background light noise level. So the critical RB coefficient $S_c$ is about $-42$ dB independent of fiber length.

2.4 Coherent Rayleigh Backscattering (Case 3: One Isolator is Placed in Position a)

In this case, both RB and back-reflection are isolated from fiber laser source. But we still found laser noise jumping in some conditions. It is due to coherent Rayleigh backscattering\(^3\).

When we used a 13.5 km lead fiber, the backscattering power is quite low, below $-72.6$ dBm, but the interferometer noise is higher than normal, as shown in Fig. 4 (b). This is due to the interference of output signal $I_o$ and backscattered light $I_{bs(t)}$ which is the Rayleigh backscattering component of reflection light $I_{t1}$, as shown in Fig. 2. So the output power is written as:

$$<I_o>=<I_o> + a_1I_{bs(t)}$$  \hspace{1cm} (2)

where $<>$ denotes a time average, $I_o$ denotes the signal to detector, $a_1$ is coefficient which relates the coupling of the backscatter component $I_{t1}$ through the system to the detector, and depend on the fiber and interferometer losses, and the interferometer phase bias.

The coherent Rayleigh backscattering induced noise is not observed in 1 km lead fiber, but is obvious in 13.5 km fiber. We can consider that the back-reflection intensity is about $-20$ dBm, and the backscattering coefficient is $-73$ dB/m for 1550 nm light in single mode fiber, so the backscatter intensity for 1 km fiber is $-63$ dBm, below the background noise level, thus the CRBS-induced noise in 1 km fiber is neglectable. But it cannot be ignored if the lead fiber exceeds 13.5 km while the backscattered light is $-53$ dBm above the background noise level.

To eliminate the excess noise generated by CRBS in a extreme long-lead-fiber system, one isolator put in position “a” is not enough, another isolator put in “b” is needed to suppress the reflection light, so the backscattered light $I_{bs(t)}$ as well as the CRBS-induced phase noise is eliminated.

![Fig. 4](image)

Fig. 4. Phase noise of Michelson interferometric demodulation system: (a) excess noise free and (b) excess noise induced by optical feedback such as reflection, Rayleigh backscattering and CRBS.

3. Conclusions

We have investigated the excess noise induced by reflection, Rayleigh backscattering and coherent Rayleigh backscattering. The maximum tolerable intensity back-reflection coefficient $R_c$ and backscattering coefficient $S_c$ into a fiber distributed feedback (DFB) laser with lead fiber
length from 1 m to 37.5 km before the onset of instabilities were discussed. \( R_c \) was found to decrease with increasing lead fiber length while \( S_c \) is about \(-42\) dB independent of fiber length. The coherent Rayleigh backscattering (CRBS) would induce negligible noise with a lead fiber as long as 13.5 km. An efficient approach to eliminate the excess noise is to add isolators in the system, one isolator is enough for relatively short lead fiber, but two isolators are needed for a long lead fiber such as 13.5 km.

References


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