論 文 の 内 容 の 要 旨

論文題目　Performance Improvement and Dynamic Grating Detection in Brillouin Optical Correlation Domain Reflectometry with Introducing Lock-in Detection Scheme

（ロックイン検出法の導入によるブリルアン光相関領域リフレクトメトリでの性能向上とダイナミックグレーティングの測定）

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Optical fiber sensing technology based on Brillouin scattering is used to realize the distributed measurement of strain and temperature along an optical fiber. When optical fibers are embedded in various structures, such as aircrafts, buildings, roads, bridges, and so on, the structural health monitoring (SHM) can be realized. The fibers constitute fiber optic nerve system, and ensure the security of the structures and the society.

The distributed optical fiber sensing technology includes several different types. One of them is called correlation domain technique. The spatial localized Brillouin scattering can be extracted by utilizing the synthesis of optical coherence function (SOCF) to manipulate the correlation or interference nature of the laser source by its frequency modulation, which provides the distributed strain and/or temperature information along the optical fiber. Basically, there are two kinds of correlation based techniques, namely, Brillouin optical correlation domain analysis (BOCDA) and Brillouin optical correlation domain reflectometry (BOCDR). The BOCDA utilizes stimulated Brillouin scattering (SBS), so it has higher signal-noise-ratio (SNR), but requires both end access to the fibers. On the other hand, the BOCDR needs only one end access. However, its signal is weak and noisy, and the performance is not competitive compared with BOCDA, because it is dependent on spontaneous Brillouin scattering (spBS). Furthermore, the lock-in detection scheme is applied in BOCDA to enhance the small signal.

However, it is unavailable to introduce the lock-in scheme in BOCDR so far. Additionally, distributed measurement of Brillouin dynamic grating (BDG) has been realized in BOCDA to achieve high sensitivity and discriminative temperature/strain sensing. However, it has not been realized in BOCDR.

The aim of this thesis is mainly focusing on these two parts: (1) Proposing the lock-in detection scheme in BOCDR, and (2) distributed measurement of BDG in BOCDR by using the proposed lock-in detection scheme. These two parts are original works for the BOCDR system.

1) In this thesis, the lock-in detection scheme is proposed and demonstrated in BOCDR system. The weak and noisy Brillouin signal is obtained through interference between the Brillouin scattering and a reference light led from the same laser source as that for the Brillouin pumping. Then, the Brillouin spectrum is acquired by an electrical spectrum analyzer (ESA) in the basic BOCDR. In the proposed system, the spectrum data are output as an analog signal from the ESA and processed by a lock-in amplifier (LIA). With this new scheme, the small signal in BOCDR is amplified effectively, and the SNR of the system is enhanced. The measurement becomes fast and effective. By designing a new system using the lock-in detection scheme and amplifying a small spontaneous Brillouin signal with a lock-in amplifier, a Brillouin scattering spectrum with a stable shape is obtained.

By additionally introducing a periodical on/off phase modulation for the chopping of the lock-in detection, the undesired optical background spectrum in the BOCDR output is effectively reduced. A 20 cm fiber section with a large (7,000 με) strain is clearly measured. Additionally, a scheme to avoid the limitation in the laser FM amplitude in the basic BOCDR, which indicates the spatial resolution limitation, is proposed based on the LIA-BOCDR. The effective sensing point (ratio of the measurement range and the spatial resolution) is enhanced to 5,000 points, and the phase modulation scheme proposed and used to suppress the background noise realizes the measurement with only one frequency sweeping. The laser FM modulation amplitude could exceed the basic limitation without deteriorating the Brillouin signal.

2) In this thesis, the BDG reflection is measured in BOCDR system for the first time. The BDG measurement provides another way to realize the strain and/or temperature sensing with a higher sensitivity. It is also the method for discriminative sensing of strain and temperature.

We originally propose a method for measurement of the BDG in BOCDR, and demonstrate basic results showing the BDG reflection in a polarization maintaining fiber (PMF). As the signal is weak and noisy in the designed system, the lock-in detection scheme is also utilized in this BDG-BOCDR system.

The original experimental system including the lock-in detection scheme is designed and fabricated for the measurement. The BDG reflection could be measured under the condition of the laser FM for the position-selective measurement of the correlation domain technique. Some problems still exist in the BDG-BOCDR system, including the pump depletion, the SBS threshold increase induced by the laser FM, and the background noise. The control of the pump depletion and the suppression of the background noise are required to realize a fully distributed measurement of the BDG in BOCDR.