Low Coherence Doppler Lidar with High-power DFB-LD

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Abstract: A compact Doppler lidar was developed with a unique DFB-LD. This DFB-LD is a bulk device with the CW power of 2.7W[max]@3A by itself and the center wavelength of 974nm. Its spectrum width is about 10pm[max]. The coherence length and output power was optimized to 0.8m and 1.76W, respectively by adjusting the device temperature and the forward current. The low coherence Doppler lidar system was designed with this unique device. The concrete lidar setup was fabricated with an optical fiber interferometer and a differential amplifier. The Doppler echo of the wind at the measurement point, which is matched with the reference path distance, is detected and interfered with the reference light. In the experiment, a rotating reflector was utilized as wind. The rotating speed of 1 – 10m/s was measured with the accuracy of 0.03m/s. The mist flow was measured with this lidar system. the system sensitivity and the detectable maximum distance were estimated.

Keywords: DFB-LD, lidar, low coherence, Doppler, wind, sea wave

1. Introduction

The compact Doppler lidar is the successful innovation in the wind measurement market. Compared with the current wind measurement apparatuses such as anemometer, radiosonde, and Doppler sodar, Doppler lidar is remote sensing, putting in a position and covering a certain direction up to 1km. The typical compact Doppler lidar has a laser light source which consists of Distributed Feedback Laser Diode (DFB-LD) and an optical fiber amplifier. It has the optical output power of a few Watts. The beam keeps its coherency within a few hundred – kilo meters.[1]-[3] There are plural commercialized products, while most of them have a blind area in near range and its range resolution is not so high (a few tens meters).

The low altitude wind has a quick activity especially just on the ground surface. Eddies of wind around structures and wind on the sea and river surface have such strong and rapid dynamics. Interaction between the wind and sea wave motion causes the complex behavior of boundary mixing. The sea wave observations were conducted by a lidar for trial.[4]-[6] It is not enough to observe only the sea wave motion; the atmospheric dynamics should be monitored. Wind measurement is adequate for that parameter.

In this study, firstly, we developed the LED mini-lidar to observe the sea wave motion with sallow angle.[7]-[9] The sea wave dynamics could be visualized with the atmospheric activity on the sea surface. The interaction between them is vivid and suggestive for the new acknowledge. The direct wind measurement with remote sensing is ideal following to the rapid wind motion with high accuracy. Here, we proposed the low coherence Doppler lidar. It has a unique DFB-LD as a beam transmitter. It has the optical output of 2.7W[max] by itself, while its spectrum width is <10pm. With this low coherence light source, we started to build up the Doppler lidar. We will report the concept of this low coherence lidar and concrete set-up.

2. Concept of low coherence Doppler lidar

Low coherence interference occurs when the measurement path matches with the reference path in an interferometer. The reference path length becomes an off-set range in this lidar set-up. At an arbitrary distance (off-set range), the wind measurement is possible by changing the reference path length. The interference width (distance) is equal to the coherence length and it depends on the spectrum width. Laser diode has the characteristics to broaden the spectrum width when the optical output increases. The
bulk type DFB-LD we used has a peak in the change of the spectrum width. Its output power is 2.7W [max]. The spectrum width will be changed by the forward current and device temperature. To enlarge the coherence length on the condition of keeping a certain output power, the forward current and the temperature are adjusted.

The air cell size depends on the altitude, especially as a target of the low altitude atmosphere. Within the altitude of a few meters on the ground surface, this air cell size is of the order of 1 – a few meters. When the coherence length is of the order of 1 – a few meters, the air cell is regarded as the interference signal source. On contrary, the air cell flows with the wind, that is, its flow motion becomes rapid owing to the low altitude. Therefore, the low coherence Doppler lidar requires the necessary conditions that the coherence length of the lidar light source should match with the air cell size and that the lidar summation time to get the data should follow to the quick motion due to the low altitude atmosphere.

3. Bulk type DFB-LD control

Bulk typed DFB-LD we used has the output of 2.7 W [max] with the wavelength of 974 nm. It is produced by Hamamatsu Photonics K.K. The nominal feature is that its spectrum width is 10 pm [max] at the device temperature of 25 °C. We adjusted the forward current and the device temperature to enlarge the coherence length with keeping the high output power of more than 1W. The coherence length is measured by a fundamental interferometer. The result shows in Figure 2 and 3. The output optical power had a linear increase forward current from 0.4 A (Threshold) to >2A. In that range of the forward current, the spectrum width had a maximum (10 pm), that is, it is narrow cross the maximum. The coherence length depends on its feature. The spectrum width becomes narrower, the coherence length gets longer. Figure 3 shows such a behavior of the coherence length on each temperature. As a result, we decided the control condition of the bulk type DFB-LD of the forward current of 2A and the temperature of 35°C. Its output optical power was 1.76W and the coherence length was 0.8m.

![Fig. 1 Concept of DFB-LD based Doppler lidar.](image)

![Fig. 2 Optical output of DFB-LD.](image)

![Fig. 3 Coherence of DFB-LD.](image)
4. Fundamental measurement and lidar setup

For the Doppler measurement, optical system was assembled as shown in Figure 4. The output beam was enlarged to 30mmφ and collimated with the beam divergence of 3 mrad. The interferometer was structured with a beam splitter and a reference path. The first target was a rotating retro-reflector. It is an imitated moving target of wind speed. The photodiode was used as a detector with an iris and a focusing lens. The high-speed spectrum analyzer was utilized to deduce a signal frequency. The rotating retro-reflector reflected the beam in its rotation partially, and the spectrum analyzer took the trigger signal to synchronize with rotating the reflector.

Figure 5 shows the measured velocity of the rotating retro-reflector analyzed by the detected Doppler frequency. Comparing with actual rotating speed, the result had high linearity with an error of +/- 0.03m/s. The target changed more diffusive ones, too. The system had the same result as shown in Figure 5.

Next, the target shifted to the water mist, which was generated by a fog generator. The fog was forced to follow with a certain speed by a flow guide tube and a fan. Mist speed was measured in 6 minutes with an anemometer as reference. It fluctuated from 0.38m/s to 1.21 m/s. Average speed was 0.72 m/s. The interference signal could be detected on its spectrum with 35 s with the Doppler measurement. The result was analyzed as 0.63 m/s. It had the difference of spectrum width compared with a retro-reflector’s case, that is, the fog had the fluctuation of flow, and the detected spectrum had its width of 0.2MHz. It is converted to the wind speed deviation of +/- 0.05 m/s.

Then we replaced the optical system to the lidar set-up. The bulk optics changed to the fiber optics to reduce the background light and to improve stability and compactness. The reference path of the fiber optics was led by a glass plate in front of the transmitting beam unit. The reference path length was adjusted by the optical fiber length. It was tested from 2m – 11m. The receiver optics was utilized a Maksutov Cassegrain telescope of the aperture of 90mmφ. A balance detector (C12668-01, Hamamatsu Photonics K. K.) was installed into the optics to increase the signal-to-noise ratio. The optical fiber was fixed to the telescope with a coupling lens. The same experiment with the fundamental one was conducted and obtained the same quality result.
5. Discussion

The fundamental experiment of the low coherence Doppler lidar was successfully performed. Not only the moving hard target and soft target such as water mist flow were detected, too. The transmitting and receiving efficiency was evaluated with this lidar setup. As the receiving intensity was decreased by a ND filter, its decay trend of the interference intensity was measured. In the case of the threshold of 0 dBm, the approximate line indicated that the minimum detectable signal was 0.7 nW. The near range detection is also considered. The combination of Cassegrain telescope and coupling lens to the single mode optical fiber restricts the observation range. Especially in the lab-experiment, the observation range is so near (<10m), and its transmitting and receiving efficiency is low (2%). When the optical fiber coupling efficiency is improved to 30%, the minimum detectable signal of 0.7 nW is equivalent to the far small signal of 180m ahead. The observation range has an ability to enlarge up to 1km because of the optical output power.

Actual wind measurement is still undergoing. The current magnification of the signal is not enough. We now make proceeded the theoretical approach for electronics. Signal-to-noise ratio from the atmosphere is estimated with the balance detector and an additional amplifier. The bulk type DFB-LD is convenient for small device, easy access, and design free. On contrary, the beam intensity distribution is unevenness. Its divergence is ellipse, too. We considered that the influence of its unevenness was small for the Doppler wind measurement, while the interference intensity will be influent to its low coherency.

In this low coherence Doppler lidar, the measurement range is a point, that is, restricted in a coherence length of about 1m. To shift the measurement point or enlarge the measurement range, the reference path length of the interferometer should be changed. To make it realize, the optical fiber selector is available. Depending on the channel number, the measurement range can be increased.

The single processing and visualization of the wind data should be specialized. The commercialized spectrum analyzer is utilized for current analysis. The sweep time and repetition frequency is restricted under the wider measurement frequency range. It will also be a benefit for compactness and light weight.

We plan to apply this low coherence lidar into the surface atmosphere measurement on sea surface. Interaction between the sea wave motion and the surface atmosphere is interested. On a fisher boat and a treasure boat, the shallow angle measurement is possible. The other application is interesting, too. The eddies of wind around structures, updraft from evaporation on soil and urban car activity on load cause the small and rapid wind dynamics. They are the target of this lidar.

6. References