Study on the Influence of Small Attitude Angle on Lidar Wind Measurement Results

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Abstract. When carrying on wind profile measurement of offshore wind farm by Floating Doppler lidar technique, the platform often produces motion response under the action of ocean environment load. The motion response affects the accuracy of lidar wind measurement.In this paper, the synchronous observer experiment is designed to study the influence of small attitude angle on the accuracy of laser radar's wind measurement,giving an example of comparing the wind measurement data of two lidars, and carrying out the linear regression statistical analysis for all the experimental correlation data.It is found through experiments that the small attitude angle has less influence on horizontal wind speed and wind direction, and has a greater impact on vertical wind speed.

1. Introduction

With the rapid development of global offshore wind power, many countries has also increased the development and utilization of offshore wind energy resources. Offshore wind power industry has a bright future, and it[1] will gradually develop into large-scale and deep sea areas in the future. At the beginning of the development of offshore wind energy, it is essential to collect the short-term and long-term wind profile data of high precision and high reliability over relevant sea areas and in the corresponding height range, which is an important basis for offshore wind energy assessment, wind field location and offshore wind field operation and maintenance.In accordance with the standards of International Electro technical Commission(IEC), the common method of collecting offshore wind profile data is to build a corresponding number of offshore wind towers in the corresponding sea areas. However, the wind towers are only suitable for long-term wind profile data collection, which is obviously inappropriate for short-term measurements, whether from design and construction, costs and difficulty of operation and maintenance, or flexibility of using .

Floating lidar systems gain more and more in importance for the realisation of cost-efficient offshore wind resource assessments. These kinds of systems may not only offer measurement data that are more complete than those from present offshore meteorological masts (further measurement heights due to the used lidar technology) but have also significant advantages in terms of the associated costs for the provision, installation and final removal of the devices.In order to promote the application of Floating lidar system into China's offshore wind power project, reducing the cost of offshore wind resource assessment to bring the greatest benefits to the owners. In this paper, the experiment is designed to study the influence of attitude angle (roll and pitch) on the accuracy of the lidar.Its performance needs to be tested and verified according to a well-defined scheme. G.A Cool[2]used the numerical model programs of lidar to study the influence of ocean parameters on wind measurement results of floating lidar. G. Wolken-Mohlmann[3, 4] used the Floating lidar wind measurement technology to observe the wake wind of the offshore wind field.Songhua Wu [5, 6] was the first one to study the wind profile data of offshore wind fields through Dongfanghong No.2 equipped with Doppler lidar, and accumulated a large number of observation data of horizontal wind speed and vertical wind speed of sea-air boundary layer.Through the design of synchronized observational experiments, Han X[7] studied the influence of dynamic and static attitude angles on the accuracy of lidar.

In order to promote the application of Shipborne lidar system into China's offshore wind power project, reducing the cost of offshore wind resource assessment to bring the greatest benefits to the owners. In this paper, the experiment is designed to study the influence of attitude angle (roll and pitch) on the accuracy of the lidar.

2. Wind Field Inversion Principle

Laser technology is one of the most mainstream laser measurement technologies in the world. With its own technical advantages and characteristics, laser measurement technology not only can simultaneously measure wind speed and direction data at different heights, but also obtains the same wind shear analysis results as the tower.

The working principle of Doppler laser radar: After light incident to an atmospheric molecule or aerosol, the subsequent scattering signal will generate Doppler shift relative to the incident laser signal. When the atmospheric molecules or aerosol particles move along the radial velocity v with the action of wind speed, the frequency f_0 of single frequency laser is scattered with the moving atmospheric molecules or aerosol particles. The frequency of scattered light will produce Doppler frequency shift Δf_D, The size of the Doppler frequency shift is proportional to the radial wind speed v:

$$\Delta f_D = 2 f_0 \frac{v}{c} = \frac{2}{\lambda_0} v$$

3. Synchronous Observation Test

3.1. Test Situation

In CSSC Luzhou Zhenjiang Marine Auxiliary Machinery（E 119° 33′ 63″ ; N 32° 10′ 85″）, simultaneously observing the wind speed and wind direction of twelve height layers at the same location through the opening of No.5 and No.6 Doppler lidar. The No.5 Doppler lidar is mounted on a fixed platform, and the No.6 Doppler lidar is mounted on a three degree of freedom platform, and the motion attitude of the three degree of freedom platform is controlled by setting different motion parameters.The three-degree-of-freedom platform always maintains 3 degrees of roll and -3 degrees of pitch.The simultaneous observation test lasted for half a day.

3.2. Test Instrument

Figure 1. Experimental setup

As shown in Fig 1, apparatus for testing mainly includes three degree of freedom platform, wind measurement lidar, and SMC IMU attitude instrument. Three degree of freedom platform system, composed of Stewart mechanism, computer control system, drive system, pump station and other components, is a complex mechanical and electrical integration product. The platform can be used for marine environmental test and multiple motion simulation, custom sea conditions, and custom motion performance;SMC IMU attitude instrument is mainly used to measure the instantaneous attitude of Doppler lidar. The basic working principle of the SMC IMU attitude instrument is based on the Newtonian mechanics law. By measuring the acceleration of the carrier in the inertial reference system, integrating it with time and transforming it into the navigation coordinate system so as to obtain the speed, yaw angle and location information in the navigation coordinate system;Doppler lidar uses the Molas B300 series developed by Nanjing Mulei Laser company, which has the characteristics of high spatial and temporal resolution, high wind measurement accuracy, low power consumption, stability and convenience.The laser radar uses VAD technology to obtain the wind profile, and the measurement of the radial wind speed is carried out simultaneously at 12 height layers with the elevation of 62 ° in 8 directions.Three dimensional freedom platform, inertial navigation system, part of the performance parameters of laser radar as shown in Table 1.

Table 1. Experimental instrument performance parameters

Molas B300 lidar		3-DOF motion platform		SMC IMU attitude indicator	
sampling frequency	1s	Dead weight	3000 kg	Static angle accuracy	0.02 °RMS
range	40-300 m	Roll range	±15 °	Dynamic angular accuracy	0.02 °RMS
Height level	12	Pitch range	±10 °	Roll accuracy	0.03 °RMS
Speed accuracy	0.1 m/s	Heave range	±1 m	sampling frequency	0.01 s
Direction accuracy	1 °	power	341 KW	Roll range	±30 °
Speed range	0-60 m/s	Supply voltage	AC380 V	Heave range	±10 m
temperature range	-30-50 °	Actuator stroke	2.1 m	Heave accuracy	5 cm
Humidity range	0-100	Cooling method	Water cool	Acceleration accuracy	0.01 m^2/s

3.3. *Test Results*

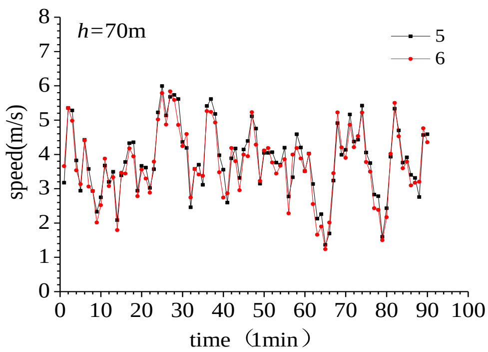


Figure 2. Horizontal wind speed contrast chart

Fig 2 is a random selection of the horizontal wind speed comparison diagram which shows that there is a small difference in the two horizontal wind speed, and the overall trend of the horizontal wind speed and vertical wind speed is the same.

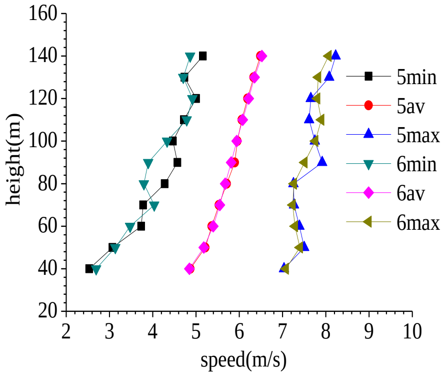


Figure 3. Wind speed contrast chart

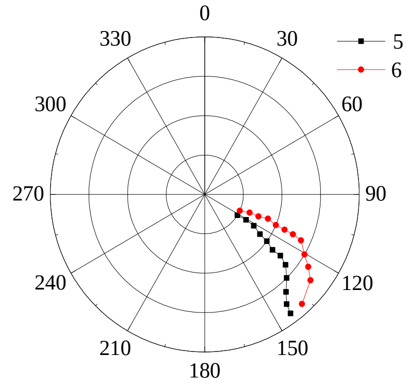
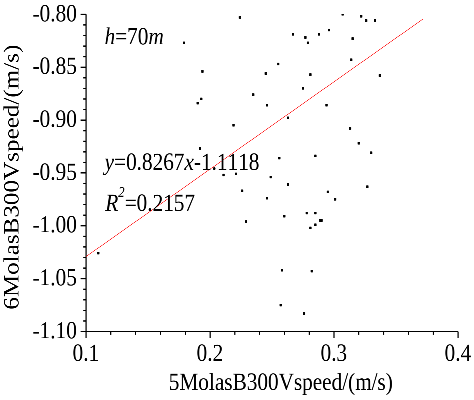
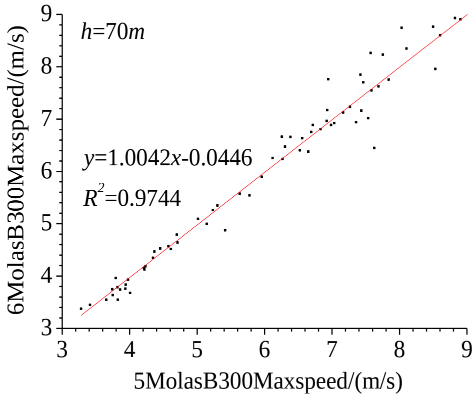


Figure 4. Wind direction rose chart

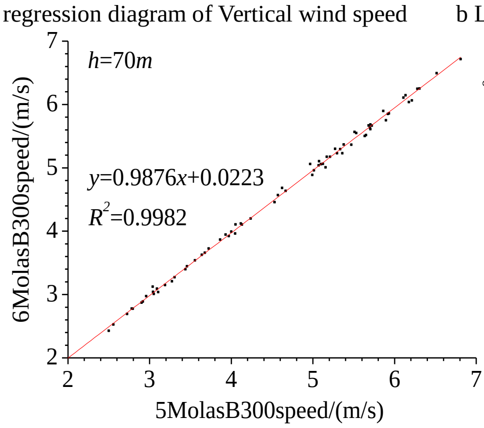
Fig 3 and fig 4 show the wind profile data observed by two Doppler lidar on June 8, 2017,in which a Doppler lidar is at the condition of rolling 3° and pitching -3° .Seeing from fig 3 and fig 4, maximum wind speed, minimum wind speed and wind direction of ten minutes at the 12 height levels are obviously different, but the average wind speed in ten minutes, two sets of laser radar measurement results have good consistency. It can be concluded that attitude angle has little influence on the average wind speed of lidar wind measurement data, but the influence on wind direction, maximum wind speed and minimum wind speed is relatively large.Using linear regression analysis can clearly see the correlation.



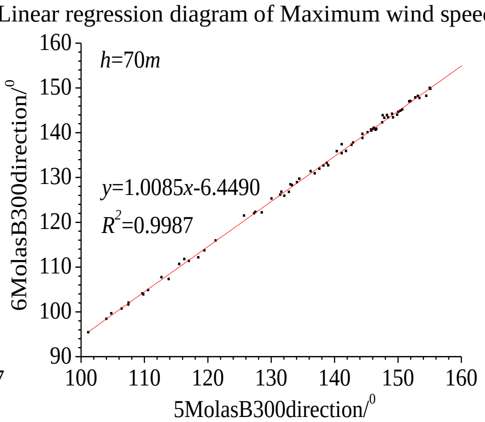
a Linear regression diagram of Vertical wind speed



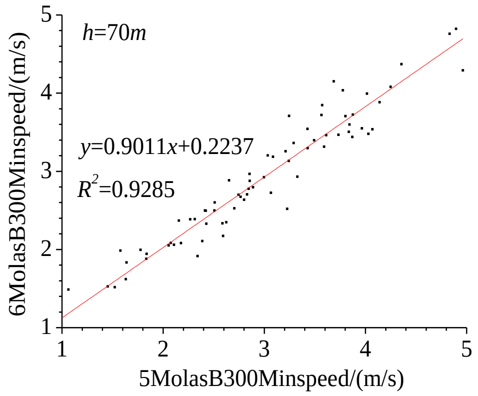
b Linear regression diagram of Maximum wind speed



c Linear regression diagram of wind speed



d Linear regression diagram of wind direction



e Linear regression diagram of Minimum wind speed

Figure 5. Linear regression diagram

In this paper, linear regression analysis of experimental data to study the small attitude angle on the lidar wind measuring accuracy.Fig 5 shows the linear correlation between the maximum wind speed, the minimum wind speed, the vertical wind speed, the average wind speed and the wind direction for the two LIDARs at the 70m level from 18:00 on June 8, 2017 to 0:36 on June 9, 2017. It can be seen from Figure 5 that the measured coefficient of vertical wind speed is 0.2157.It Belonging to low correlation.The Correlation coefficient of maximum wind speed, average wind speed, wind direction and minimum wind speed were 0.9744, 0.9982, 0.9987 and 0.9285 respectively, which were highly correlated.The Correlation coefficient of horizontal wind speed and direction of wind is very close to 1, and is similar at other levels.It can be concluded that the correlation between the vertical wind velocities measured by the two LIDARs is very low, which is the primary consideration for the subsequent motion compensation algorithm.Horizontal wind speed and direction have good correlation. There is also a high correlation between the maximum wind speed and the minimum wind speed, but the correlation is slightly lower than the correlation between the horizontal wind speed and the wind direction.

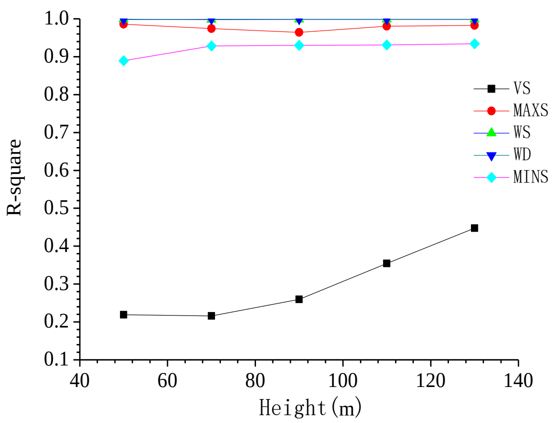


Figure 6. Data **comparison** diagram of R-square

Fig 6 is a statistical comparison of the wind profile data of two laser wind lidars at each high level.As you can see from fig 6:The coefficient of average wind speed and wind direction is above 0.99, which is very close to 1.The coefficient of determination is consistent with the changing trend of height,the wind measurement data of two lidars show a high correlation.The coefficient of maximum wind speed and minimum wind speed is lower than the coefficient of average wind speed and wind direction.The coefficient of the maximum wind speed is obviously higher than the minimum wind velocity measurement coefficient,the coefficients of both of them are above 0.90 and still have good correlation.The coefficient of vertical wind velocity is obviously lower than that of other measured data, and it shows unrelated conditions.However, the coefficient of vertical wind velocity shows an increasing trend with the increase of altitude.It can be seen from the above that in the case of small attitude angles. The small attitudes angle has little effect on the average wind speed and wind direction measured by laser wind radar, but it has less influence on the measurement of maximum wind speed and minimum wind speed. However, the effect on vertical wind speed accuracy is obvious.

4. Conclusions

In this paper, the linear regression analysis of two lidar wind measurement data is carried out by the synchronous observation test. The following conclusions are drawn:

(1)The 3 ° attitude angle has little effect on the average wind speed measured by the lidar, and there is a small difference between the measured maximum wind speed, the minimum wind speed and the wind direction.

(2)The small attitude angle has less influence on horizontal wind speed and wind direction, and has a greater impact on vertical wind speed.

It is worth noting that the conclusions obtained in this paper are based on the current limited experimental data, which will continue to be improved.

5. References

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