An innovative method to calibrate a spinner anemometer without use of yaw position sensor

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1 Introduction

A spinner anemometer (iSpin) is an anemometry platform consisting of three sonic anemometers, placed on the spinner of a wind turbine. The strength of iSpin lies in measuring the flow in front of the rotor area, rather than behind it, like a conventional cup anemometer. iSpin is therefore an excellent option when information is desired about the flow right before it enters trough the rotor swept area and can be used to measure yaw misalignments and flow inclination but also to measure power curves with a high accuracy. A visual representation of iSpin can be seen in the figure below. iSpin is produced by ROMO Wind and is currently installed on a fleet of 300 turbines across Europe.

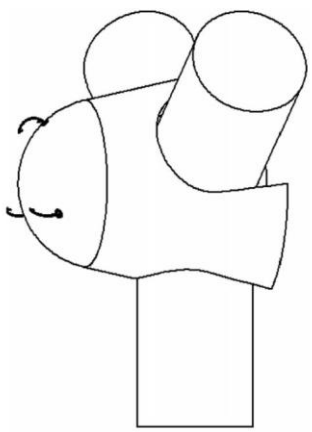


Figure 1: Visualization of an iSpin measurement setup. Three sonic anemometers are mounted on the spinner of a turbine with a 120 degree angle between them. Source: (CAC/CBC, 2012)

2 Approach

Before iSpin can be used to measure yaw misalignment, it needs to be calibrated to account for different spinner layouts using a Kalpha calibration. Previous calibration methods used to calibrate iSpin for flow angle measurements were based on a reference yaw misalignment signal measured with a yaw position sensor (Pedersen, Demurtas, & Zahle, 2014). The yaw position sensor is normally present in wind turbines for control purposes; however, such a signal is not always available for a spinner anemometer calibration. If the need for a yaw position sensor could be omitted, it would greatly contribute to the flexibility of iSpin. Therefore, an innovative method to calibrate the spinner anemometer without a yaw positions sensor was developed.

When calibrating an iSpin system two dimensionless calibration constants are used: Kalpha and K1. These constants are used in the so-called inverse and direct equations, developed by DTU Risø (Pedersen, Demurtas, & Zahle, 2014). The purpose of these equations is to relate the parameters measured by iSpin's three separate sonic anemometers to physical parameters such as the horizontal wind speed and the yaw misalignment angle. Transformations imposed on the iSpin measurements are necessary to account for a rotating reference frame fixed to the spinner, which is in turn inclined according to the shaft inclination and oriented in the direction of the yaw position of the turbine.

Two of the main measurements that iSpin provides are yaw misalignment and wind speed in front of the turbine. In order to measure a correct wind speed, it is of utmost importance that the yaw misalignment is calibrated accurately. To illustrate this, the figure below can be used; it can be seen that the measured wind speed $U_{measured}$ is related to the actual wind speed U by the yaw misalignment gamma. The accuracy of the wind speed U is therefore directly dependent on the yaw misalignment gamma.

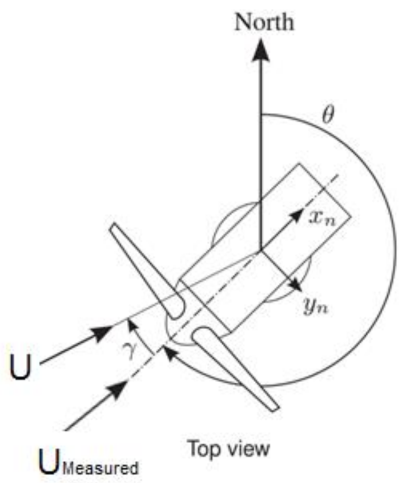


Figure 2: Top view of a wind turbine with x and y coordinate system imposed as used by ROMO Wind

The inverse and direct equations mentioned earlier take the figure above into account and compute a horizontal wind speed for a known yaw misalignment. For this to be possible it is important that the yaw misalignment is known as accurately as possible, which means that the Kalpha calibration factor must be accurately determined.

On the other hand this means that when Kalpha is not accurately determined, the horizontal wind speed will only be calculated accurately for a yaw misalignment of zero degrees. For yaw misalignments greater than zero degrees the (faulty) yaw misalignment will cause the wind speed vector components to be computed inaccurately.

This relationship between the yaw misalignment and wind speed was used to develop an innovative method to calibrate an iSpin system, without the use of a yaw position sensor.

3 Methodology

The underlying assumption in this abstract is:

For a correctly calibrated system, the wind speed as measured by the iSpin system is unaffected by the yaw misalignment of the turbine.

In order to test this assumption, data has been used from a Kalpha test, where the turbine is yawed in and out of the wind 6 times to +/- 60 degrees yaw misalignment. A Kalpha test is commonly used by ROMO Wind to obtain Kalpha calibration constants.

Plotting the Kalpha corrected wind speed versus the Kalpha corrected yaw misalignment gives reason to believe that the wind speed is not independent of the yaw misalignment for all Kalpha values. Results for Kalpha ranging from Kalpha=1 to Kalpha=4 for a Kalpha test done on an arbitrary turbine can be seen in the figure below.

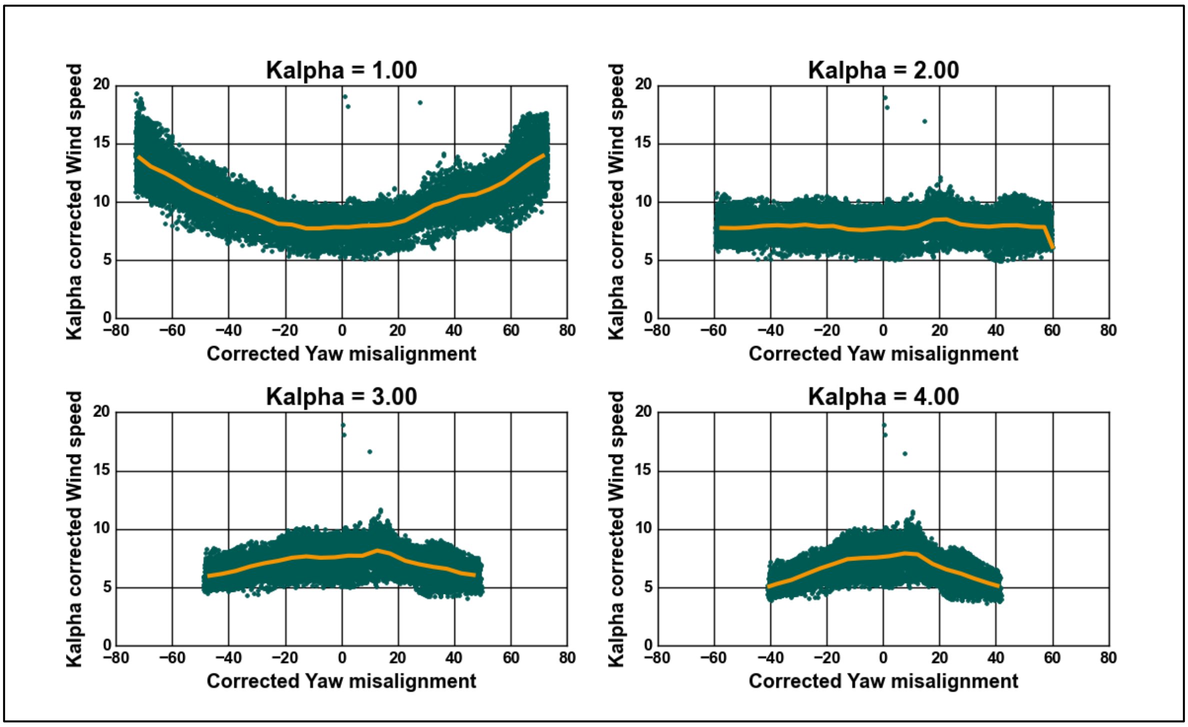


Figure 3: Wind speed as a function of yaw misalignment for four different Kalpha values.

If the assumption stated above is true, then the correct Kalpha for this particular test is around 2.00, because at this value the measured wind speed is not dependant on the yaw misalignment any more. It can be seen that for a Kalpha that is too low the plot curves upwards, while for a Kalpha that is too high the plot curves downwards.

In order to find a Kalpha based on this method an iterative procedure was performed with the following steps:

1. Correct the data using K1=1 and Kalpha =1 (Default values)
2. Fit a horizontal line to the yaw misalignment versus wind speed plot
3. Compute the Root Mean Square Error (RMSE) of the fit.
4. Adjust Kalpha:
    a. Increase Kalpha for curves curling upwards
    b. Decrease Kalpha for curves curling downwards
5. Iterate until a minimum in the RMSE is found

4 Results

The method described above was applied on a Kalpha test performed by ROMO Wind. The relationship between the RMSE and Kalpha is plotted below. In this example it can be seen that Kalpha equals 1.46, because that is where the RMSE is at a minimum.

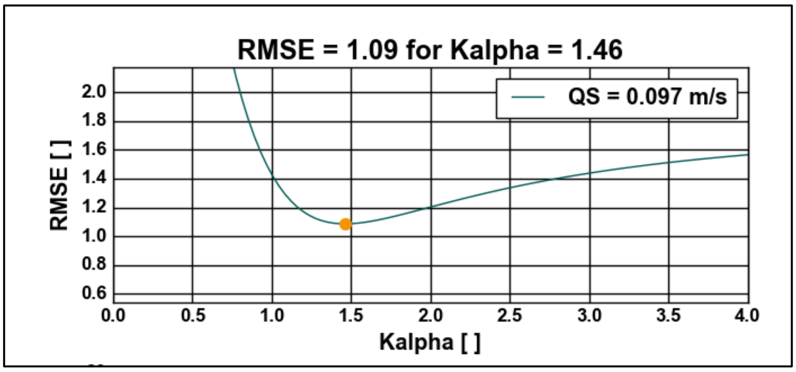
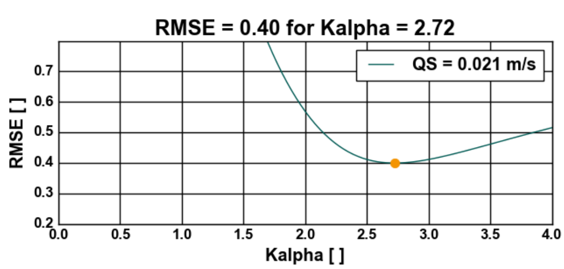
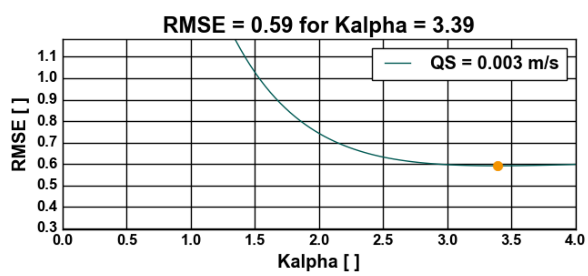


Figure 4: Relationship between RMSE and Kalpha

In order to evaluate whether a test can be considered a good or a bad test, a quality score has been developed. The quality score is the difference in RMSE, when decreasing Kalpha by 0.1. This can be interpreted as the slope of the line to the left of the minimum in Figure 4. The quality score is defined as follows:

$$QS = (RMSE(K_\alpha - 0.1) - RMSE(K_\alpha))/0.1$$

The difference between a good and a bad quality score can be illustrated graphically as follows:

Good quality score	Bad quality score
	

For a good quality score, there is only one minimum RMSE and the corresponding Kalpha is very clearly defined. For a bad quality score, Kalpha can be anything because the minimum of the RMSE curve is not clearly defined.

The relation of the quality score with respect to turbulence intensity and mean wind speed can be seen in the figure below. Note that a low turbulence intensity generally corresponds to a good tests. Since low turbulence intensities normally occur when wind speeds are high, it is recommended to perform the Kalpha test only at high wind speeds.

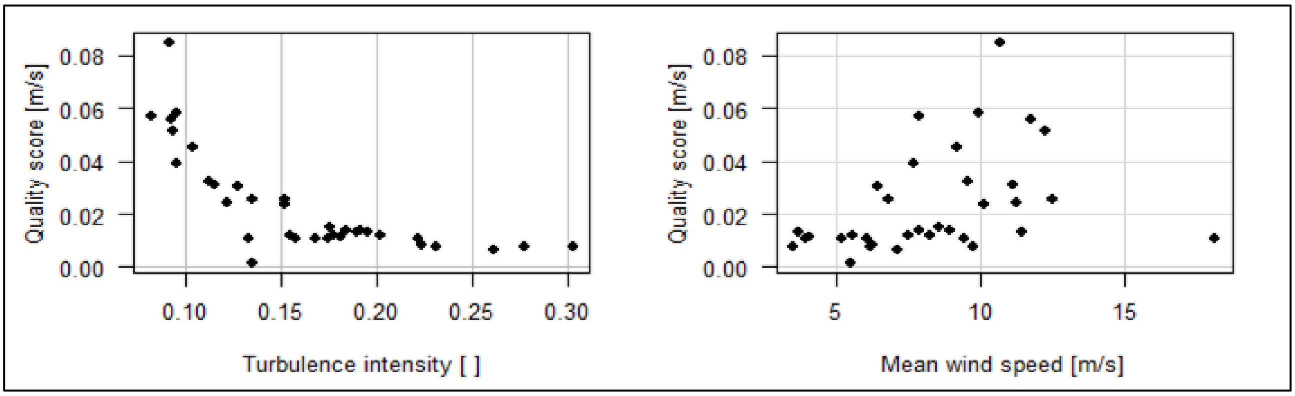


Figure 5: Relationship between quality score, turbulence intensity and mean wind speed during the test

The quality score also increases with increasing yaw range. This means that the quality of the test increases, when the turbine is yawed, for example, +/- 70 instead of +/- 60 degrees. A plot of the yawing range versus the quality score can be seen in the figure below.

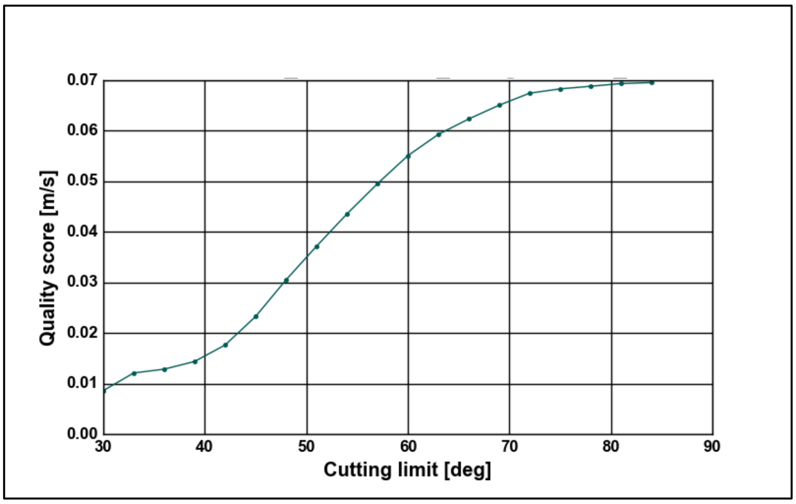


Figure 6: Quality score versus yawing range (cutting limit)

5 Conclusions

From the results presented above, an optimal Kalpha test procedure was devised. The most important conclusions are:

1. The quality of the Kalpha test increases as the turbine is yawed to more extreme angles.
2. The quality of the Kalpha tests stabilizes around a yawing range of +/-80 degrees
3. The quality of the Kalpha tests increases for a lower turbulence intensity
4. Quality scores below 0.01 are generally unacceptable.

The recommended Kalpha test procedure is therefore:

1. Yaw range: $\pm 90^0$ with respect to the mean wind direction
2. Mean wind speed: > 6 m/s
3. Yaw in/out repetitions: 6
4. Rotor position: One blade pointing downwards
5. Measurement frequency: 10Hz
6. No wake of another nearby turbine

The method was found to give similar results compared to the traditional method where a yaw position sensor is used as a reference. The results were furthermore found to be more robust (less dependent on user inputs) and therefore more accurate. Additionally this method shows that a trustworthy wind speed can be measured in front of the turbine, which is of great value for measuring absolute power curve measurements and a definite step forward for the wind industry.

6 Bibliography

CAC/CBC. (2012). *CBC DECISION/CLARIFICATION SHEET: Use of Spinner Anemometers.*

Pedersen, T. F., Demurtas, G., & Zahle, F. (2014). Calibration of a spinner anemometer for yaw misalignment measurements. *WIND ENERGY*.