Power curves
- use of spinner anemometry

Troels Friis Pedersen
DTU Wind Energy
Professor
Spinner anemometry

Spinner anemometry – using the airflow over the spinner to measure wind speed, yaw misalignment and flow inclination angle

![Graph: Yaw error versus wind speed (all sonic sensors)]

![Graph: Flow inclination angle versus wind speed (all sonic sensors)]
Spinner anemometry

Spinner anemometry can be used on all types of spinners
- Semi-spherical
- Parabolic
- Pointed
- Flat (not experienced yet)
Spinner anemometry

Why use of spinner anemometry?

- A spinner anemometer has the advantage of measurements being performed in front of the rotor without flow distortions disturbing the sensor.
- Due to rotation a spinner anemometer measures flow angles without mounting and adjustment errors.

Environmental parameters:
- other wind turbines
- terrain roughness
- terrain obstacles
- RIX number
- upstream rotor induced flow
- Wind:
  - turbulence
  - yaw error
  - flow inclination angle
  - air density

anemometer type and class
- blade root vortex
- swirl induced flow
- blade root wake
- nacelle induced flow
- profiled blade induced flow
- control system software version
- control parameters
- operational mode - rpm & pitch
- mounting height
- mounting structure
- mounting position
- safety railings
- aviation lights
- nacelle induced flow
- blade root vortex
- swirl induced flow
- blade root wake
- profiled blade induced flow
- control system software version
- control parameters
- operational mode - rpm & pitch
- mounting height
- mounting structure
- mounting position
- safety railings
- aviation lights

Vertically rotating anemomer
- A vertically rotating anemometer measures flow angles without the need for mounting and adjustment.
Spinner anemometry

Measurements on Vestas V80 2MW (Horns Rev I type)
- Tjæreborg site
- Met mast at distance 1.5D
- Cup and vane at hub height 60m
Spinner anemometry

Calibration of two spinner anemometer constants $k_1$ and $k_2$

Calibration for angular measurements $k_\alpha = k_2/k_1$
Spinner anemometry

Calibration of $k_1$ constant and extraction of induction function
Determination of Nacelle Transfer Function (NTF – IEC61400-12-2)

$$a = \frac{U_{\text{cup}} - U_{\text{spin}}}{U_{\text{cup}}}$$

Extracting induction function
Wind speed standard deviation of spinner anemometer is equal to that of the mast cup anemometer.

Turbulence is measured correctly by the spinner anemometer when the wind speed is corrected for the induction.
Spinner anemometry

Measurement of yaw misalignment and flow inclination angle

- Yaw misalignment for all directions
- Flow inclination angle for all directions
Spinner anemometry

Measurement of yaw misalignment versus flow inclination angle from different sectors in wind farm, 30sec averages

- Yaw misalignment versus flow inclination angle
  - Low roughness, wake-free sector
  - High roughness, wake-free sector

- Yaw misalignment versus flow inclination angle in wake behind turbine 3, 2D

- Wake swirl from upfront wind turbine
Spinner anemometry

Energy loss due to yaw misalignment
Re. www.romowind.com

Figures re. J.Højstrup
Spinner anemometry

Measurement of nacelle power curve according to IEC61400-12-2 (NPC)

Correction for induction


**Spinner anemometry**

Measurement of rotor power curve (RPC)

A normalized power curve for horizontal (or axial) flow wind speed:

- Corrected for induction
- Normalized for air density
- Normalized for yaw misalignment by $\cos^2$ relation
- Normalized for flow inclination angle by $\cos^2$ relation
- Could additionally be normalized for turbulence intensity

![Graphs showing power versus wind speed normalization](image)

**Induction correction and normalization**
Spinner anemometry

Measurement of rotor power curve (RPC)
- Compared to IEC standard power curve

Standard IEC power curves

Rotor power curve
Conclusions

- Spinner anemometer measures horizontal wind speed, yaw misalignment and flow inclination angle
- Calibration of angular measurements by yawing turbine in and out of the wind
- Calibration of wind speed measurements by measurements during operation and relating wind speed to met mast or lidar
- Calibration gives $k_1$ and $k_2$ spinner anemometer constants and induction function
- By correction for induction function the spinner anemometer measures turbulence intensity correctly
- By correction for induction the spinner anemometer measures power curves according to IEC61400-12-2 (NPC)
- A proposed generic rotor power curve (RPC), corrected for induction, and normalized for air density, yaw misalignment and flow inclination angle reduces scatter and increase power curve