Certification of a small wind turbine

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EAZ Wind

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Preface

This report contains the work I have done for the company EAZ wind. I would like to thank Timo Spijkerboer and Ijssebrand Ziel for their effort in guiding me through the internship and the company as a whole for giving me the opportunity to do the internship and willingness to answer all my qestions. Also I would like to thank my supervisors at the university of Twente, dr. ir. Arne van Garrel and prof. dr. ir. C.H. Venner.

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Introduction

The company EAZ wind has grown in around five years from a start-up company into a company with around 30 employees. A lot of turbines have been placed mainly in the province of Groningen. As the company size increases, the abroad becomes more interesting. As certification is obligatory in most countries, the company needed someone to help in this process. One of the first things that is needed are better wind measurements. This is necessary for the certification, but is also very important for internal use. A more extensive description of the company may be found in appendix A.

Another reason for the need of better wind measurements is the model the company uses to predict the power yield at a location before a turbine is placed. The company responsible for this model is WindBarb. This company has a large database of historical wind data and uses the Dutch “harmonie” model as boundary conditions combined with neighbouring obstacles to predict the power yield at a specific location. A wish from the company is to have better data at 15 meter of an obstacle to be able to predict the effect of obstacles better. This obstacle should not be in the main wind direction so it would not influence the main measurements too much. Therefore, in the search of a location, it should preferably have an obstacle in a non dominant wind direction.

One of the other important things is to update the mechanical calculations. The calculations where made for 10 kW electricity yield, but recently, the inverter was set to be able to handle 15 kW. The most important load cases are checked for problems, but not everything is done yet. This calculations are also necessary for the IEC norm.

Notes regarding the report

In this report I will discuss the different things that I was involved in. I will start with the part about the wind measurements and later on I will discuss the different load cases of the wind turbine and lastly some other projects I was part of.

I have chosen to keep the choice of certification body out of the report since I was only partially involved in this choice. The choice was mainly based on the total certification costs and the feeling we got with the companies. The certification body that was chosen is SGS. The department responsible for wind turbine certification is located in Spain. SGS will handle the total certification process and will hopefully certify the turbine once all is well. I was able to ask a lot of questions to this company regarding wind measurements and the load cases. I will refer to this company as “the certification body”.

Looking back, there are a lot of things that could be done more efficiently. To name an example, I started searching for possibilities to do the wind measurements before we had chosen a certification body. The norm for the wind measurements IEC61400-12-1 does not clearly state that it is not allowed to carry out wind measurements and analyse the wind data within the company. We discovered that after a conversation with the certification body. Unfortunately, the choice for a certification body came quite late in the process. Knowing this sooner, I would have invested more time in searching for external companies able to carry out the wind measurements. A more in depth evaluation of my functioning in the company and things that could be done more efficiently may be found in appendix B.

Introduction to IEC61400

The International Electrotechnical Commission (IEC) is a Swiss organization making norms for electronic devices. They made the most important norm for for wind turbines, namely IEC61400. Most countries in the world require the wind turbine to be certified according to IEC61400, or a norm based on IEC61400.

The norm consists of several documents. I will introduce three of them in more detail, namely IEC61400-2 [1], IEC61400-12-1 [2] and IEC61400-22 [3].

IEC61400-2

This part of the norm is specially made for small wind turbines. Small wind turbines are defined as wind turbines with a rotor area of less than 200 m^2. Since the “EAZ-Twaalf” (the wind turbine made by EAZ wind) has a rotor diameter of 12 meter, the turbine is indeed a small wind turbine according to the norm.

This part of the norm mainly describes the mechanical and safety requirements of the wind turbine. There are different simplified load cases described in this part of the norm and the company should be able to prove that their wind turbine is strong enough to pass all of them. One of the other things in this part of the norm is the duration test. This is a test of half a year (including wind measurements) and there should be no visible damage after that period of time.

IEC61400-12-1

This part of the norm describes how the power curve measurement should be carried out. It specifies the requirements of the measurement location and the requirements regarding obstacles in the neighbourhood of the wind turbine. If obstacles are too large, it specifies the angle that should be excluded from the data. It also states the requirements of the sensors (precision etc.) and the way they should be calibrated. The things that should be measured at minimum are the following:

- Wind speed
- Wind direction
- Temperature
- Air pressure

The wind speed is the most important part of the measurements. The wind direction should be measured to exclude certain angles when the meteorological mast or wind turbine is either in the wake of the wind turbine or in the wake of another obstacle. The temperature and pressure are measured to calculate the air density. It is optional to measure the humidity of the air, but this is often done in practice.

IEC64100-22

This part of the norm describes the total procedure that has to be followed in order to certify a wind turbine. Only companies accredited by the IEC are allowed to certify a wind turbine. When a producer of wind turbines wants to certify their wind turbine, that company has to choose a accredited certification body to do the certification process with. The producer delivers all the required information to the certification body and that company checks if everything is done according to the norm.

When the producer want to carry out the wind measurements by themselves, the certification has to check the setup at the test site and the certification body is also in charge of the data analysis. Things that have to be checked are not only the sensors and logging system, but also the surrounding objects and shape of the landscape.

When a company changes the design of the wind turbine, the certification body has to approve these changes or else the certificate is no longer valid.

Power curve measurement

This chapter contains the work I have done on the power curve measurements. It describes the procedure followed to finds a suitable location for the wind measurements and the selection of equipment to do the measurements.

Selection of a test site

To reduce costs, it was decided early on that the measurements should be carried out at a location where there is already a wind turbine present. The certification body prefers to do the wind measurement at their dedicated test site in Spain, but this would mean that a wind turbine has to be build especially for that cause. That is too expensive. It is however quite hard to find a suitable location since the norm is quite strict regarding obstacles in the neighbourhood. Luckily during my internship, the IEC61400-12-1 norm was updated to the 2017 version. This version is a bit less strict regarding the maximum size of obstacles.

To find the best possible test site, a few things should be kept in mind:

- Small amount of obstacles
- No obstacles in the main wind direction
- Willingness to cooperate of the owner

The total amount of locations was reduced by looking at the points above for each location. The willingness of the owner is of course a very important factor. The remaining locations where analysed according to the norm. The obstacles where located with Google Earth and the height of the obstacles was analysed using the data of AHN ("Actueel Hoogtebestand Nederland"). If an obstacle is considered significant according to the norm, a part of the wind data cannot be used. The significance of obstacles should be evaluated from both the location of the turbine and the location meteorological mast. The norm also provides a method to find the size of the angle that should be excluded.

The norm states to following rules to determine whether an object is significant or not:

Distance	Allowed height at that distance
$x<2L$	$h<1/3(H-0.5D)$
$2L<x<4L$	$h<2/3(H-0,5D)$
$4L<x<8L$	$h<(H-0,5D)$
$8L<x<16L$	$h<4/3(H-0,5D)$

In these equations is:

x	horizontal distance between the obstacle and the mast
L	distance between the mast and the turbine
h	maximum allowed height without the obstacle being significant
H	hub height of the turbine (15 m)
D	rotor diameter of the turbine (12 m)

The distance between the meteorological mast and the turbine should be $2D < L < 4D$. The recommended distance is $L = 2.5D$. In the case of the "EAZ-Twaalf" this results in a distance between the turbine and the meteorological mast of $L = 30\,\mathrm{m}$. Taken the values as described above, this results in the following table:

Distance	Allowed height at that distance
$x < 60\,m$	$h < 3\,m$
$60\,m < x < 120\,m$	$h < 6\,m$
$120\,m < x < 240\,m$	$h < 9\,m$
$240\,m < x < 480\,m$	$h < 12\,m$

If an obstacle is larger than the value in the table, the possible difference in wind speed between the meteorological mast and the wind turbine is considered too much and an angle has to be excluded form the wind rose. The following formula is given to calculate the exclusion angle:

$$\theta = 1.3 \arctan\left(2.5 \frac{D_e}{L_e} + 0.15\right) + 10$$

In this equation is:

θ	size of the exclusion angle
L_e	horizontal distance to the object
D_e	equivalent rotor diameter

De equivalent rotor diameter of an object is calculated using the following formula:

$$D_e = \frac{2 l_h l_w}{l_h + l_w}$$

In this equation is:

l_h	height of the obstacle
l_w	width of the obstacle seen from the wind turbine or the meteorological mast

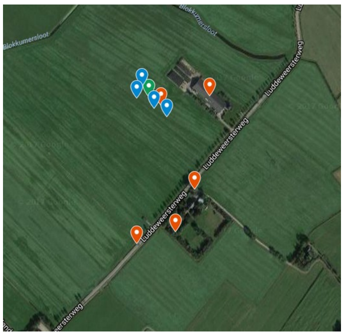
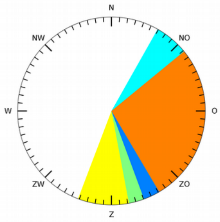
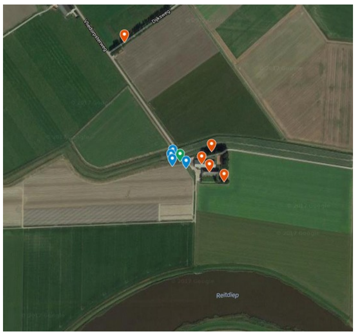
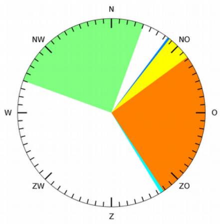
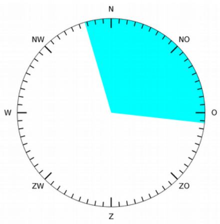
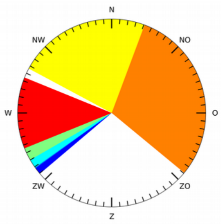
Overview of the location	Excluded angles and comments
 Hertog	 This looks quite nice except that part of the south-west is blocked by trees on the side of the road.
 Gaaikema	 This looks good. The south-west is completely free of obstacles and the light green angle to the north might not be significant.
 Overgaauw	 This looks very good. The only significant is the farm to the north. The only problem of this location is that the farmer grows corn on the field to the south-west.
 Vergeer	 This location is quite bad. The farm to the west blocks a large part of the wind rose.

Table 1: Analysis of possible test sites

Now the search for a suitable test site can be started. The dominant wind direction in the Netherlands is south-west, so that wind direction should be free of obstacles. Furthermore, a minimum of obstacles in other directions is desired. In table 1, some of the analysed locations are shown with the wind rose showing the excluded angles from the obstacles. As said, in this first analysis, the obstacles are assessed only seen from the wind turbine. For a further analysis, the obstacles should also be assessed seen from the meteorological mast.

Conclusion

From the analysis, two locations are most suitable. The first is “Overgaauw” and the second is “Gaaikema”. Since Overgaauw grows corn which may influence the measurements, it was decided to ask Gaaikema first if he would allow the measurements on his field. He turned out be be very enthusiastic about helping the development. Unfortunately, this year he also planned on growing corn. Since he was very open to the measurements it was decided to do the measurements there unless in further analysis the corn field turns out to be serious problem.

Selection of equipment

The norm poses a couple of clear requirements regarding the measurement equipment. The variables that should be measured at minimum are the following:

- Wind speed
- Wind direction
- Temperature
- Air pressure
- Energy yield

The wind speed and energy yield are of course the main variables to make a power curve. The air pressure and temperature are used to calculate the air density and correct for this in the power curve. Furthermore, the wind direction is necessary to see if the wind is coming from the excluded angle. In most temperature sensors for use outdoors, a humidity sensor is included as well.

Options

There are different possibilities to do the measurements that I will discuss below.

Buy equipment and do the measurements ourselves

The main advantage of this option is that EAZ owns the equipment. In a lot of cases it is convenient to own wind measurement equipment. That way, when the design of the wind turbine changes, the change in the power yield can be measured too. Before searching for equipment, it is important to have an idea of the desired setup. According to the norm, one should measure with at least one anemometer, but a second one (to check the calibration of the main one) is highly recommended. The main anemometer should be located at hub height within a small tolerance. The first 0.75 meter below the main anemometer, there should be no objects that might intervene with the incoming wind flow. The shape of the tube used for that part should be equal to the one used when calibrating the anemometer.

The first 4 meters below the anemometer, there are no objects allowed outside an imaginary cone with a steepness of 1:11. The wind vane, control anemometer and temperature sensor should therefore be located at least 4 meter below the main anemometer. To use the control anemometer also to measure the change in wind speed over the rotor plane, it was decided to place the control anemometer and wind vane 5 meter below the main anemometer (according to the norm, the difference in wind speed over the rotor plane can best be measured between 2/3 and 1 time the rotor radius below hub height). The temperature sensor should also be as close to hub height as possible and protected by a radiation shield. The pressure sensor may be much closer to the ground. In figure 1, the proposed design is displayed.

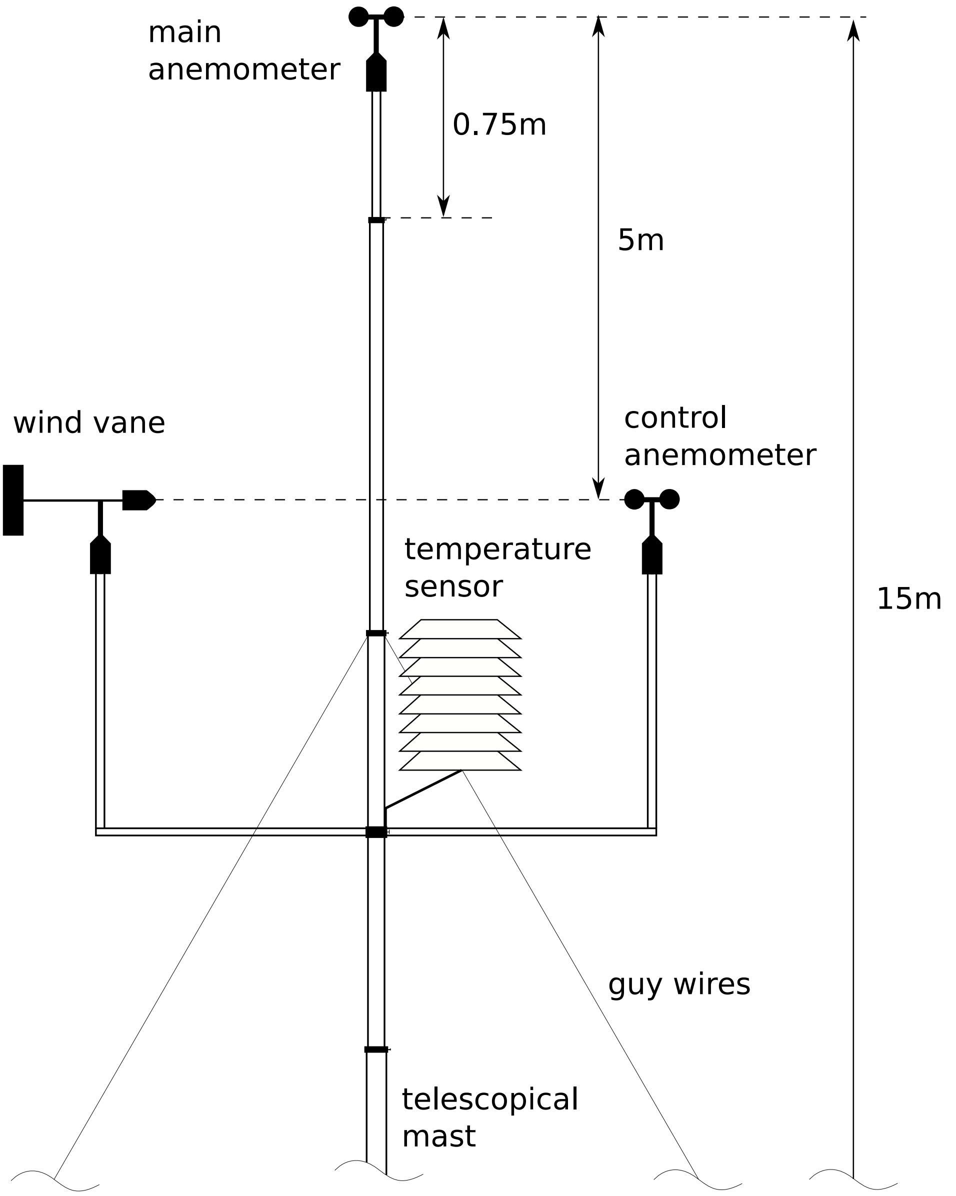


Figure 1: Meteorological mast layout

With this information, it is possible to start the search for the right equipment. It should also be kept in mind that the equipment should have the right tolerances as described in the norm. After a lot of research, the following equipment was found:

Mast

- Clark QT series telescopic mast
- Clark tripod
- Guy wires and other accessories

The total costs of the mast are around €2600. The equipment needed to mount the sensors is not included in this price yet.

Sensors and logging

- 2x Anemometer Vento First class (calibrated)
- Wind vane Thies Compact TMR (calibrated)
- Temperature / Humidity sensor
- Radiation shield for temperature sensor
- Air pressure sensor
- Logging system Meteo-40S
- Cables and other accessories

The total costs of the sensors and logging system is around €5000 including calibration. As said, it is not required to measure air humidity, but those sensors are often combined, and it gives a better approximation of the air density.

Energy yield

- Bi-directional power sensor

The costs of this sensor is around €500. That does not yet include the current transformer needed to measure such high currents and the necessary cables.

Rent equipment and do the measurements ourselves

The main advantage if this is possibly lower costs. Unfortunately this turned out to be as expensive as buying or even more expensive. Therefore this possibility was dropped.

Outsource the measurements

The main advantage of this option is that is is easy. The external company has all the knowledge and equipment to do the measurements. This company produces a power curve that is directly usable for the certification body. The raw data can still be used for analysis within the company. After some analysis, two possible parties where selected. The first one was the university of Brussels. They where quite cheap, but they turned out not to be fully qualified to do the measurements. The remaining party was “Ingenieurbüro Frey”. They have a lot of experience in doing power curve measurements and are fully accredited by the IEC to do the measurements. The total costs are around €18.400.

Conclusion

It is nice to own a meteorological mast for future use, but according to the norm, a company is not allowed to analyse the data by itself. A accredited company should accompany the measurements and process the data. Since a lot more costs are involved when an external company analyses the data, the buying options was not very economical any more. Also it would be very time consuming to do all the measurements exactly according to the norm. Therefore it was decided that the measurements would be done by “Ingenieurbüro Frey”. The raw data can still be used for internal analysis and possibly to improve the WindBarb model.

The chosen test site (Gaaikema) was very suitable according to Ingenieurbüro Frey. The corn field would not be a big problem they thought, since the wind is measured at the same altitude as the hub height of the wind turbine. The increased roughness length does however cause the wind speed to decrease faster when going down than it would when there would be no corn field. That might decrease the power yield slightly. It was decided that this loss is acceptable since the power curve is not used as advertising as for large wind turbines.

Unfortunately it took a long time and a lot of consultation to reach this conclusion. Therefore I will not be around any more when the wind measurements start. The measurements will start around the first of august.

Load case analysis

A few different options exist to check the strength of the design according to IEC61400-2. The strength can be checked by simulation, by full scale experiments or the simplified load cases can be used. The original design of the "EAZ-Twaalf" was based on the simplified load cases combined with BEM simulations. I redid all the simplified load cases with the actual values. In the design phase, things like masses of components could only be estimated, but now the actual values are known, it is important to check the calculations. This is also required in the certification process.

Symbols

The symbols used in this document are listed below.

A_b	Cross sectional area of blade at root
A_t	Cross sectional area of turbine tower section
A_{proj}	The frontal area of a blade
A_{pitch}	The area of a blade when fully pitched
B	Number of blades
b_b	Width of blade at root
C_d	Drag coefficient of blades
C_l	Lift coefficient of blades
C_t	Thrust coefficient of blades
$C_{d,tower}$	Drag coefficient of turbine tower
D_t	Outer diameter of tower section
D_s	Outer diameter of shaft
d_s	Inner diameter of shaft
e_r	Distance from centre of gravity of the rotor to rotation axis
g	Acceleration due to gravity
h_b	Height of blade at root
$I_{x,b}$	Second moment of inertia in x-direction of blade at root
$I_{y,b}$	Second moment of inertia in y-direction of blade at root
I_t	Second moment of inertia of turbine tower section
J_b	Mass moment of inertia of blade seen from rotation axis
L_{rb}	Distance between rotor centre of mass and end of the rotor shaft (failure point)
L_{rt}	Distance between rotor centre of mass and yaw axis
L_t	Length of tower section
m_b	Mass of a blade
m_{ph}	Mass of rotor without blades
m_r	Mass of the rotor (including blades)
n	Design rotations per minute
n_{max}	Max rotations per minute
P	Power output wind turbine
Q	Rotor torque
R	Blade radius
R_{cog}	Distance from rotation axis of rotor to centre of gravity of blade

t_t	Thickness of tower section
u_r	Unbalance of rotor
V_{avg}	Average annual wind speed
V_{design}	Design wind speed
V_{e50}	50 Year extreme wind speed
V_{ref}	Reference wind speed
z	Height above ground
z_{hub}	Hub height
γ_f	Partial safety factor for loads
γ_m	Partial safety factor for materials
λ	Tip speed ratio
σ_{max}	Maximum allowed stress after the safety factors are applied
σ_{yield}	Yield strength of material
$\sigma_{ultimate}$	Ultimate stress of material
ω	Design rotational speed
ω_{max}	Maximum rotational speed (corresponding to max. rotations per minute)
ω_{yaw}	Max yaw rate

Values

Below are the different values used in the calculations, with some explanation how they where obtained.

Rotational speed and tip speed ratio

The design tip speed, rotational speed and maximum rotational speed are:

$$\lambda = 7$$
$$n = 80\,\text{rpm}$$
$$n_{max} = 160\,\text{rpm}$$

so:

$$\omega = 8.4\,\text{rad/s}$$
$$\omega_{max} = 16.8\,\text{rad/s}$$

Note that the maximum rotational speed should be confirmed by measurements (this has not yet been done. This should be quite simple since the rotational speed is measured already).

Power and torque

The power produced by the wind turbine is at its maximum:

$$P = 15\,\text{kW}$$

The torque is therefore

$$Q = P/\omega = 1.8\,\text{kNm}$$

Basic dimensions of wind turbine

Some basic dimensions of the wind turbine are listed below:

$$z_{hub} = 15\,\mathrm{m}$$
$$R = 6\,\mathrm{m}$$

Class of wind turbine and wind speeds

The wind turbine class is class IV. This means by definition:

$$V_{ref} = 30\,\mathrm{m/s}$$
$$V_{avg} = 6\,\mathrm{m/s}$$

Also the extreme 50 year wind speed can be determined using these values. The extreme wind speed may be calculated using:

$$V_{e50}(z) = 1.4\,V_{ref}(z/z_{hub})^{0.11}$$

At hub height, the extreme wind speed is therefore equal to:

$$V_{e50}(z_{hub}) = 1.4 * 30(15/15)^{0.11} = 42\,\mathrm{m/s}$$

Blades

The blades are rectangular at the root with the following dimensions:

$$h_b = 0.35\,\mathrm{m}$$
$$b_b = 0.20\,\mathrm{m}$$
$$R = 6\,\mathrm{m}$$

The section modulus for a rectangular area may be calculated as follows:

$$W_b = \frac{1}{6} b_b \cdot h_b^2$$

Therefore:

$$W_{x,b} = 3.3 \cdot 10^{-3}\,\mathrm{m}^3$$
$$W_{y,b} = 1.5 \cdot 10^{-3}\,\mathrm{m}^3$$

The mass of one blade is equal to:

$$m_b = 60\,\mathrm{kg}$$

The mass moment of inertia is found with SolidWorks and equal to:

$$J_b = 375\,\mathrm{kg/m}^2$$

This should be a more realistic (measured) value, especially since it has quite a high influence on the gyroscopic part of maximum yaw load case.

The distance from the centre of gravity of a blade to the rotation axis is measured to be equal to:

$$R_{cog}=2.2\,\mathrm{m}$$

The projected area of the (non pitched) blades is equal to (without the part at the root that is clamped by metal parts):

$$A_{proj,b}=1.78\,\mathrm{m}^2$$

The projected area of the 90 degree pitched blades is equal to (again without the clamped part):

$$A_{proj90,b}=0.425\,\mathrm{m}^2$$

Tower

The tower is slightly taller than the hub height since a small part of the tower is underground. The tower is made out of four tubular sections with different lengths, diameters and thicknesses. The values are listed below (starting from the tower root to the hub).

Section 1

$$L_{t1}=5000\,\mathrm{mm}$$
$$D_{t1}=406.2\,\mathrm{mm}$$
$$t_{t1}=20\,\mathrm{mm}$$

Section 2

$$L_{t2}=5600\,\mathrm{mm}$$
$$D_{t2}=355.6\,\mathrm{mm}$$
$$t_{t2}=16\,\mathrm{mm}$$

Section 3

$$L_{t3}=3600\,\mathrm{mm}$$
$$D_{t3}=237\,\mathrm{mm}$$
$$t_{t3}=12.5\,\mathrm{mm}$$

Section 4

$$L_{t4}=1000\,\mathrm{mm}$$
$$D_{t4}=193.7\,\mathrm{mm}$$
$$t_{t4}=8\,\mathrm{mm}$$

For a tubular cross section, the section modulus may be calculated as follows:

$$W_t = \frac{\pi}{4R_t}\left(R_t^4 - r_t^4\right) = \frac{\pi}{2D_t}\left(\left(\frac{D_t}{2}\right)^4 - \left(\frac{D_t}{2} - t_t\right)^4\right)$$

This results in the following values:

$$W_{t1} = 2.24 \cdot 10^{-3}\,\mathrm{m}^3$$
$$W_{t2} = 1.39 \cdot 10^{-3}\,\mathrm{m}^3$$
$$W_{t3} = 6.37 \cdot 10^{-4}\,\mathrm{m}^3$$
$$W_{t4} = 2.08 \cdot 10^{-4}\,\mathrm{m}^3$$

The projected area per tower section (needed to calculate extreme wind speed load) is equal to:

$$A_t = D_t L_t$$

Per section this results in:

$$A_{t1} = 2.03\,\mathrm{m}^2$$
$$A_{t2} = 1.99\,\mathrm{m}^2$$
$$A_{t3} = 0.98\,\mathrm{m}^2$$
$$A_{t4} = 0.19\,\mathrm{m}^2$$

Shaft

According to IEC61400, shaft loads should be calculated at the first bearing. However, in the case of the 'EAZ-Twaalf', there is no rotating shaft. The hub is rotating and there is a static shaft. Since in that case it does not make sense to calculate shaft loads at the first bearing, it was decided to calculate shaft loads at the tower connection, right before the reinforcement. At the mast connection, the structure bearing the loads is a tubular pipe section with the following dimensions:

$$D_s = 143\,\mathrm{mm}$$
$$d_s = 148.3\,\mathrm{mm}$$

This results in the following section modulus:

$$W_s = \frac{\pi}{4R_s}\left(R_s^4 - r_s^4\right) = \frac{\pi}{2D_s}\left(\left(\frac{D_s}{2}\right)^4 - \left(\frac{d_s}{2}\right)^4\right) = 1.86 \cdot 10^{-4}\,m^3$$

The cross sectional area of the shaft is equal to:

$$A_s = \frac{\pi}{4}\left(D_s^2 - d_s^2\right) = 4.97 \cdot 10^{-3}\,m^2$$

As said, the loads are normally calculated at the first bearing. The distance between the centre of mass of the rotor and the first bearing is an important measure. In this case, the distance between the centre of mass of the rotor and the mast before the reinforcement was chosen as this distance. This distance is:

$$L_{rb}=0.3\,\mathrm{m}$$

For the yawing load case, the stress is calculated at another position. Since the yawing moment is almost equal through the shaft, this force is calculated right behind the bearing closest tot the tower since it has the smallest diameter there. The axis is hollow with the following dimensions:

$$D_{s,2}=143\,\mathrm{mm}$$
$$d_{s,2}=80\,\mathrm{mm}$$

This results in the following section modulus:

$$W_{s,2}=\frac{\pi}{2D_{s,2}}\left(\left(\frac{D_{s,2}}{2}\right)^4-\left(\frac{d_{s,2}}{2}\right)^4\right)=2.59\cdot10^{-4}\,m^3$$

The distance to the centre of gravity is:

$$L_{rb,2}=0.10\,\mathrm{m}$$

Rotor

The rotor (everything that rotates) has a total mass of:

$$m_r=800\,\mathrm{kg}$$

The distance from the centre of mass of the rotor to the yaw axis is equal to:

$$L_{rt}=0.65\,\mathrm{m}$$

In wind force calculations, the hub is seen as a cylinder with a diameter and length of:

$$D_r=1.29\,\mathrm{m}$$
$$L_r=0.57\,\mathrm{m}$$

Tail

The area of the tail, seen from the side is equal to:

$$A_{tail}=5.87\,\mathrm{m}^2$$

The distance between the tail connection to the tower, right before the reinforcement and the tail plate centre is equal to:

$$L_{tail-tower}=4.7\,\mathrm{m}$$

The tubular section of the tail has the following dimensions at the tower connection:

$$D_{tail}=152\,\mathrm{mm}$$
$$t_{tail}=10\,\mathrm{mm}$$

This results in the following section modulus:

$$W_{tail} = 1.49 \cdot 10^{-4}\,\mathrm{m}^3$$

Material constants

Tower

The tower consists of four different steel pipe sections. The strength is a bit different per section but it is a small difference. Therefore, the lowest strengths will be presented here.

$$\sigma_{yield} = 355\,\mathrm{MPa}$$
$$\sigma_{ultimate} = 470\,\mathrm{MPa}$$

Blades

The blades are made out of wood reinforced with glass fibre and epoxy. The strength of wood will be presented here. The class of the wood (larch) is GL24h. Wood has different strengths in different directions. The different strengths are presented here:

$$\sigma_{bending} = 24\,\mathrm{MPa}$$
$$\sigma_{tens,0} = 14\,\mathrm{MPa}$$
$$\sigma_{tens,90} = 0.5\,\mathrm{MPa}$$
$$\sigma_{comp,0} = 21\,\mathrm{MPa}$$
$$\sigma_{comp,90} = 2.4\,\mathrm{MPa}$$

The "tens" subscript means tension and the "comp" subscript means compression. The "0" means in the fibre direction and "90" means perpendicular to the fibre direction.

Safety factors

For every type of load determination, a safety factor is required. According to IEC61400-2:

Load determination method	Fatigue strength, γ_f	Ultimate strength, γ_f
Simplified equations	1.0	3.0
Simulation model	1.0	1.35
Full scale measurement	1.0	3.0

In this case, the simplified equations are used, and therefore, the safety factors for fatigue loads and extreme loads are equal to 1.0 and 3.0, respectively.

Also for materials, a safety factor should be used. A difference is made whether or not the material is fully characterised. The term "full characterisation" is used when a lot of properties about the material are known (even things like UV degradation and geometry effects). The following safety factors should be used for materials according to IEC61400-2:

Material characterisation	Fatigue strength, γ_m	Ultimate strength, γ_m
Full characterisation	1.25 [A]	1.1
Minimal characterisation	10 [B]	3.0
[A] Factor is applied to the measured fatigue strength of the material [B] Factor is applied to the measured ultimate strength of the material		

The final design strength of the materials may be calculated by combining the safety factors:

$$\sigma_{design} = \frac{\sigma_{char}}{\gamma_f \gamma_m}$$

Where:

σ_{design}	design strength
σ_{char}	characteristic strength (ultimate/yield/fatigue strength)
γ_f	safety factor for loads
γ_m	safety factor for materials

For both the steel pipe sections (mast and tail) and the wood (blades), material certificates are available. The steel pipe sections are tested according to EN 10204:2004-10 and the material code of the wood (GL24h) is part of the EN standard Eurocode 5 (EN 1995).

Since no information about fatigue is known for the steel pipe sections, the ultimate strength will be used to calculate the allowed fatigue load. The maximum loads for the steel pipe sections become:

$$\sigma_{fat,steel} = \frac{470}{1*10} = 47\,\text{MPa}$$

$$\sigma_{extr,steel} = \frac{355}{3*1.1} = 108\,\text{MPa}$$

For wood the stresses are mostly in bending direction I will use the bending strength as reference, however, this might not be the best choice. Again, no information is present about the fatigue strength. Also there is no information known about the ultimate strength. Therefore, I will use the yield strength in bending direction to calculate the maximum allowed fatigue strength. However, this is very conservative.

$$\sigma_{fat,wood} = \frac{24}{1*10} = 2.4\,\text{MPa}$$

$$\sigma_{extr,wood} = \frac{24}{3*1.1} = 7.3\,\text{MPa}$$

Locations of the stresses

The stresses in the wind turbine are calculated at the locations that were thought to be the most heavily subjected to stresses. The stresses on the turbine tower are calculated at the lower side of the tower sections. The forces on the blades are calculated at the blade root, just before the steel part holding the blade. The stresses on the tail are calculated at the connecting point to the turbine tower, right before the reinforcement. The shaft loads are calculated at the position right before it is reinforced. As said, for the yawing load case, the bending moment is almost equally large on all positions, so the yawing force will be calculated at the position with the smallest diameter, namely the point right after the bearing. See figure 2 for the locations.

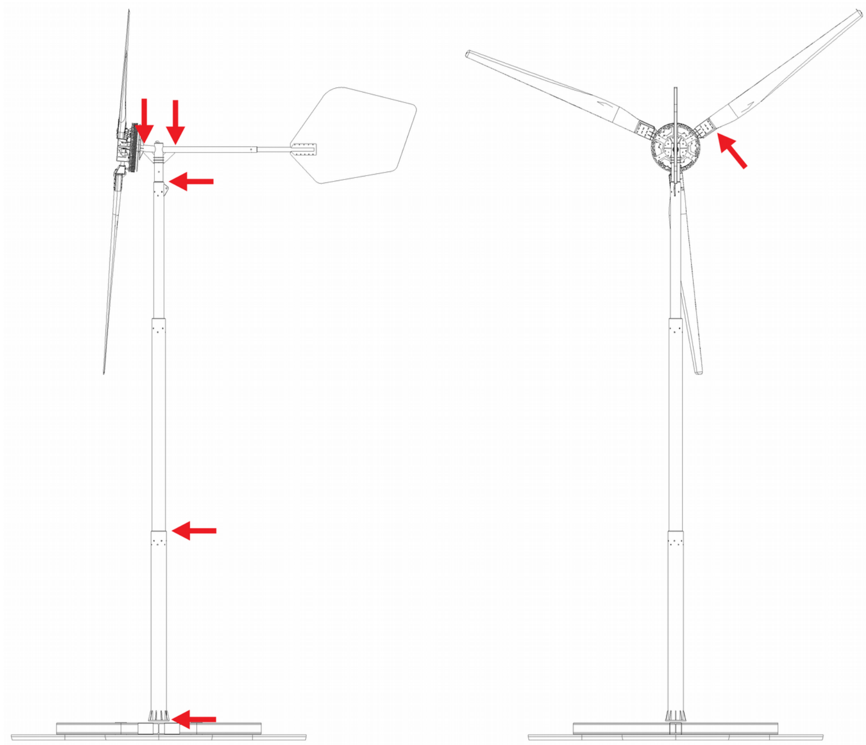


Figure 2: Locations of the calculated stresses

Load Cases

The simplified load cases are presented here. The values will be used without further introduction as they where discussed before.

Load case A: normal operation

Blades

This load case is about the fatigue loads on the different parts of the wind turbine. The fatigue loads on the blades are given by:

$$\Delta F_z = 2 m_b R_{cog} \omega^2$$

$$\Delta M_x = \frac{Q}{B} + 2 m_b$$

$$\Delta M_y = \frac{\lambda Q}{B}$$

With the previously presented values this results in:

$$\Delta F_z = 18.5\,\mathrm{kN}$$
$$\Delta M_x = 3.19\,\mathrm{kNm}$$
$$\Delta F_y = 4.18\,\mathrm{kNm}$$

The total resulting stress on the blade is equal to:

$$\Delta \sigma_{zz} = \frac{\Delta F_z}{A_b} + \frac{\Delta M_x}{W_{y,b}} + \frac{\Delta M_y}{W_{x,b}}$$

With all values known, this results in a total stress of:

$$\Delta \sigma_{zz} = 2.8\,\mathrm{MPa}$$

This is above the design fatigue strength of $2.4\,\mathrm{MPa}$, but since the allowed fatigue strength was calculated using the yield strength and not the ultimate strength, this load case will not be a problem when the ultimate strength is used.

Tower

For the tower, the fatigue load is a horizontal force on the shaft (and therefore the tower) given by:

$$\Delta F_x = \frac{3}{2} \frac{\lambda Q}{R}$$

This results in a force of:

$$\Delta F_x = 3.13\,\mathrm{kN}$$

The stress at the lower section of each section may be calculated using:

$$\Delta\sigma_{zz}=\frac{\Delta F_x L_t}{W_t}$$

The resulting fatigue stress in each section is:

$$\Delta\sigma_{zz1}=21.3\,\mathrm{MPa}$$
$$\Delta\sigma_{zz2}=23.0\,\mathrm{MPa}$$
$$\Delta\sigma_{zz3}=22.6\ \mathrm{MPa}$$
$$\Delta\sigma_{zz4}=15.1\,MPa$$

These are all below the design fatigue stress of $47\ \mathrm{MPa}$

Shaft

For the shaft, the total stress is a combination of torsion, compression and bending. The force in axial direction was already calculated and equal to:

$$\Delta F-x=3.13\,\mathrm{kN}$$

The bending moment is given by:

$$\Delta M=2m_r\,g\,L_{rb}+\frac{R}{6}\Delta F_x$$

This results in a bending moment of:

$$\Delta M=7.84\ \mathrm{kNm}$$

The torsion moment is given by:

$$\Delta M_x=Q+2m_r\,g\,e_r$$

When no better value is known for the unbalance, a value of $e_r=0.005R$ should be used. There is actually a better value is known, but since the influence of this term is only small, the more conservative value will be used. The resulting torsion moment is equal to:

$$\Delta M_x=2.26\,\mathrm{kNm}$$

The resulting stresses are listed below:

$$\sigma_{comp}=\frac{\Delta F_x}{A_s}=0.63\,\mathrm{MPa}$$

$$\sigma_{bend}=\frac{\Delta M_x}{W_s}=42.2\,\mathrm{MPa}$$

$$\tau_{tors}=\frac{\Delta M}{2W_s}=6.08\,\mathrm{MPa}$$

The total stress should be calculated as a combination of the previous stresses in the following way:

$$\Delta\sigma_{eq}=\sqrt{(\Delta\sigma_{comp}+\Delta\sigma_{bend})^2+3\Delta\tau_{tors}^2}=44.1\,\mathrm{MPa}$$

This is below the design fatigue stress of $47\,\text{MPa}$.

Load case B: yawing

When the wind direction changes, the rotor rotates accordingly. This exerts among other things a gyroscopic force on the blades. Since the yaw system is passive, the maximum yaw rate is given by:

$$\omega_{yaw} = 3 - 0.01(\pi R^2 - 2)$$

This results in a maximum yaw rate of:

$$\omega_{yaw} = 1.89\,\text{rad/s}$$

Blades
The moment on the blades caused by yawing is calculated using:

$$M_y = m_b \omega_{yaw}^2 L_{rt} R_{cog} + 2\omega_{yaw} J_b \omega + \frac{R}{9} \Delta F_x$$

The force in the equation is equal to the horizontal force calculated in load case A. The resulting moment on the blades is equal to:

$$M_y = 14.3\,\text{kNm}$$

This results in a stress of:

$$\sigma_{zz} = \frac{M_y}{W_y} = 6.1\,\text{MPa}$$

This is below the design stress of $7.3\,\text{MPa}$.

Shaft
As said, this stress is calculated right behind the last bearing. The bending moment for a three or more bladed turbine on the shaft is given by:

$$M_{shaft} = B \omega_{yaw} \omega J_b + m_r g L_{rb,2} + \frac{R}{6} \Delta F_x$$

This results in a bending moment of:

$$M_{shaft} = 21.6\,\text{kNm}$$

And finally in a stress of:

$$\sigma_{shaft} = \frac{M_{shaft}}{W_{s,2}} = 83.9\,\text{MPa}$$

This is below the design stress of $108\,\text{MPa}$.

Load case C: yaw error

The yaw error also exerts a bending moment on the blades, which, for an error or 30 degrees, is given by:

$$M_y = \frac{1}{8} \rho A_{proj,b} C_{l,max} R^3 \omega^2 \left[1 + \frac{4}{3\lambda} + \frac{1}{2} \left(\frac{1}{\lambda} \right)^2 \right]$$

When no data is available:

$$C_{l,max} = 2.0$$

This results in bending moment of:

$$M_y = 9.34 \text{ kNm}$$

And the resulting stress is equal to:

$$\sigma_{zz} = 4.0 \text{ MPa}$$

This is below the design stress of 7.3 MPa .

Load case D: maximum thrust

When the turbine is operating a maximum thrust, a force is exerted on turbine tower. This force is calculated by:

$$F_x = C_t \frac{1}{2} \rho (2.5 V_{avg})^2 \pi R^2$$

According to IEC61400-2, the thrust coefficient should be taken equal to:

$$C_t = 0.5$$

The resulting horizontal force on the turbine shaft is equal to:

$$F_x = 7.81 \text{ kN}$$

The stresses per tower section can be calculated using:

$$\sigma_{zz} = \frac{F_x L_t}{W_t}$$

This results in the following stresses:

$$\sigma_{zz1} = 53.1 \text{ MPa}$$
$$\sigma_{zz2} = 57.4 \text{ MPa}$$
$$\sigma_{zz3} = 56.4 \text{ MPa}$$
$$\sigma_{zz4} = 37.5 \text{ MPa}$$

These are all well below the design stress of 108 MPa .

Load case E: maximum rotational speed

Blades
When the turbine is rotating at maximum rotational speed, the blades are subjected to a centrifugal force given by:

$$F_z = m_b R_{cog} \omega_{max}^2$$

This results in force of:This results in force of:

$$F_z = 37.1\,\mathrm{kN}$$

The resulting stress is equal to:

$$\sigma_{zz} = \frac{F_z}{A_b} = 0.5\,\mathrm{MPa}$$

This value is below the design stress of $7.3\,\mathrm{MPa}$.

Shaft
Because of unbalance in the rotor, the shaft is also subjected to a bending moment given by:

$$M_{shaft} = m_r g L_{rb} + m_r e_r \omega_{max}^2 L_{rb}$$

The same value for the unbalance will be used as in load case A. This results in a bending moment of:

$$M_{shaft} = 4.38\,\mathrm{kNm}$$

And finally in a stress of:

$$\sigma_{shaft} = \frac{M_{shaft}}{W_s} = 23.5\,\mathrm{MPa}$$

This value is below the design stress of $108\,\mathrm{MPa}$.

Load case F: short at load connection

When there is a short at the load connection, the high load will cause a high torque on the turbine. The torque on the shaft caused caused by the short at the load connection is calculated using:

$$M_{x,shaft} = G\,Q$$

In the absence of more accurate values:

$$G = 2.0$$

Therefore, the shaft torque is equal to:

$$M_{x,shaft} = 3.58\,\mathrm{kNm}$$

Blades

The moment on the blade is given by:

$$M_x = \frac{M_{x,shaft}}{B} + m_b g R_{cog}$$

This results in:

$$M_x = 2.49\,\text{kNm}$$

The resulting stress is:

$$\sigma_{zz} = \frac{M_x}{W_x} = 1.1\,\text{MPa}$$

This value is below the design stress of $7.3\,\text{MPa}$.

Shaft

The moment on the shaft is already calculated. The resulting stress is found using the following formula:

$$\tau_{shaft} = \frac{M_{x,shaft}}{2 W_s} = 9.6\,\text{MPa}$$

This value is below the design stress of $108\,\text{MPa}$.

Load case G: shutdown

In the case of the EAZ wind turbine, the braking is done by short-circuiting the turbine. This means that this load case is identical to the previous one (load case F).

Load case H: extreme wind loading

In this load case, the turbine responds as intended in really high wind speeds. For this turbine, the blades are fully pitched due to the high wind load and the turbine is short-circuited to stop the rotor movement.

Blades

In the case of fully pitched blades, the force on each blade is dominated by drag:

$$F_{x,b} = C_d \frac{1}{2} \rho V_{e50}^2 A_{proj90,b}$$

When the wind comes from the front, the pitch system is working as it should, and is therefore pitched 90 degrees, so only a small area is subjected to the wind. The force coefficient for a blade is assumed to be:

$$C_f = 1.5$$

Note that in reality this value is much lower since the blades are fully pitched. The drag coefficient of an airfoil parallel to the wind is very low, even if part of the blade is not completely parallel because of the twist of the blade. However, this load case is not critical so it does not matter.

The force on each blade is equal to:

$$F_{x,b}=0.69\,\mathrm{kN}$$

The resulting moment is equal to:

$$M_x=\frac{1}{2}R\,F_{x,b}=2.07\,\mathrm{kNm}$$

The resulting stress is equal to:

$$\sigma_{zz}=\frac{M_x}{W_x}=0.5\,\mathrm{MPa}$$

This value is below the design stress of $7.3\,\mathrm{MPa}$.

Hub
The hub is seen as a flat cylindrical plate from the front. The drag coefficient of a flat plate is assumed to be:

$$C_f=1.3$$

The force on the hub is calculated using:

$$F_h=C_f\frac{1}{2}\rho V_{e50}^2 A_{hub,\,front}$$

This results in a force on the hub of:

$$F_h=2.12\,\mathrm{kN}$$

Tower
The tower is also subjected to forces due to the high wind speeds. The bending moment per section is a result of several different forces. The main force is the force calculated before, namely the force on the blades. The total force is a sum of the forces per blade and the force on the hub:

$$F_{x,shaft}=B\,F_x+F_h=4.19\,\mathrm{kN}$$

Also each section of the tower has a drag force that cannot be neglected. The force per section (in the middle of each section) is equal to:

$$F_t=C_f\frac{1}{2}\rho V_{e50}^2 A_t$$

The force coefficient for circular cross sections with a characteristic length larger than 0.1 meter (which all sections are) is equal to:

$$C_f=0.7$$

This results in the following forces per tower section:

$$F_{t1} = 1.54\,\mathrm{kN}$$
$$F_{t2} = 1.51\,\mathrm{kN}$$
$$F_{t3} = 0.745\,\mathrm{kN}$$
$$F_{t4} = 0.147\,\mathrm{kN}$$

These different forces have different arms compared to the lower parts of the tower sections. For example, for the first tower section, the moment is calculated as follows:

$$M_{t1} = F_{x,shaft}(L_{t1}+L_{t2}+L_{t3}+L_{t4}) + F_{t1}\left(\frac{1}{2}L_{t1}\right) + F_{t2}\left(L_{t1}+\frac{1}{2}L_{t2}\right) + F_{t3}\left(L_{t1}+L_{t2}+\frac{1}{2}L_{t3}\right) + F_{t4}\left(L_{t1}+L_{t2}+L_{t3}+\frac{1}{2}L_{t4}\right)$$

All together this results in the following moments at the lower parts of the tower sections:

$$M_{t1} = 90.8\,\mathrm{kNm}$$
$$M_{t2} = 54.0\,\mathrm{kNm}$$
$$M_{t3} = 21.2\,\mathrm{kNm}$$
$$M_{t4} = 4.27\,\mathrm{kNm}$$

The resulting stress is calculated using:

$$\sigma_t = \frac{M_t}{W_t}$$

This finally results in:

$$\sigma_{t1} = 40.6\,\mathrm{MPa}$$
$$\sigma_{t2} = 38.9\,\mathrm{MPa}$$
$$\sigma_{t3} = 33.3\,\mathrm{MPa}$$
$$\sigma_{t4} = 20.5\,\mathrm{MPa}$$

These values are below the design stress of $108\,\mathrm{MPa}$.

Load case I: parked wind loading, maximum exposure

This load case is similar to the previous load case, but in this case, the yaw mechanism fails, and the stresses should be calculated for wind from all directions. The wind speed is lowered to the reference wind speed. The force on each component is given by:

$$F = C_f \frac{1}{2}\rho V_{ref}^2 A_{proj}$$

Frontal
Blades

The resulting force on the blades is equal to:

$F_b = 0.35\,\mathrm{kN}$

This results in the following stress (the section modulus is taken in x direction since the blade is fully pitched):

$$\sigma_{zz} = \frac{F_b}{W_x}\frac{R}{2} = 0.3\,\mathrm{MPa}$$

This value is below the design stress of $7.3\,\mathrm{MPa}$.

Hub
The hub is again considered a flat plate similar to the previous load case. The only difference is the wind speed. Therefore the force will be shown without further calculations:

$F_h = 1.08\,\mathrm{kN}$

Tower
The tower calculations are done similarly to the previous load case. The only difference is that the reference wind speed is used instead of the fifty year extreme wind speed. Without further derivations, the stresses are presented below:

$\sigma_{t1} = 20.7\,\mathrm{MPa}$
$\sigma_{t2} = 19.8\,\mathrm{MPa}$
$\sigma_{t3} = 17.0\,\mathrm{MPa}$
$\sigma_{t4} = 10.5\,\mathrm{MPa}$

These values are below the design stress of $108\,\mathrm{MPa}$.

Side
Tail

In this case, there is a large force on the tail of the wind turbine. The friction coefficient of a flat plate is assumed to be:

$C_{f,tail} = 1.5$

Now we can calculate the force by the wind on the tail:

$$F_{tail} = C_{f,tail}\frac{1}{2}\rho V_{ref}^2 A_{tail}$$

This results in:This results in:

$F_{tail} = 4.87\,\mathrm{kN}$

At the tower connection, this force is translated into a moment:

$M_{tail} = F\,L_{tower-tail} = 24.3\,\mathrm{kNm}$

It is assumed that the force by the wind on the tubular tail sections can be neglected. The resulting stress at the tower connection is equal to:

$$\sigma_{tail}=\frac{M_{tail}}{W_{tail}}=154\,\text{MPa}$$

This is above the design stress of $108\,\text{MPa}$. However, since this force is quite well predictable since the tail is a simple flat plate, it is safe to use a lower safety factor in this case. When the safety factor for loads is lowered to 2, the allowed stress is $161\,\text{MPa}$.

Hub
The hub is again considered a flat plate similar to the previous load case. The only difference is the wind speed. Therefore the force will be shown without further calculations:

$$F_h=1.08\,\text{kN}$$

Tower

For the stress on the tower, it is assumed that the torque on the tower caused by the force on the tail can be neglected since the bending stress on the tower is much higher. The stress is calculated the same way as before, with the force on the tail as horizontal force on the tower. This results in the following stresses on the tower:

$$\sigma_{t1}=48.4\,\text{MPa}$$
$$\sigma_{t2}=49.7\,\text{MPa}$$
$$\sigma_{t3}=46.4\,\text{MPa}$$
$$\sigma_{t4}=30.0\,\text{MPa}$$

These values are below the design stress of $108\,\text{MPa}$.

Rear
This is almost the same as the frontal load case. However, the wind comes from the other direction which means that the blades are not able to pitch as they normally would. Therefore there will be a lot more drag on the blades.

Blades
Again, the drag on the blades is assumed to be:

$$C_d=1.5$$

The force on the blades is equal to:

$$F_B=\frac{1}{2}C_{d,B}\rho V_{ref}^2 t\,.\,A_{proj,b}=1.4\,\text{kN}$$

This results in the following stress on the blades:

$$\sigma_{zz}=\frac{F_b}{W_y}\frac{R}{2}=1.9\,\text{MPa}$$

Tower
The rest is similar to the frontal case. The resulting mast stresses are listed below:

$\sigma_{t\,1} = 42.9\,\mathrm{MPa}$
$\sigma_{t\,2} = 43.9\,\mathrm{MPa}$
$\sigma_{t\,3} = 40.6\,\mathrm{MPa}$
$\sigma_{t\,4} = 26.2\,\mathrm{MPa}$

These values are below the design stress of $108\,\mathrm{MPa}$.

Conclusion

Not all the load cases are passed without problems. The main load case that remains a problem is the last one. The tail force here is too high. The lowering of the safety factor is only allowed for well predictable forces according to IEC61400-2. Whether or not the force may be called well predictable should be confirmed by the certification body.

Another thing to discuss with the certification body is the location of the shaft loads. Since there is no rotating shaft in the design, it is hard to find a suitable location to calculate the stresses.

Other Projects

Sometimes I was quite dependant on companies to respond and had some spare time. During this moments I did a few other projects that I will discuss here.

EAZ Preview

Sometimes when a new turbine would be placed, the neighbours were worried about the change their view. Normally someone from EAZ would go to those people to explain that the turbine is quite small and show some images of the turbine to put them at ease. However, this costs a lot of time, so they where looking for a way to make things easier. Since I have experience in website development, I was asked to look for a possibility to put an overlay over Google StreetView images showing the EAZ turbine.

Unfortunately Google does not support overlays when they are further away than around 50 meters. The reason for this is that Google does not only collect images, they collect depth data as well, so they know the distance of each pixel of the image. However, apparently the sensor Google uses is not able to find the depth information more than about 50 meters away.

What I did to solve this limitation is getting the raw panorama images from the Google server (around 90 separate images) and joining them back together. Then I use a Javascript 3D canvas library called THREE.js to project those images onto a sphere with the camera point in the middle of the sphere. Next controls are added to make it appear like the normal Google StreetView. Now I can project the windmills anywhere in 3D space.

To determine the size of the image I use is an adapted version of the camera formula:

$$H_{px} = H_{obj} F / L$$

Where:

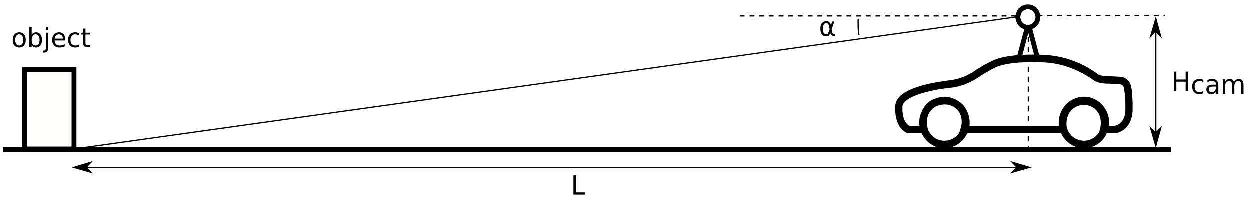
H_{px}	pixel size of the image
H_{obj}	actual size of the object
F	factor that has to do with the focal length (and conversion to pixels)
L	distance of the object

Since the size of the windmill is always the same, I can include that into the factor, resulting in:

$$F = H_{px} L$$

When I know this factor, I can calculate the image size at any distance. Fortunately, there are a few EAZ-Twaalf turbines in Google StreetView, so I could calculate this factor by putting my overlay image on the same place as the actual turbine.

Another problem was to put the turbine at the right spot vertically. The equation for this follows from the following image:



So the position angle of the projected image is simply equal to:

$$\tan\alpha = \frac{H_{cam}}{L}$$

Knowing this angle, I can project the image at any distance (for example, I could also project the image at $L/2$, but I should project it a little higher since the angle remains constant). I defined the angle β as the angle from looking straight up, down to the base of the obstacle. When the horizon is at 90 degrees (which it is when the earth would be flat, but is a very good approximation), $\beta = 90 + \alpha$. Unfortunately, roads are not always horizontal, and Google does not correct for this. Therefore, the horizon is not always at 90 degrees, but I found values anywhere between 87 and 93 degrees. This has quite a big influence on how realistic the position of the turbines look. Therefore I made a tool to correct the horizon. Everyone visiting the website is able to correct the horizon in a specific StreetView Panorama. This corrected value is saved in a database so the horizon looks right for the next person visiting that specific panorama.

I will not go too much into the horizon correction method, but basically a 3D circle is plotted in a plane described by two normalised vectors on the x and z axis (the x axis is to the right, the y axis up and the z axis into the paper). I made two points points to correct the horizon. The first one always points in the direction of the wind turbine and the second one 90 degrees to the right. On dragging, the new location of the point is translated into the vectors on the x and z axis and the circle is redrawn.

The result may be viewed on the following URL: http://preview.eazwind.com

Accelerometer data analysis

There are a few different accelerometer and magnetometer sensors on the turbine to log things like rotational speed. The magnetometer analyses the magnets to find the rotational speed and the accelerometer is used for the same purpose. However, the sensors could be used for a lot more. The magnetometer might be able to detect the magnetic north and therefore the yawing direction and the turbine and the accelerometer data could be used to analyse vibrations.

I tried parsing the data, but unfortunately, the software in the turbine turned out to have errors and it was not logging all the information. Therefore, I did not continue this analysis. The scripts I made to analyse the data might be useful in the future when the data is correct.

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Appendix A – Description of the company

EAZ wind is a company founded about five year ago by a few alumni from the university of Twente and Saxion university of applied sciences. They wanted to make small wind turbines financially profitable. In the design of this wind turbine they chose to look as little as possible at the design of large wind turbines. This resulted in a wind turbine of twelve meter hub height and three blades with a length of six meter each. The blades are made out of wood, which is easily recycled and has good fatigue characteristics. The pitch mechanism does not work electrical as in most large wind turbines, but is completely mechanical.

The design lifetime of the turbine is twenty years. However, the current turbines do not have such a long lifetime. The current design has some errors and the company is slowly working towards a design that actually has a lifetime of twenty years while repairing the older turbines when necessary. This was accounted for in the costs, but also assumes that the company keeps growing in order to have enough money to be able to replace the broken parts. This is ambitious, but might also be the only way to keep the costs low.

The wind turbine should be able to repay itself in about ten years, which is in the same range as solar panels. The turbine is mostly placed at farms, where permits are relatively easily obtained. More than fifty turbines have been placed so far, and hundred more will be placed the coming year. For now, almost all the turbines have been placed in the province of Groningen. The company has good contacts with the local authorities in that region, and winds are strong there. However, there are plans to go abroad. The first place where they want to start is Germany, just on the other side of the border in Groningen.

Currently, the company has about 30 employees, and has transformed itself from a start-up into a small company. The company is situated in two locations. The design is done in the Hague together with the building of the hub and pitch mechanism. The larger parts (such as the tower and blades) and the electronics are made in Hoogezand.

Appendix B – Reflection on functioning

Before I started at EAZ wind I already had a few meetings at both locations (since for the measurements I had to know something about the logging system and sensors of the turbine, I went to Hoogezand and talked to the electronics designer and went to a turbine to get a feel of the actual product). This also gave the opportunity to get a better understanding of the work I would be doing and meet the people I would be working with.

However, when my internship started I found it hard to know where to start. After reading the norm (a lot of times) I found it hard to transform that information into actions. I should maybe have been more clear about this and should have discussed more with Timo (my main supervisor at the company. However I felt like I was already asking too much at the start. What would have helped me at this time was maybe some clear deadlines and once or twice a week a meeting to discuss my progress. This is also part of what I discussed in the evaluation with the company. For the next intern they will plan clear meetings to discuss the progression.

Something else that I found hard was the phase where I was searching for different alternatives for the wind measurements. The main thing I did was emailing or calling companies to ask the different prices. I do not really like this and I am not good at negotiating the price. Therefore I did not do as much as I would have liked per day. I also had a lot of time where I could not do anything since I was waiting for responses of the different companies.

Furthermore I think I functioned quite good in the company. I was invited to different technical meetings, giving me a nice insight on the different problems in the technical design. The collogues at the company were very kind and willing to answer all my questions. I loved the way they work together. At lunch time, the whole company sits together at a large table and EAZ provides the food for lunch giving a nice domestic ambiance and makes sure everyone really gets to know the other people working at the company. There is no obvious hierarchy in the company which, as I do not like having people above me, suited me very good.

I also enjoyed my car rides with Timo (going to farms for the wind measurements) where I learned a lot about how they started the company and their philosophy and plans to grow the company and more general discussions about all kind of subjects.

Since the subject of the internship did not always interest me, I found it sometimes hard to stay focussed and not skip the more boring parts. I think the wind measurements could have been started earlier on if I would have focussed more on finding the best alternative sooner. However, I preferred calculating the load cases and was therefore sometimes slow in my responses to the different companies I asked to help with the wind measurements. However, at some point we decided to start the wind measurements after the corn season, which made it less important to start the measurements as soon as possible. But I did found out again that I do not like organizational tasks and prefer doing practical and technical work. However, despite my dislike, I think I found good deals for the measurement equipment and I think we made the best decision to outsource the measurements in the end.