NTNU	TEP 4175: Energy from Environmental Flows
Department of Energy and Process Engineering	Laboratory Work Handed out: Friday 2015-09-29 Edited: 2015-10-06

DESCRIPTION OF THE WIND TURBINE TEST RIG

Axial Flux Generator

The instrumentation for the axial flux generator test rig is shown in the illustration below. This is for you to have a picture of how it will look like in the wind tunnel for the final testing.

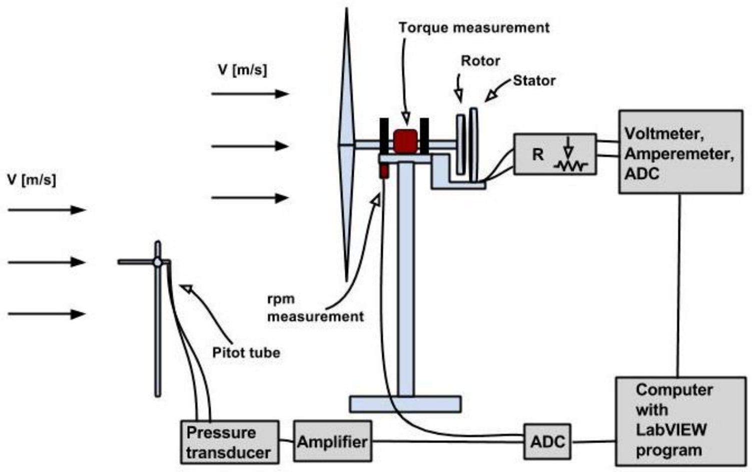


Figure 1: Axial flux generator test rig and instrumentation

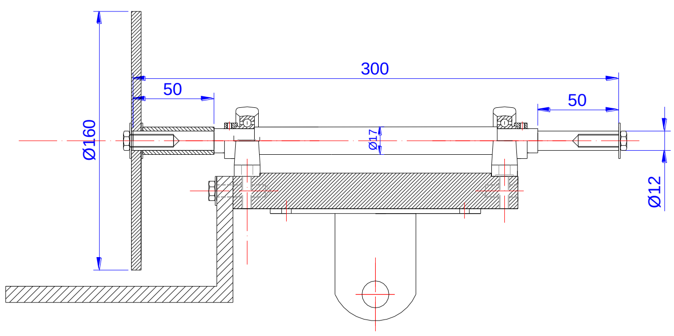


Figure 2: Rotor dimensions

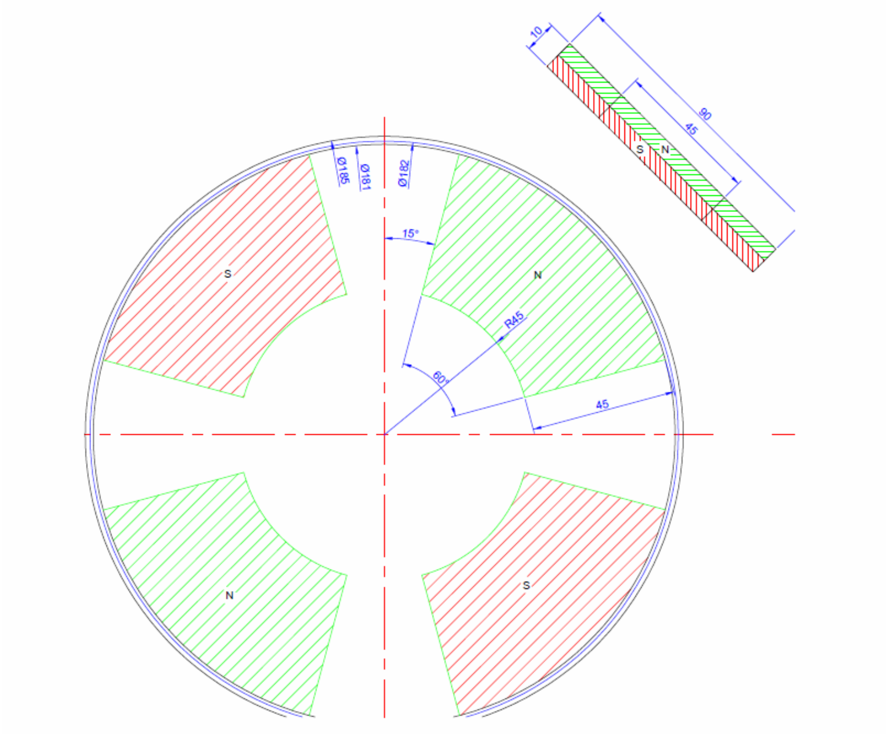


Figure 3: Axial flux generator rotor and permanent magnets

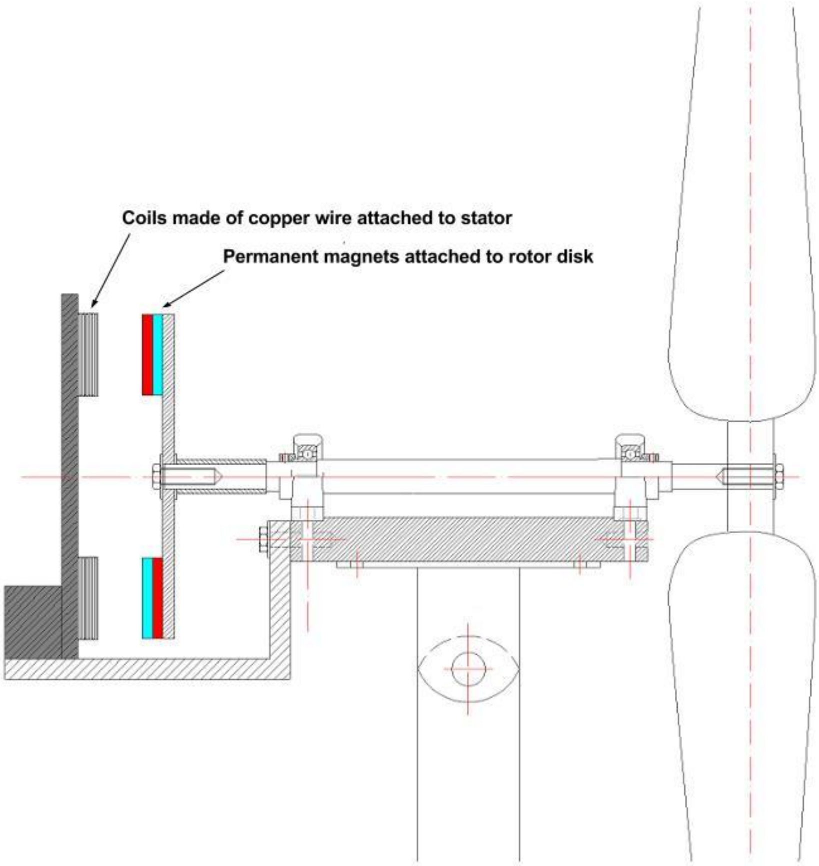


Figure 4: Axial flux generator

Radial Flux Generator

The test rig for the radial flux generator is shown in the illustration bellow. The picture illustrates the instrumentation of the test rig in the wind tunnel.

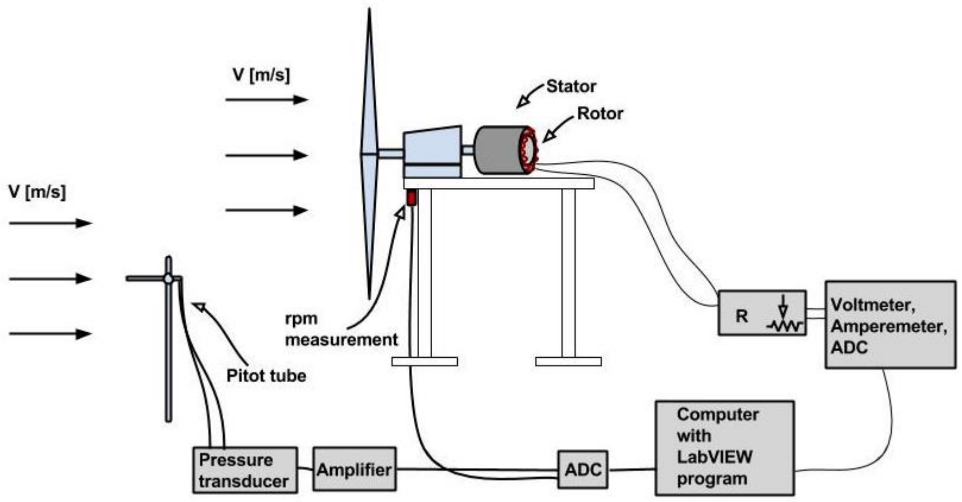


Figure 5: Radial flux generator test rig

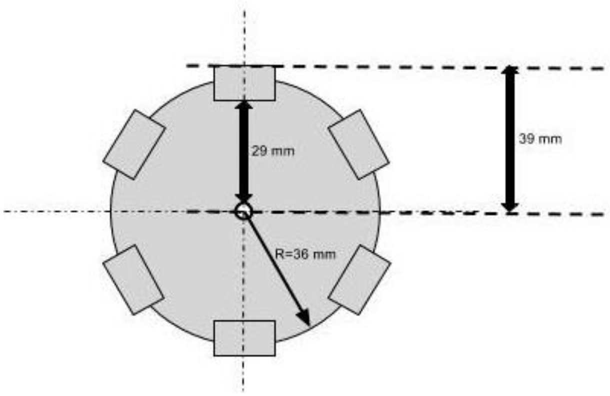


Figure 6: Radial flux generator rotor

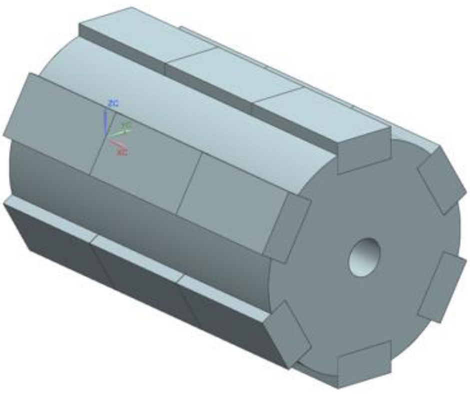


Figure 7: 3D-model of generator rotor, from student report, EiT, Spring 2015

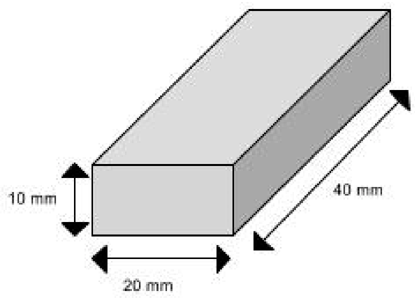
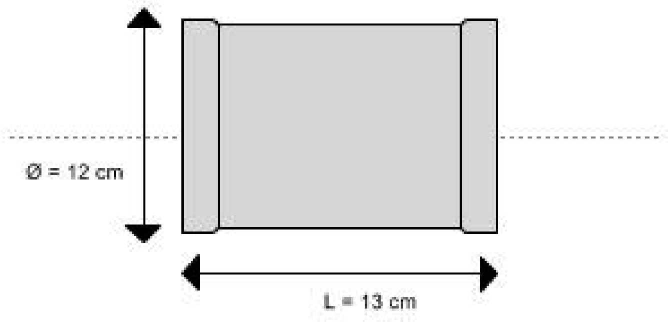


Figure 8: Permanent magnets for the radial flux generator

For the radial flux generator there are three permanent magnets per pole, with a total length of 120 mm.



Outer circumference for the generator stator: 37 cm. The coils are placed and fastened on the inner surface of the stator.

Figure 9: Radial flux generator stator

The Turbine

The turbine rotor is to be milled out of an Ebaboard plank. The dimensions of the turbine can not exceed the dimensions of the material you have available.

- Dimensions of the Ebaboard plank: 900*60*100 mm
- Flexural modulus Ebaboard L-1: 570 MPa
- For the milling you also have to make sure the rotor is not milled too thin. If so, the material will not withstand the milling. Make sure the blade has a minimum thickness of 2mm.

The blade also needs frame and support for the milling. Therefore, design your blade with support structures according to the picture below. Manually carve the support structure after the milling is finished.

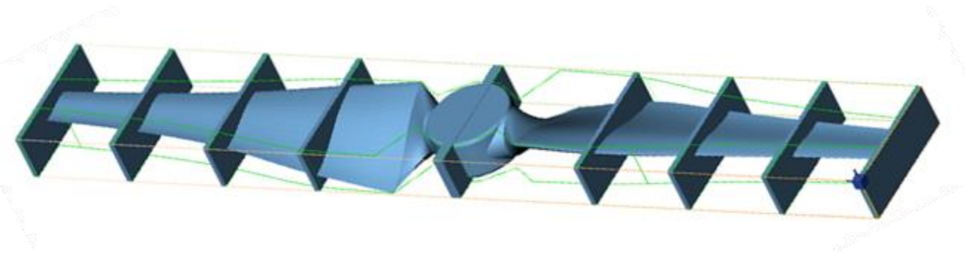


Figure 10: 3D-model of the support structure for the turbine blade

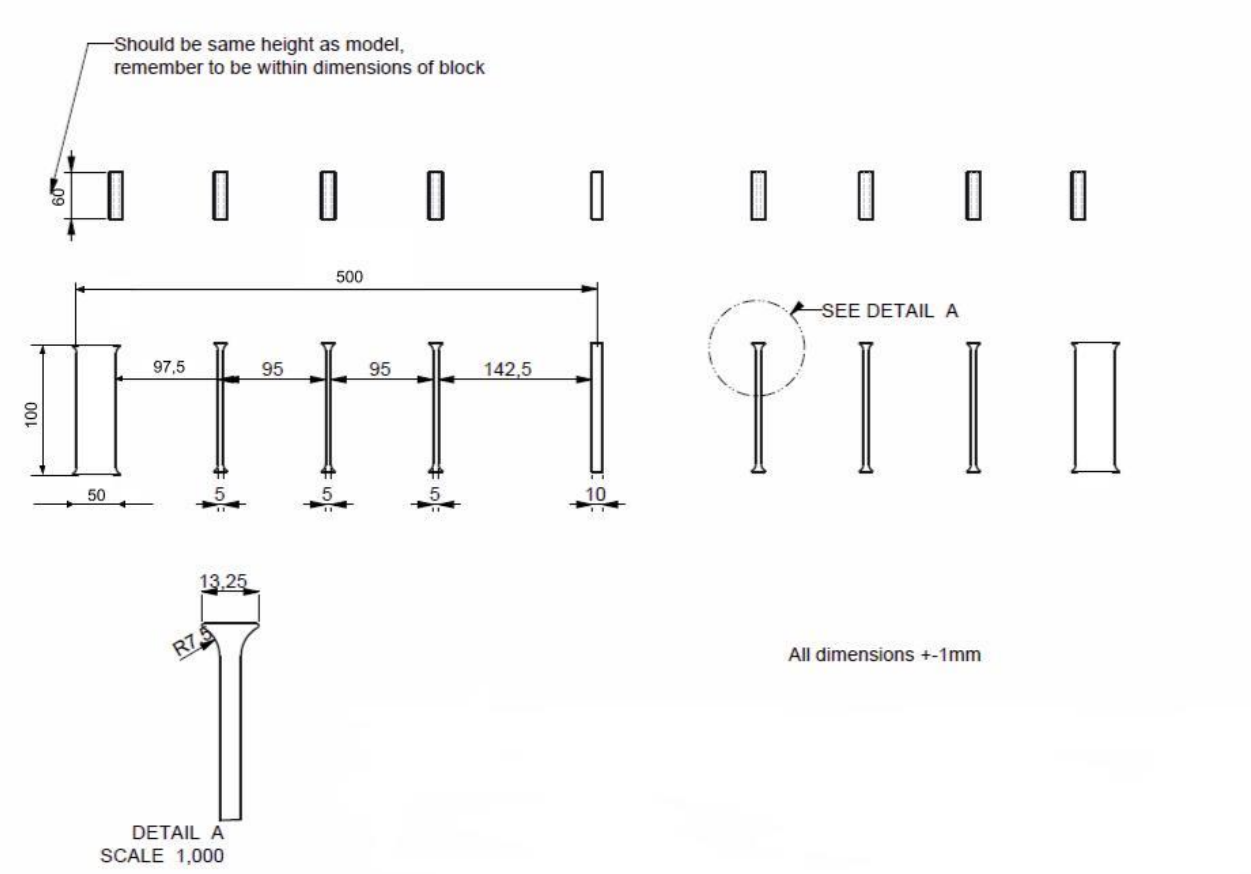


Figure 11: Support structure for the blade

The generator

Technical data for the permanent magnets

For the axial flux generator

- Dimensions: OD180, ID90, α 60°, 10 (a) mm
- Magnetic properties: Br >= 1,24T, jHc > 1400 kA/m

For the radial flux generator:

- Dimensions: 40*20*10 mm
- Magnetic properties (rectangular permanent magnets): Br >= 1,29T, jHc 860-955 kA/m

Technical data for the copper winding wire

You can choose between two copper winding wires with different size: Cu Ø1,2 and Ø1,4.

For Cu Ø1,2 mm:

- $R = 0,0152\ \Omega / m$ at $20\,^{\circ}C$

For Cu Ø1,4 mm:

- $R = 0,0112\ \Omega / m$ at $20\,^{\circ}C$

Design of the Generator

For the design of the generator a few values need to be estimated;

- $X_s\,[\Omega]$ - Reactance
- $B_p\,[T]$ - Flux density at stator coil level

These estimates should be analyzed after the laboratory test of the generator is completed; the results of the analysis should be included in the report.

Reactance Values for the Generator (X_s)

The following estimated values for the synchronous reactance X_s could be used as a starting point for the design of your generator. Note that there is a large uncertainty regarding these estimates.

For the axial flux generator

- Single-phase: $X_s \approx 1,2\ [\Omega]$ at 1600 rpm

For the radial flux generator

- Single-phase: $X_s \approx 0,9\ [\Omega]$ at 1000 rpm
- Three-phase: $X_s \approx 0,2\ [\Omega]$ at 1000 rpm

Flux Density (B_p) Estimates

- For axial flux generator: $B_p = 0,10\ T$
- For radial flux generator: $B_p = 0,12\ T$

Test Procedure for the Generator

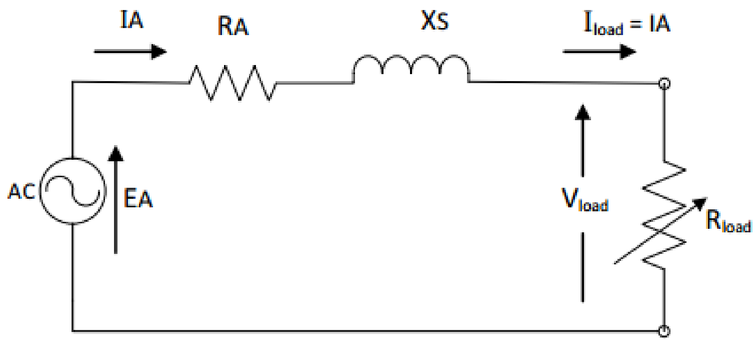


Figure 12: Equivalent circuit of a round rotor synchronous generator feeding a resistive load

Measure without R_{load} ($R_{load} = \infty$) at different rotational speeds

- $E_A [V]$ - Induced voltage, $f(B_p, A_{coil}, \omega_m, N_{coil}$, distance from magnet to coil)
- $R_A [\Omega]$ - Resistance of the coils, $f(\rho, A_{wire}, L_{wire}, T)$, measured by means of e.g. universal instrument

Measure with the variable load R_{load} at different rotational speeds

- $I_A = I_L [A]$ - Line current (max current 10 Ampere)
- $V_T [V]$ - Terminal voltage
- $P_{load} [W]$ - Electric power delivered to the load
- $\tau [Nm]$ - Torque
- $n [rpm]$ - Rotational speed

Analysis of the Generator Test Data

Calculate

- Efficiency: $\eta_G = \frac{P_{out}}{P_{in}}$
- $X_s\,[\Omega]$ - Reactance (is estimated before designing the generator, calculated after test)
- Flux density, B_p, at the stator coil level (based on the measured value for E_A)

Compare

- Measured value for R_A with calculated value (in design process)
- Efficiency - design vs. measurement
- $X_s\,[\Omega]$ - design vs. measurement
- B_p - design vs. measurement

Data Sheet for the Test Procedure

1)

Vary the rotational speed with open circuit and note the corresponding induced voltage. Test for e.g. five different rotational speeds; 100, 500, 1000, 1500 and 2000 rpm. Create a graph based on your results.

2)

Connect the circuit to R_{load} and obtain the following parameters by varying the load and the rotational speed. Test for three different rotational speeds (Tip: Calculate the load needed in order to obtain the highest output power and run the test with this resistance, with a higher resistance and with a lower). Calculate R_{load} for each load case and fill in the value in the table. Create a graph for each rotational speed. Remember, there is a difference between 1-phase and 3-phase;

- $R_{3\,phase}^{per\ phase} = \frac{V_{phase}}{I_{phase}} = \frac{V_{phase}}{I_L} = \frac{V_{LL}/\sqrt{3}}{I_L}$
- $R_{1\,phase} = \frac{V_L}{I_L}$

$n[rpm]$	$I_L\,[A]$	$V_T\,[V]$	$P_{out}\,[W]$	$\tau\,[Nm]$	P_1	P_2	P_3	$R_{load}\,[\Omega]$
1200								
1500								
1800								