NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Drivetrain design for the NREL 15 MW Offshore Reference Turbine

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Proposed Generator design

- **Radial flux PM machine**

Configuration	Outer rotor-inner rotor	Remarks /Comments
Location	Upwind	
• Rated torque	20.64 MNm	
• Rated speed	7.54 rpm	
• Tangential stress	40 kN/m^2	
• Peak air gap flux density	0.7-1.2 Tesla	
• Specific current loading	60kA/m	(higher for liquid cooled machine)
• Type of cooling	Air cooled	either air/Liquid-cooled

Proposed drivetrain layout

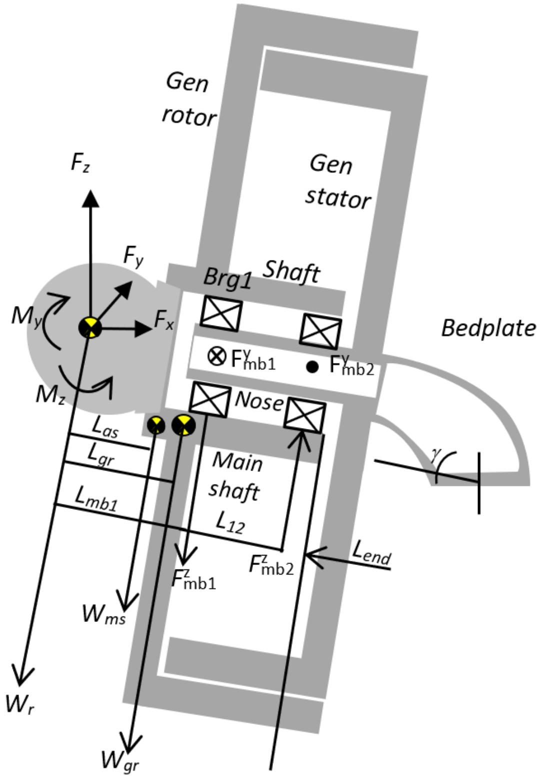
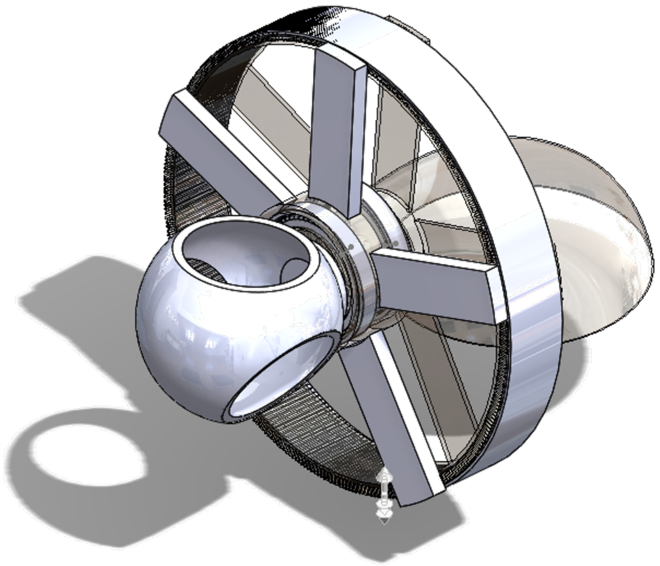


Figure 1. Force diagram in a direct drive main shaft

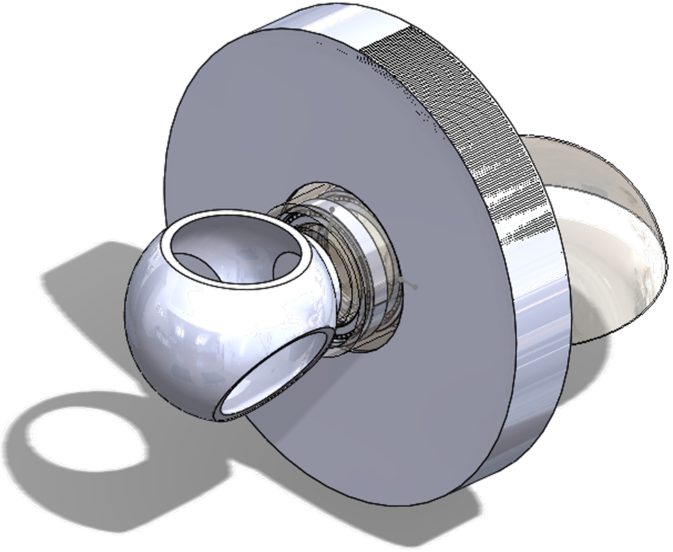
Configuration	Outer rotor –inner stator
Bearings	Double bearing
Support structure arrangement	Single-sided spoke arms or discs
Optimization Objective	Mass
Target full load efficiency	94 %

Spoke arm and disc configurations



Type 1

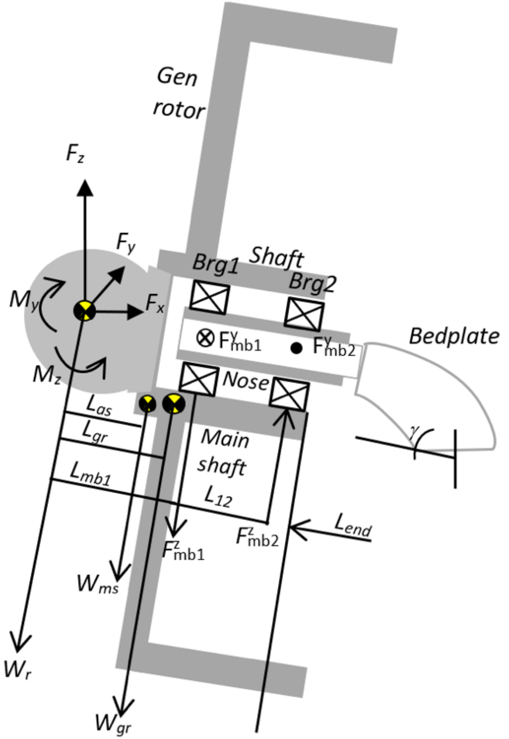
Support structure consisting of single-sided wheels with spoke arms



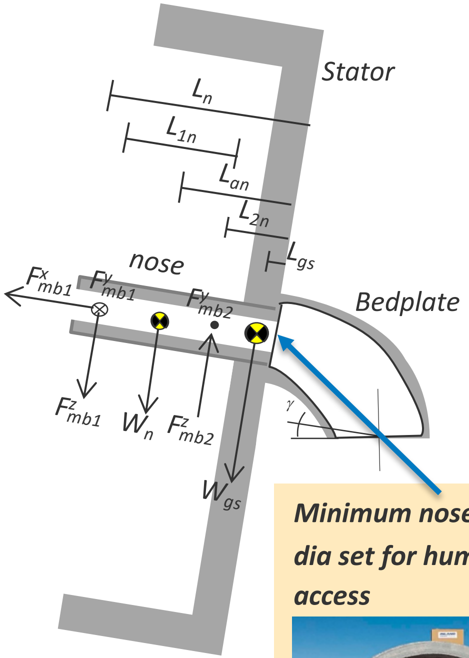
Type 2

Support structure consisting of single-sided wheels with discs

Main Shaft and nose modeling



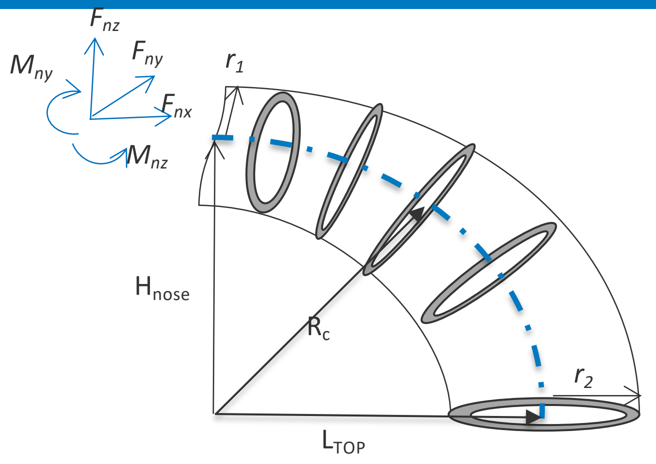
- Hollow cylinders of constant wall thicknesses.
- Outer diameters and thicknesses determined from von mises stress criterion
- Loads computed along the shaft length and reactions computed at the bearing locations
- Length determined iteratively after checking for deflections at the bearing and generator locations.
- **Thickness –a design variable**



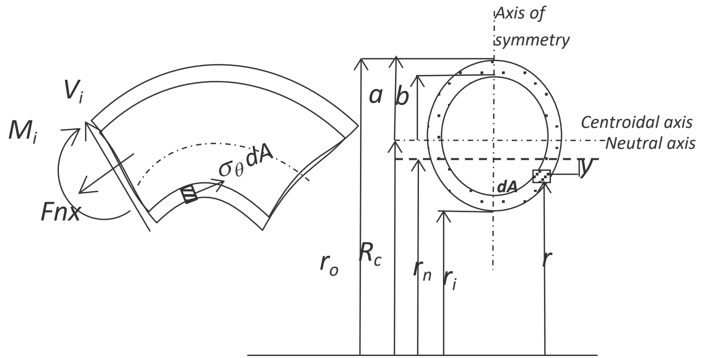
Minimum nose inner dia set for human access

Bedplate modeling

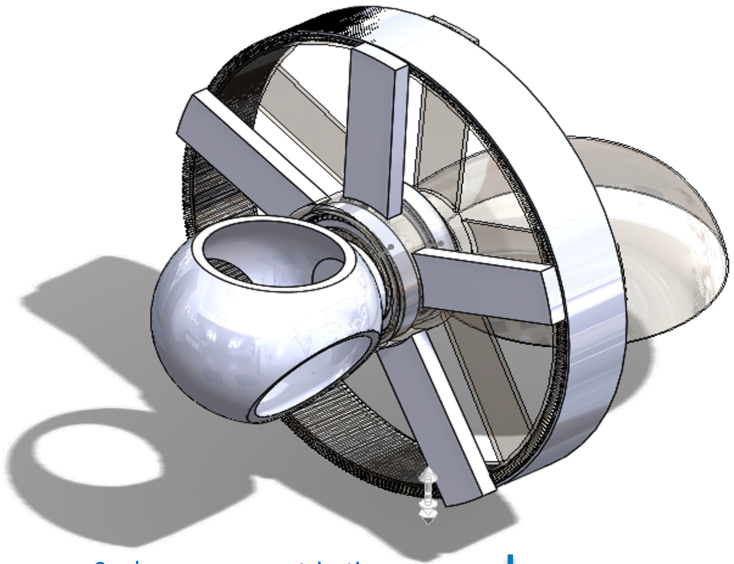
- Modeled as a hollow curved cantilever beam with elliptical profile .
- Discretized using multiple circular hollow sections.
- The path traversed along each centroid is also assumed to be an ellipse.
- Smaller cross-section(radius r_1) at the nose and a larger cross-section (radius r_2)
- Loads computed in Frame3DD.
- Designed to resist stresses(hub loads and gravity) computed using Roark's Formulas[1] for curved beams- normal stresses from bending, shear stress from torque and shear forces and radial stresses from moments and thrust.
- **Wall thickness is a** design variable (L_{TOP} and H_{nose} can also be)

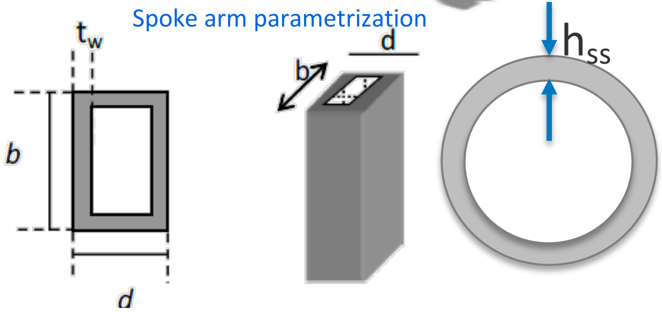


Bedplate modeled as a curved beam



GeneratorSE: support structure modeling- type 1

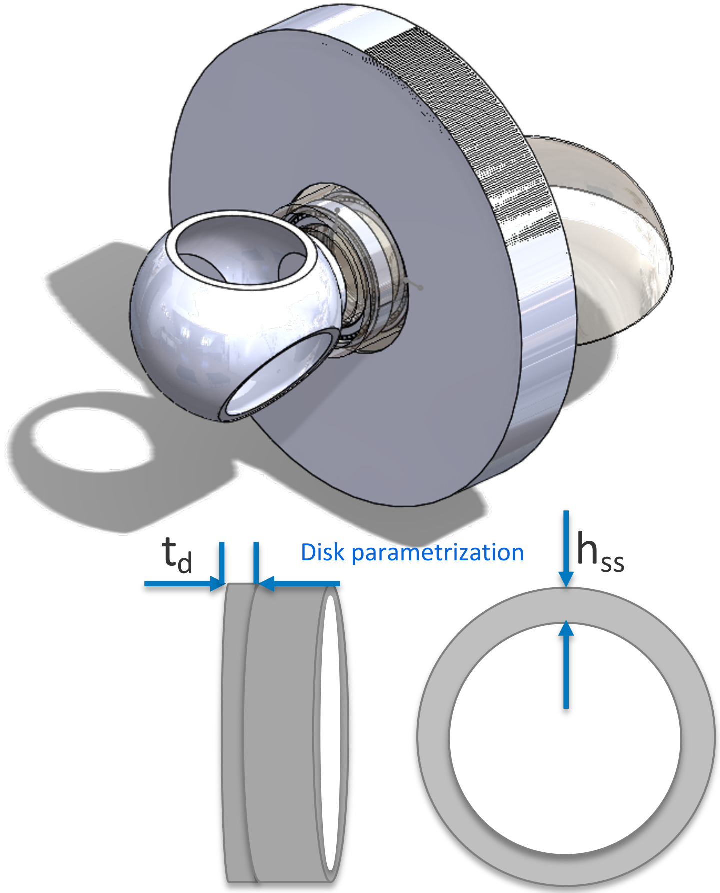




- Rotor and stator structures modeled as single sided spoke wheels with certain rim thicknesses supporting the weight of the active materials.
- Each spoke parametrized by a depth *d*, circumferential dimension *b* and thickness t_w.
- Designed to minimize air-gap deflection; analytical models adapted from McDonald [2]
- **The number of spokes, arm dimensions and rim thicknesses are design variables.**

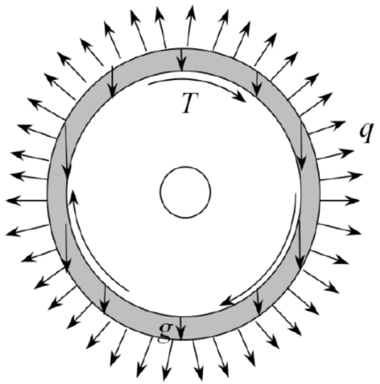
GeneratorSE: A Sizing Tool for Variable-Speed Wind Turbine Generators

Generator support structure modeling- type 2

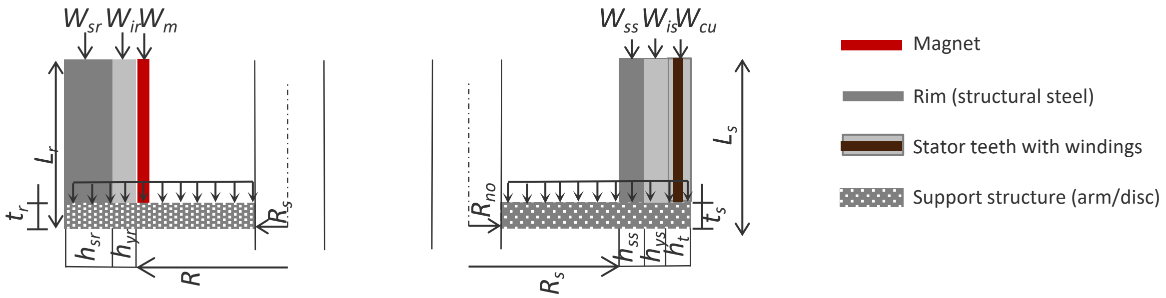


- Rotor and stator structures modeled as single sided disks with certain rim thicknesses supporting the weight of the active materials.
- Each disc parametrized by its thickness.
- Designed to minimize air-gap deflection; analytical models adapted from McDonald [2]
- **Disk and rim thicknesses are design variables.**

Generator support structure deflection modeling

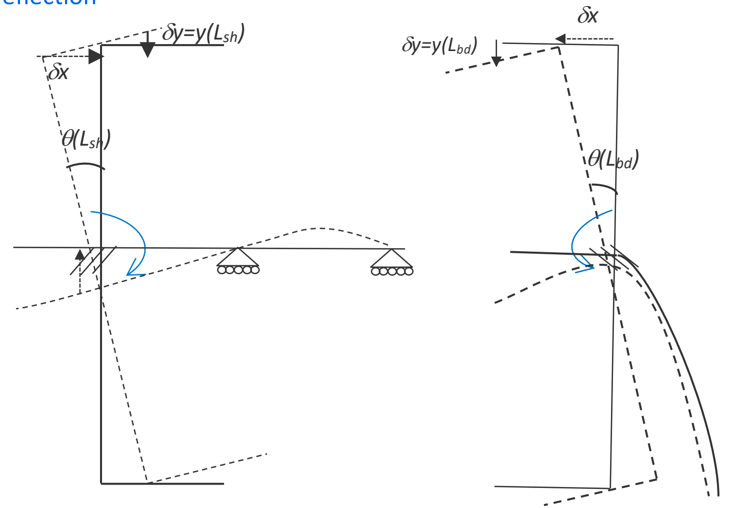


Loads used for computing deflection



e.g., weight components contributing to axial deflection

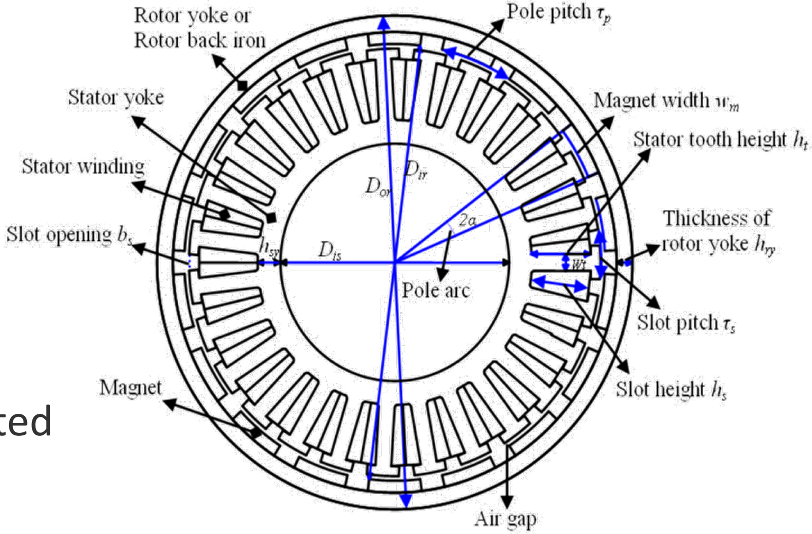
- Goal :Limit deflections caused by normal Maxwell stresses (q) , shear stress (torque (T)) and gravity(g)
- Torque constraint : $r^2 l \geq \dfrac{T}{2\pi\sigma}$, σ =40kPa
- Deflections at the shaft and bedplate factored into axial and radial components



Deflection at the shaft and nose/bedplate ends from bending

Electromagnetic design

- Fractional slot , double layer concentrated winding machine.(Slot/pole =6/5)
- Magnet width/pole pitch assumed to be 70%
- 0.15<Aspect ratio (L/D)<0.3
- Maximum flux densities in the core limited to < 2Tesla
- Winding current density limited to 3-6A/mm^2
- Specific current loading limited to 60kA/m
- Leakage flux, edge effects of magnets, fringing neglected
- Analytical models based on Hung [4]
- Air-gap radius, core length, stator slot height, number of pole pairs, magnet height , stator and rotor yoke heights and tooth flux density are design variables



Exterior rotor PM machine[4]

Results summary

Parameter	Type 1 (Arms)	Type 2 (discs)
Air gap diameter (m)	12.78	12.79
Core length (m)	2.221	2.227
Pole pairs	150	150
Generator output phase voltage (V)	6399	6423
Efficiency at full load (%)	94.0	94.05
Structural mass (tons)	228	314
Active mass (magnets, copper, electrical steel)	366	346
Total Mass (tons)	**594**	**660**
Material cost (k$)	8068	8129

References

1. R.J. Roark, W. C. Young, R. G. Budynas. (2002), Roark’s Formulas for Stress and Strain. New York: McGraw-Hill.
2. A.S. McDonald, Structural Analysis of Low Speed, High Torque Electrical Generators for Direct Drive Renewable Energy Converters. PhD diss., University of Edinburgh, 2008.
3. L.Sethuraman and K. Dykes, GeneratorSE: A Sizing Tool for Variable-Speed Wind Turbine Generators, NREL/TP-5000-66462.
4. V.X. Huang, Modeling of Exterior rotor permanent magnet machines with concentrated windings, PhD diss., TUDelft, 2012.

Acknowledgments

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