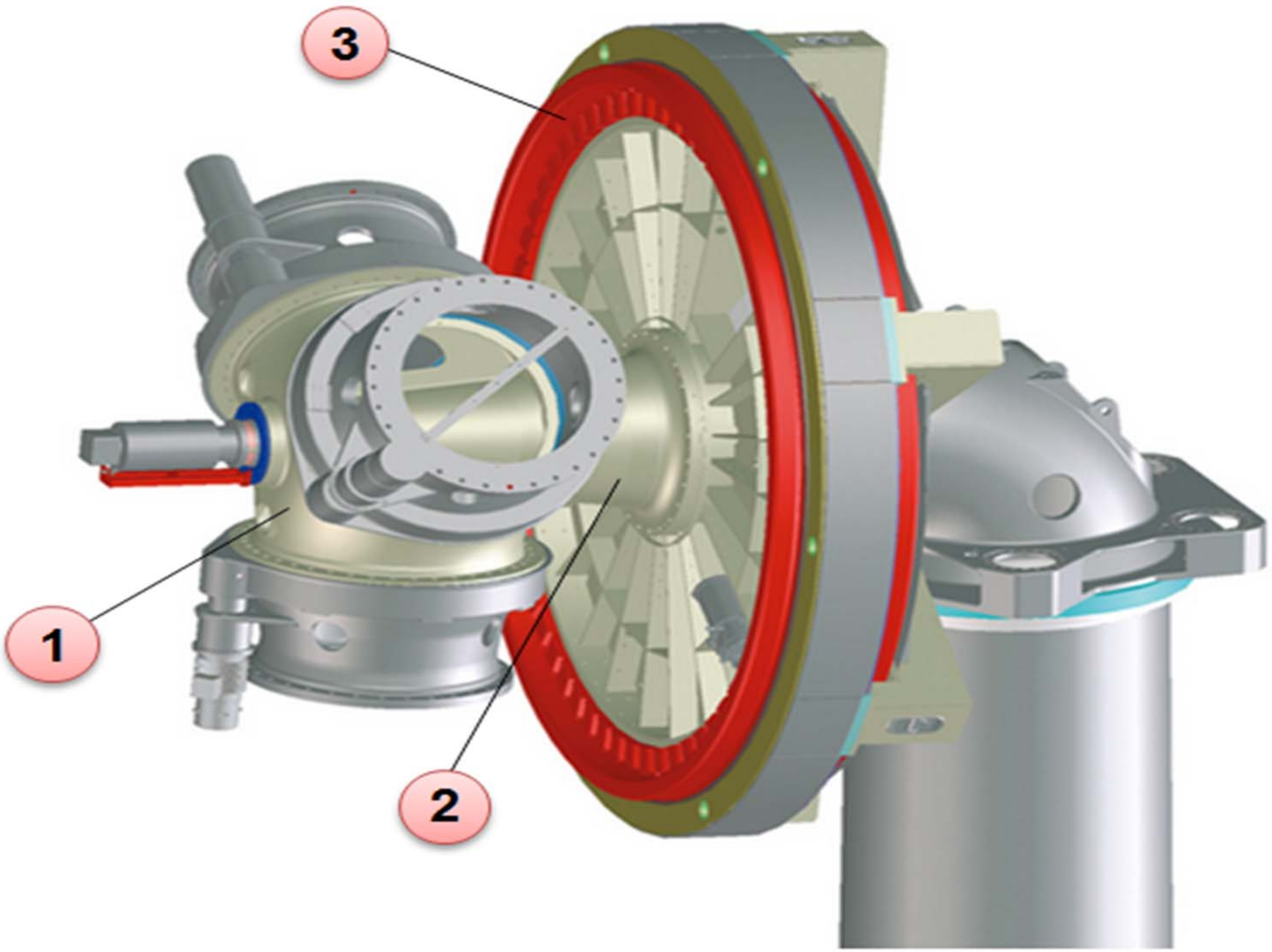
Advanced Structural Modelling and Design of Wind Turbine Electrical Generators

Pablo Jaen Sola

Alasdair McDonald & Erkan Oterkus

pablo.jaen-sola@strath.ac.uk
alasdair.mcdonald@strath.ac.uk
erkan.oterkus@strath.ac.uk

Why direct-drive?



Courtesy of Enercon

1 Rotor blade   3 Main shaft   5 Generator

2 Hub   4 Transmission gearbox

1 Hub   2 Main shaft   3 Generator

Aims

Exploration

Modelling

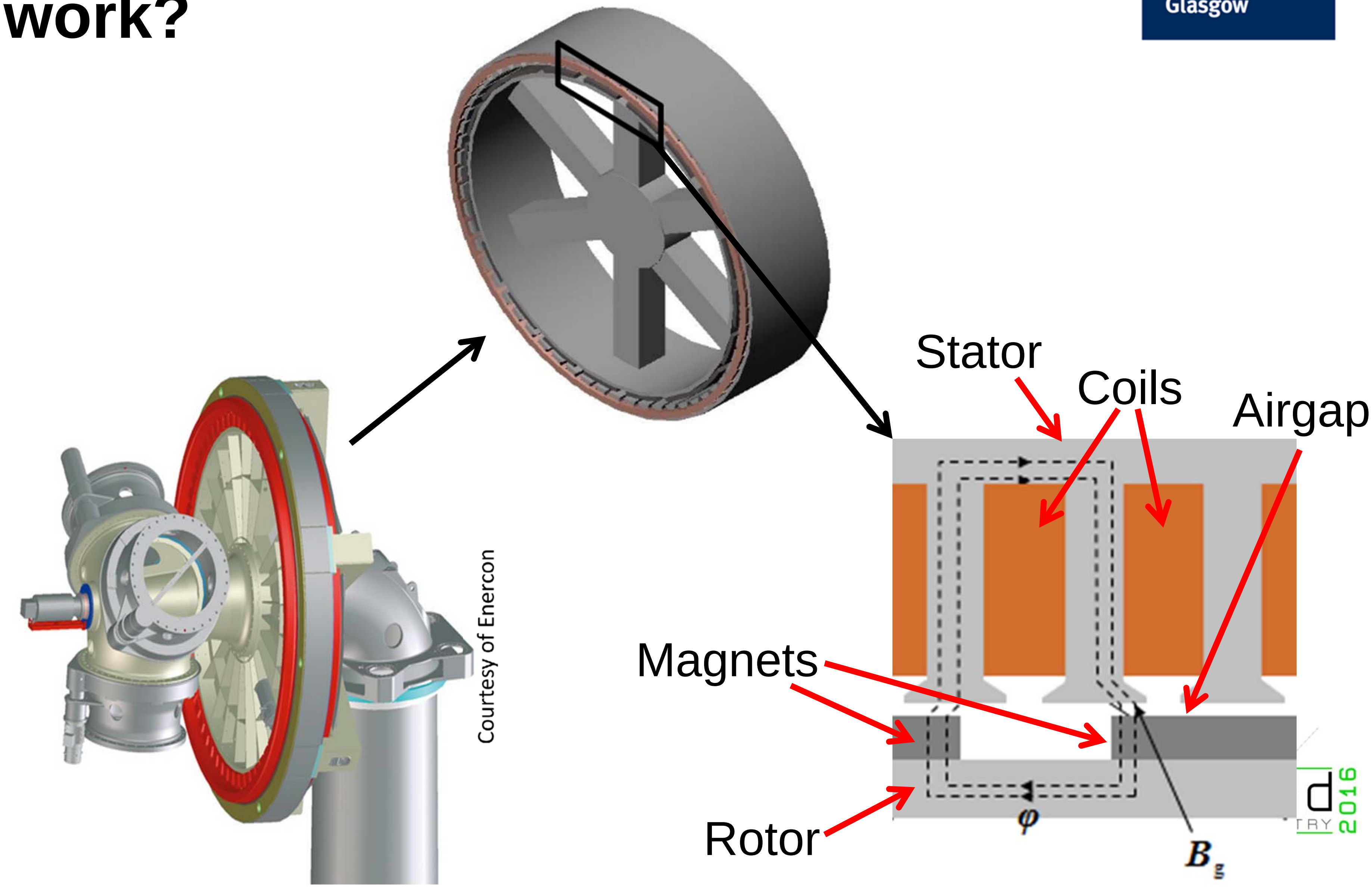
Analysis

Optimization

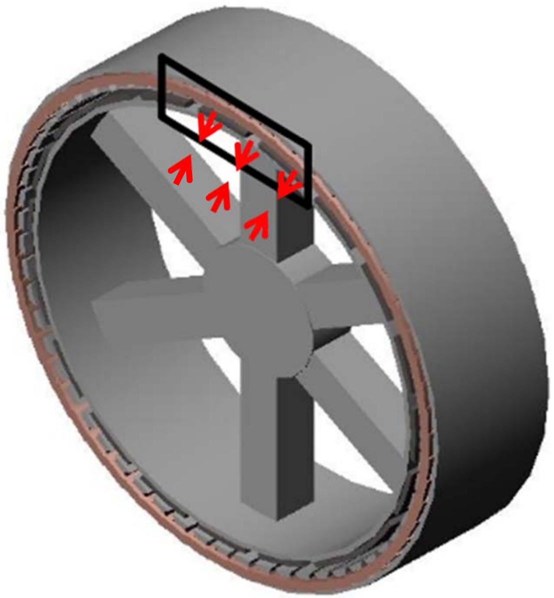
Design

Structural Analysis of Generators for Direct-Drive Wind Turbines

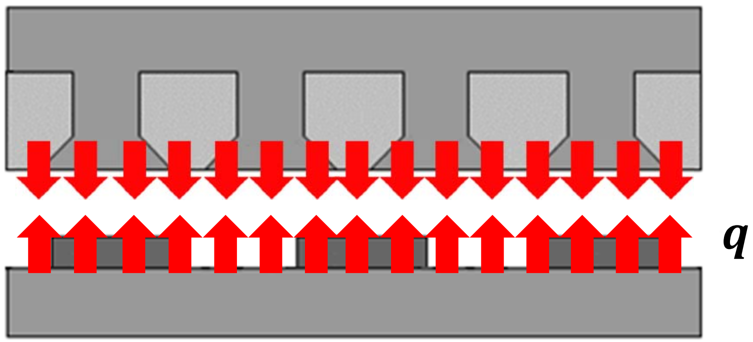
How does a direct-drive generator work?



Forces at play

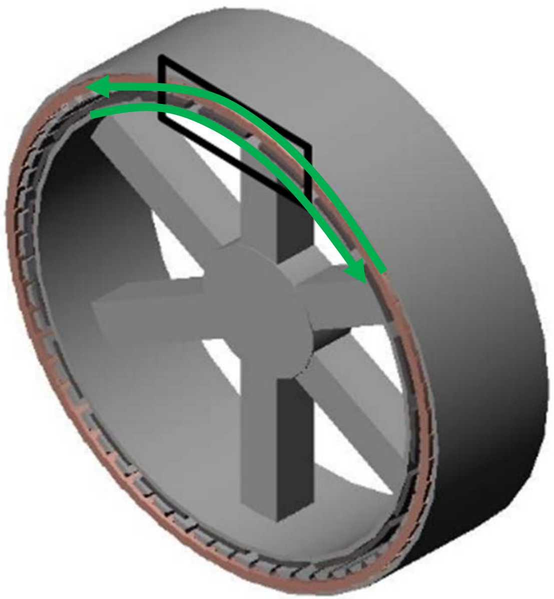


Normal stress

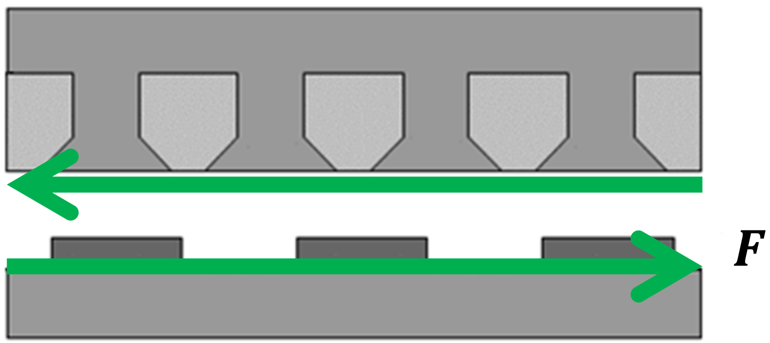


$$q = \frac{\hat{B}^2}{2\mu_0} \approx 250kPa$$

Forces at play

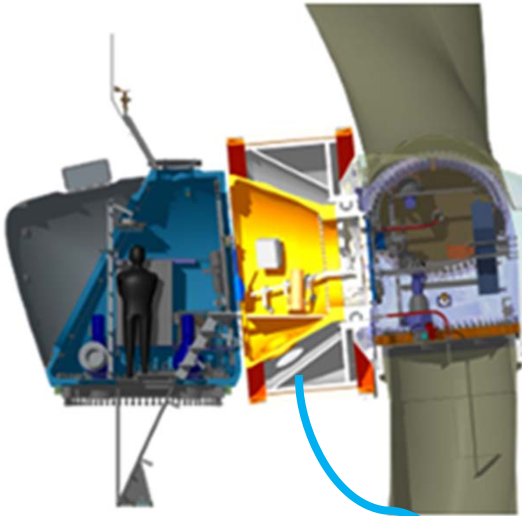


Shear stress

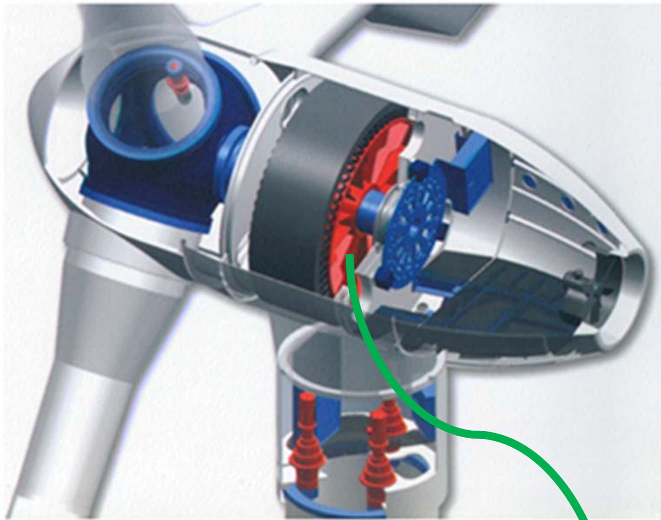


$$\tau = \frac{F}{A} \approx 40kPa$$

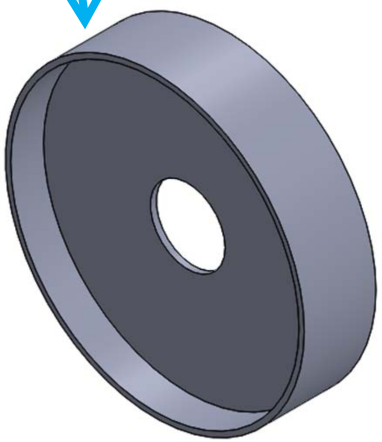
How to model a generator structure?

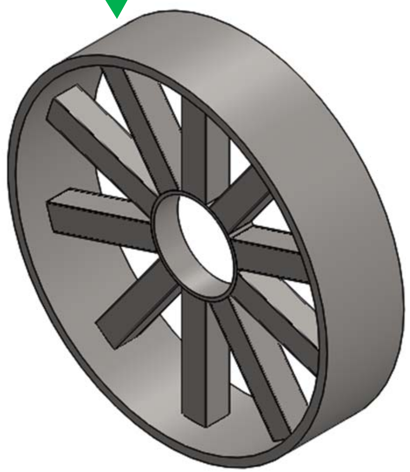


Courtesy of Harakosan Europe



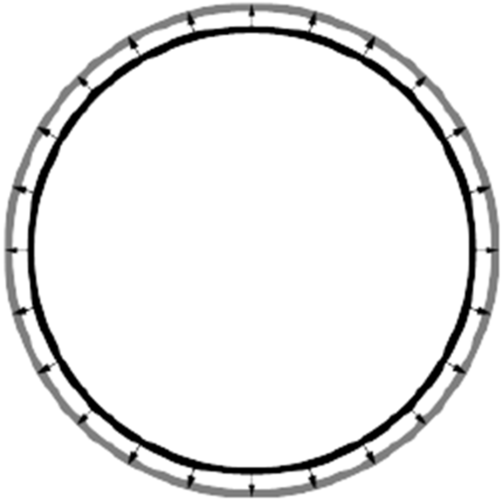
Courtesy of MTorres

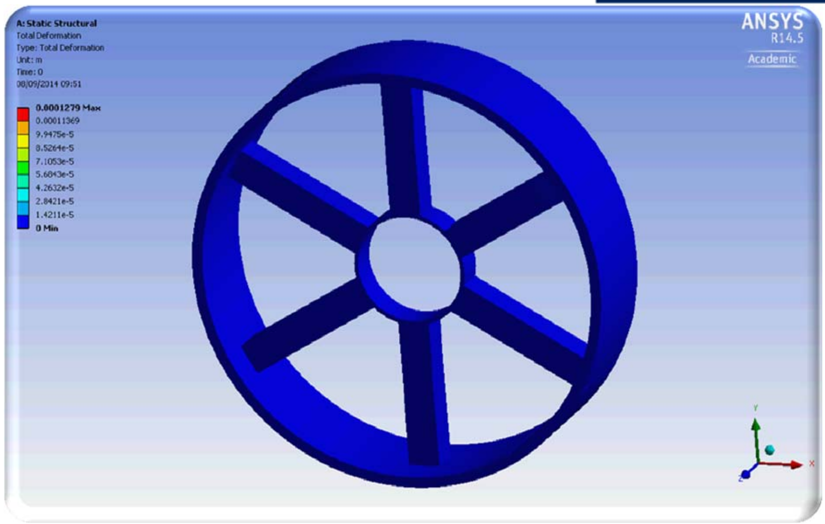




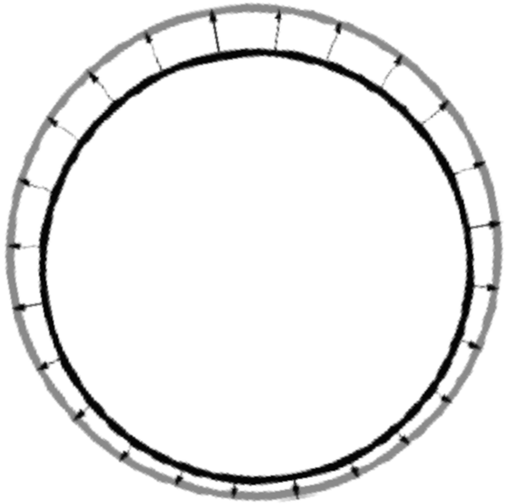
Deflection modes

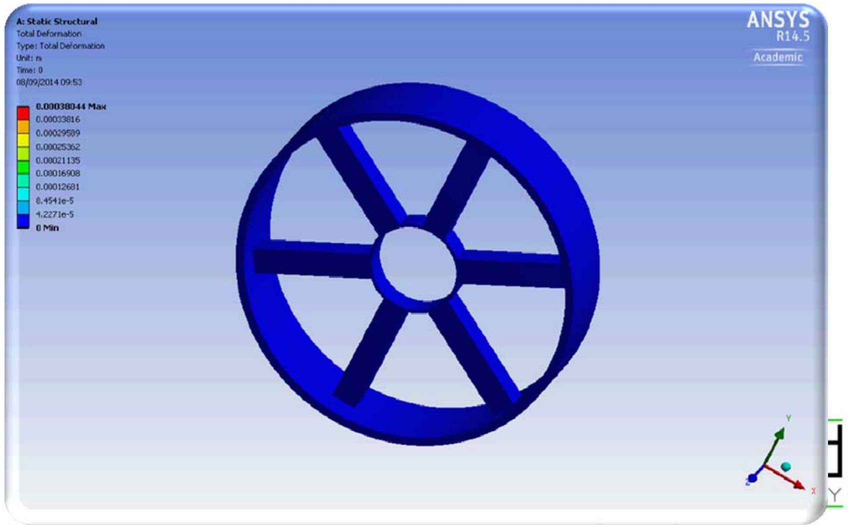
Mode 0 Uniform deflection





Mode 1 Rotor eccentricity

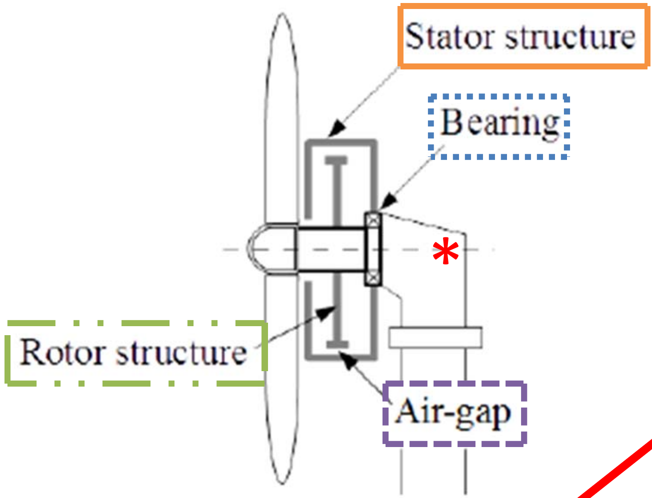




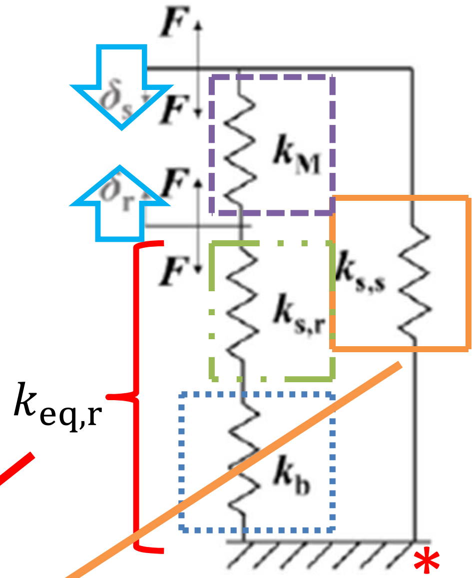
Structural stiffness

Courtesy of Enercon

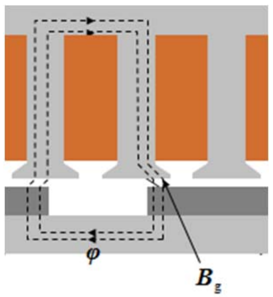
a) Direct-Drive wind turbine



b) Generator structure

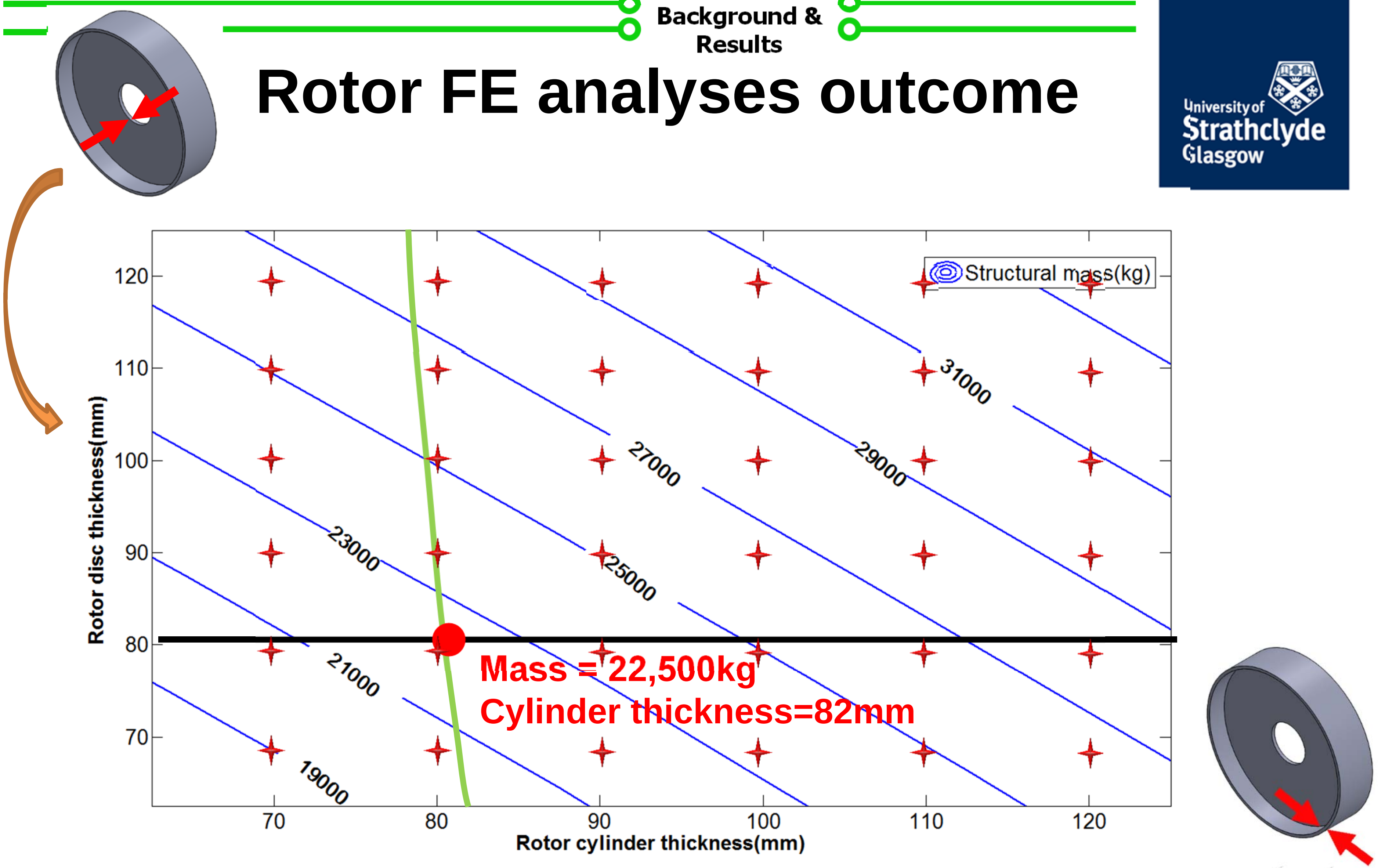


c) Generator structure showing as stiffness



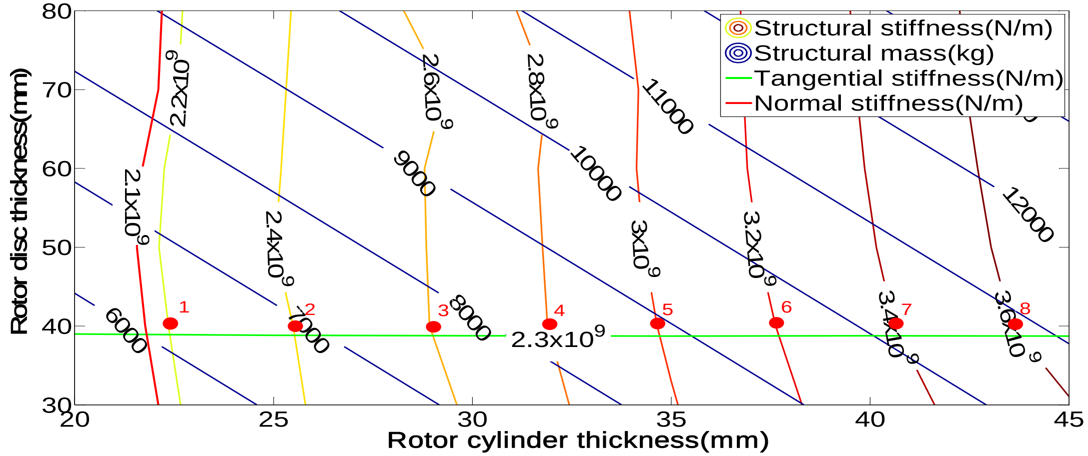
$$k_M = \frac{k_{eq,r} k_{s,s}}{k_{eq,r} + k_{s,s}}$$

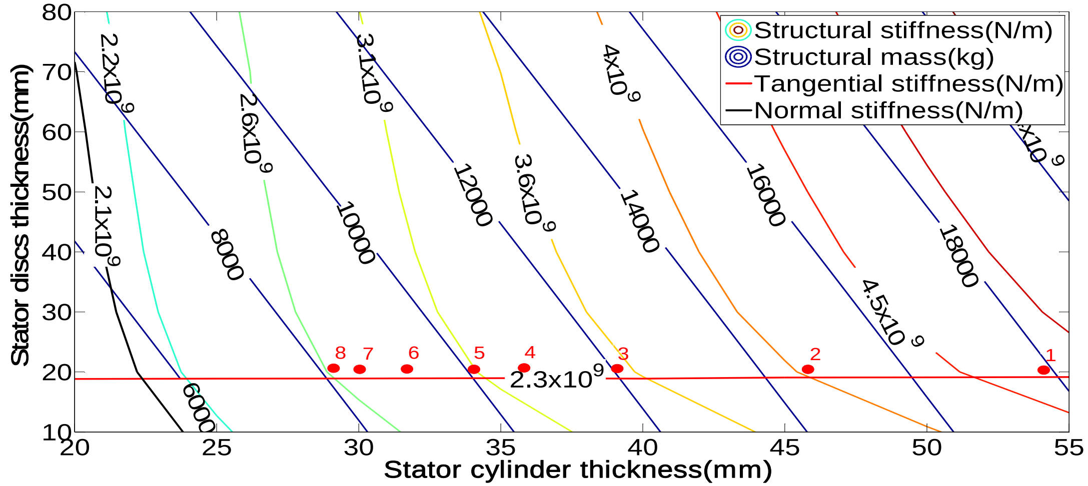
Rotor FE analyses outcome

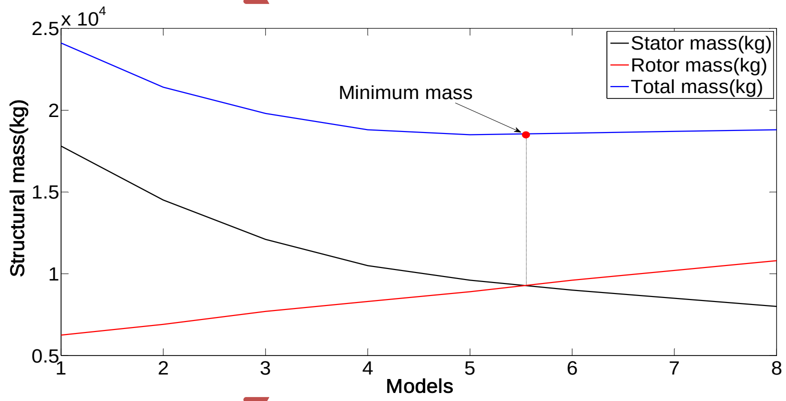


- ❖ FE analyses take a long time
- ❖ More than 6^2 FE studies carried out

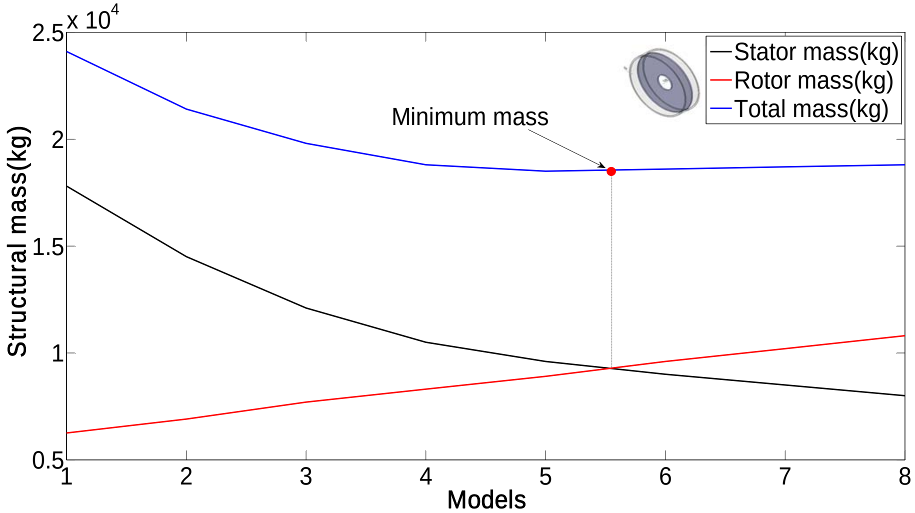
Numerical approach



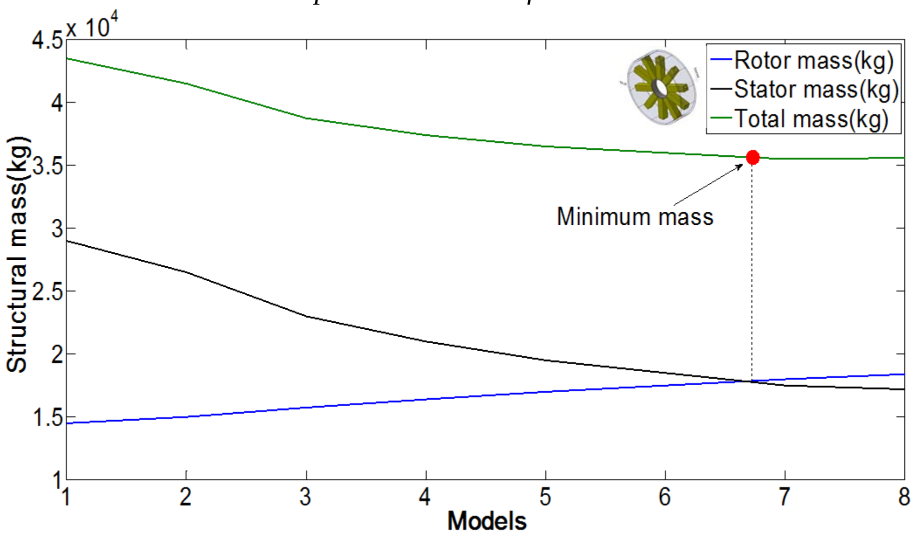




Numerical approach



Mass optimisation result for disc structures

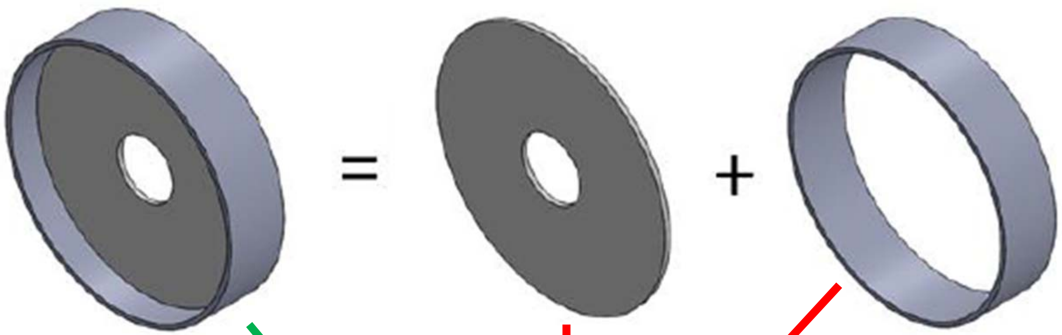


Mass optimisation result for armed structures

- ✓ Armed structures are not capable of resisting torque loads as disc structures do unless the thickness of the hollow arms is considerably increased with the consequent rise on mass
- ✓ A comparison between these two types of structures supporting the same loads shows a difference in mass of 17 tonnes

Analytical approach for rotor structures

- Allows the user to easily find out the structural stiffness of the components
- The dimensions of the constituents and their material characteristics are the input of the equations

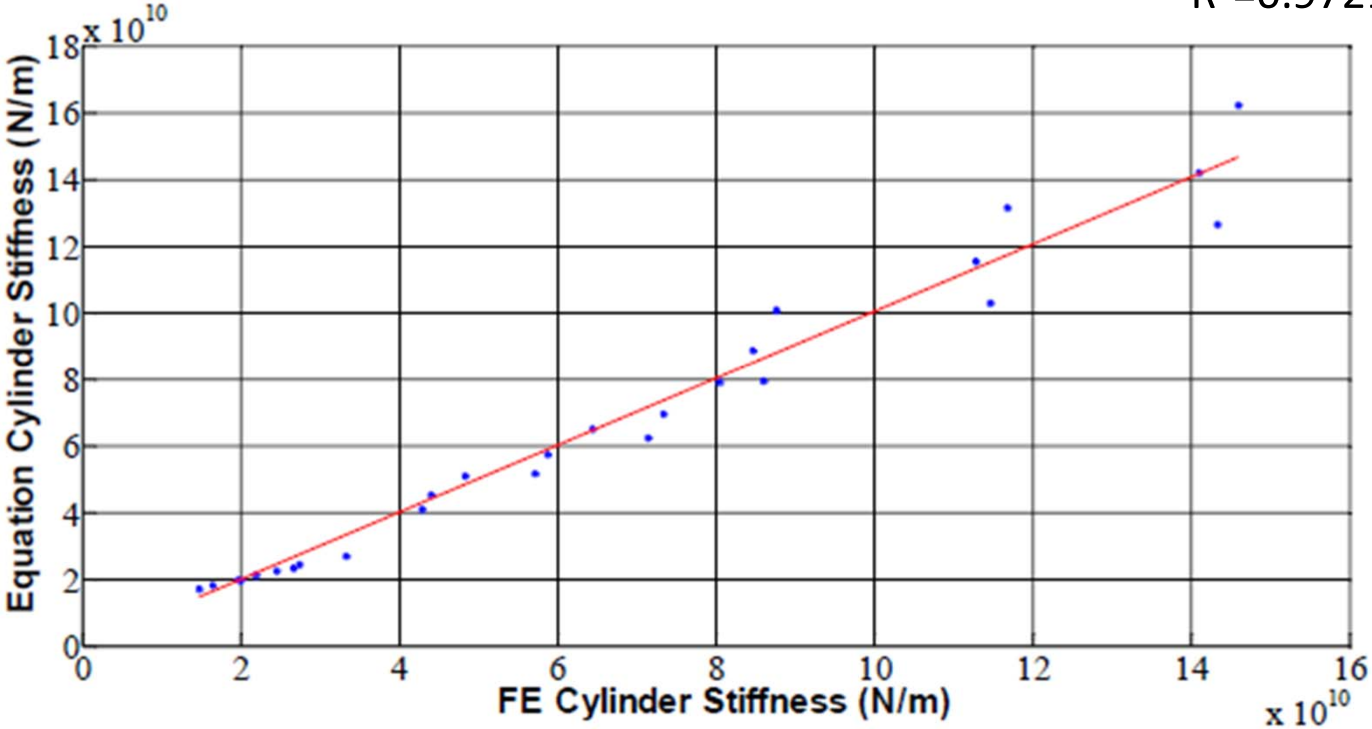


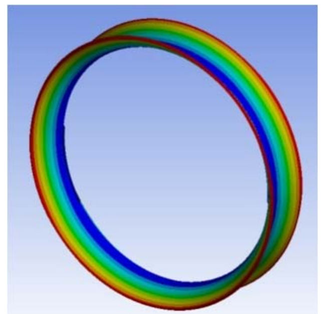
$$k_{s,r} = \frac{k_{s,d} k_{s,c}}{k_{s,d} + k_{s,c}}$$

Analytical approach for rotor structures

$$k_c = f(E, t_c, R, l, v, \gamma)$$

R^2=0.9721





Analytical approach (Summary of results)

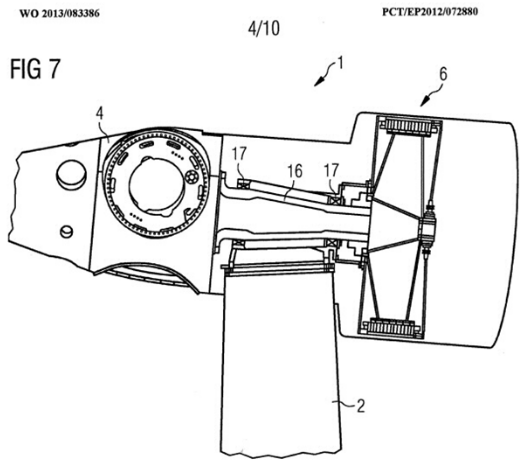
- ✓ All ***sub-structures*** forming the electrical generator were studied and expressions describing their structural behaviour obtained
- ✓ ***Good agreement*** between equation results and FE data was achieved for the all the components with ***R^2 over 0.9225***
- ✓ However, when combining these equations together, the result is not as satisfactory as expected. In the ***stator with discs*** case, the ***model*** slightly ***underestimates the stiffness*** as the equation predicts a lower contribution of the discs to the overall stiffness than what it is in reality. For ***armed structures***, the ***stiffnesses*** of the ***rotor*** and the ***stator*** were ***heavily underestimated*** as the equivalent stiffness of the arms did not have enough weight

Use of lightweight materials in electrical machine structures

Why composite materials?

- ✓ Composite materials are utilised in blades and other mass sensitive structures
- ✓ Large manufacturers, such as Siemens, are currently developing advanced composite structures for their generators

Courtesy of Siemens Wind Power



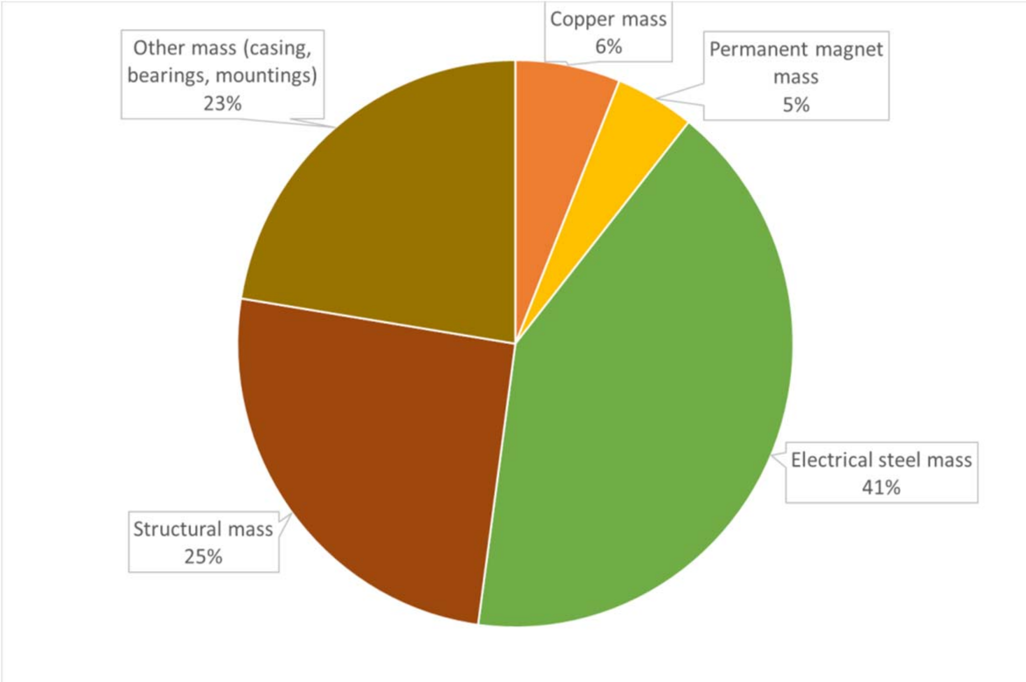
Composite material generator structure
Patent obtained by SIEMENS AKTIENGESELLSCHAFT in 2012

Case study: 100kW wind turbine drivetrain

A set of arrangements – comprising gearless and conventional geared with diverse ratios – have been analysed so as to find out the lightest possible layout.

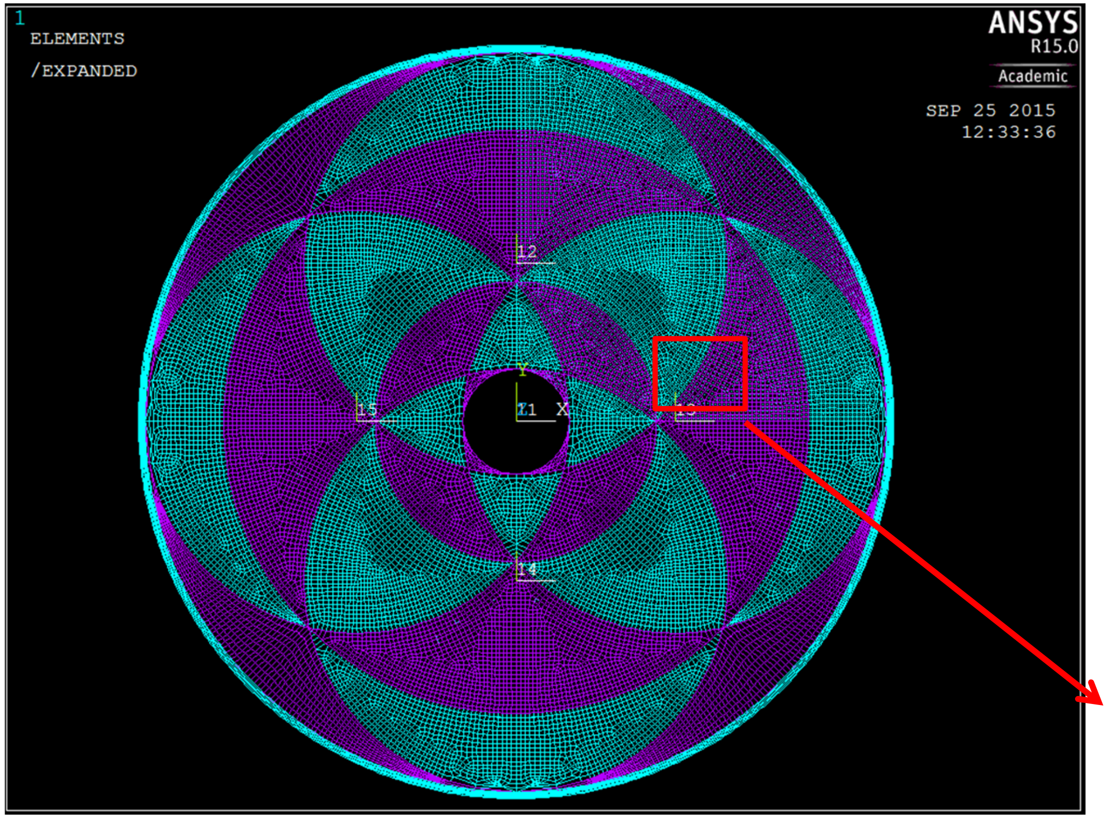
Generator masses are based on basic electromagnetic design and scaling, with the addition of modelling the mechanical design to cope with forces within the generator.

Gearbox masses are based on catalogue data for commercially available parallel and planetary gearbox units.



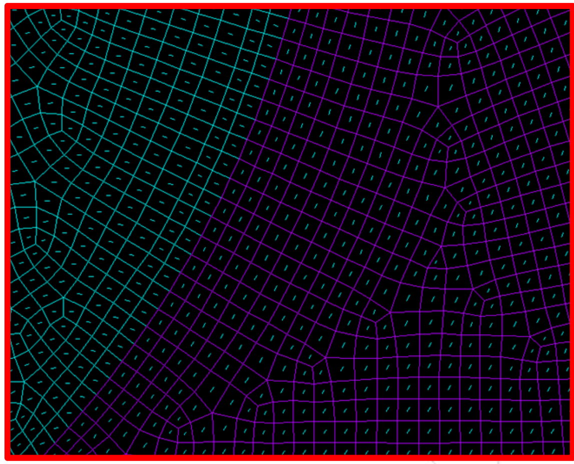
Breakdown of mass for the direct-drive generator

Lightweight composite material disc structures

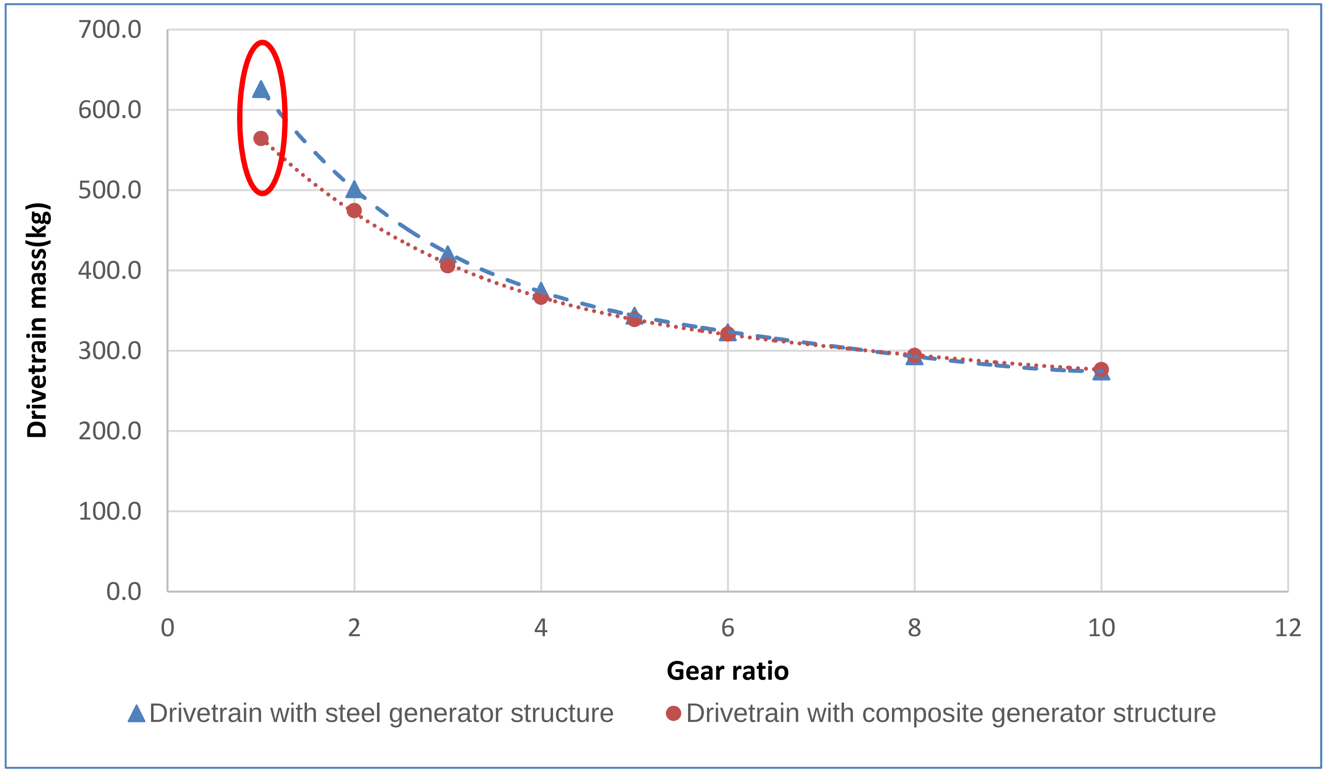


Detailed view of the composite rotor disc structure based on Morozov's flywheel model

- The generator supporting structure was assumed to be made with discs
- It was considered that the structure must be able to withstand normal stress without deforming more than 10% of the air-gap size in any direction
- Two different materials were looked at: steel and carbon/epoxy



Drivetrain mass comparison



Total drivetrain mass (mass of gearbox and generator) plotted against gearbox ratio for steel and composite generator supporting structures

A considerable reduction of the structural mass was achieved. The comparison revealed a ***10% drop*** in the ***overall weight*** for the gearless case. Nevertheless, the lightest configuration corresponded to the arrangement with a steel generator structure and a gearbox operating at a ratio of 10

Conclusions on composites

- ✓ Making use of ***carbon/epoxy***, a generator structure made with discs was designed
- ✓ Both rotor and stator disc sub-structures had a ***mosaic pattern fibre layout*** with a ***smear layer of reinforcement***
- ✓ The rotor and stator structures were ***tested under a normal expansion loads*** placed on the rim sub-structures
- ✓ The results obtained were ***compared with*** those acquired for their ***counterparts made of steel***. The study revealed that the composite generator structure performs as well as the steel structure under the mentioned load
- ✓ A considerable reduction of the overall structural mass was obtained, as it could be seen for the ***gearless case***, where a ***10% drop*** in the ***overall weight*** was achieved
- ✓ Despite of the reduction, ***the lightest configuration*** corresponded to the arrangement with a ***steel generator structure and a gearbox operating at a ratio of 10***

Questions

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