

Mechanical Engineering: Year One Capstone Assesment

2019/2020

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3	Gearbox (materials)	5
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3.2	There are many different grades of steel available – what particular properties of the steel might be required for a gearbox application, and what sorts of steel would be suitable therefore?	5
3.3	The gears will be enclosed in a housing to help hold the mechanism together and prevent the ingress of contaminants. Suggest suitable materials for this housing, ensuring you provide justification for your suggestions (taking into account a range of factors including properties, and economic issues). Given your suggestions above, qualify these by providing consideration for how such an enclosure could be manufactured. What manufacturing processes might principally be required?	5
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5.3	The world's most powerful commercial wind turbine today has a blade length of 82m and is rated at 9.5 MW. Comment briefly on the reasons why the numbers calculated using your theoretical approach above are far larger than this actual capacity.	5
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6.1	In an offshore wind turbine facility, the excess energy generated is stored using a simple compressed air storage system. The wind turbine is mechanically coupled to a compressor that has a compression ratio of 200. The compressor takes in air from the surrounding at ambient pressure and temperature conditions (p_0 , T_0) and performs a reversible adiabatic compression process. The output air from the compressor (at p_1 , T_1) undergoes a reversible isobaric heat removal process using a heat exchanger in order to reduce the temperature to T_0 . The air is then stored in a high-pressure storage facility.	5
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6.3	The heat removal in the above system is achieved by a refrigerator operating on a simple vapour compression cycle. This simple vapour compression refrigerator uses ammonia (NH_3) as the working fluid. The evaporator pressure is p_e and the condenser pressure is p_c (where $p_c/p_e=6$). The working fluid leaves the evaporator dry-saturated and enters the compressor, where it is compressed reversibly and adiabatically. Condensation at constant pressure then takes place until the saturated liquid state is reached. This is followed by throttling to evaporator pressure.	5
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7.1	Consider all the aspects covered above and compare the trade-offs in each of these categories during wind turbine design. You may also wish to consider how they are affected by the environment: water depth, ocean waves and seafloor structure. Reflect on the consequent additional challenges in building and maintaining offshore wind turbines.	5

1 Blades

1.1 For the blades of the wind turbine, composite materials are usually employed. Why is this the case?

A composite material may be employed for their favourable properties. The material of a wind turbine is likely to be a fibreglass reinforced epoxy or polyester (Iberdrola 2020). Creating such a composite yields better strength, elasticity and corrosion resistance than an alternative e.g. aluminium. The orientation of the fibres in the matrix can be specifically arranged to combat the force of the wind on the blade, reducing the probability of failure (cracking, deformation) in the material.

- 1.2 For the blades of the wind turbine, composite materials are usually employed. Why is this the case?**
- 1.3 What significant issues can you see with using composites in this engineering application? [For example, you could consider economic or environmental challenges]**
- 1.4 The power (W in J/s) produced by a wind turbine depends on blade length (B), the incoming wind speed (V), and air density (ρ). Derive one dimensionless number relevant to the problem using W as the dependent parameter. Use this dimensionless number to comment on the implications of doubling the blade length.**

Using Buckingham Pi:

$$[W] = ML^2T^{-3} \quad (1)$$

$$[B] = L \quad (2)$$

$$[V] = LT^{-1} \quad (3)$$

$$[\rho] = ML^{-3} \quad (4)$$

$$W = B^a V^b \rho^c \quad (5)$$

$$ML^2T^{-3} = L^a L^b T^{-b} M^c L^{-3c} \quad (6)$$

$$c = 1, b = 3, a = 2 \quad (7)$$

$$W = B^2 V^3 \rho \quad (8)$$

$$k = \frac{W_1}{B^2 V^3 \rho} \text{ and } k = \frac{W_2}{4B^2 V^3 \rho} \quad (9)$$

$$W_1 = \frac{W_2}{4} \quad (10)$$

$$4W_1 = W_2 \quad (11)$$

From this we can see that doubling the blade length (B), quadruples the power output of the wind turbine.

- 1.5 Considering the answer above, discuss the trade-offs associated with choosing longer blades for a turbine of a fixed height.**

Naturally, choosing larger blades for a turbine of a fixed height creates a limit to how large the blades can be before the turbine's tower would not be able to structurally support the weight of the blades. Hence, using larger blades requires the use of stronger materials in order to support their weight. Using stronger materials is more expensive to procure and manufacture, driving up initial costs. If the turbine cannot produce enough power to become economically viable over its lifetime, this would cause problems for the manufacturer.

2 Gearbox (dynamics)

- 2.1 Derive a simple relationship for the gear ratio expressed as a function of number of teeth in the sun and ring gears of an epicyclic (or planetary) gear train.
- 2.2 Perform a conceptual design of an epicyclic gear system for a 1.5 MW wind turbine if the three blades spin at a design speed of 12 rpm and the high-speed shaft in the generator needs to spin at 1680 rpm. Provide information on the configuration of your proposed planetary gear set (note: the 5 laws of planetary gearing – see the provided videos) and the input/output torque ratio that can be achieved by your system. Neglect friction and assume that the angular acceleration of the gears (which are rigid and non-deformable) is zero. You must indicate the number of teeth in each gear and provide a schematic drawing.
- 2.3 Wind gusts and turbulence lead to misalignment of the drive train and premature failure of the gear components. How could this be mitigated?
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3 Gearbox (materials)

- 3.1 For the gears in the gearbox of the wind turbine, steel would normally be the material of choice. Why is this the case?
- 3.2 There are many different grades of steel available – what particular properties of the steel might be required for a gearbox application, and what sorts of steel would be suitable therefore?
- 3.3 The gears will be enclosed in a housing to help hold the mechanism together and prevent the ingress of contaminants. Suggest suitable materials for this housing, ensuring you provide justification for your suggestions (taking into account a range of factors including properties, and economic issues). Given your suggestions above, qualify these by providing consideration for how such an enclosure could be

URL: *<https://www.iberdrola.com/press-room/top-stories/wind-turbines-blades>*