Wind Turbines

Observations about Wind Turbines

- Wind turbines are symmetrical and balanced
- A balanced wind turbine rotates smoothly
- An unbalanced turbine settles heavy-side down
- Most wind turbines have three blades
- Wind turbines start or stop spinning gradually
- Wind turbines extract energy from the wind and convert it into electrical energy

6 Questions about Wind Turbines

- How does a balanced wind turbine move?
- Why does the wind turbine need a pivot?
- Why does a one-blade turbine spin unevenly?
- Why do blade weights and orientations matter?
- Why do giant turbines start and stop so slowly?
- How does energy go from wind to generator?

Question 1

- How does a balanced wind turbine move?
  - Is a balanced wind turbine horizontal?
  - Is a horizontal wind turbine balanced?

Physics Concept

- Rotational Inertia
  - A body at rest tends to remain at rest
  - A body that's rotating tends to keep rotating

Physical Quantities

- Angular Position
  – an object's orientation
- Angular Velocity
  – change in angular position with time
- Torque – a twist or spin

Newton's First Law of Rotational Motion

- A rigid object that's not wobbling and that is free of outside torques rotates at a constant angular velocity.

Balanced Wind Turbine

- All by itself, a balanced wind turbine
  - experiences zero net torque
  - has a constant angular velocity
- Its angular velocity is constant when it is
  - motionless and horizontal
  - motionless and tilted
  - turning steadily in any direction

Question 2

- Why does the wind turbine need a pivot?
  - How would a pivotless wind turbine move?

Center of Mass

- The point about which an object naturally spins
- A free object rotates about its center of mass while its center of mass follows the path of a falling object

Wind Turbine's Pivot

- The wind turbine needs a pivot to
  - support the weight of the turbine
  - prevent the turbine from falling
  - permit the turbine to rotate but not translate
- Placing the pivot at turbine's center of mass
  - allows the turbine to spin about its natural pivot
  - minimizes the forces required of the pivot

Question 3

- Why does a one-blade turbine spin unevenly?
  - How does a torque affect a wind turbine?
  - How does gravity exert a torque on the turbine?

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Physical Quantities

- Angular Position
  – an object's orientation
- Angular Velocity
  – change in angular position with time
- Torque – a twist or spin
- Angular Acceleration
  – change in angular velocity with time
- Rotational Mass – measure of rotational inertia

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Newton's Second Law of Rotational Motion

- An object's angular acceleration is equal to the net torque exerted on it divided by its rotational mass. The angular acceleration is in the same direction as the torque.

angular acceleration = net torque/rotational mass

net torque = rotational mass · angular acceleration

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Forces and Torques

- A force can produce a torque
- A torque can produce a force

torque = lever arm · force
(where the lever arm is perpendicular to the force)

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A One-Blade Turbine's Uneven Rotation

- Blade's weight produces a torque on the turbine
  - Turbine undergoes angular acceleration
  - so turbine's angular velocity changes
- Direction of gravitational torque
  - reverses every half-turn
  - so turbine's angular speed fluctuates as it spins

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Question 4

- Why do the blades' weights and spacing matter?
  - Why are most wind turbines so symmetrical?

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Net Torque

- The net torque on the wind turbine is
  - the sum of all torques on the wind turbine
  - responsible for the turbine's angular acceleration
- If net torque is zero, angular velocity is constant

Balancing the Blades

- Each blade experiences a gravitational torque
  - Left blade has ccw torque (weight · lever arm)
  - Right blade has cw torque (weight · lever arm)
- If those torques sum to zero,
  - turbine experiences zero gravitational torque
  - turbine is balanced

Center of Gravity

- Wind turbine's center of gravity
  - is the effective location of the turbine's weight
  - coincides with the turbine's center of mass
- When turbine's center of gravity is at its pivot,
  - it experiences zero gravitational torque
  - it is balanced
- A symmetrical three-blade turbine is balanced

Question 5

- Why do giant turbines start and stop so slowly?
  - How does blade length affect wind torque?
  - How does blade length affect rotational mass?

A Blade's Wind Torque

- A blade's wind torque is proportional to
  - the wind's force on the blade
  - the blade's effective lever arm
- Doubling the length of a blade
  - increases its wind force by a factor of 2
  - increases its effective lever arm by a factor of 2
  - increases its wind torque by a factor of 4

A Blade's Rotational Mass

- A blade's rotational mass is proportional to
  - the blade's mass
  - the square of blade's effective lever arm
- Doubling the length of a blade
  - increases its mass by a factor of 2
  - increases its lever arm by a factor of 2
  - increases its rotational mass by a factor of 8!

Turbine Size and Responsiveness

- A wind turbine blade's
  - wind torque increases in proportion to its length^2
  - rotational mass increases in proportion to its length^3
- The larger the wind turbine,
  - the slower its angular accelerations
  - the longer it takes to start or stop turning

Question 6

- How does energy go from wind to generator?
  - How does a rotating system do work?

Rotational Work

- Wind does translational work on a turbine blade:
  - wind exerts a force on blade
  - blade moves a distance in direction of that force
  - so energy moves from wind to wind turbine
- Turbine does rotational work on a generator
  - turbine exerts a torque on generator
  - generator turns an angle in direction of that torque
  - so energy moves from wind turbine to generator

Summary about Wind Turbines

- Without air or generator, balanced wind turbine
  - experiences zero gravitational torque
  - rotates at constant angular velocity
- Wind forces produce torques on turbine's blades
- Generator exerts opposing torque on turbine
- Wind turbine turns at constant angular velocity
- Energy goes from wind to turbine to generator