Rotational Mechanics

Next Generation Science Standards

NGSS Science and Engineering Practices:

- ☐ Asking questions and defining problems
- ☐ Developing and using models
- ☑ Planning and carrying out investigations
- ☑ Analyzing and interpreting data
- ☑ Using mathematics and computational thinking
- ☐ Constructing explanations and designing solutions
- ☐ Engaging in argument from evidence
- ☑ Obtaining, evaluating, and communicating information

NGSS Cross-cutting Concepts:

- ☐ Patterns
- ☐ Cause and effect
- ☑ Scale, proportion, and quantity
- ☐ Systems and system models
- ☐ Energy and matter
- ☑ Structure and function
- ☐ Stability and change

NGSS Disciplinary Core Ideas:

- ☑ PS2.A: Forces and Motion

Initial Prep Time

Approx. 5 min. per apparatus

Lesson Time

1 – 2 class periods, depending on experiments completed

Assembly Requirements

- None

Materials (for each lab group):

- Horizon Vertical Axis Wind Turbine STEM Kit
- Electric fan
- Metric ruler
- Horizon Renewable Energy Monitor or multimeter (optional)

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Lab Setup

- You should attach the magnets to the bottom blade plate (as described in Step 1 of the Assembly Guide) before students start their experiments. Be sure the magnets with the red dots are on opposite sides of the plate.
- You may find it useful to test out different blade configurations before your students arrive to see which ones work best with the speed of your particular fans. In general, lower wind speeds will work best with more blades, while faster speeds will require fewer blades.
- Lab includes small parts that can go missing easily. Set up a resource area for each lab table or for the entire class to minimize lost pieces.

Safety

- With a powerful fan in front of them, the turbine blades can move very quickly. Students should keep their hands and faces at a safe distance and wear safety goggles at all times.
- Be sure to install the turbine properly so that it will not move or topple over while running. Placing a rubber mat, foam padding, or a thin book under the base helps stabilize the turbine if the underlying surface is too smooth. Placing adhesive tape on the Base Extender also helps secure the turbine to a solid surface.
- If the turbine falls over while running, do not try to catch it. Extending the Base Extenders will increase the footprint of the base and reduce the chance of it toppling over. Please note that one of the Base Extenders must be aligned in the prevailing wind direction to effectively prevent it from toppling over.

Notes on Wind Energy Kit

- A small, handheld fan won't be powerful enough to turn the turbine blades. Be sure to use a large, desktop fan.
- A fan with multiple settings is ideal and will allow your students to conduct more experiments about how the turbines operate at different wind speeds. If you don't have a fan with multiple speeds, you can simulate different wind speeds by adjusting the distance between the fan and the turbine, but turbulence will cause some variation in your data.

Common Problems

- Placing a rubber mat, foam padding, or a thin book under the base helps stabilize the turbine if the underlying surface is too smooth. Placing adhesive tape on the Base Extender also helps secure the turbine to a solid surface.

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Goals

- Assemble a vertical-axis wind turbine
- Measure the parameters of its motion
- Make calculations based on data

Background

Linear motion, in one dimension and in a straight line, is relatively easy to understand. People, vehicles, billiard balls, elevators, and countless other examples travel in linear directions all the time, so it's simple to apply the concepts of linear motion to everyday life. But when things move in a circle, things get a little more complicated.

A rotating object is constantly accelerating, even if it's moving at the same speed all the time. Yes, that really is as strange as it sounds. The reason is that velocity is a vector quantity: it has a magnitude (like 5 m/s or 50 mph) and a direction. A rotating object is constantly changing the direction it's moving (imagine the always-changing view from a carousel) so that means its velocity is always changing, and any change in velocity is defined in physics as an acceleration.

For this reason, it's easier to talk about an object's angular velocity (abbreviated with the Greek letter omega: ω) which is a measurement of the angle the object goes through in a certain amount of time. It's easy to imagine an object completing one revolution every second, for example.

The angular velocity is closely related to what's known as the object's period: the time it takes to complete one rotation. The period is abbreviated T in physics, so we get this equation:

$$\omega=2\pi/T$$

Where 2π is the number of radians in a complete circle. We can also calculate the velocity of the object traveling in the circle just by knowing how large the radius (r) of the circle is:

$$v=2\pi r/T$$

So objects farther out on a circle, even if they are rotating at the same rate as objects closer to the center, are traveling faster. If a bunch of people hold hands and try to move in a circle, the people near the center will hardly have to move at all while those on the end might have trouble running fast enough to keep up.

In this activity, we will use a vertical-axis wind turbine to explore rotational motion and make adjustments to it to try and maximize its angular velocity.

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Procedure

1. Your vertical-axis wind turbine has different slots so that you can assemble your wind turbine with two, three, or four blades. Which configuration do you think will be most effective at producing an electric current?
2. Look at the base for the turbine. It has two coils of wire inside it. Why do you think the coils of wire are necessary?
3. The stator is the part of the turbine that doesn't move. It's the thin rod that fits in the small hole in between the coils of wire. Why does your turbine require a part that remains stationary?
4. Once your stator is in place, you can begin constructing your rotor. First you'll have to decide how many blades you want. You can tell where the blades should go by following the color-coded markings on the top and bottom plates of the rotor.
5. You can tell the top blade plate from the bottom because the bottom of the rotor has four magnets attached to it. Why are magnets necessary?
6. Insert the aluminum rotor pole into the hole in the middle of the bottom blade plate. What purpose does the rotor pole serve?
7. Attach the desired number of blades to the appropriate color-coded slots on the bottom of the rotor.
8. Fit the top blade plate onto the blades and rotor pole, again lining up the appropriate color-coded slots with the turbine blades.
9. Use the blade plate lock to secure the top of the blade plate.
10. Lower the assembled rotor onto the stator on the base.
11. Attach the LEDs to the base using the red and black wires. Why do you think we need two wires?
12. Turn on the fan and observe what happens. Record your observations below.

Observations

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Experimentation

1. Try changing the number of blades in your turbine. Does anything change about how the turbine rotates or the amount of electric current supplied to the LEDs? Record your observations below:

Number of Blades:	Observations:
2	
3	
4	

2. Move your fan farther away from your turbine. What's the farthest distance it can be before your LEDs no longer light up? Record your observations below:

Number of Blades:	Distance (cm)	Observations:
2		
3		
4		

What arrangement worked at the farthest distance?

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3. To measure the revolutions per minute of your turbine, you'll need a stopwatch and some masking tape. Put a piece of masking tape on one of your blades. Have one group member operate the stopwatch and another stand next to the turbine to count the revolutions. (It's easier to count if you stand next to the turbine and count the times the taped blade comes over the top.)

Have the timekeeper say "Go!" once the turbine is turning and count the number of times the taped blade completes a revolution. Stop counting at exactly 15 seconds. You can then multiply your count by 4 to get the total revolutions per minute. Record your data below.

If your turbine spins too fast to measure in this way, use the Horizon Renewable Energy Monitor as described in the next section.

Trial:	Rev. Count (for 15 seconds):	RPM (4 x Count):
1		
2		
3		
4		

Average RPM:

4. Convert your average RPM to the period of rotation (T):

Avg. RPM:________ / 60 = ___________Revolutions/second

1/(Rev per second) = _____________ Seconds/revolution = T

5. Calculate the angular velocity (ω):

ω = 2π/T = 2π/__________ = ______________

6. Calculate the velocity (v) of the outermost edge of the fan.

Radius (measure from center of fan rotor to outer edge) = ___________ cm

v = ωr = ________ x ___________ = _______________

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Measurement

1. Skip questions 1-4 if you've already completed the RPM experiment from above. Press the Select button on the Renewable Energy Monitor until you see Watts, Joules, and RPM displayed. Record your RPM below:

The Horizon Renewable Energy Monitor can't detect RPM below 200.

RPM: ______________

2. Use this RPM measurement to calculate the velocity of the outermost edge of the fan. First, convert your average RPM to the period of rotation (T):

Avg. RPM:________ / 60 = __________Revolutions/second

1/(Rev per second) = ____________ Seconds/revolution = T

3. Calculate the angular velocity (ω):

ω = 2π/T = 2π/_________ = _____________

4. Calculate the velocity (v) of the outermost edge of the fan.

Radius (measure from center of stator to outer edge of rotor) = __________ cm

v = ωr = ________ x __________ = ______________cm/sec * 100 = _________ m/s

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5. How fast would the outer edge of your turbine blades be moving if it had the same RPM but it was a full-sized vertical-axis wind turbine generator, with a radius of 2m?

Students should use the $v = \omega r$ equation, with the same value for ω but 2m for r. They don't need to convert cm/s to m/s.

6. The speed of sound is 343.2 meters per second. Could a full-sized vertical-axis turbine move at the speed you calculated without breaking the sound barrier?

The speed they calculated will be in excess of the speed of sound if they measured more than 80 RPM. If that's the case, then no, a full-sized turbine could not move at that speed.

Analysis

1. Make a scientific claim about what you observed while running your wind turbine.

Claim should reference the turbine's capabilities.
Example: "The turbine can't spin at more than 250 rpm with this fan."

2. What evidence do you have to back up your scientific claim?

Evidence should cite data in Observations and/or Experimentation sections.
Example: "Our fastest measurement was 244 rpm with the three blades."

3. What reasoning did you use to support your claim?

Reasoning can draw from Background section and/or other materials used in class.
Example: "Since we tried all three configurations, the only way it could spin faster would be if the blades were redesigned or if the turbine was changed in a different way."

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4. Design an experiment that would test whether its better for a vertical-axis turbine to be positioned closer to or farther from the ground.

There are many possible answers, but students should describe how they would alter the turbine's height, how they would measure the impacts of that change, and have clear control and experimental groups in their description.

Conclusions

1. A full-sized horizontal-axis wind turbine has blades that are 40m in radius. If the outer edges travel close to the speed of sound (343.2 m/s), they could tear themselves apart under the stress. What would be the maximum RPM you would recommend for a full-sized horizontal-axis wind turbine so that it wouldn't be in danger of breaking?

Use the velocity equation:

$$v = \frac{2\pi r}{T} \qquad 343.2 = \frac{2\pi 40}{T} \qquad T = \frac{80\pi}{343.2} \qquad T \approx 0.732$$

$$\frac{Rev}{sec} = {}^{1}/_{T} \approx 1.366 \qquad RPM = \frac{Rev}{sec} * 60 \approx 81.93$$

So in order to avoid getting close to the speed of sound, horizontal-axis turbines shouldn't spin at more than 60-70 RPM, about one revolution per second.

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2. Comparing your calculations from above with your experimental results, would you expect a full-sized horizontal- or vertical-axis turbine to spin faster?

Vertical-axis turbines will spin much faster than horizontal-axis turbines.

3. How could you change your vertical-axis turbine to get it to produce more electricity? Describe an experiment you could run to test your proposed change:

Students may have many different acceptable answers (such as changing the shape of the blades, using different materials, increasing the blade surface area, and more), as long as they can provide a method for implementing the change they suggest and measuring the effects of that change. There should be clear control and experimental groups in the description.

4. Based on your experiments, do you feel that a vertical-axis turbine makes a good electricity generator? Why or why not?

Students can answer "Yes" or "No" as long as they are able to back up their assertion with evidence from their experiments, information from the background, or other facts discussed in class.