

The Mag Mile and...Torque?

Chicago River Classroom Activity

Summary

Students learn about gears and torque. They then build a model of the Michigan Avenue Bridge gears and calculate the increased torque provided by the gear chain.

Background

Built in 1920, the Michigan Avenue Bridge is a double leaf, double decker, fixed counterweight bascule trunnion bridge. The bridge's two leaves are the two spans that come from either bridge tower and meet in the middle. Each leaf is also double decker, allowing for traffic to move on two levels. The leaves are actually part of Michigan Avenue itself. When the bridge opens to let boats through, each leaf moves up into an almost vertical position. Each leaf weighs 3, 750 tons.

The word bascule is French for see saw. The bridge works in just that way. Each leaf balances on a trunnion (the same things used to fix a cannon to its stand). A trunnion is like a big pin sticking through the bridge leaf so it can pivot. Because the pivot point is not in the middle of the leaf, but rather close to one end, a counter weight is needed on the shorter end. The counter weight balances the torque (torque = force X distance, and refers to rotational motion) of the two ends. Torque takes into account both the differences in length and the effect of gravity. The counterweight is stored in a great underground pit. The bridge is so accurately balanced that if there is a coat of paint on it, it could become unbalanced.

The bridge is lifted by a series of gears, which allow for a very small motor (108 horse power per leaf). Each gear has a different number of teeth. The teeth are what allow the gears to fit together and move each other. The difference in the number of teeth between two gears is called the "gear ratio". This also corresponds to diameter. Usually smaller gears will have fewer teeth just because they have a smaller diameter and can only hold so many teeth!

Grade Level: 9th – 12th

Duration: 45 min

Objectives:

1. Students will understand the way the gear train in the Michigan Avenue Bridge works.
2. Students will understand how the amplification of torque enables a small motor to lift a huge bridge.

Materials:

- ◆ Sturdy large paper plates made of heavy cardboard (4 per group of 3 students)
- ◆ Sturdy small paper plates (3 per group of 3 students)
- ◆ Poster board (1 per group of 3 students)
- ◆ Paper fasteners (4 per group of 3 students)

Standards:

12.D.4a, 12.D.5a

For example, consider this gear pair:

The larger gear has 72 teeth and the smaller gear has 18. The gear ration is 4:1. This means that for every one rotation of the larger gear the smaller gear spins four times. The work is displaced throughout the gear system so that the motor doesn't burn out during the lift. In other words, the power that is used to lift the bridge stays the same, but the gears allow the torque to increase along the gear train. You get more "bang for your buck" because of the distance that the gear train provides.

For example, suppose a motor exerts 1,000 foot pounds of torque. If it connects to two pairs of gears, the first having a gear ratio of 4:1 and the second having a gear ratio of 5:1, the torque exerted by the last gear in the train is 20 times greater than the torque from the motor itself. This means that the last gear is now exerting a torque of 20,000 foot pounds: a far larger force.

The same concept applies to why you open something with a crowbar. If you just tried to pry open a tight lid on a large wooden box with your fingers or a screwdriver, it wouldn't work. If you inserted a crowbar into it, the distance (or length) between you (the force pushing down) and the box is greater. Even though the force is the same, the torque increases because the distance increased. The greater the distance the power is distributed through, the greater the force that is exerted.

Procedure

- ◆ Discuss the way in which bridge gears work and torque.
- ◆ Let students know that they will be building a model of the Michigan Avenue Bridge's gear system.
- ◆ Divide students into groups of three. Pass out instructions and materials.

Answers to Student Questions:

Calculating Power:

2. It would take 1154.6 kilocalories of energy to lift one bridge leaf (roughly the amount of calories in a frozen pizza!)
3. Because the torque needed to lift the bridge is very high. Torque is force X distance.

Calculating Torque:

1. Multiply the torque of the motor throughout the gear ratio on the train. There is a 4:1 ration in each pair so the torque of the bull gear is 64 times larger than that of the motor. So $64 \times 125 = 8,000$ foot pounds.

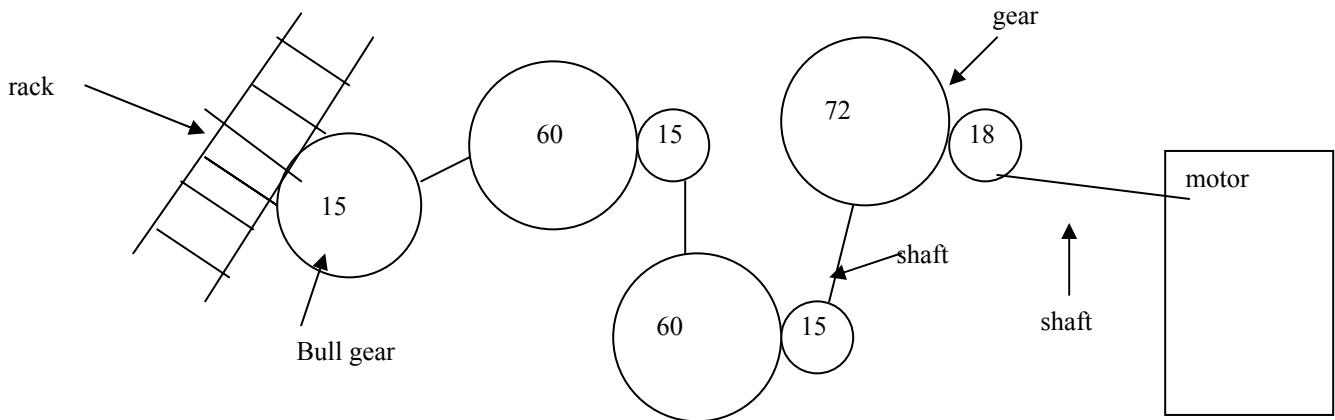
Mag Mile and Torque?: Student Instructions

Understanding the Gear Train

You will be making a model of the Michigan Avenue Bridgehouse gear train (series of gears) using paper plates.

The following is a diagram of the gear train. The number inside each “gear” is the number of teeth that gear has. Small gears that intersect with larger gears are powering the larger gear. If two gears are connected by a shaft, it is indicated with a line. A shaft is a rod connecting one gear with another, so the two gears are spinning at the same rate.

The “bull gear” is the large gear that actually engages the rack which pulls the trusses on the leaf down so the leaf lifts up. It’s kind of like climbing a rope.



Making the Gears

Use the small paper plates for the small gears and the large paper plates for the large gears. The bull gear will be made out of a large paper plate even though it has a small number of teeth, because it is a big and heavy gear.

Calculate the width of the teeth

To figure out what width to make each tooth for each gear use the following equation:

width of each tooth = $\pi d \div (2 \cdot (n+1))$ (where n is the number of teeth in the gear you are making, and d is the diameter of the plate in **centimeters**).

For example, suppose you need 18 teeth and you are using a plate with a diameter of 15.5 cm.

$$\pi(15.5) \div 2 \cdot (18 + 1) = 2.6$$

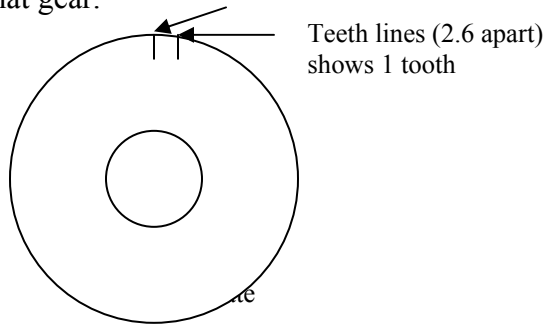
This means that each line should be 2.6cm apart.

Fill in the following chart:

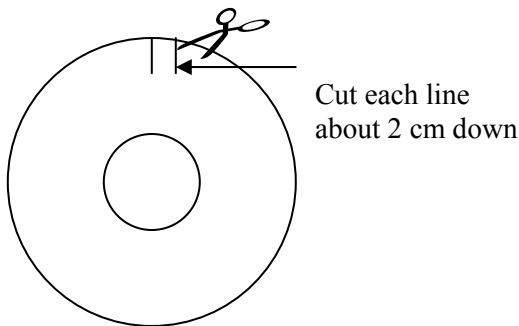
Size of Gear/Plate	Diameter of Plate	Number of Teeth	Width between Lines
Large (bull gear)		15	
Small		15	
Large		60	
Large		72	
Small		18	

Cutting out the gears

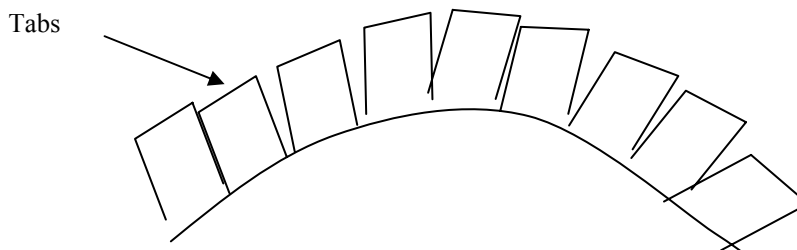
1. Measure the width of the teeth out on the plate. Make a line every how many centimeters you calculated for that gear.



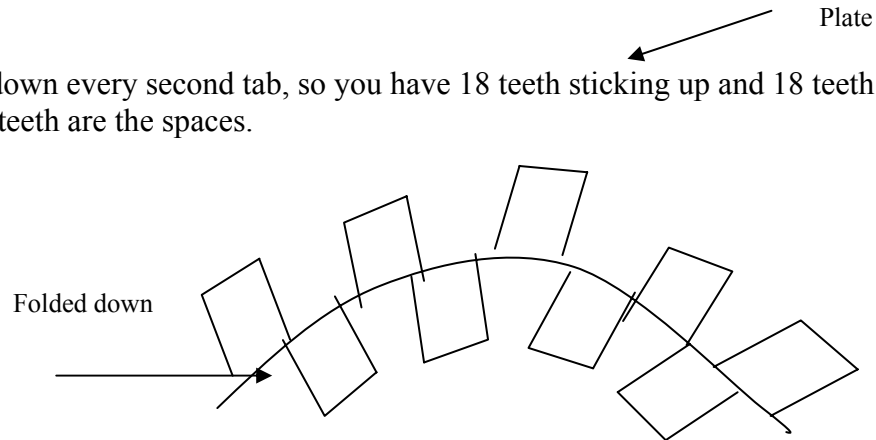
2. Once you have all of the lines drawn, carefully cut 2 cm down from the edge along each line, pointing the scissors toward the center of the plate.



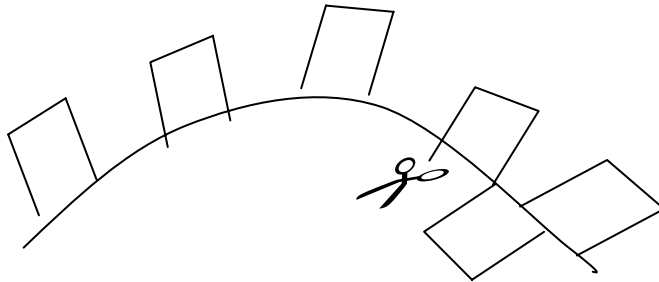
3. After you have cut each line, you'll notice that you have tabs all along the plate. These are the teeth! At this point you should have twice as many teeth as you need. (So if you need 18, there should be 36 tabs)



4. Now, fold down every second tab, so you have 18 teeth sticking up and 18 teeth folded down. The folded teeth are the spaces.



5. Cut off all of the folded down teeth to create the spaces.



6. You now have a gear with the right number of teeth!
7. Follow the above instructions to make every gear in the gear train diagram. Remember to use the correct size plate!

Attaching the gears to the board

1. Once the gears are all completed it is time to start fastening them. Punch a small hole in the middle of each gear.
2. Follow the diagram of the gear train at the beginning of the instructions. The gears that are supposed to intersect are drawn right next to each other. These are the gears whose teeth will mesh together and will turn each other.
3. Place the gears in the pattern by putting the fastener through the gear and then the board. Make sure intersecting gears are close enough to each other so that their teeth interact and can move each other.
4. If a gear is connected to another gear by a shaft, attach the first gear like all the others. Place the connected gear on the other side of the board. Fasten it to the board using the same paper fastener. The fastener will be going through the first gear, then the board, then the second gear. Tape the fastener to both gears.

5. Once you have all of the gears on the board, turn the very first one that you put on (the 18 toothed large gear). You can see all of the gears on both sides working! You are acting as the 108 hp motor that engages the gears.

Calculating

Power

1. A 108 horse power motor takes one minute to lift each leaf of the Michigan Avenue Bridge. Suppose you were going to take over for the motor in lifting the bridge leaf.
2. How many kilocalories would it take for you to lift one bridge leaf?
Use the equation $P=E/T$ (power = energy/time)
Note: You will need to do some conversions. Horse power can be converted to watts (joules/sec) and watts can be converted to kilocalories.
3. Logically, you know it would be impossible for you to open the Michigan Avenue Bridge leaf yourself, even though a direct conversion to kilocalories for the energy needed would cause you to think otherwise. So, why couldn't you get the bridge to open?

Torque

The gear train exists in the bridge lifting mechanism to increase the torque. How much is the torque increased? I.e. how much torque does the bull gear have? Try to figure it out using the gear ratios and 125 foot pounds of torque for the motor.