Student Notes

Mechanical Advantage

1.0 Introduction

In this investigation, students will learn the relationships between gear ratio, axle speed, and torque. Students will use the Vex Robotics System in a laboratory setting and conduct scientific inquiry-based experiments to determine the effect of gear ratio on an axle's speed and strength. Students will use the Vex starter kit to construct a gearbox that will allow them to test these mechanical principles. Students will gain an understanding of math and science concepts related to gears, angular speed, and torque.

By manipulating a device's gear ratio, engineers can adjust for speed and strength. In this lesson, students will first be introduced to the scientific concepts that allow such control, and then, through experimentation, learn how to achieve these results on a working model.

2.0 Theory

2.1 Introduction to torque

Torque is a measure of the rotational influence that a force has on an object. It is measured by multiplying the force by its distance from the object's center of rotation. This may sound confusing at first, but a common example will add clarity to the concept. Imagine trying to close a heavy door. If you concentrate your effort near the door's hinges, you will find that it is quite difficult. But if you instead focus your strength near the other edge of the door, you will see that a gentler force can get the job done. Feel free to try this out! When you are pushing near the hinges, the distance from the fulcrum, which is called the "lever arm," is very short. When you are pushing near the edge of the door, the lever arm is much longer. Since the torque, or the influence on the door's rotation, is equal to the product of the force and the lever arm, a weaker force can create the same rotation just by being distant from the center of rotation.

In motors, torque is a measure of rotational strength. Imagine a plow attempting to push a heavy object. The wheels on the plow must have great rotational strength, or torque, to power the vehicle forward. Similarly, a motor lifting a heavy object must have great rotational strength.

2.2 Gear Ratio

In simple systems, the gear ratio is the ratio of the number of teeth on a driven gear to the number of teeth on a driving gear. The driving gear is the origin of the rotation, and is usually powered by a motor. The driven gear is influenced by the driving gear, and is usually connected to a wheel.

Student Notes

First, let's explore what happens when the driving gear is larger than the driven gear. Imagine that a gear attached to a motor (a driving gear) has 50 teeth. Imagine that this gear is turning a second gear (a driven gear) that has 10 teeth, and that the driven gear is on a wheel's axle. Since the calculation for gear ratio is teeth on driven gear: teeth on driving gear, the gear ratio in this case is 1:5. Now, each full rotation of the driving gear will cause 5 complete rotations of the driven gear. As a result, a wheel placed on the driven axle will rotate 5 times faster than a wheel placed on the motor's axle. So, the simple addition of a gear allows an engineer to immediately change the maximum speed of a device! But note that the gear ratio also influences the axle's torque. The rotational strength of the driven axle is now 5 times smaller than the rotational strength of the driving axle. Also note that the effect that gear ratio has on speed and torque is linear- a gear ratio of 5:1 changes both the speed and torque by a factor of 5.

If the driving axle is smaller than the driven axle, the gear ratio will have the opposite effect on the device. Now, a full rotation of the driving gear will not cause a full rotation of the driven gear, which means that the angular speed of the driven axle will decrease. However, the torque of that driven axle will now increase. As before, the relationship between gear ratio and these two factors is linear.