Purpose

This analysis will focus primarily on the planetary steering wheel on the Sensory playset project. The gearset will be mounted in the upper section of the playset where other sensory items will be. The device combines an interactive gear mechanism with a steering-wheel-like interface, allowing the exposed gears to be spun by hand.

The content in this document will focus on how the gears interact with one another, along with how forces are transferred between meshing gear and whether the gear teeth and supporting components can withstand the forces associated with repeated use. One important note is making a usable gear interface for young children to use it with little flaws. The herringbone tooth geometry will also be examined on how it affects the forces acting on the gears and their supports.

Design Features and Specs

Parameter	Specs
Centered Sun Gear	17 teeth, fixed
Outer ring gear	Rotational, not fixed
Planet gears	Free to rotate
Pressure Angle	30 Degrees
Tooth Form	Herringbone, 0.8-tooth-pitch twist
Size	?????

Evaluation

A gear train will be designed with a computer aided design (CAD) initially to get the desired shape. This will establish which components are fixed, which can rotate and how the gear teeth engage.

The goal was to get a central gear (sun), surrounding gears (planetary), and an outer ring gear. The teeth of the surrounding gears mesh with adjacent components, allowing movement to be transferred throughout the mechanism, a big steering wheel. Additionally, in a herringbone gear, the opposing sections can substantially cancel the axial thrust that would otherwise be produced by a single-helical gear. Making the planetary geartrain rotate about its axis with minimal flaws. An additional benefit of the herringbone interface is that it can be 3D printed in place and will not separate, making it impossible for gears to fall out or get lost.

Kinematic Gear Motion

The first part of the analysis will examine the kinematic relationships between the gears. The numbers of teeth and rotational constraints will be used to determine how the gears rotate relative to one another when a child applies an input rotation. This will help establish whether the gear arrangement produces the intended interactive movement.

The following equations are needed to analyze the angular velocity of the planet gears:

$$N_r = N_s + 2N_p$$

N_r is number of gear teeth on ring gear.

N_s is number of gear teeth on sun gear

N_p is number of gear teeth on planet gear

$$N_s (\omega_s - \omega_c) + N_r(\omega_r - \omega_c) = 0$$

(Assumming ω_s is fixed)

$$\omega_c = (N_r / N_s + N_r) \omega_r$$

$$\omega_c = [N_r / (17 + N_r)] \omega_r$$

(The sun-planet mesh is measured relative to the carrier)

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Sun-Planet Mesh Relationship

$$N_s (\omega_s - \omega_c) + N_p(\omega_p - \omega_c) = 0$$

$$\omega_p = (1 + N_s / N_p)$$

With a fixed sun gear, the planet centers orbit together in the same direction as the ring gear at a higher angular speed.

Input Torque and Tooth Force

The second part will examine the forces associated with manually rotating the gears. The torque applied by a user can be approximated using the following equation:

$$T_{in} = F_{Hand} * R$$

The equation above relates the force applied by the user to a torque acting on the rotating gear.

Gear tooth Force

From there, the torque and gear geometry can be used to approximate the tangential forces acting on the gears. That can be found using the following formula:

$$T_{mesh} = F_t * r_p$$

$$F_t = T_{mesh} / r_p$$

(r_p and d_p are the pitch radius and diameter of the analyzed gear, not the overall device radius.)

The torque at a gear mesh is not automatically the same as the hand-input torque.

T_{mesh} = Torque being transmitted by the gear at the mesh.

F_t = Tangential force at the gear teeth

R_p = gear pitch radius

Pressure angle and herringbone geometry

The pressure angle describes the direction of the tooth contact force in the gear's transverse plane. When the child spins the outer ring, the gear teeth generate radial forces in addition to the forces producing rotation. Those radial forces must be supported by the gear axles, bearings, or other supporting features.

With a pressure angle of 30 degrees the radial force can be found using the following equation:

$$F_r = F_t \tan(30 \text{ degrees})$$

$$F_r = .577F_t$$

F_t= Tangential force, which transmits torque and causes rotation.

F_r = Radial force, which acts along the line connecting the gear centers.

The radial forces act on the gears and their supports.

Tooth Geometry Calculation

A herringbone gear has teeth that twist in opposite directions across its width, creating a V-shaped pattern. Begin by calculating the spacing between consecutive teeth. The following equation will be used for teeth spacing:

$$\theta_{pitch} = (360° / N_s)$$

$$\theta_{pitch} = (360° /17)$$

$$\theta_{pitch} = 21.8 °$$

$$\Delta\theta = 0.8 (21.8°)= 16.94°$$

This is the angular shift of the tooth profile, not the helix angle. The actual helix angle depends on the gears pitch radius and how far the tooth twists across its thickness.