Reconfigured Gearbox and Flywheel System for Multi-Mode Wave Energy Converter (MWEC)

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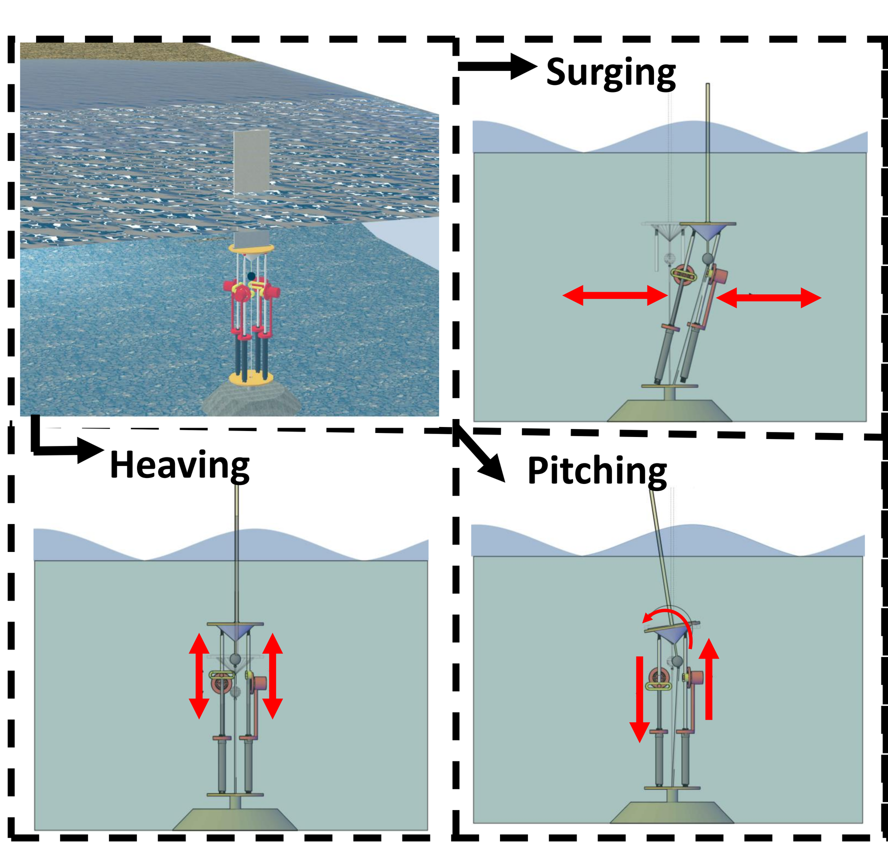
Integration of a three-stage epicyclic differential gearbox and flywheel in the PTO mechanism of the MWEC allows consistent power generation in random sea state.

Multi-Mode Wave Energy Converter (MWEC)

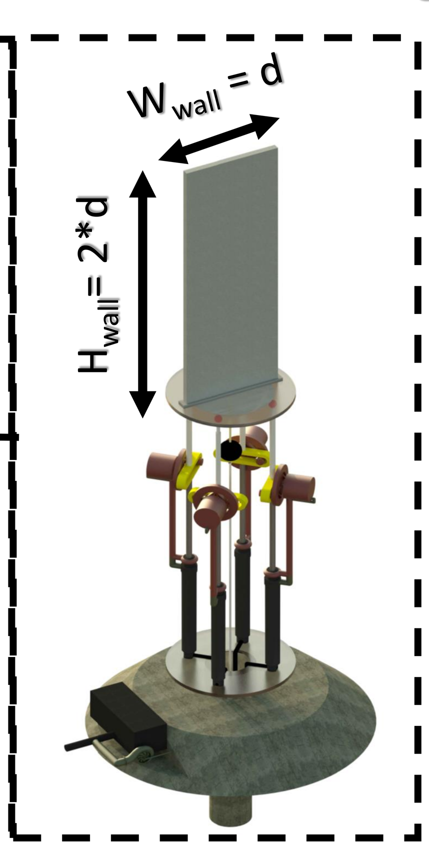
Traditional Wave Energy Converters (WECs) exhibit fluctuating energy generation due to their reliance on single response modes, limiting efficiency in diverse wave conditions. To address this, a novel Multi-Mode Wave Energy Converter (MWEC) has been proposed. The MWEC employs a double pendulum mechanism, incorporating a rocking panel system and a pendulum mass within a buoyant platform. This design enables the device to dynamically resonate and harness energy from a broader spectrum of wave frequencies. Key components and their functions include:

- Multi-mode dynamic capabilities: The platform effectively converts surging, heaving, and pitching motions into linear piston movement.
- Rocking panel system: Interacts with incoming wave forces to generate motion.
- Pendulum mass and buoyant platform: Provide essential restoring forces for stability.
- Power Take-Off (PTO) system: A scotch yoke mechanism transforms linear piston motion into rotational energy, which is then amplified by a three-stage epicyclic differential gearbox before powering a BLDCPM motor.

Kinematic Admissible Motion of the MWEC



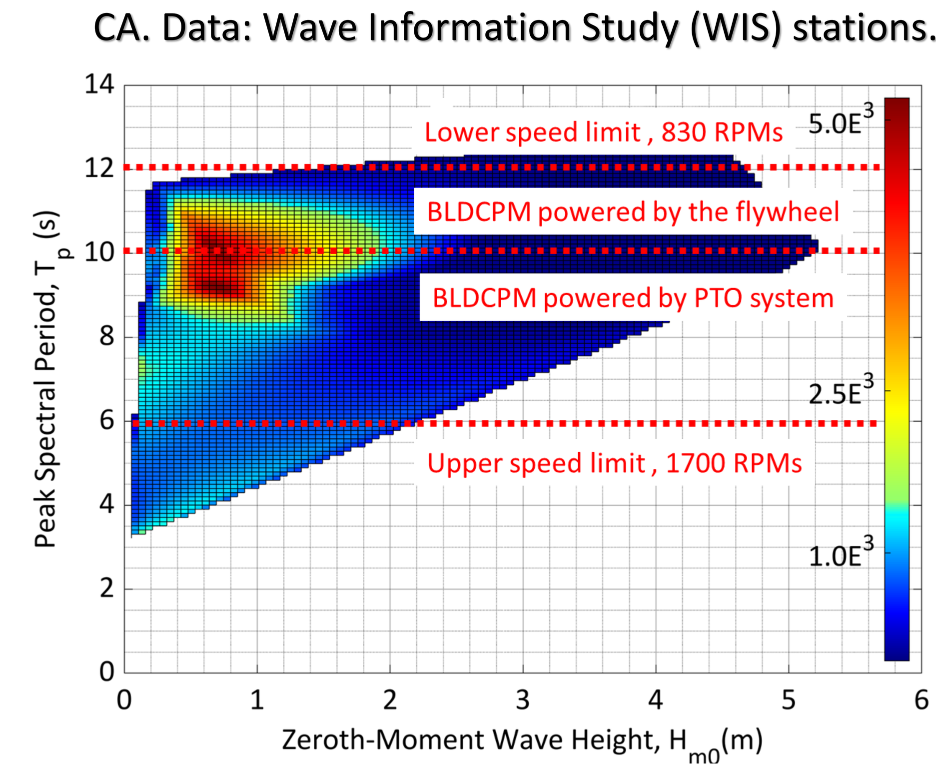
MWEC Platform Design



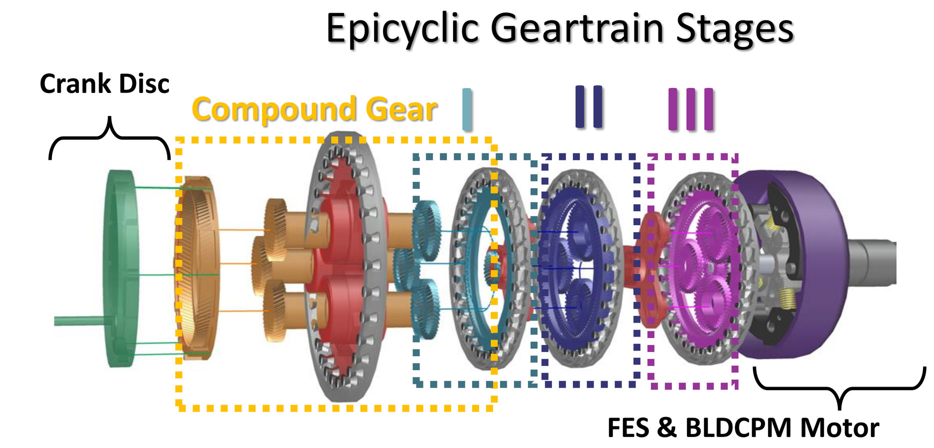
PTO Mechanism: Three-Stage Epicyclic Differential Gearbox with Flywheel

(a)

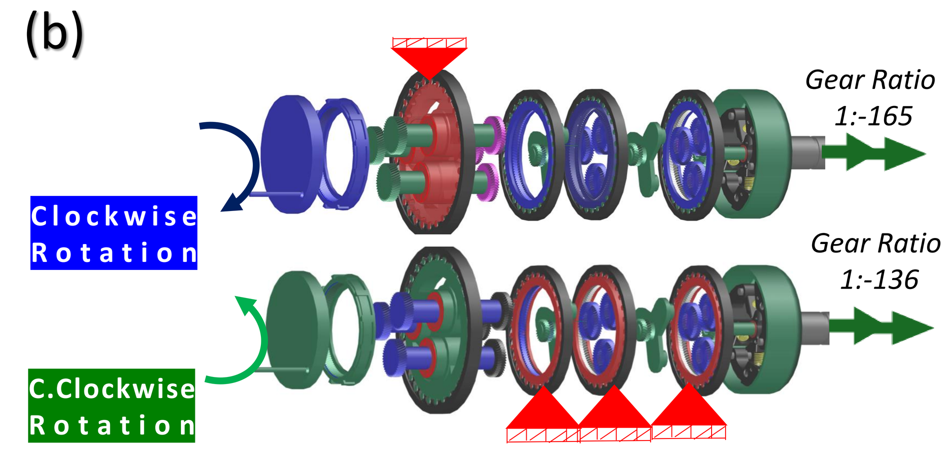
Wave Condition Scatterplot for Santa Barbara, CA. Data: Wave Information Study (WIS) stations.



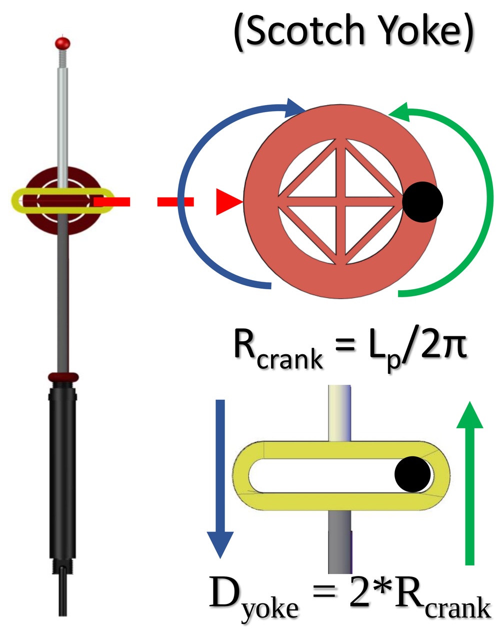
Epicyclic Geartrain Stages



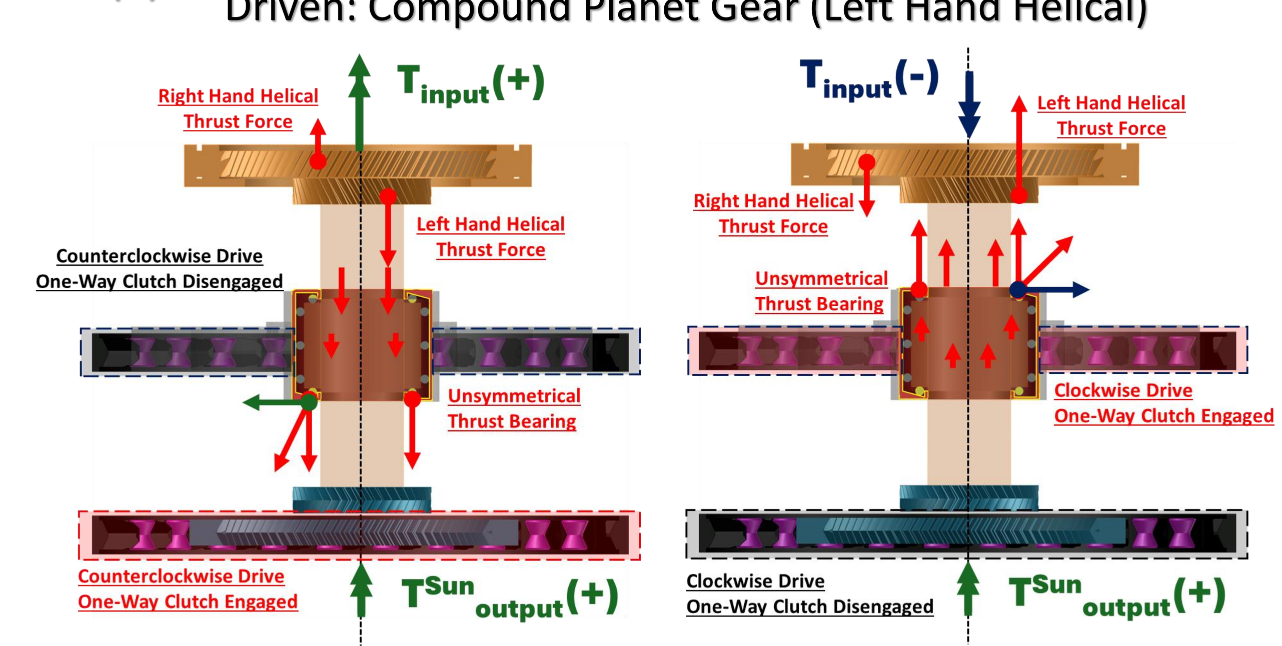
(b)



Linear Motion to Rotation (Scotch Yoke)



(c) Driver: Yoke Ring Gear (Right Hand Helical)
Driven: Compound Planet Gear (Left Hand Helical)



(a) Flywheel Energy Storage (FES)

Targeting **70% of the combined inertia of the gearbox and motor**, the flywheel has to potential to dampen rotational oscillations and enhance system reliability. This design uses a centrifugal clutch to connect the flywheel to the gearbox output shaft, enabling adaptive system response to varying wave conditions. By adjusting the tension spring stiffness within the clutch, the engagement and disengagement point can be tailored for specific wave conditions. In regions like **Santa Barbara, CA,** characterized by long, high-energy waves, the flywheel:

- Acts as mechanical energy storage for long, high-energy waves, which would not be able to produce high RPMs due to the limitation of the Scotch Yoke's available stroke length.
- It can absorb excess torque from overly large waves that could potentially damage the gearbox and the motor.
- Outputs the stored mechanical energy in a consistent manner during high wave intensity periods.
- Once it has provided enough energy to the motor and has slowed down, it engages once more with the gearbox driving shaft.

(b) One-Way Rotation Gearbox

Relying on cam-link mechanisms for converting linear wave motion into rotational energy provides a challenge due to required predetermined linear motion limits and the fluctuating periodicity of ocean waves. To maximize energy capture, the MWEC incorporates an in-house developed three-stage differential epicyclic gearbox. This design enables continuous one-way rotation of the BLDCPM motor by:

- Directly coupling a ring gear to the crank disc, allowing simultaneous input of torque and angular velocity.
- Utilizing a compound planetary gears in **Stage I** acting as a dual drive by meshing with both the ring gear and sun gear of **Stage** I. Rigid rotation is eliminated with one-way roller clutches.
- Connecting the ring gears of **Stage II** and **Stage III** to the **Stage I** ring gear, ensuring kinematic compatibility.
- The planetary carriers of **Stage II** and **Stage III** are driven by the previous' stage sun gear to ensure maximal speed amplification. The sun gear of **Stage III** directly drives the axle connected to the flywheel and the BLDCPM motor.

This configuration allows for uninterrupted power extraction from both phases of the wave's reciprocating motion by possessing **similar gear ratios in both excitations.**

(c) Thrust Activated One-Way Clutch

One-way roller bearings are strategically integrated to provide kinematic constraints within the epicyclic gear train and guarantee unidirectional power generation along with eliminating unwanted rigid motion.

- The compound planetary gear carrier in **Stage I** is connected to the gearbox's housing using one-way roller bearings, which permit only clockwise rotation.
- Ring gears of **Stage I, II, and III** are conversely allowed only counterclockwise rotation by similar means.

To help mitigate vibrations arising from the dynamic wave environment, specific gear designs were implemented.

- Most gears feature a double helical (herringbone) profile with a 30-degree helix angle to reduce noise and vibration.
- However, the ring gear on the crank disc and its corresponding planet gears utilize a 15-degree single helical design.

By employing a right-hand (RH) helical ring gear and left-hand (LH) helical planet gears, the resulting thrust forces can be utilized to secure the carrier tightly on the one-way clutch during a clockwise rotation, or indirectly fix the ring gears onto their corresponding constraints during a counterclockwise rotation. This comes as a direct result of the carrier's asymmetrical cross-section.

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