TECHNICAL NOTE

# Coaxial PTO Drives for Wave, Tidal, and Oscillating Water Column Air Turbines


AUTHOR

**John Clark Hanna**

Hanna Wave and Tidal Power Drives



ABSTRACT

This technical note describes a novel self-rectifying coaxial powertrain that supports four major marine renewable energy systems: (a) surface floating buoys; (b) submerged buoys; (c) bi-directional tidal converters; and (d) Oscillating Water Column self-rectified air turbines. In each application, the coaxial power take-off mechanically rectifies bi-directional fluidic flows to spin one or more one-way generators. The mechanical drive system has two sets of impeller blades, each rotating independently of the other and are energized by the motion of waves or tides.



Keywords: PTO, surface buoy, Oscillating Water Column, tidal converter, air turbine


## Surface Buoy, Tidal Converter, or OWC Air Turbine Operation

The Surface Buoy iteration has its generator drive shaft offset at a 90° angle from the primary coaxial drive line. The 90° bend removes the generator from the flow path so the oscillating air column can pass in and out freely through the top of the floating buoy. The 90° bend also allows for an *unrestricted* bi-directional flow inside the OWC air turbine and tidal turbine designs. The 90° iterations have the coaxial drive shafts and blade sets orientated so they will counter rotate from one another. Figures 1 and 2 provide details of the drivelines for both types of buoys—subsurface and surface. The driveline in Figure 2 can also be applied to bi-directional tidal, surface buoy and jetty-based or rigid floating platform-based converters. Figure 3 shows the 90° coaxial bevel gear. The tidal and air turbine iterations have the impeller blades and coaxial drive shafts surrounded by a circular enclosure or nacelle, which is open at both ends, thus allowing unrestricted bi-directional flows to pass through freely. Videos of an early tidal prototype can be viewed on YouTube (Wetgen, 2018).

## Subsurface Buoy

In the submerged buoy, the device is a rigid two-body structure where the impeller blades are attached to a coaxial drive line positioned inside an Acceleration Tube (Figure 4). The submerged buoy is a proven design that exists in the public domain. What is new is how the subsurface buoy employs two types of power take-offs (PTOs) to harvest the internal bi-directional flows: The first PTO uses the impeller-driven coaxial drive to mechanically spin a main generator. The second PTO is a closed loop pneumatic system that drives one or more auxiliary turbogenerators. The auxiliary turbogenerators provide stored DC power for the main generator's electromagnetic field coils. This arrangement eliminates the need for expensive rare-earth permanent magnets in the main generator.

### Subsurface Operation

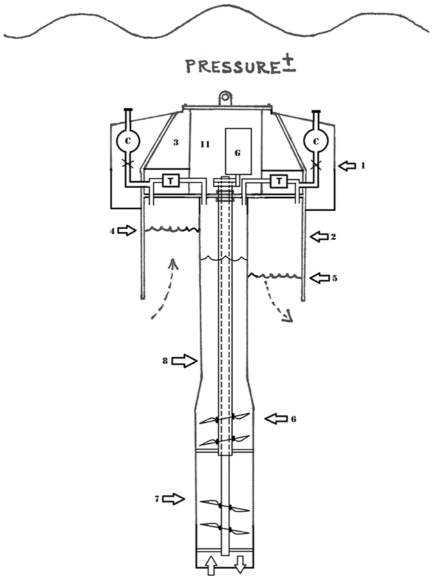
When there are no waves, the free surface level of water inside the Mantle and Acceleration Tube are at the same level. When a passing wave crests above the buoy, the pressure differentials between the upper and lower portions of the buoy are altered and this creates a downward force that pushes out the water from the lower opening in the Acceleration Tube while, simultaneously, water is drawn into the Mantle opening. This causes the free surface air/water interface to rise inside the Mantle and lower inside the Acceleration Tube. When the wave crest lowers, an inverse action takes place that draws water into the Acceleration Tube and is pushed out at the Mantle opening. This perpetual reciprocating cycle allows the free surface of water to rise and fall within the Acceleration Tube. The reciprocating water flows will energize the coaxial drive PTO. Simultaneously, the fluctuating air/water interface acts like a piston, forcing air through the turbogenerator(s) and passing the air on to the Mantle's air containment cavity. The reciprocating air drives the auxiliary self-rectified turbine PTO in a closed-loop system. The reciprocating water flows spin the self-rectified impeller PTO.

### Subsurface Buoy Mechanical PTO

The subsurface buoy's primary mechanical drive is an impeller system. Two or more stacked sets of

## FIGURE 1

Drivetrain for subsurface power buoy PTO.

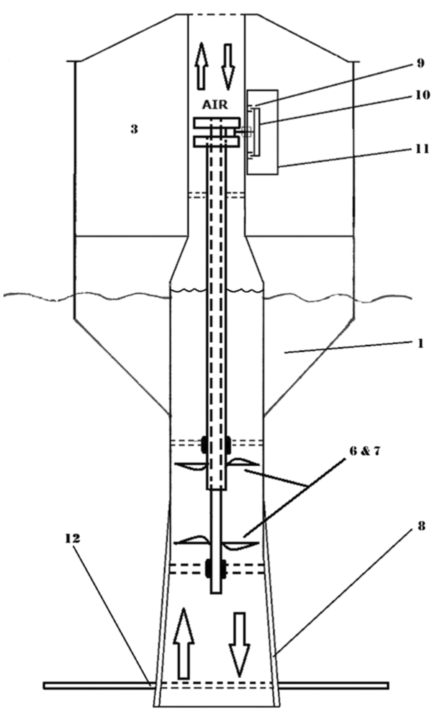



flat, symmetrical rotor blades are attached to coaxial drive shafts. One-way bearings in each shaft allows them to engage in one direction only as the water flows pass back and forth across the impeller blades. Water is 784 times denser than air so the mechanical PTO will develop high torque values to drive the main generator.

The buoy is submerged below the ocean surface and attached to the sea floor. The device is out of view from shore and can operate within the Littoral Zone at relatively shallow depths from 80 to 150 ft. The device is a hollow, two-body structure consisting of a Mantle and an Acceleration Tube. Both structures are rigidly attached to each other, and the entire assembly can be held in a semi-vertical position by a three-point catenary anchoring system. Alternatively, submerged buoys can be fixed to the sea floor or held within the legs of off shore oil rigs.

## FIGURE 2

Driveline for jetty-based OWC, surface buoy or tidal drive.




## FIGURE 3

Ninety-degree coaxial bevel drive.

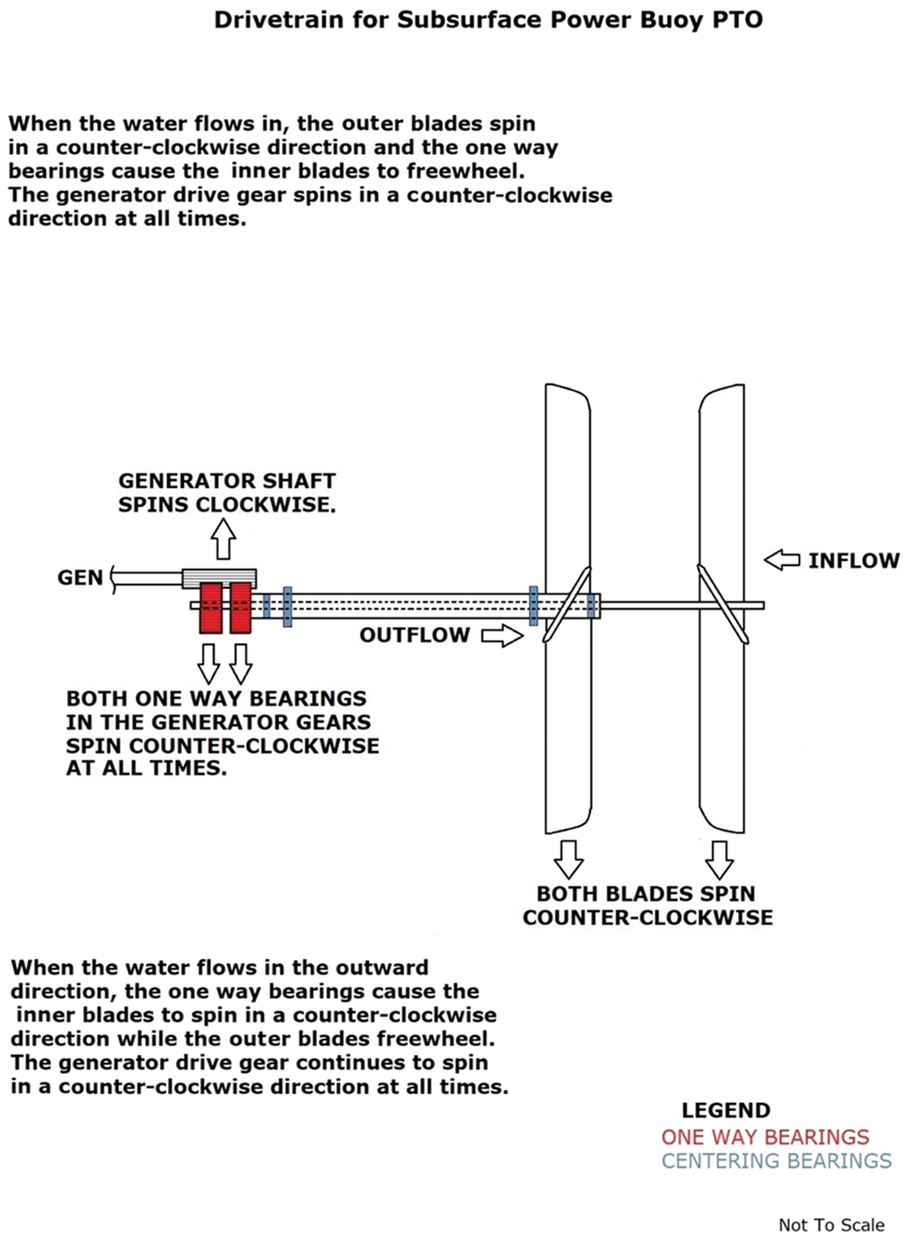
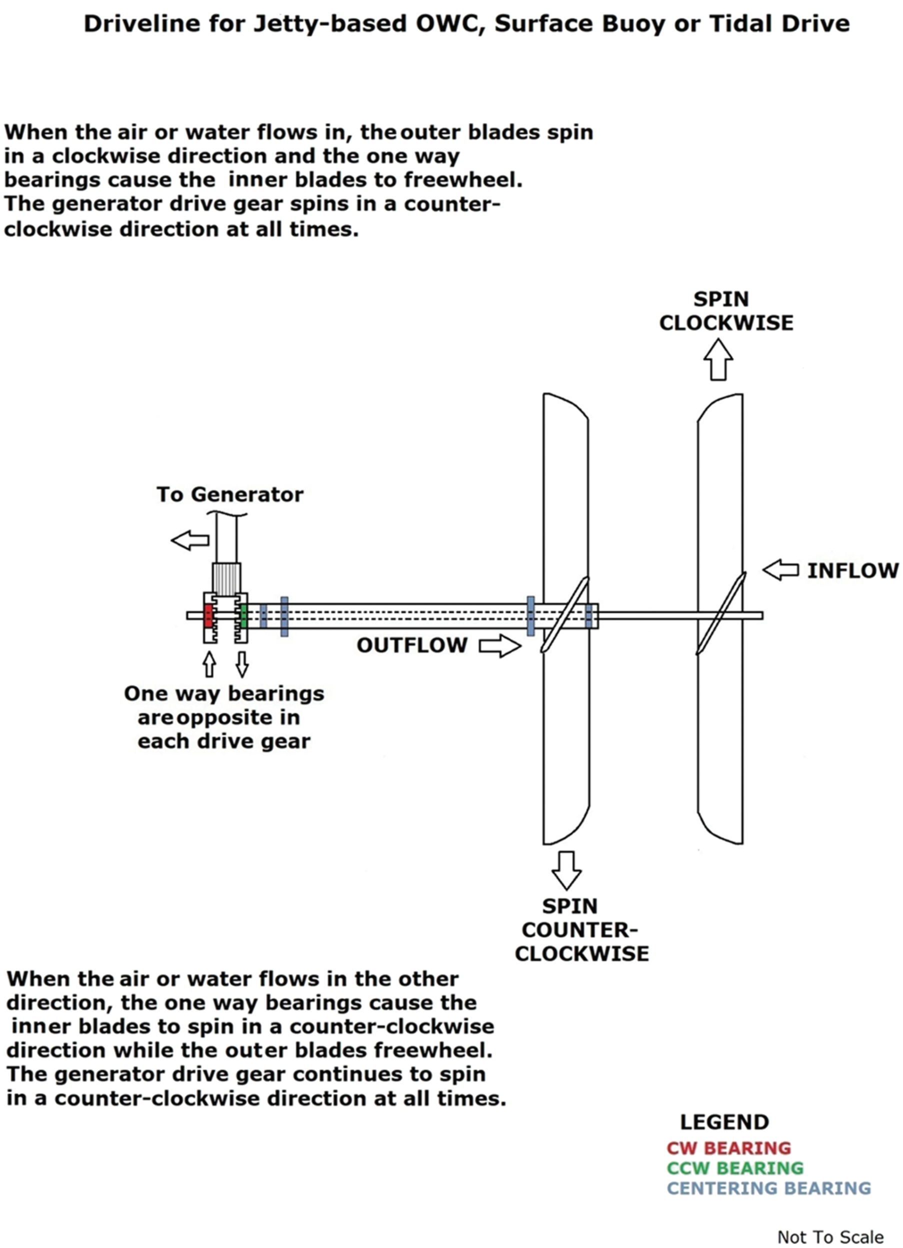


**FIGURE 4**

Subsurface buoy.




Compressed air tanks and sensors maintain a precise volume of air between the Mantle and Acceleration Tube. The compressed air tanks are periodically re-charged by a work vessel. The design allows a direct, highly efficient, one-to-one energy transfer to the PTO. The direct-drive PTO generates power in real-time synchronicity within the variable ranges of oceanic wave periods and amplitude. Being able to operate below the surface eliminates the need for complex reactive phase controls or latching methods designed to match resonant wave frequencies and to compensate for reflecting wave losses common to all surface point absorber buoys. The submerged buoy has a higher likelihood of survival in extreme sea states. A continuous wave-activated bi-directional flow of water fluctuates inside the Acceleration Tube of the OWC buoy. Both PTO systems are energized by these flows. The subsurface buoy's mechanically-driven PTO is made up of two pipe shafts with one drive shaft centered inside the other. Centering bearings are distributed between the shafts, allowing each drive line to rotate freely from the other.

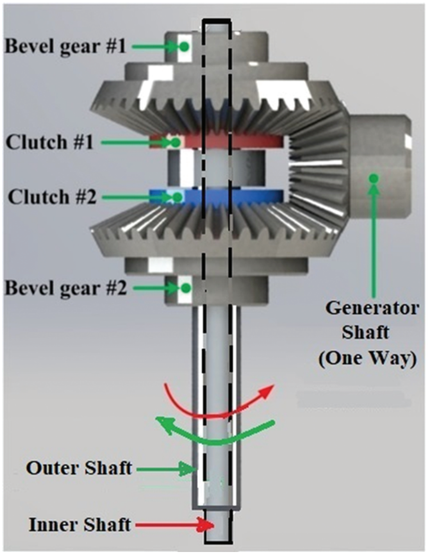
At the low end of the Acceleration Tube, the inner drive pipe extends beyond the outer drive pipe. The extended inner pipe has two stacked sets of impeller blades attached. The other outer pipe also has two stacked sets of impeller blades, and these blades are mirror-images of the other set.

In order to create a mechanical one-way drive that will spin a generator in one direction only, the PTO design calls for two sprag-type, one-way, clutch bearings to be attached to the upper ends of both drive shafts, one bearing located on top of the other. The inner races of the two clutch bearings are fixed to their respective shafts, and the outer races are keyed inside two stacked drive gears that have identical outside diameters. Thus, when one shaft rotates in one direction, the other shaft will simply freewheel. The active shaft's driving gear will engage the generator pinion gear to spin it in one direction only while simultaneously the other driving gear will freewheel. Then, when the water flow reverses, the drive modality also shifts; the former drive shaft will now freewheel while the second drive shaft engages and will now drive the generator.

Therefore, when water flows in one direction inside the Acceleration Tube and the upstream (driving) set of blades are activated by the passing water, the downstream set of blades will rotate independently and freewheel. It is also important to note

**FIGURE 5**

Surface buoy.




that regardless of how turbulent the downstream water might become as it comes off the driving blades, the disengaged downstream blades will be unaffected by any turbulence or cavitation. The downstream flows coming off the drive blades might cause the downstream blades to spin in the reverse direction or slowly spin in the driving direction or simply stay stationary. Notably, the disengaged downstream blades are unaffected by the engaged upstream drive blades. The upstream blades are always the dominate drive blades that capture the bi-directional flows.

### Subsurface Buoy Pneumatic PTO

The subsurface buoy employs a second way to harvest wave energy to energize one or more self-rectified air turbine PTOs. The weight of passing surface waves will cause water to rise and fall within the Accelerator Tube. The free surface of water at the air/water interface acts like a piston. As the water level rises inside the Accelerator Tube, the trapped air is compressed and is forced through one or more auxiliary turbo-generators installed inside a water-tight compartment. After passing through the turbines, the air travels into the buoy's Mantle. As incident waves pass above the submerged buoy, the pressure differentials created by the waves cause the buoy's entrapped air to pass back and forth from the Mantle to the Acceleration Tube in a continuous cycle. This bi-directional air flow is channeled through the auxiliary self-rectified turbines and generates DC power for battery storage. The auxiliary turbines can be optional impulse-type, Wells reaction-type, or the Hanna-designed impulse/reaction type (Hanna, 2013). The auxiliary air turbine(s) drive generators that can produce power for the grid or, alternatively, develop low-voltage DC power for charging on-board batteries to power electronic payloads and/or provide power for the main generator's electro-magnetic field windings. This arrangement eliminates the need for costly rare-earth permanent magnets in the main generator.

## Background of The Invention

The coaxial drive for wave and tidal energy conversion was first described in a 2023 patent application (Hanna, 2023). However, the patent application was abandoned. Instead, the coaxial concept is being offered as an open-source technology with a desire to help stimulate the developing Blue Economy. Notably, coaxial drives have been successfully used in aircraft for decades. Two examples are the Douglas XB-42 (1944) and the Mirocopter SCH-2A (2021). There are no existing self-rectifying coaxial drivetrain patents that use waves or tides as the prime mover.

## Prior Art

Examples of prior art subsurface Wave Energy Converters and tidal converters are: Oceana Energy Co., U.S. 9,359,991 B2 and CA3001696C; M3 Wave; CalWave Power Technologies; 40South Energy; Bombora Wave Power; Verdant Power that uses HydroWing/Inyanga Tech tidal turbines; a submerged buoy that uses a Wells air turbine PTO by Seung Kwan Song (Song, 2013) called SPA-OWC: U.S. 9,518,556 B2 (patent now expired); another expired patent by W.W. Hirsch: U.S. 7,199,481 B2; international patents by Archimedes Wave Swing Ocean Energy Ltd: WO2017/025765Al and U.S. 10,711,760 B2; the Dutch company Symphony Wave Power has a submerged buoy that shares its operational cues from the AWS buoy; a patent by Marine Power Systems called WaveSub, WO20010007418A2; and patents held by Ocean Power Technologies: U.S. 6,768,217 B2, 6,933,623 B2 and 6,768,216 B1.

Examples of prior art surface WECs that use direct-drive PTOs are the WaveEL buoy developed by the Swedish company Waves4Power; a dual rotor WEC by the U.K. company HydroWing/Inyanga Tech (Hanna, 2013) U.S. 8,358,026; and a dual PTO WEC by Ocean Motion Technologies (Hanna, 2014) U.S. 8,745,981.

## Brief Description of the Figures

The subsurface iteration (Figure 4) requires that both sets of impeller blades rotate in the same direction. This mechanical PTO turns a top-mounted, one-way drive gear that spins the buoy's main generator. The oscillating air/water interface within the Acceleration Tube drives one or more air turbines to spin secondary generators. The secondary generators can either add power to the main generator's output or they can generate low-voltage DC power for payload electronics and/or for the main generator's electromagnetic field windings.

## Nomenclature for Figures 4 and 5

G) Main Generator
C) Compressed Air Tanks and Valves
T) Auxiliary Turbogenerators
1) Flotation Chamber
2) Mantle
3) Payload Compartment
4) Water Level at Wave Crest
5) Water Level at Wave Valley
6) Outer Coaxial Shaft Blades
7) Inner Coaxial Shaft Blades
8) Acceleration Tube
9) Generator Multi Pole Stator Windings
10) Flywheel/Generator Rotor
11) Sealed Generator Compartment
12) Damping Plate


## Corresponding Author:

John Clark Hanna
Hanna Wave and Tidal Power Drives
E-mail: wetgen@gmail.com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