

Circular-Slide Wave Energy Converter

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Background - previous project

Sonobuoy Wave Energy Module (SWEM) for Naval Air Systems Command

- An energy-harvesting module to extend the life of standard sonobuoys from hours to days.
- Compact: fits inside cylinder 36" long x 4-7/8" diameter.
- Direct drive system: forced by linear (heave) motion.
- Contains rotary generator & energy management electronics.
- 3 sea test demonstrations.
- Detailed Matlab Simulink prediction software.
- Performed at QinetiQ North America (QNA): 2010 - 2012.

Circular-Slide Wave Energy Converter

Objectives

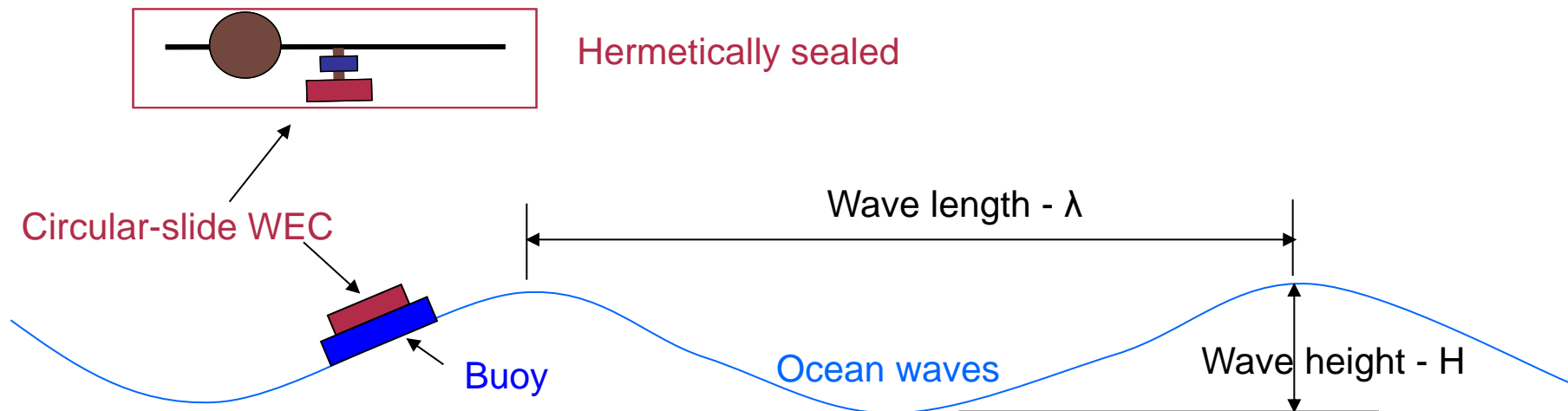
- Develop a new concept to harvest wave energy and extend the life of large ocean buoys.

Approach

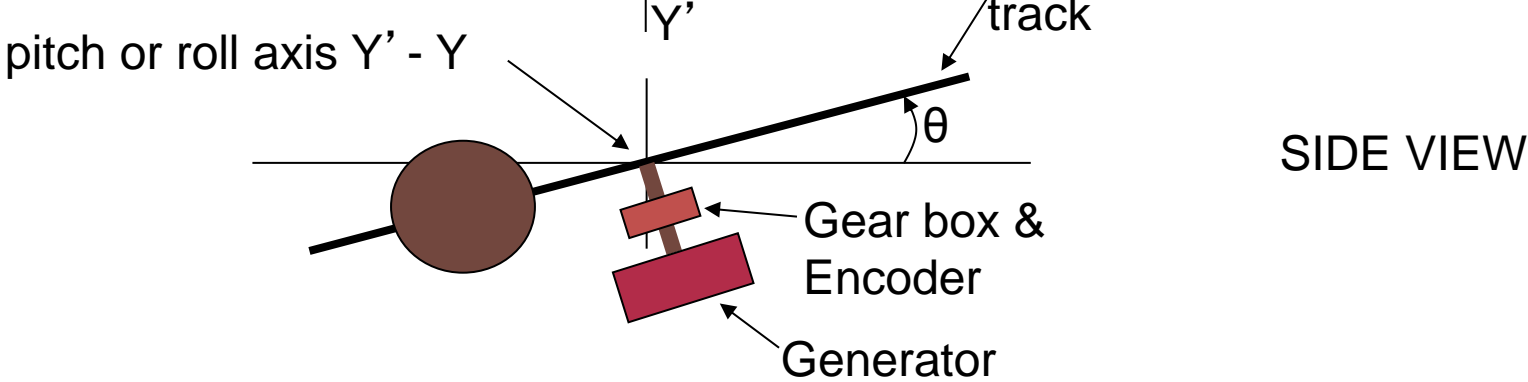
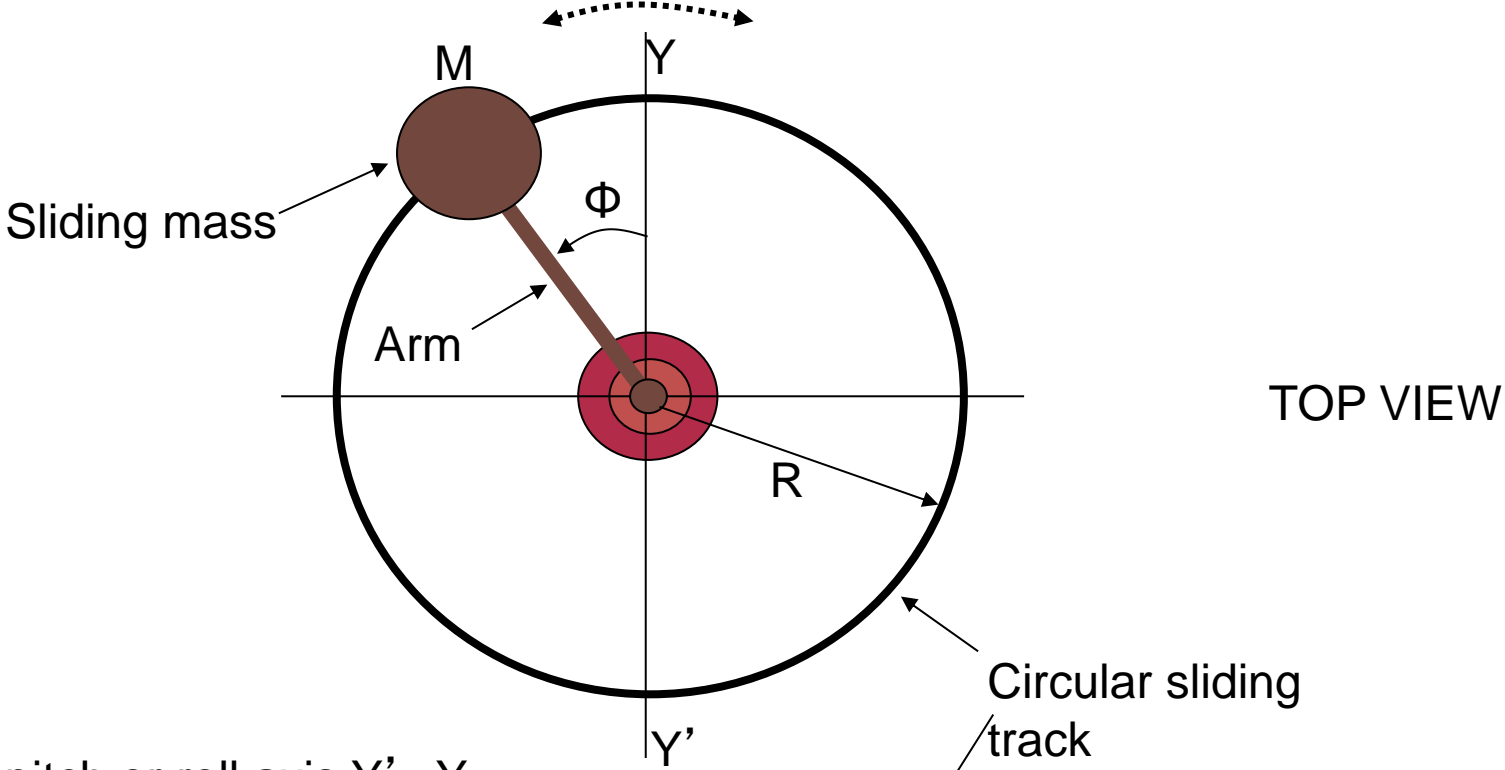
- Build on knowledge gained during Navy SWEM project.
- Extend lifetime from days to months.
- Change from linear (heave) drive to circular (pitch/roll) drive.
- Avoid need for drag resistance.
- Seal moving parts to avoid weather effects.

Basic Concept

- A Wave Energy Converter with mass that slides in circular trajectory under gravity and spins a generator in response to wave-induced buoy pitch/roll.
- Measure angular displacements with an encoder.
- Use the generator as a motor to maintain resonance with an “artificial” spring (eSpring) by applying instantaneous torque that is slowly adapted to the wave period.
- Mount all components inside hermetically sealed box to protect from harsh ocean environment.



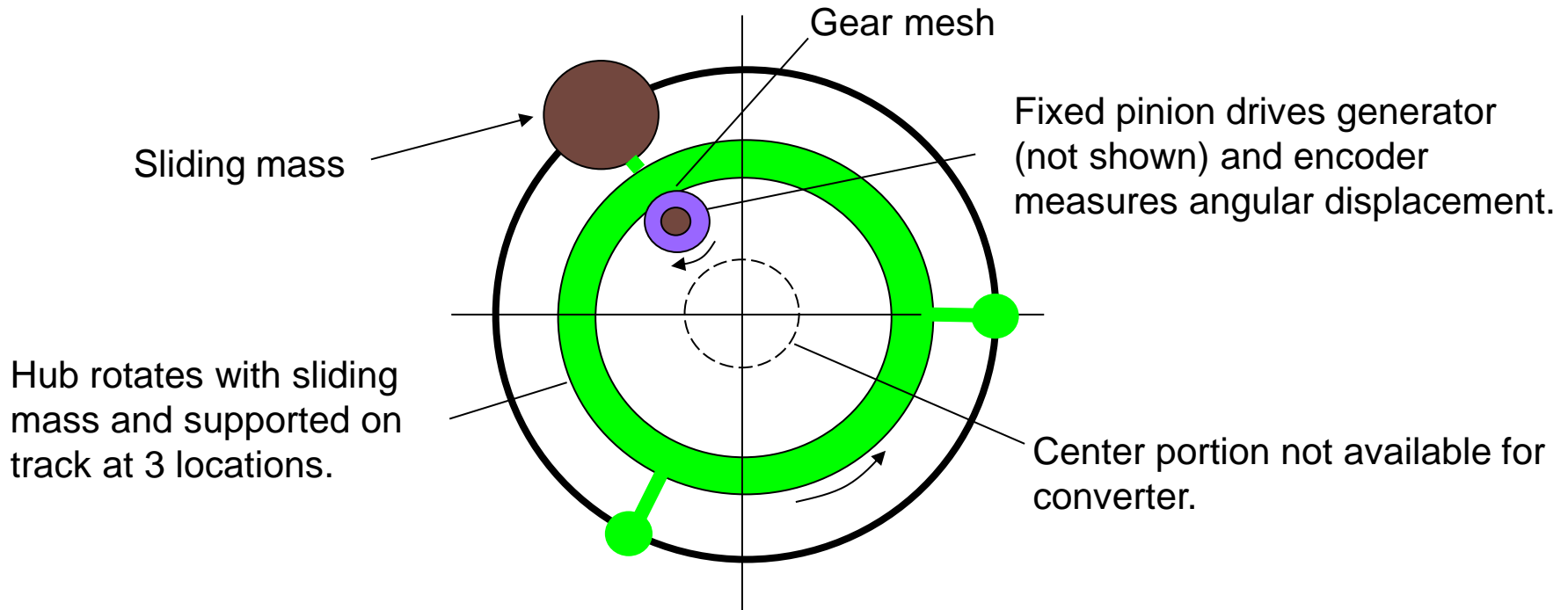
Major Components (Center pivot)



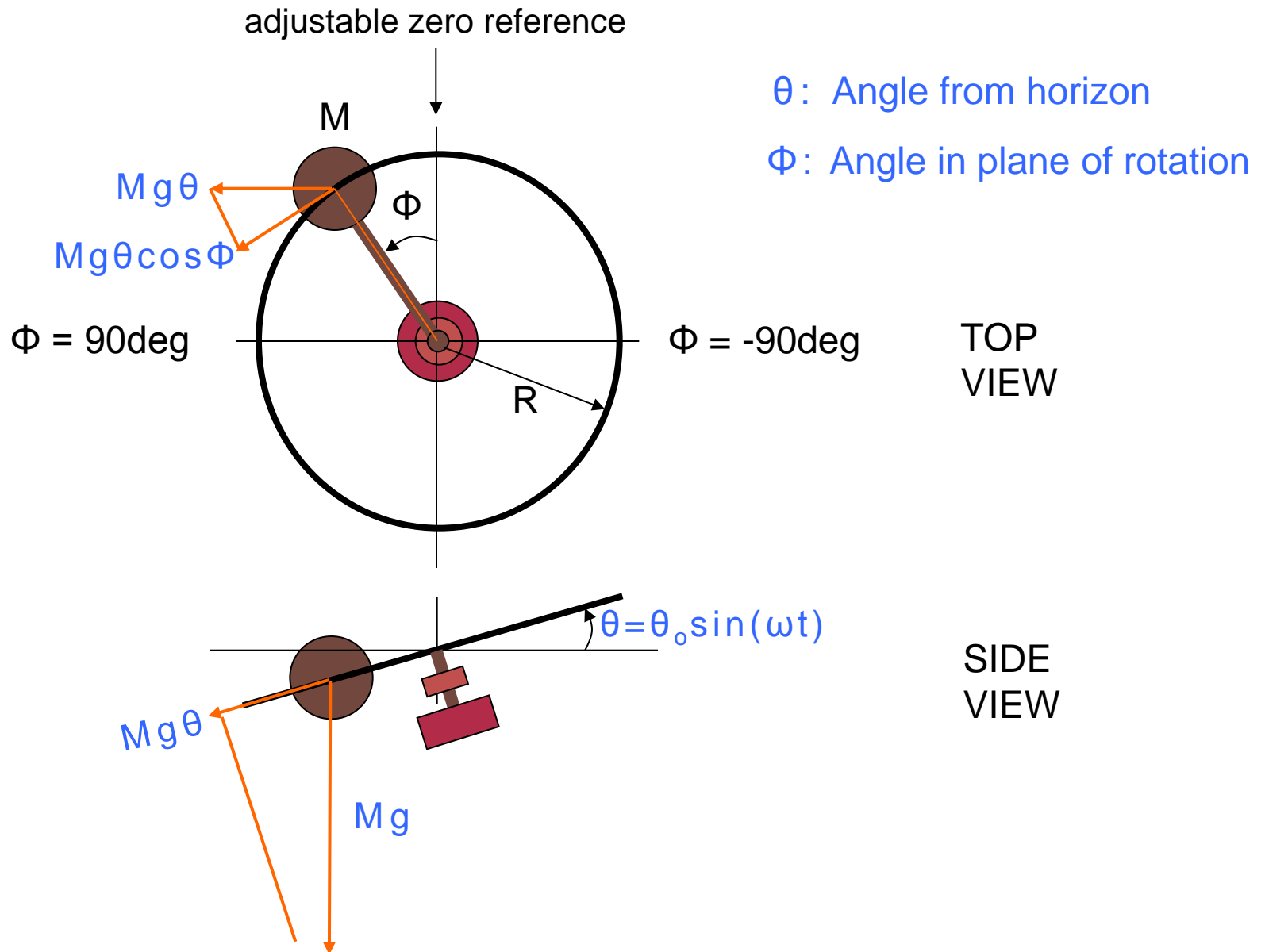
Alternative Design (Concentric hub)

If the center axis is unavailable, the CS-WEC could be modified:

1. The connecting arm would be replaced by a hub with a center hole; the rotating hub would be supported at three points on the circular track.
2. The hub would be made with gear teeth, which drives a pinion connected to the generator; the gearbox is replaced by the hub ring gear and pinion.



Forces



Analysis for Sinusoidal waves

$$MR^2 \frac{d^2 j}{dt^2} + B \frac{dj}{dt} + Kj = Mg \sin(q) \cos(j) R$$

Non-linear eqn of motion.

Inertial torque

eSpring torque

Damping torque

External torque

where

Φ = sliding mass angular displacement, rad

t = time, s

M = sliding mass, kg

R = circular track radius, m

B = damping coefficient, Nm-s/rad

K = artificial torsional spring constant, Nm/rad

g = gravitational constant = 9.81 m/s²

$q = q_o \sin(\omega t)$ = dominant wave frequency, rad/s

T = dominant wave period, s

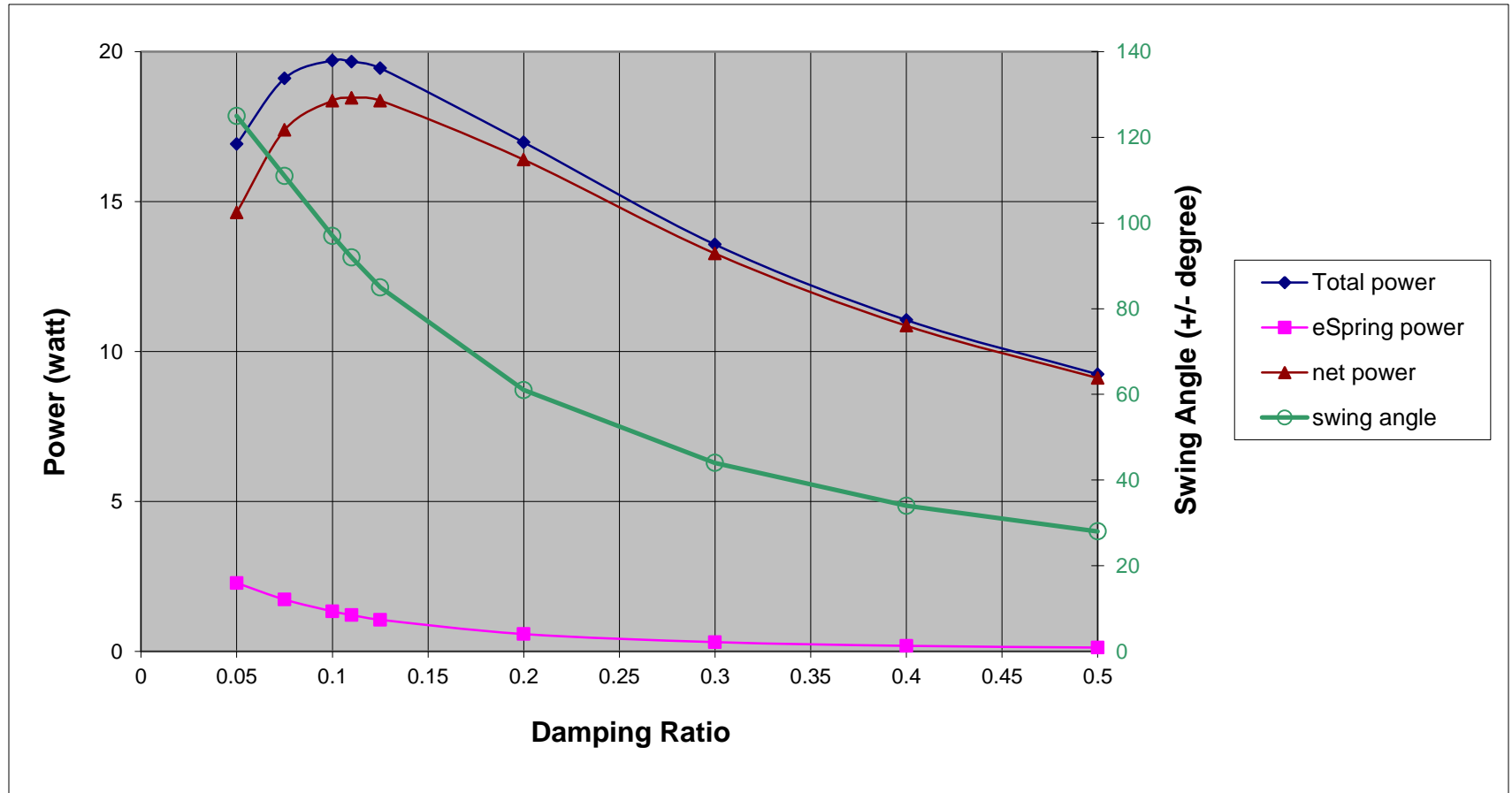
$q_o = \frac{H}{2} \frac{2\rho}{l} = \frac{(2\rho)^2}{2g} \frac{H}{T^2} \gg 2 \frac{H}{T^2}$ buoy incline angle

H = significant wave height, m and

$l = \frac{gT^2}{2\rho}$ = deep water wave length, m

Trick: Measure Φ and use the generator as a motor to control K , such that $K = MR^2 \omega^2$. Then, the artificial eSpring torque cancels the inertial torque and the system becomes resonant and harvests maximum power.

Power vs Damping Ratio for $M=100\text{kg}$; $R=2\text{m}$



- Maximum harvested power occurs at ± 90 deg of swing angle.
- eSpring power consumption is insignificant.

Power Scaling Law for Tuned CS-WEC in Swell

Under this resonant condition (with ± 90 deg of swing angle), a scaling law for power can be written as:

$$P = 20 \pi \eta M R H / T^3$$

where η = system efficiency. The average power of a tuned circular-slide wave energy converter is directly proportional to M, R, H and inversely proportional to T^3 .

Examples: For swell with 2-m height and 10-s period, the scaling law predicts average power (in watts) for a CS-WEC with efficiency of 0.75 to be:

	Radius (m)		
Mass (kg)	0.5	1.0	2.0
25	1	2	5
50	2	5	9
100	5	9	18

Conclusions

1. We introduce a new WEC concept; *i.e.*, the Circular-Slide Wave Energy Converter, which can be mounted under or on a buoy. It utilizes wave pitch and roll instead of heave. A mass slides on a low-friction circular track due to gravity when the track is tilted by waves.
2. The sliding mass spins a generator to produce electrical power. The average power is directly proportional to the sliding mass, track radius, & wave height and inversely proportional to wave period cubed.
3. The CS-WEC does not use mechanical springs; it measures angular motion of a sliding mass and controls generator torque. An artificial eSpring keeps the system in resonance for maximum power.
4. The power consumption of the artificial eSpring can be low and affordable by properly designing the generator/motor.
5. This concept can be hermetically sealed to reduce environmental degradation.