The Effect of Pendulum Configuration on Energy Harvesting Efficiency Across Different Wave Conditions

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Ocean energy is a mostly unexplored renewable energy source. Conventional wave energy converters are limited by moving parts prone to deterioration and narrow frequencies ranges, which reduces efficiency and increases maintenance. This study examines replacing a linear single-pendulum converter with a nonlinear double pendulum system to improve energy output and reliability under irregular wave conditions. The system was tested using both 10,000 computer simulations and 250 physical experiments. In the simulations, the motion of the double pendulum was modeled under thousands of different wave scenarios to predict energy output and system behavior. Physical experiments were conducted using horizontal and vertical drawers slides with tilting to mimic ocean waves. The physical movement was varied in randomized patterns to replicate Sinusoidal, Multi-frequency, and Stochastic wave conditions. Periods when the system failed to produce sufficient power, which were called “dead-zones,” were recorded to assess reliability. Results show that the double-pendulum produced significantly more energy and had fewer periods of inactivity. Simulations showed a 3.47 times higher mean energy output and physical experiments showed a 2.23 times higher output. Dead times decreased by 94%. The double pendulum system also captured energy across a wide range of wave frequencies rather than stalling at a single frequency or peaking at a specific one. These results demonstrate that chaotic double-pendulum systems can significantly improve both the efficiency and reliability of wave every harvesting. When scaled up, this technology could provide consistent coastal power and help make ocean power a practical and dependable source of renewable energy.

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