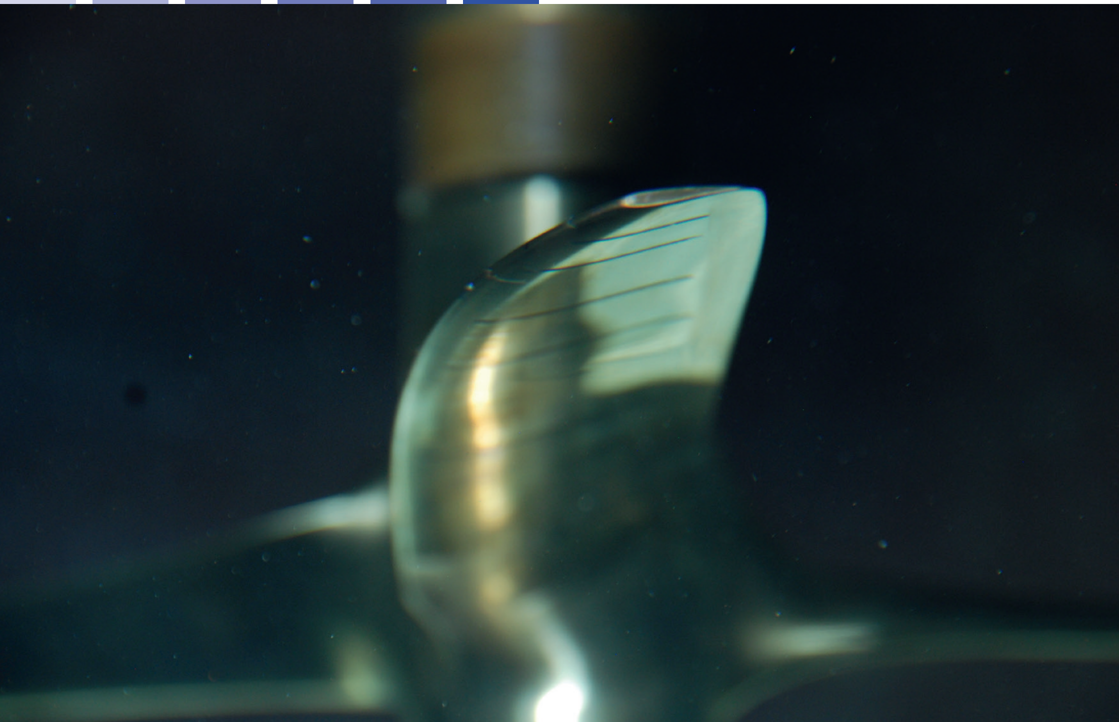
Small Horizontal Axis Free-Flow Turbines For Tidal Currents

Nicholas Kaufmann



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Kurzfassung

Gegenstand der Arbeit sind frei umströmte kleine Axialturbinen zur Energiegewinnung aus gezeiteninduzierten Meeresströmungen. Felder aus solchen einfachen, robust konstruierten und letztendlich preisgünstigen Turbinen sind gedacht als Alternative zu einzelnen, größeren und daher komplexeren Turbinen - mit dem Ziel, die bislang vergleichsweise hohen Stromgestehungskosten bei der Nutzung von gezeiteninduzierten Meeresströmungen zu reduzieren. Das übergeordnete Ziel dieser Arbeit ist die Entwicklung innovativer, optimaler Rotorgeometrien für diese kleinen Axialturbinen, die a) eine maximale jährliche Energieausbeute an einem gegebenen Standort ermöglichen, b) einen möglichst geringen Axialschub aufweisen, um die Kosten für ein Fundament auf dem Meeresboden oder die Fixierung von schwimmenden Plattformen niedrig zu halten, und c) günstige Kavitationseigenschaften besitzen, um mit geringer Eintauchtiefe auszukommen.

Im Rahmen der Arbeit wurde ein neues Verfahren für den hydraulischen Entwurf der Turbinenrotoren entwickelt. Kern der Entwurfsmethode ist die Integration des semianalytischen Blade-Element-Momentum-Verfahrens und eines Kavitationsmodells in ein multikriterielles Optimierungsverfahren. Regelungskonzepte für Turbinenausführungen ohne und mit Blattverstellung (fixed- und variable-pitch) wurden berücksichtigt. Für vier Klassen des Strömungsenergieangebots wurden jeweils optimierte fixed- und variable-pitch-Turbinen entworfen.

Im Vergleich zum Entwurf mit einer klassischen Methode ist der prognostizierte jährliche Energieertrag der optimierten fixed-pitch Turbinen zwischen 22% und 27% höher. Mit optimierten variable-pitch Turbinen ist der Vorteil noch größer. Die neue Entwurfsmethode wurde durch umfangreiche Modellversuche in einem Schlepptank und einem Kavitationstunnel erfolgreich validiert. Darüber hinaus wurde die vorhergesagte Leistungs- und Schubkurven einer ausgewählten Turbine in seriennaher Großausführung mit einer mehrmonatigen Messkampagne in einer realen Gezeitenströmung bestätigt.

Abstract

This thesis deals with small horizontal axis free-flow turbines for harnessing the kinetic energy of marine currents driven by the tidal cycle. Arrays of such small and robust turbines represent an alternative to the currently investigated large and more complex single-rotor devices - with the prospect of reducing the overall cost of electricity generated from tidal currents. The overall objective of this work is the development of innovative optimal rotor geometries for these small horizontal axis turbines which feature a) the maximum annual energy production at a given site of deployment, b) a minimum axial thrust in order to reduce cost for foundation at the seabed or for mooring of a floating platform, and c) a minimum sensitivity to cavitation for a low immersion depth in case of floating platform systems.

Within this thesis, a novel turbine design method, tailor-made for small horizontal axis turbines, is developed. Key feature is the integration of an enhanced semi-analytic blade-element-momentum method and a cavitation inception model into a multi-objective optimization scheme. Control strategies for fixed- und variable-pitch turbines are included. For four generic classes of tidal current velocity distributions, representing potential tidal current resources of different energy levels, fixed- und variable-pitch turbines are designed.

The predicted annual energy production of the optimized fixed-pitch turbine is between 22% and 27% above a classical design. The optimized variable-pitch versions promise even larger improvements. The new design method has been validated successfully within comprehensive model scale turbine tests in a towing tank and cavitation tunnel. Moreover, in several months' full-scale tests in a real tidal current, the predicted power and thrust characteristics of a selected close-to-production turbine was confirmed.

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