Heat Transfer in a Liquid Piston Near Isothermal Air Compressor/Expander

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Objective

Our objective is the creation of a cost effective and local energy storage system for offshore wind turbines using an “open accumulator” high pressure compressed air approach. This system relies on a combined hydraulics and pneumatics approach to attain both high energy density and high power density. A critical element to our approach is an efficient air compressor/expander which operates nearly isothermally.

Motivation

Options for Energy Storage Compatible with Wind Turbines

Batteries:
~ Good energy density
~ Poor power density
~ Material cost/availability
~ Life cycle and recycling
~ AC/DC Conversion

Pumped Hydro/Reversed Pump Hydro:
~ Cheap
~ Poor energy density
~ Limited deployment (large elevation change required)

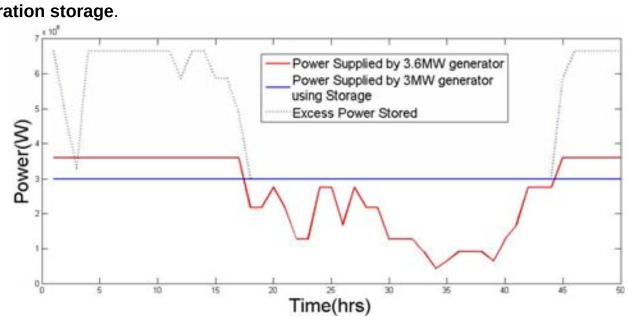
Compressed Air Energy Storage (CAES)
~ Poor efficiency (<50%)
~ Poor power density
~ Limited deployment (Underground cavern required)

Open Accumulator Approach with Near-isothermal Liquid Piston Compressor/Expander

~ Improved energy density and high power density through combined pneumatic/hydraulic **open accumulator approach**

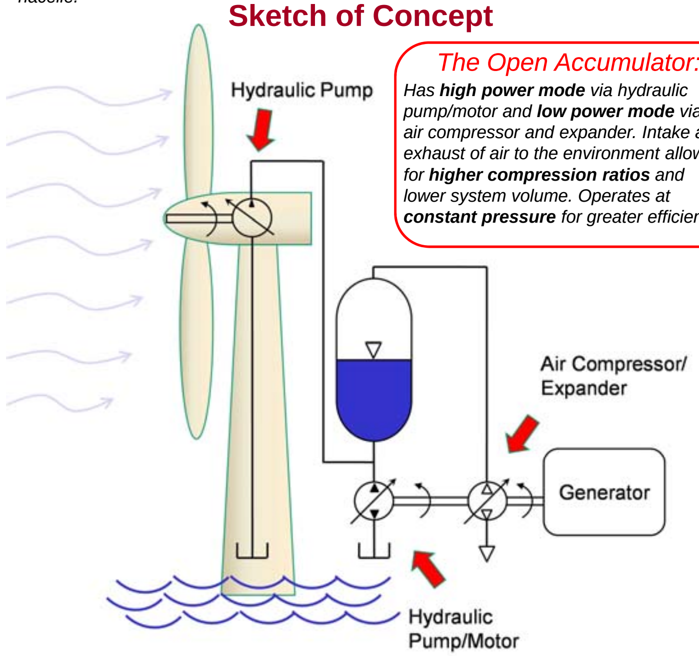
~ high efficiency and low volume conversion through a **near isothermal liquid piston air compressor/expander.**

~ Generator and transmission sized for demand, not peak supply, by **pre-electric generation storage**.



Wind data was provided by CapeWind Project <capewind.whgrp.com>. The red line shows the power provided to the grid with a 3.6MW generator (an average of 2.5MW). The solid blue line is the constant power provided with a 3MW generator. The dotted blue line is the excess power that will be stored. For this simulation, a 7MW hydraulic pump is placed in the nacelle.

Sketch of Concept



The Open Accumulator:

*Has **high power mode** via hydraulic pump/motor and **low power mode** via air compressor and expander. Intake and exhaust of air to the environment allows for **higher compression ratios** and lower system volume. Operates at **constant pressure** for greater efficiency.*

The Liquid Piston Air Compressor / Expander

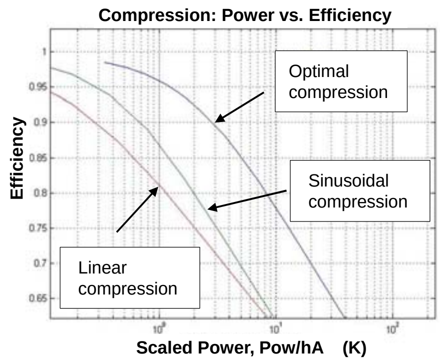
The Heat Transfer Challenge:

When air is compressed or expanded adiabatically it will change in temperature. The final temperature is calculated by

$$T_{final} = T_{initial} r^{\frac{\gamma-1}{\gamma}}$$

*Where **r** is the ratio of the final pressure to the initial pressure. Our proposed ratio of 350 results in temperatures reaching **1588 K** during compression and **59 K** during expansion. These numbers highlight our need for heat transfer. Reasonable values will be within 50 K of the ambient. **Power** and **efficiency** requirements as well as **size constraints** add to the challenge.*

Optimal Compression and Expansion Trajectories



Significant advantages in power and efficiency over as hoc compression trajectories are obtained by optimization (see left)

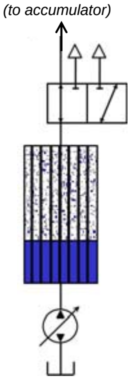
The optimal trajectory is in three stages and takes the form:
1) Adiabatic compression
2) hA-dependent near-isothermal compression
3) Adiabatic compression

Heat Transfer Enhancement by Porous Media and Droplets

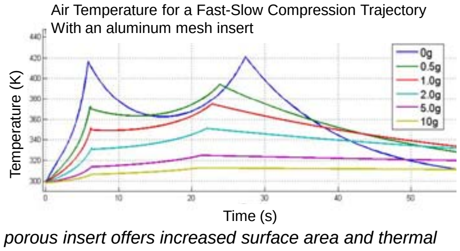
We are considering several methods to enhance the heat transfer. The enhancement is due to three possible effects:

1) increased surface area
2) increased thermal capacitance of air space
3) increased mixing on air.

The optimal solution will likely incorporate a variety of strategies.



A liquid piston could be made to pass through channels or a porous grid of material to increase surface area. Droplets sprayed from the top of the chamber increase surface area and promote mixing. The compressed air is stored in the accumulator.



A porous insert offers increased surface area and thermal capacitance and is one of the heat transfer strategies we are investigating. Mathematical models help us predict the temperature (see above) and experiments (left) are used to verify our models.

Acknowledgements

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