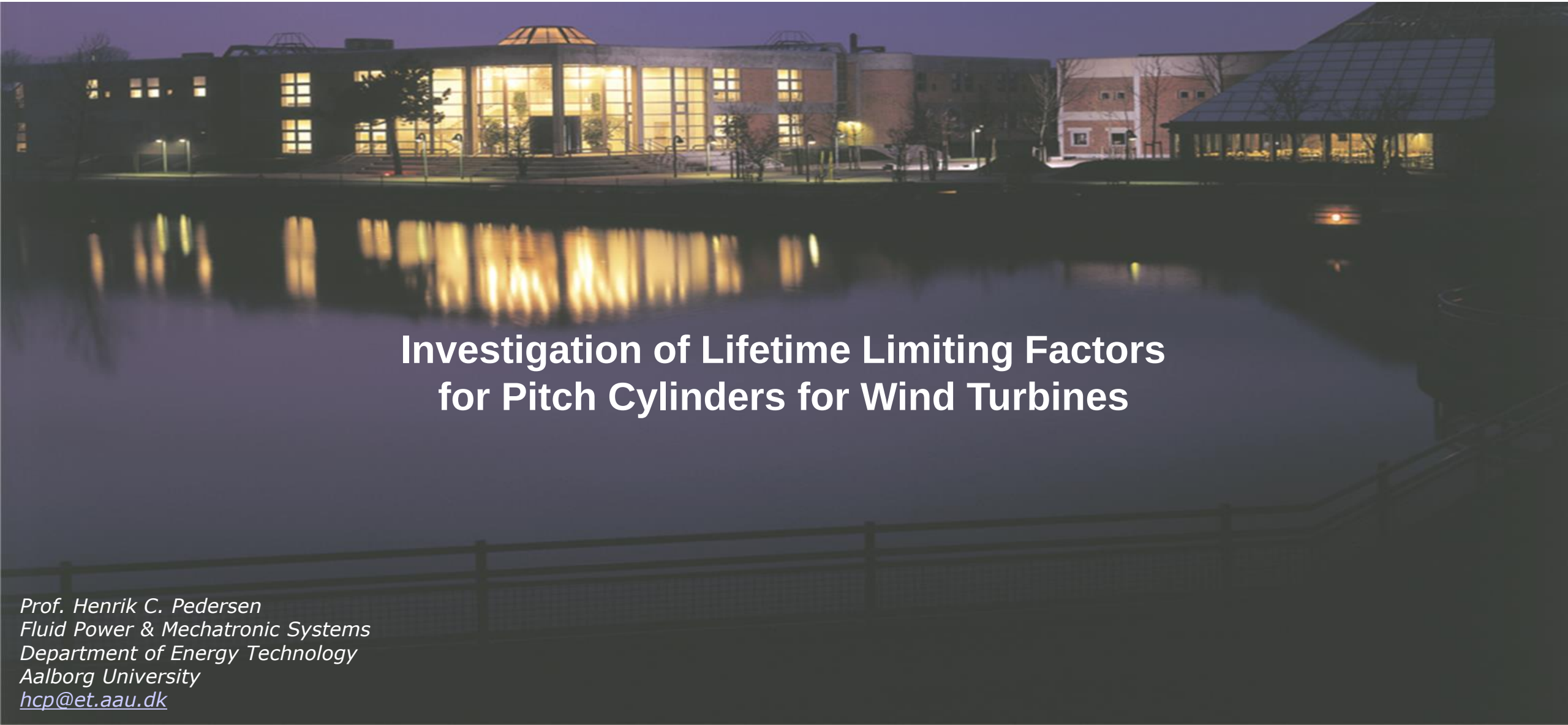

Investigation of Lifetime Limiting Factors for Pitch Cylinders for Wind Turbines

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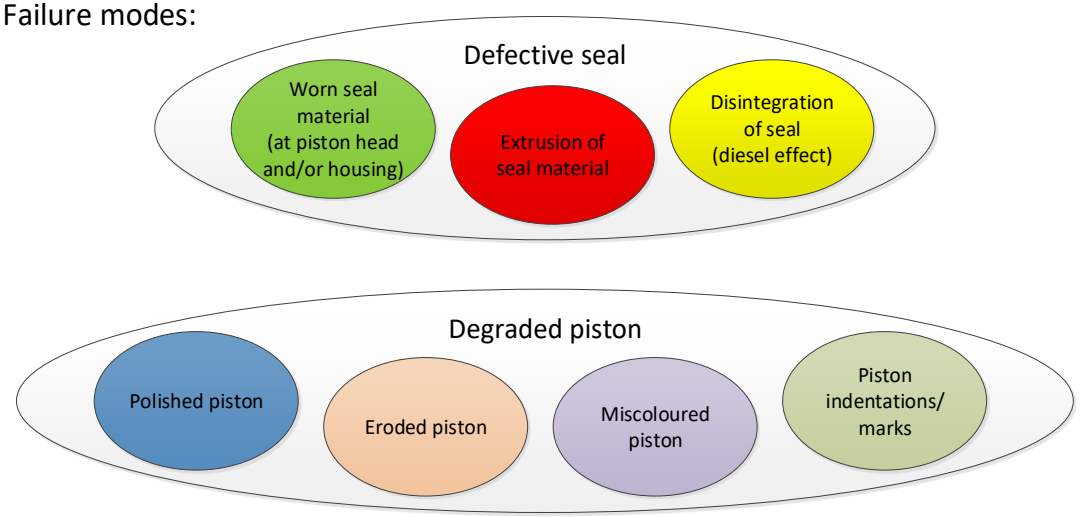
Presentation Outline

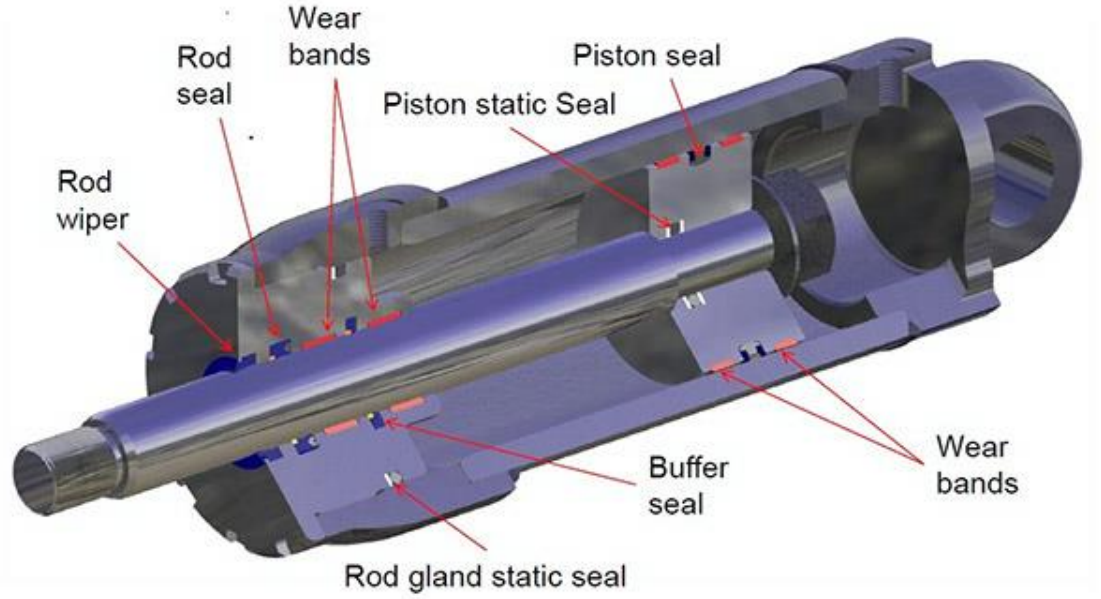
- Project Background
- Existing Knowledge
- Project Focus
- Addressing Main Concerns: Confidentiality & Knowledge Spread
- Summary

Project Background – What is the Problem?

- Hydraulic cylinders are typically tested according to the ISO 10100:2001 standard for acceptance tests of fluid power cylinders
- Experience has shown that this test is nowhere representative for pitch cylinder operation ⇒ cylinders wear out much faster than expected

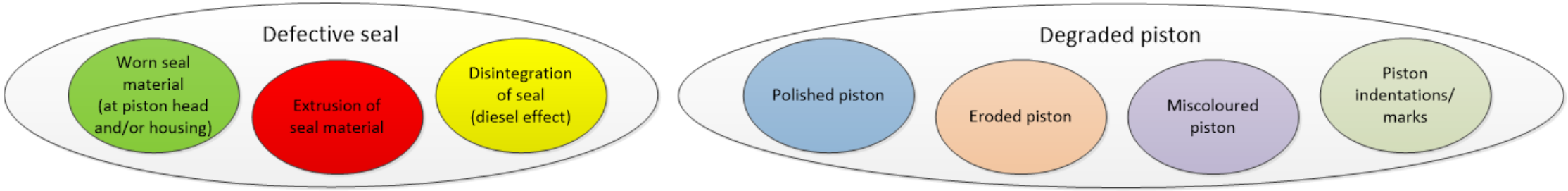
Failure modes:



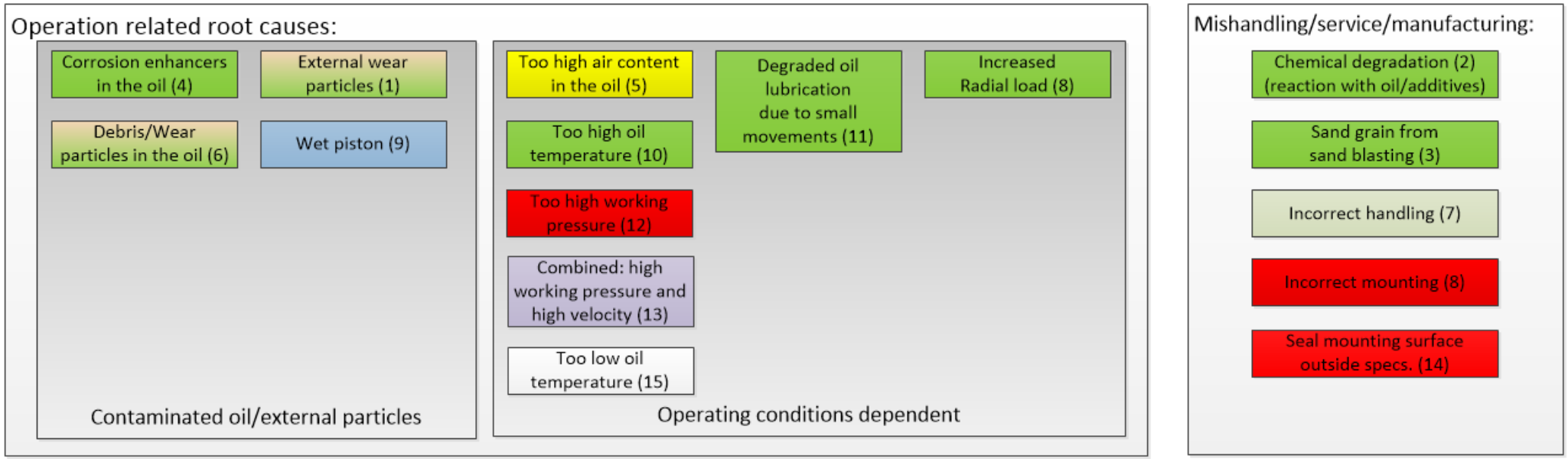


Correlating Failure Modes and Root Causes

Failure modes:



Root causes:

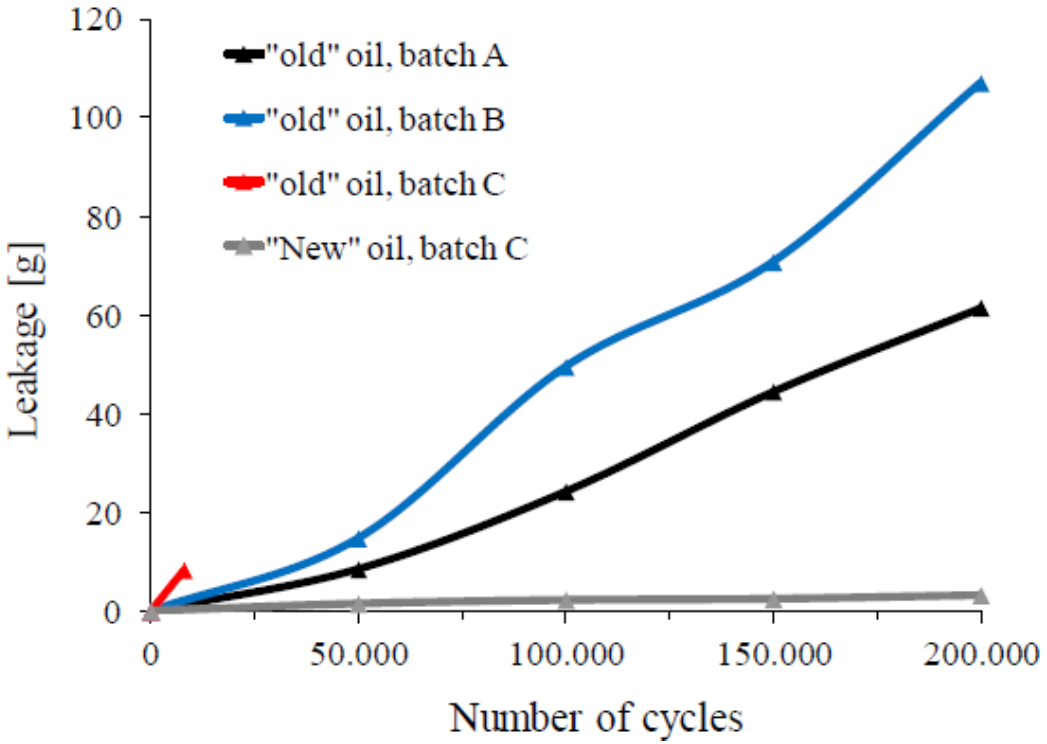


Main Findings (Existing Knowledge)

- External leakage is the main problem
  - Internal leakage is secondary
  - Structural damage is not a problem
- Material combinations (and rod surface, i.e. roughness and hardening) have significant influence on failure rate
- The critical operating conditions are repeated short strokes with low velocity
- Primary seal fails/wears out faster than secondary seal
- Ageing of o-rings leads to lost compression and hence ultimately failure
- Rod imperfections (dents and marks from mishandling) may be root cause for several failures

Main Findings (Existing Knowledge)

- Oil properties and condition have significant influence on both faults, wear and friction
  - Air leads to cavitation and nitration
  - Silicium particles are critical wrt. wear
  - Copper reduces lifetime (acts as catalyst) – not a real problem with todays designs
- "Macroscopic analysis" (i.e. at system level) yields no/very limited information
  - Oil samples from tank may not be representative as they may show limited or no contamination/ degradation
  - Overall oil temperature may not be a good measure for local oil temperatures in critical parts of the cylinder

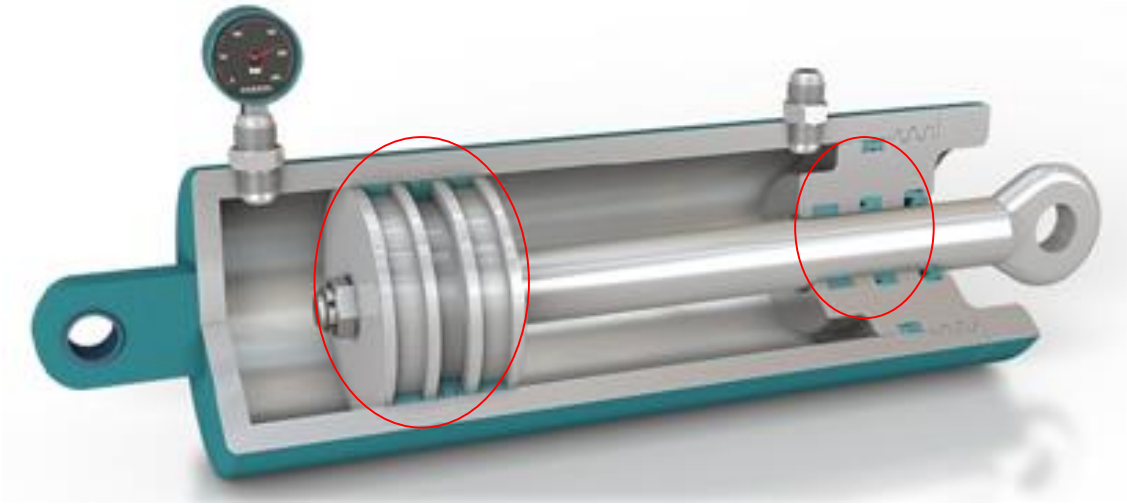


Results from "Improving Reproducibility of Seal Test Results", by Thomas Larsen & Torben Andersen, Trelleborg

Main Findings

- Laboratory tests ("one parameter tests") tend to show that no failure will occur and/or that the expected lifetime should be higher than what is seen in reality

- "Stationary oil" in the cylinder may be a problem ⇒ "Microscopic analysis" may be required
  - Micro pitch motions lead to break-down of additives near the seals
  - Radicals formed by broken down additives and base oil may damage the entire oil
  - There are indications that debris gathered at sealings and local heating of oil has significant effects



About the Project

- Initiated by the industry partners together with the Danish Wind Industry Association (VMI)
- Driven by a desire of being better to both test and predict the lifetime of pitch cylinders.
- The project is too big and requires knowledge from all parts of the supply chain to be undertaken by only one party
- Aalborg University and Vindmølleindustrien are the neutral partners

VINDMØLLEINDUSTRIEN

AALBORG UNIVERSITET

Parker

TRELLEBORG

FRITZ SCHUR ENERGY

Vestas

SIEMENS Gamesa

LIND JENSEN HYDRAULIC

ExxonMobil

Project Objectives

Technical objectives:

1. To obtain a better understanding of how (selected) possible root causes and the coupling between these effects the seal leakage for a hydraulic pitch cylinder and hence the lifetime

2. To use the knowledge to develop systematic test methods for pitch cylinders – based on pitch cylinder operating conditions

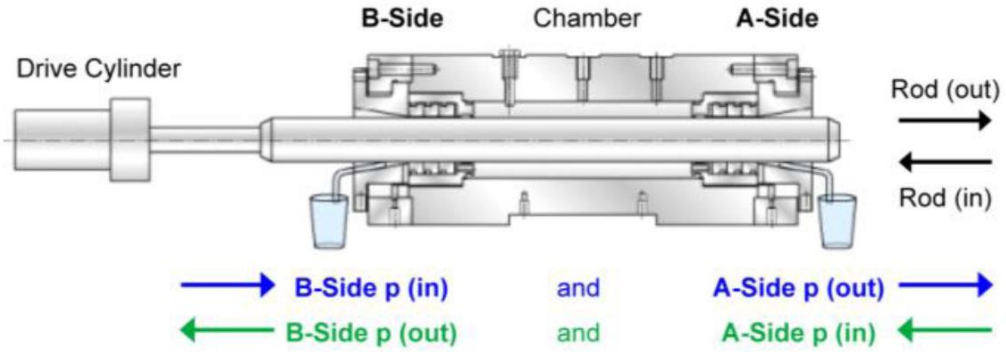
3. Development of test equipment suited for testing the local effects near the seals

Project Outcome

Expected outcome:

- A database of knowledge about how the different factors and the combination of these (root causes) affect the wear of pitch cylinders
- A method for how to transform real wind turbine operating conditions into representative accelerated test profiles
- Partly standardized tests that may be used for testing design changes

Project Approach



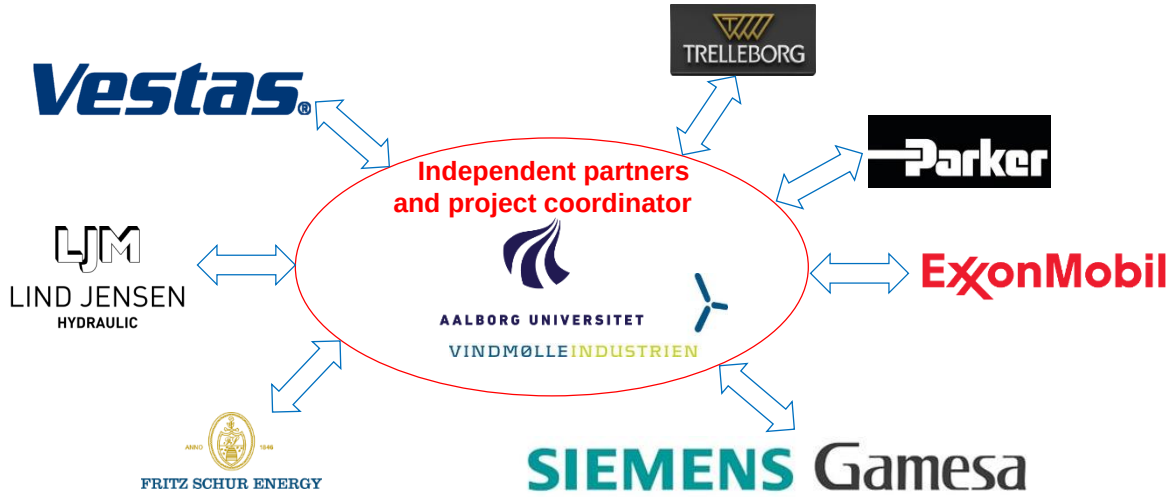
- Focus on "microscopic" analysis:
  - Stationary oil in a small enclosed chamber
  - Limited number of parameter variations:
    - Particles (size, type and concentration)
    - Oil temperature
    - Pressure
    - Oil viscosity (new and used oil) – this will be for specific oil types
  - Test are made for specific cylinder designs
- Limited time duty cycles – with extrapolation of results
  - Duty cycle largely dominated by short stroke low velocity (small lubrication layer height and small fluid circulation near seals)
- Parameters monitored
  - Local temperature and temperature distribution (near seals)
  - External leakage
  - Pressure
  - Force (friction)
  - Wear (offline 3D measurement)
  - Oil analysis (offline)
  - Local particle build up (visual inspection and/or scraping)

The Benefit of the Project

- The obtained method and analysis could/should be used to:
  - better evaluate possible design changes
  - determine whether a given design will improve the lifetime of a cylinder relative to current designs
- May ideally be used to predict very rough estimates for cylinder lifetime/whether a cylinder will hold for a specified time (by extrapolating obtained data)
- Plus: much better overview of wear problems related to pitch system operation

Addressing the Main Concerns
(In bed with your colleagues, competitors and customers…)

How do we avoid sharing or spreading company/design sensitive information (both internally in the project and outside)?



- *Aalborg University will be responsible for all information handling*
  - *Information sharing will be bilateral between individual partners and AAU (all information treated confidentially)*
  - *The results will processed by AAU and approved by partners individually before presented to the group*
  - *In general: Any IPR belongs to the partly creating this (no IPR is expected in this project)*

Addressing the Main Concerns – How do we Share Results?

How do we avoid sharing or spreading company/design sensitive information (both internally in the project and outside)?

- The test results will be anonymized and "only" the general conclusions will presented - the overall results of the project will be of general nature, i.e. methods for how to devise the tests

- Design specific results will not be shared

Addressing the Main Concerns – How do we Avoid

- Do we end up with a method or procedure which others (low cost/quality manufacturers) may just copy?
  And that wind turbine OEMs may approve designs by?

The simple answer is no!

- The outcome will be a set of test methods and a knowledge database that will be partly design specific
  - Test sequences will be very dependent on turbine operation – we will devise a method for how to transform operating patterns into suited test sequences
  - The results obtained in the project may be used for understanding how to best accelerate tests

Summary

- Pitch cylinder failure may be the result of many different root causes or combinations hereof:
  - the failure mechanics are not fully understood
  - the problem is very multi-disciplinary and requires understanding of material and oil properties, working conditions, etc.

- The current project will investigate wear effects and how the operating conditions affect the wear to:
  - Develop systematic test methods for pitch cylinders based on real turbine operation
  - Obtain a better understanding of different root causes and cylinder wear

- In general there is a need for the industry to work together, as many projects cannot be handled by one party only
  - Universities and GTS'es may be independent partners that may help overcome the confidentiality problems and aid in the problem solving

Thank you for your attention