Flexibles case

Data driven maintenance for water cooled power cables (flexibles)

Tom Ivar Pedersen
11/11 2021

Norwegian University of Science and Technology

The Idun computing cluster.

hpc.ntnu.no/idun/

NTNU
High Performance Computing Group

Idun

- How to become a shareholder
- How to get access to Idun
- Getting started on Idun
- Hardware
- Software on Idun
- Idun FAQ
- Acknowledgment

Mines Brønn

IT-support for PhD students - Mimes Brønn

«Mimes Brønn» *(or in English Mimir's well)* is a meeting place for NTNU **PhD students and IT professionals.**

The objective of Mimes Brønn is to **help PhD students** get started with their research as quickly as possible. By facilitating a **common physical location** for periods of one to four weeks, the IT department can help scientists **get started with their work faster**, reducing the time spent navigating the technological jungle.

In Norwegian: Mimes Brønn - IT-støtte for ph.d.-er

Get started

Write to orakel@ntnu.no if you are interested in more information.

MTP Quota: 140 CPUs

Account	Quota(hours)	Used(hours)
ad-iat	-	0
hf-isl	-	0
ie-idi	-	14076
ie-iel	-	8334
ie-ies	-	5256
ie-iik	-	0
ie-imf	-	501
ie-imf-tma4280	-	0
ie-itk	-	114
iv-ept	-	101742
iv-ibm	-	0
iv-igp	-	0
iv-ikt	-	0
iv-imt	-	10
iv-ivb	-	0
iv-kt	-	0
iv-mtp	-	0
mh-ikom	-	7
mh-ism	-	0
mh-kin	-	36784
nano	-	0
nv-bio	-	1202
nv-fys	-	8490
nv-fys-tem	-	0
nv-iba	-	0
nv-ibf	-	0
nv-ibt	-	110
nv-ikj	-	53667
nv-ikp	-	14107
nv-ima	-	36214
ok-hhs	-	0
propulse	-	0
share-ie-idi	722880	9486
share-ie-iel	345600	296
share-ie-imf	40320	581
share-iv-ept	40320	141
share-iv-igp	69120	753
share-iv-ivb	-	0
share-iv-mtp	100800	0
share-mh-ikom	-	9
[illegible]	[illegible]	3827
share-mh-kin-whitlock	103680	0
share-nv	-	0
share-nv-fys	69120	6207
share-nv-fys-tem	23040	250
share-nv-ikj	43200	0
share-nv/ikp	-	0
share-nv-ikp	20160	357
share-nv-ima	-	90605
su-geografi	-	16
su-ilu	-	0
support	-	6
test	-	0
training	-	0

How to get access to Idun

1. Ask your supervisor to approve access to the cluster resources.
2. Send an email to your contact person (see below) with subject "User on Idun", and provide the following information:
   - Your username
   - Your supervisor's name
   - A (very) short description of your work or project
3. Read the Getting Started on Idun page.

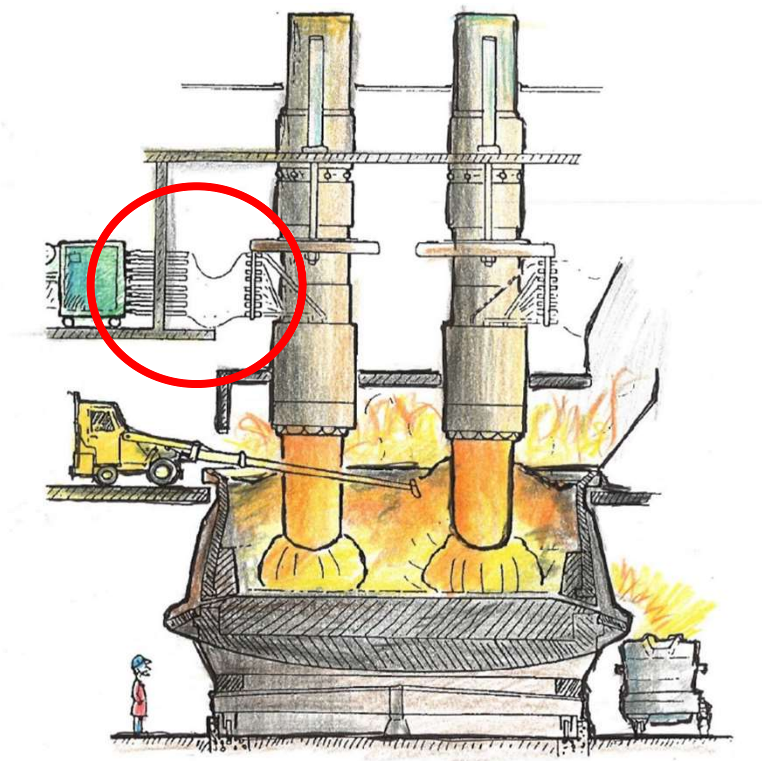
Contact Persons:

Shareholder	Contact Person
Department of Energy and Process Engineering (EPT)	Eugen Uthaug
Department of Geoscience and Petroleum	Erlend Våtevik
Department of Electric Power Engineering (IEL)	Anders Gytri
Department of Mechanical and Industrial Engineering (MTP)	Astrid de Wijn
Department of Computer Science (IDI)	Jan Grønsberg Erik Houmb

Agenda

- Presentation of context for the water-cooled power cables (flexibles)
- Presentation of available data
- Results from two master's theses
- Ideas for using data for journal paper
- Discussion

Flexibles



(Hannensson, 2016)

Functions

1. Contain water
2. Transfer electrical current
3. Transfer cooling water

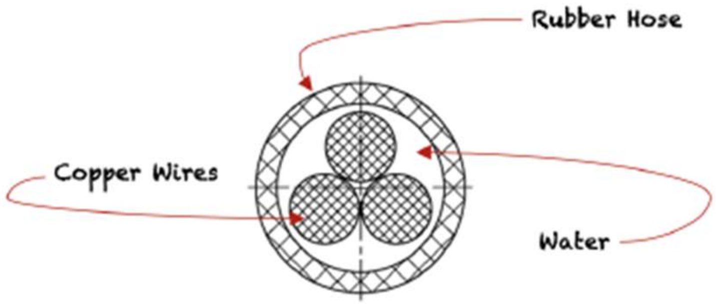


Figure 4.3: Cross-section of flexsible used for both Furnace one and two.

Figure 4.4: Cross-section of the older type of flexsible with central cooling.

Examples of failures on furnace #2

Furnace #2 “sudden loss of current”

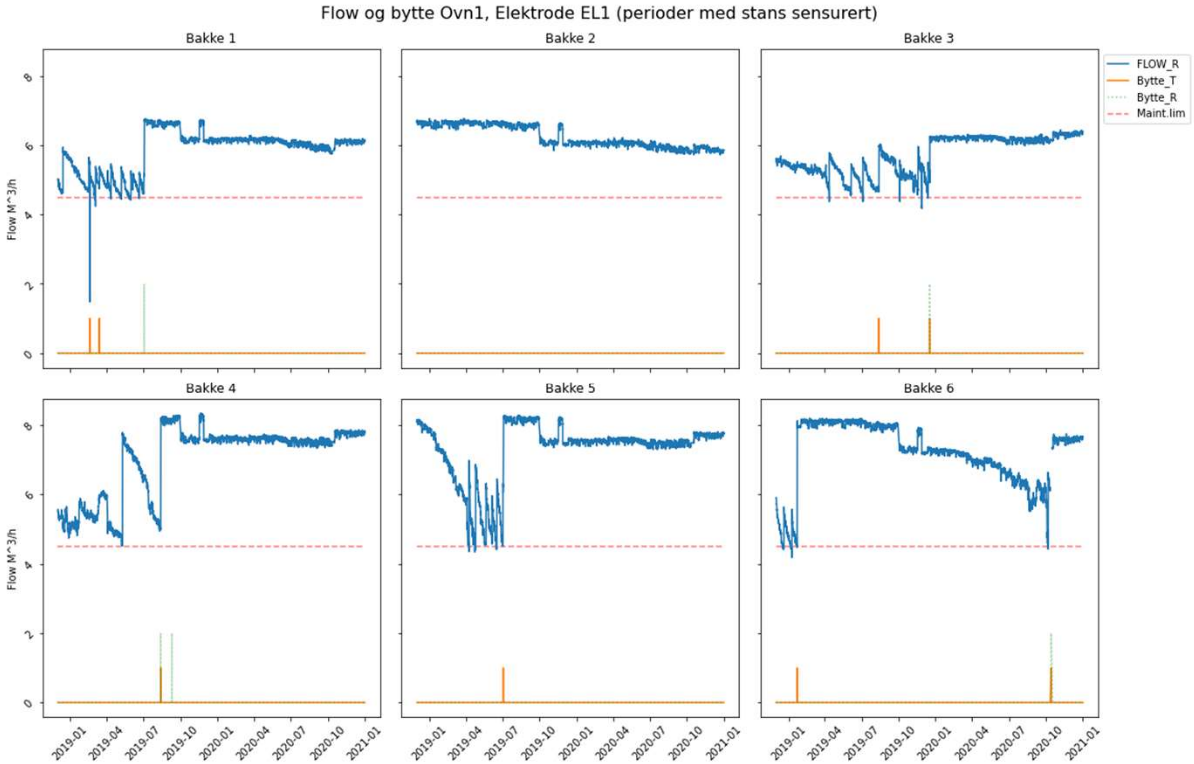
- Leads to unplanned stop and loss of production
- About 5 events in dataset
- Have no early warning of these events today

Furnace #2 damage on hose

Leakage:
- Detected by deviation in delta flow

Wear on hose
- Detected by visual inspection

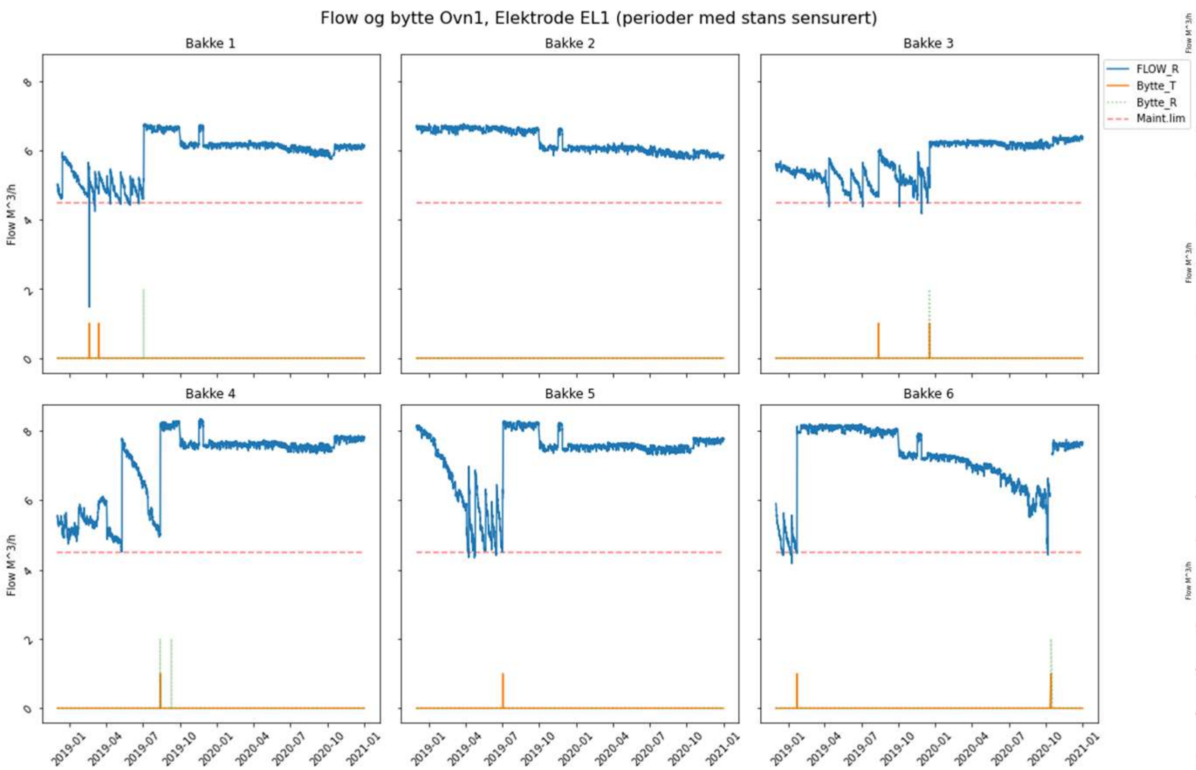
Dominant failure mode on furnace # 1: Gradual decline in cooling water flow:



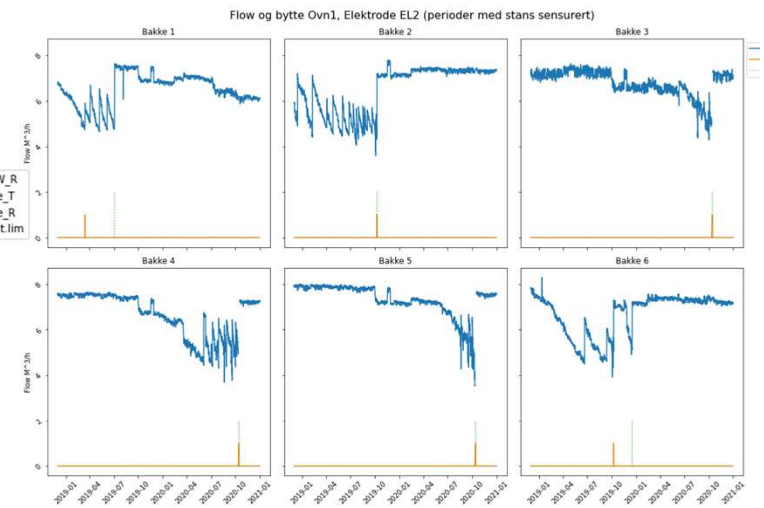
NTNU

AVAILABLE DATA

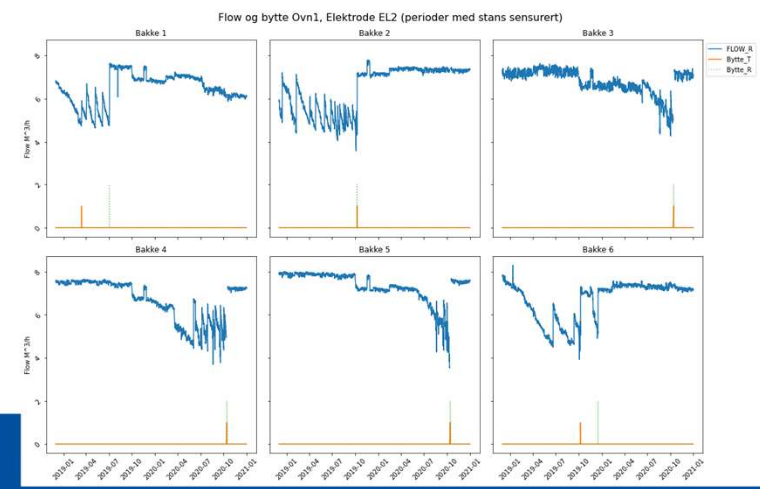
Furnace #1



Flow og bytte Ovn1, Elektrode EL1 (perioder med stans sensurert)
Bakke 1
Bakke 2
Bakke 3
Bakke 4
Bakke 5
Bakke 6
FLOW_R
Bytte_T
Bytte_R
Maint.lim
Flow M^3/h
0
2
4
6
8
2019-01
2019-04
2019-07
2019-10
2020-01
2020-04
2020-07
2020-10
2021-01

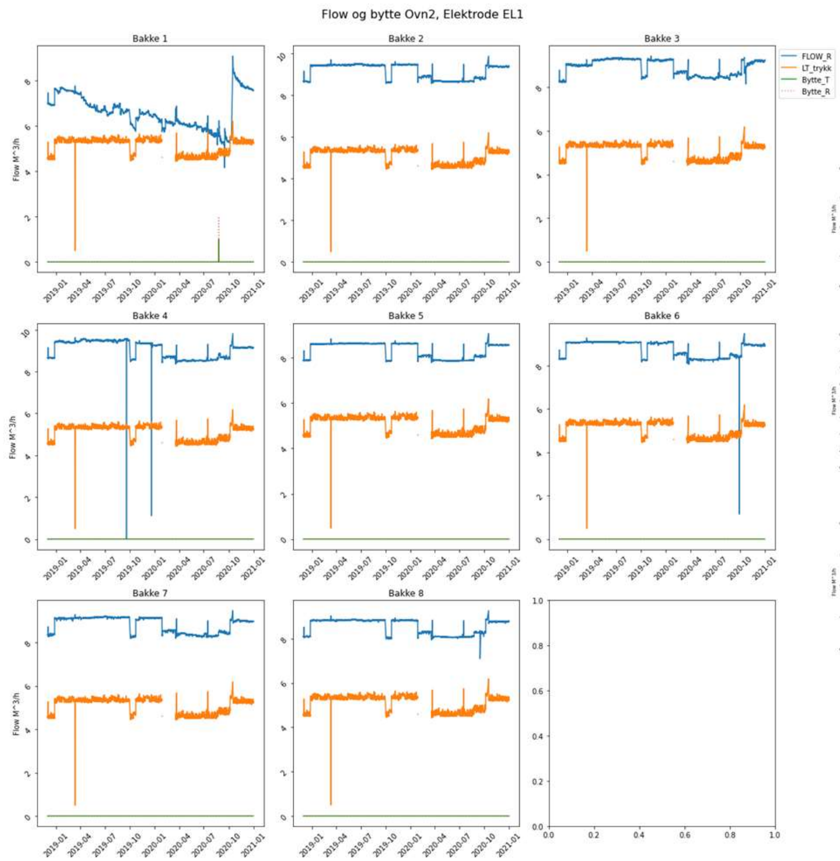


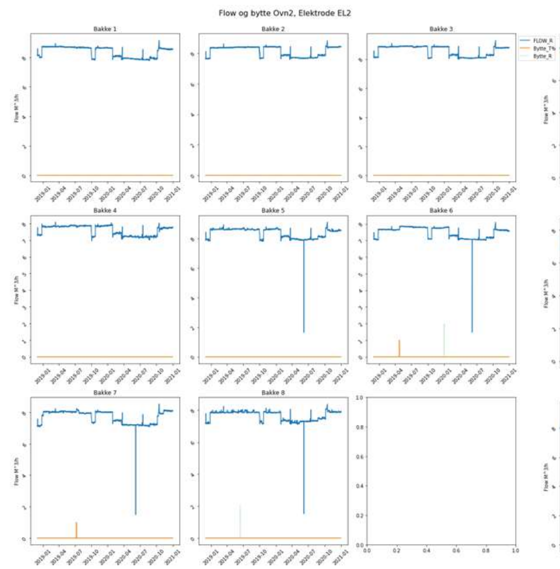
Flow og bytte Ovn1, Elektrode EL2 (perioder med stans sensurert)
Bakke 1
Bakke 2
Bakke 3
Bakke 4
Bakke 5
Bakke 6

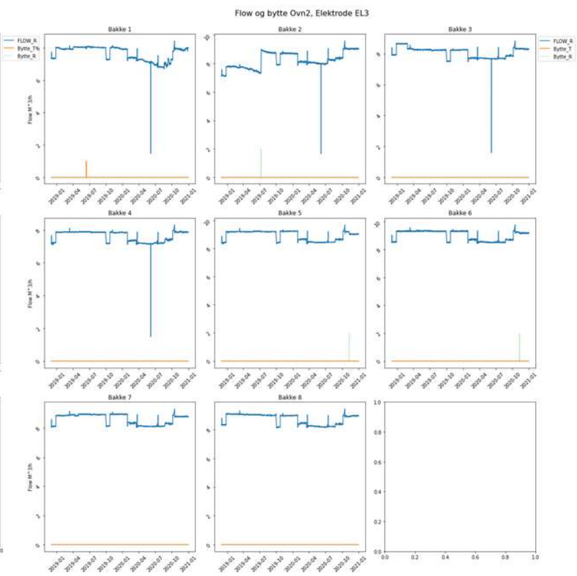


Flow og bytte Ovn1, Elektrode EL2 (perioder med stans sensurert)
Bakke 1
Bakke 2
Bakke 3
Bakke 4
Bakke 5
Bakke 6

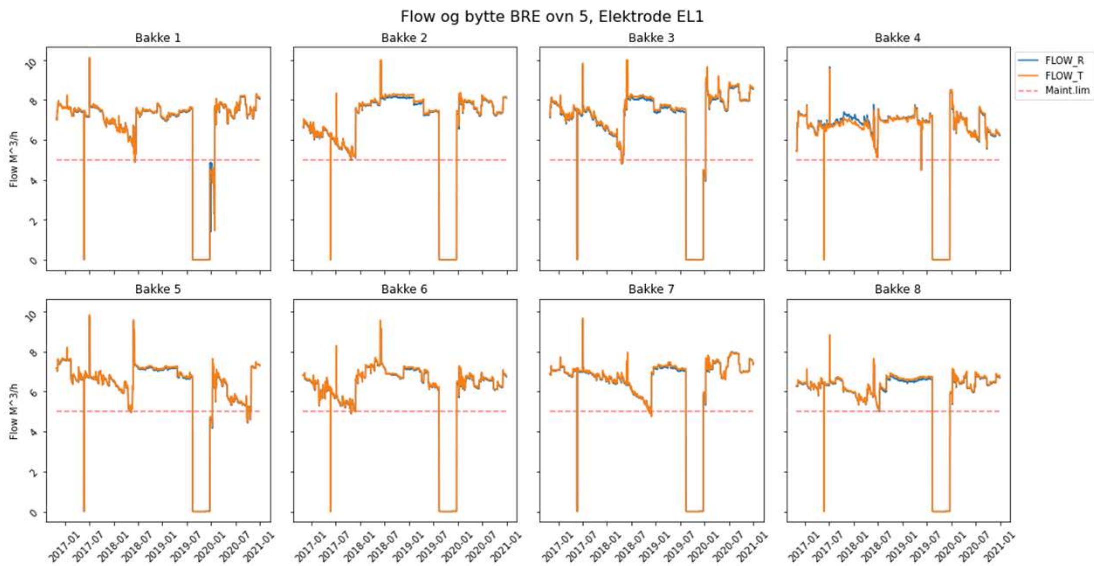
Furnace #2


Flow og bytte Ovn2, Elektrode EL1
Bakke 1
Bakke 2
Bakke 3
Bakke 4
Bakke 5
Bakke 6
Bakke 7
Bakke 8
FLOW_R
LT_trykk
Bytte_T
Bytte_R
Flow M^3/h

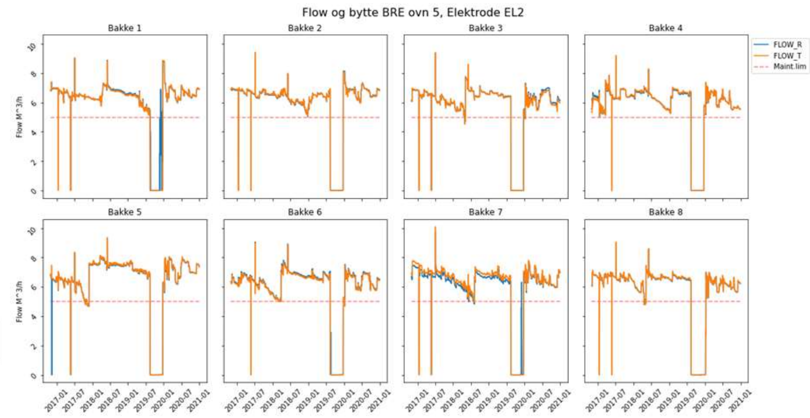

Flow og bytte Ovn2, Elektrode EL2
Bakke 1
Bakke 2
Bakke 3
Bakke 4
Bakke 5
Bakke 6
Bakke 7
Bakke 8


Flow og bytte Ovn2, Elektrode EL3
Bakke 1
Bakke 2
Bakke 3
Bakke 4
Bakke 5
Bakke 6
Bakke 7
Bakke 8

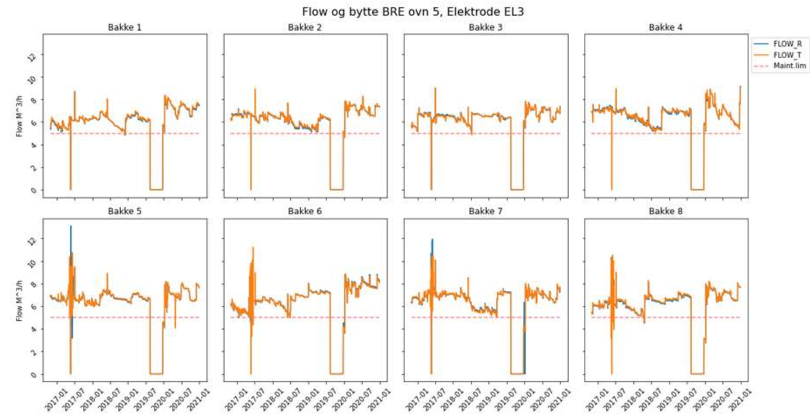
Furnace #5



Flow og bytte BRE ovn 5, Elektrode EL1
Bakke 1
Bakke 2
Bakke 3
Bakke 4
Bakke 5
Bakke 6
Bakke 7
Bakke 8
Flow M^3/h
FLOW_R
FLOW_T
Maint.lim



Flow og bytte BRE ovn 5, Elektrode EL2
Bakke 1
Bakke 2
Bakke 3
Bakke 4
Bakke 5
Bakke 6
Bakke 7
Bakke 8
FLOW_R
FLOW_T
Maint.lim



Flow og bytte BRE ovn 5, Elektrode EL3
Bakke 1
Bakke 2
Bakke 3
Bakke 4
Bakke 5
Bakke 6
Bakke 7
Bakke 8
FLOW_R
FLOW_T
Maint.lim

RESULTS FROM MASTERSTUDENTS

Two master students worked on the dataset earlier this year.

- Main idea
  - Physics-based approach vs. Machine learning for PdM
- Both students only used data from furnace 1

Håvard: Physics-Based Perspective

Master's thesis

Håvard Holm Bjørnebekk

Modeling Degradation for Prognosis in a Complex Environment - From a Physics-Based Perspective

Master's thesis in Mechanical and Industrial Engineering
Supervisor: Jørn Vatn
Co-supervisor: Tom Ivar Pedersen

June 2021

TIP1

Hypothesis on failure mechanisms

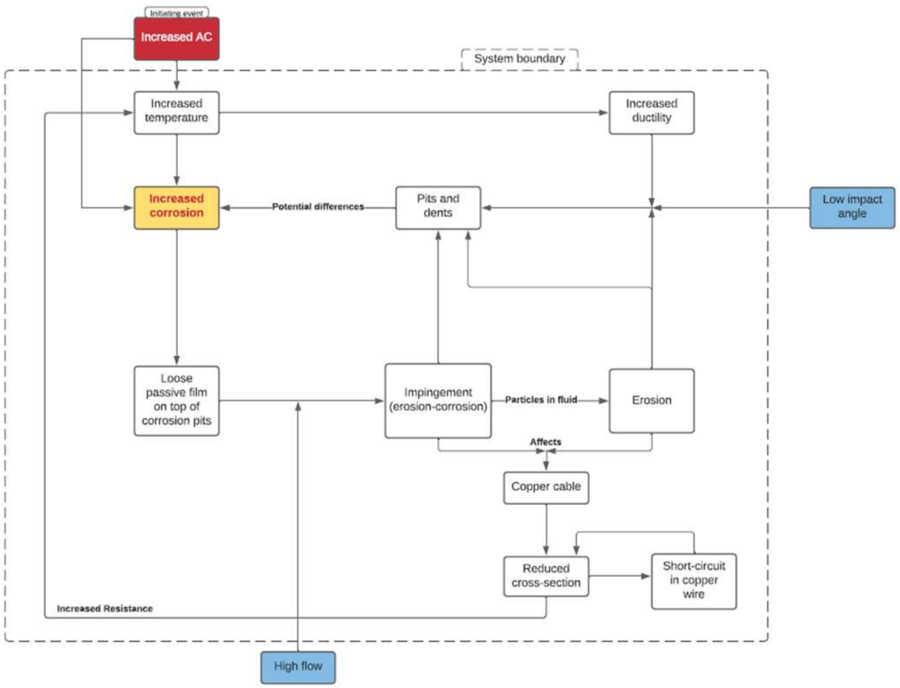


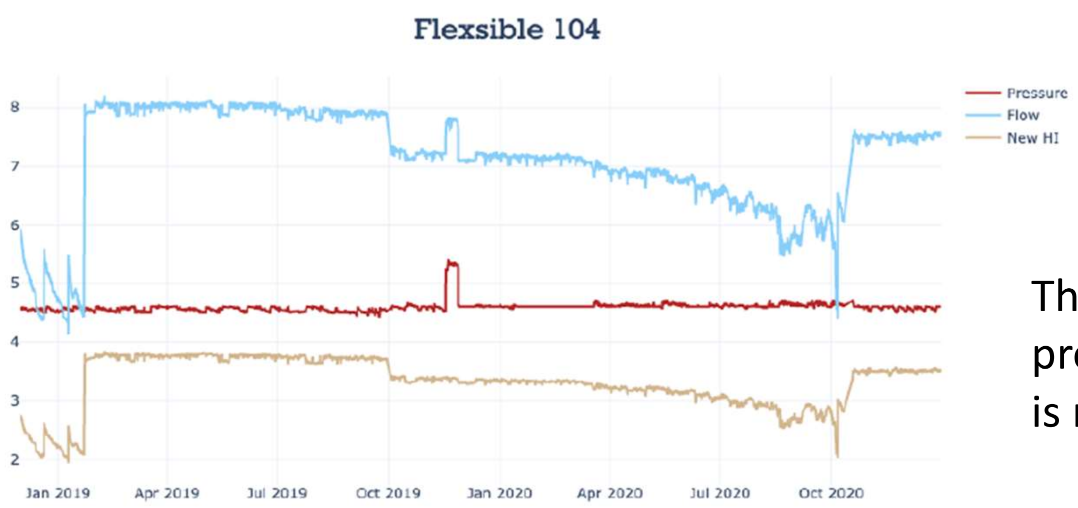
Figure 6.1: Flowchart of the hypothesized mechanism behind degrading flow.

"these findings were hard to translate into the available sensor measurements"

Slide 16

TIP1 Tom Ivar Pedersen, 11.11.2021

Constructing a new health indicator based on engeering first principles



$$HI = \frac{flow}{\sqrt{pressure}}$$

The new HI "get rid of large jumps in pressure, but the robustness of the HI is not found to improve"

Summary from Thesis

- Difficult to find literature on this specific degradation process.
  - "it was not found any physics-based model that could model the flexsibles to a sufficient degree."
- "An important finding is that equipment that seems to have rather explainable physical properties can seem to be a good case for physics-based models, but in reality, they are not. For instance, the flexsible are only made up of three parts. Still, their function relies on a much larger and complex process, which affects the interpretability of the connected sensor measurements."
- "Better understanding of the equipment's functions and physical properties can have business values on its own."
  - For instance, to remove the root cause of degradation!
- Don't have enough data (sensors) to develop physic-based models
  - Stochastic models might be appropriate.

Håkon:

RAMS
Reliability, Availability,
Maintainability, and Safety

Estimating Remaining Useful Lifetime using
Deep Learning on Water Cooled Power Cables

Håkon Grøtt Størdal

July 2021

MASTER THESIS
Department of Mechanical and Industrial Engineering
Norwegian University of Science and Technology

4 stages for Machinery prognostics:

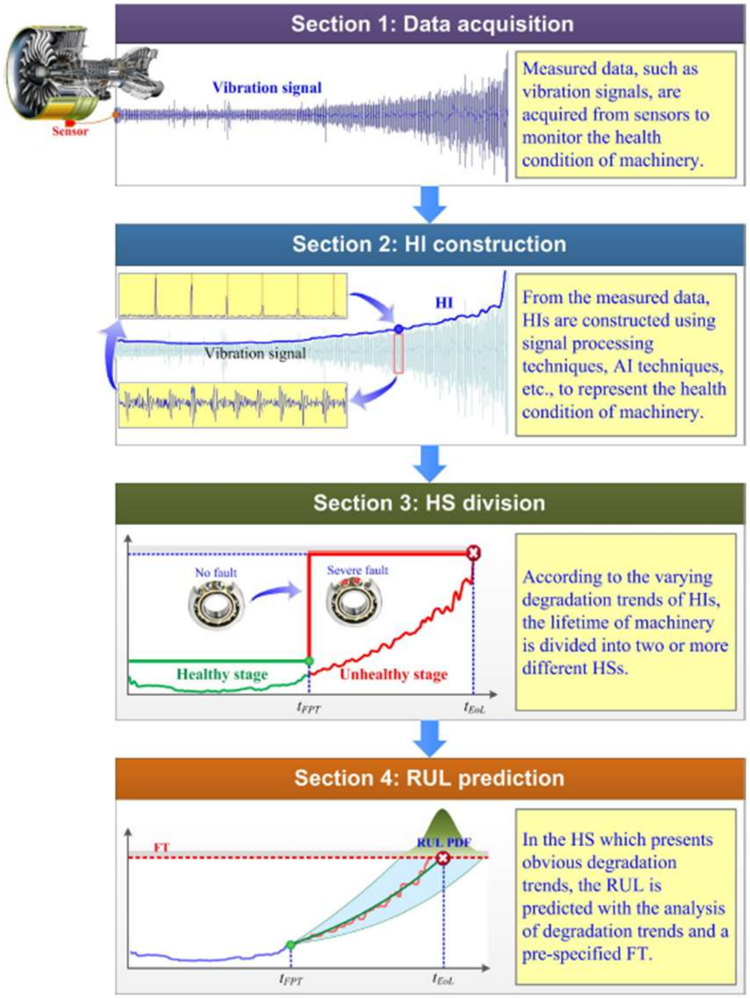


Figure 3.1: Overview of the stages in a prognostic program, given by [LEI, 2018]

Results

Results for 7 day prediction

Model	MSE
Feedforward 7 days	0.0545
LSTM 1 layer 7 days	0.0103
LSTM 4 layers 7 day	0.0123
Linear Regression 7 day	0.0388
LASSO Regression 7 days	0.0273
Random Forest 7 day	0.0246
Mean 7 days	0.709
Previous value 7 days	1.568

LSTM = Long Short-Term Memory
MSE = Mean Squared Error

4-layered LSTM model for 7 day ahead prediction (200 nodes)

Figure 6.4: Example of the predictions of the 4-layered LSTM model for 7 days ahead prediction, compared to the actual flow values. Illustrated on one of the degrading flexibles

Uncertainty based on dropout inference

Figure 6.6: Example of the same model shown in 6.4, but with the upper and lower limit of the calculated uncertainty by dropout inference.

"the uncertainty fluctuates heavily, (…) The reason for this is obscure, and it is difficult to assess the general confidence of the network for the test dataset"

Summary

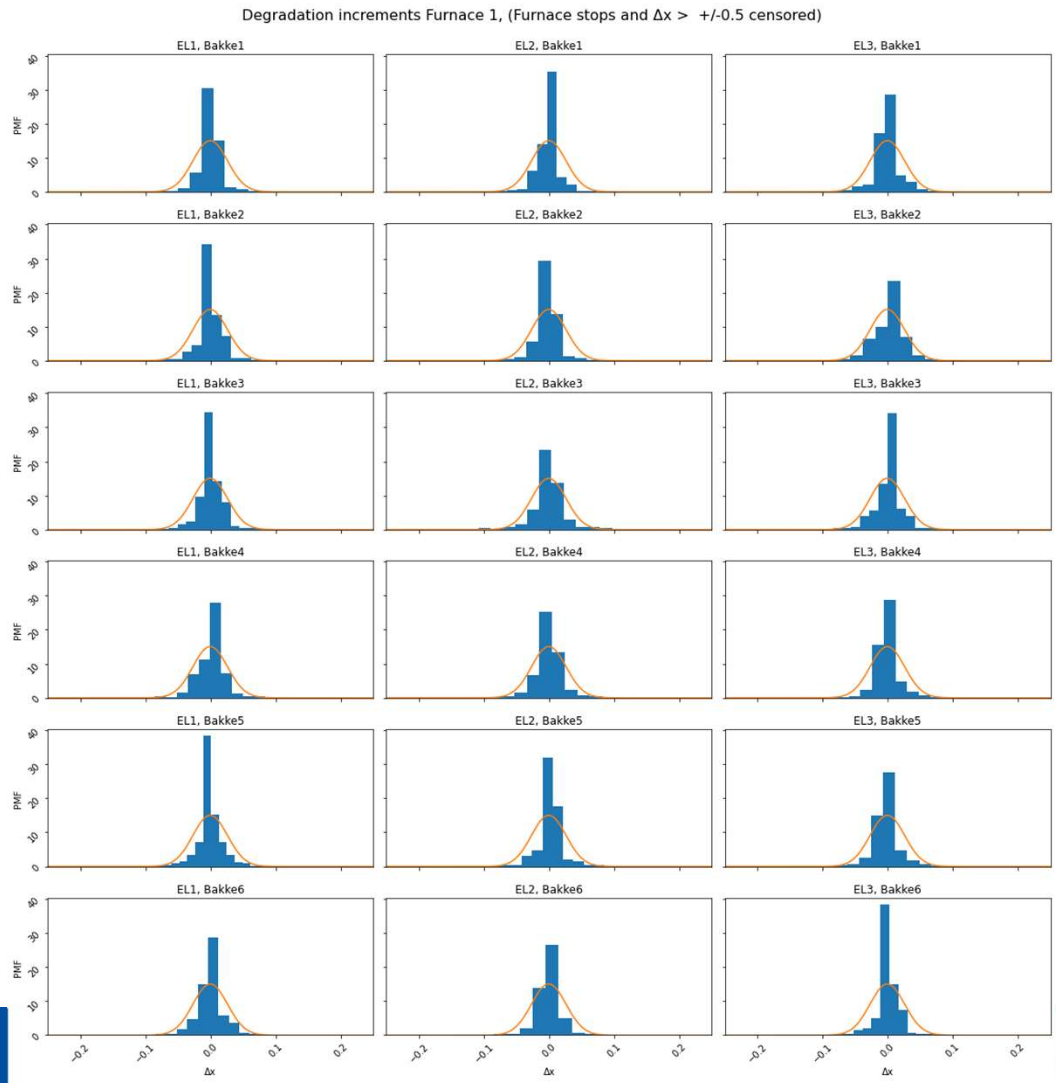
- “it is possible to model the *degrading* behavior of the flexible using data-driven approaches. Without the use of expert domain knowledge or applying physical laws, to the model.”
- “Further work with tuning hyperparameters, exploring alternative architectures or including more data is likely to improve the performance even further.”

IDEAS FOR USING THIS DATA FOR PAPER

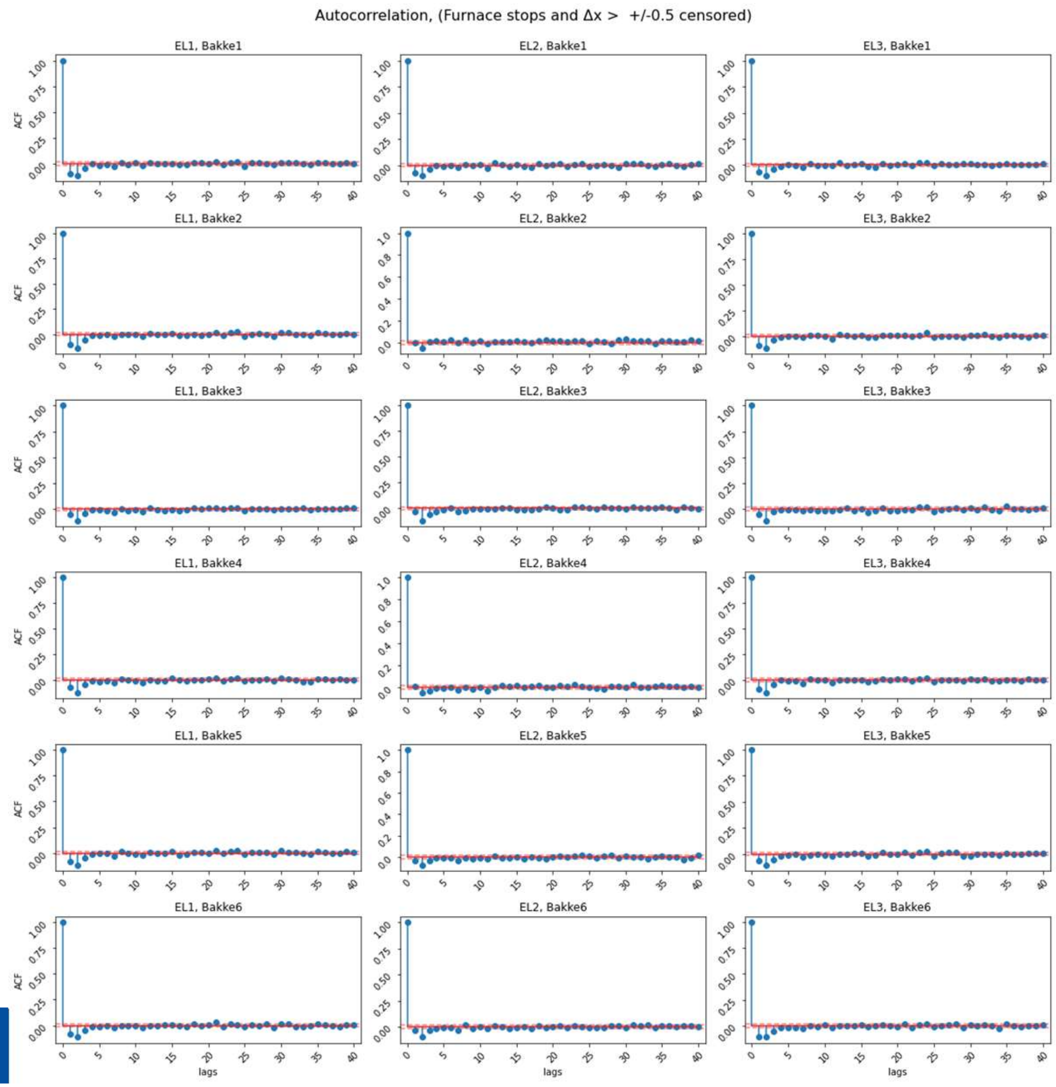
Ideas for using data

- Have started discussion with Xingheng for trying to use this data for paper on degradation modelling or maintenance optimization
- Plan to use data from furnace 1
- Model degradation as a stochastic process (Wiener process)

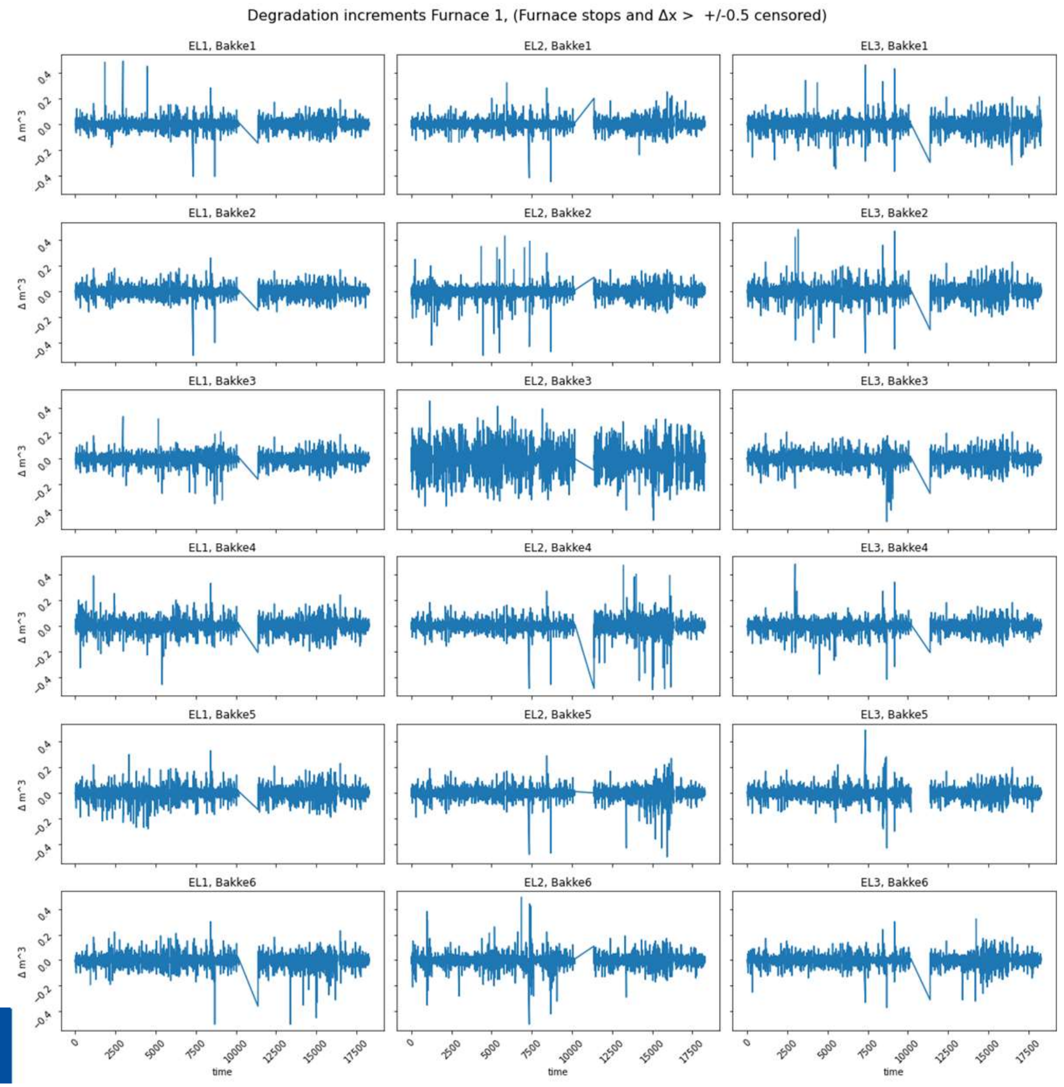
Degradation increments: Almost normally distributed



Degradation increments: Almost independent

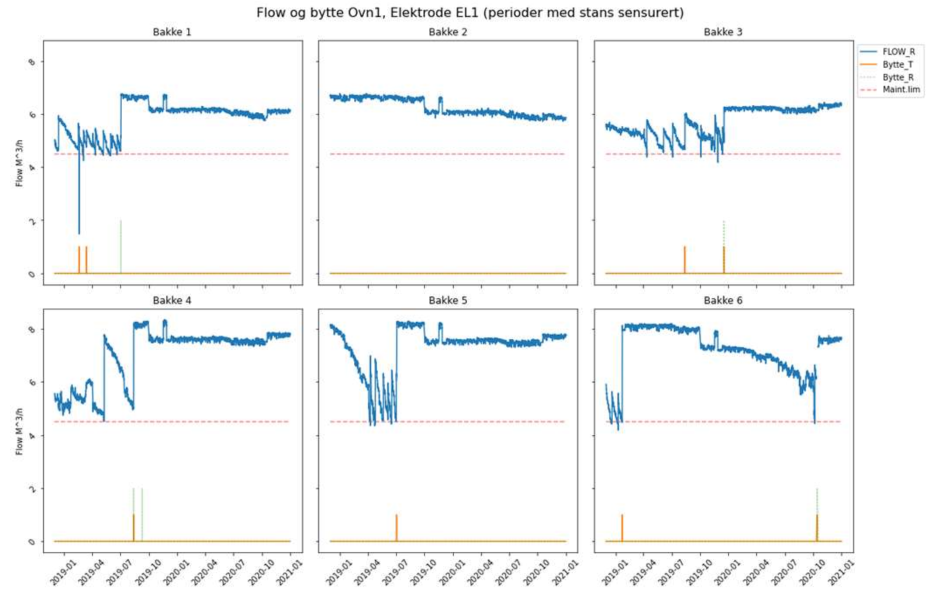


Some unit-to-unit variance?



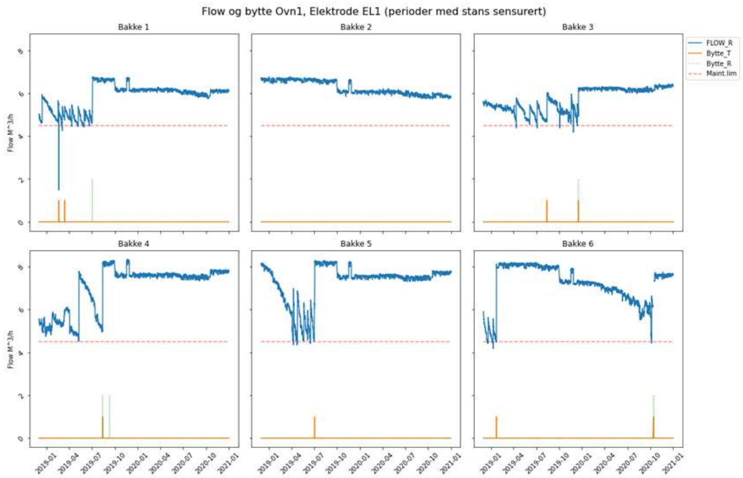
Optimization of maintenance policy with partial and perfect repair.

- Cost:
  - Cost of partial repair
  - Cost of renewal
  - Probability and cost of downtime
  - Planned production stops (maint. windows)
  - Degradation process



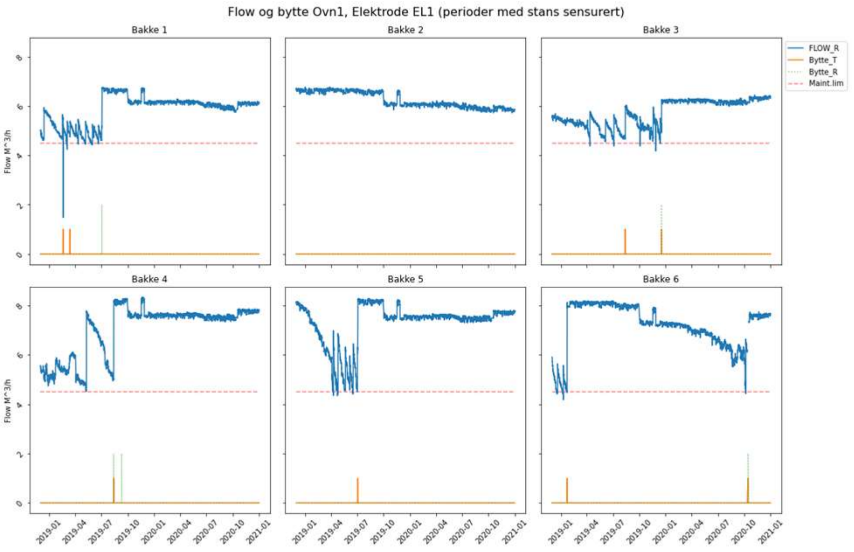
Important factors for optimization model

- Degradation process
  - What affects the rate of degradation?
    - time, cooling water flow, temperature, el.current, peaks of el. current, furnace position, type of cable, debris in cooling water, maintenance actions, no of partial repair, unit to unit variability …
  - Long term effect of partial repair?



Important factors for optimization model

- Number of flexibles that can be changes in one maintenance window?
  - Personnel
  - Spares
  - Location



Next steps

- Data exploration
  - (Plotting and PCA?)
- Remove noise (Kalman filter?)
- Find effect of partial repair
- Estimate costs
- Fit a simple Wiener model for RUL-prediction
- Build a simple MC sim for maintenance optimization

Questions or comments?