Calendar and cycling ageing combination of batteries in electric vehicles

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Outline

1. Introduction

2. Accelerated Ageing Tests

3. Analysis of results

4. Conclusion

Introduction

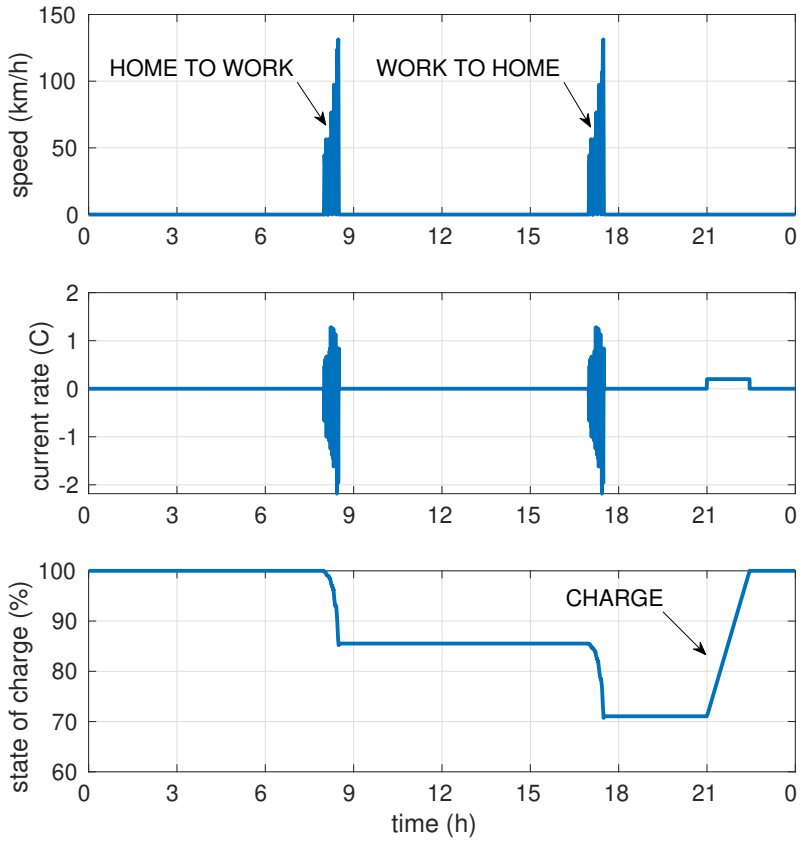
- Electric vehicles
  - Climate change and local pollution
  - Higher energy efficiency
  - Can help renewables development (smart grid)
  - Battery is the limiting factor: cost, lifetime $\Rightarrow$ limited EV range
- Battery degradation
  - Relies on ageing mechanisms (physico-chemical reactions)
  - Calendar ageing: degradation during rest time
  - Cycling ageing: degradation (directly) induced by charges and discharges
- Accelerated ageing tests
  - What is the lifetime of a battery for a given application?
  - How to optimise sizing and energy management of a battery pack for a longer life?

  $\Rightarrow$ Get an answer to these questions in a short time!

Accelerated Ageing Tests

Electric vehicle use profile

- Domestic use
  - Small electric car
  - Battery pack: 16kWh (320V x 50Ah)
- Daily trip (home-work-home)
  - example: WLTC (single trip)
  - 30 minutes
  - 23 km



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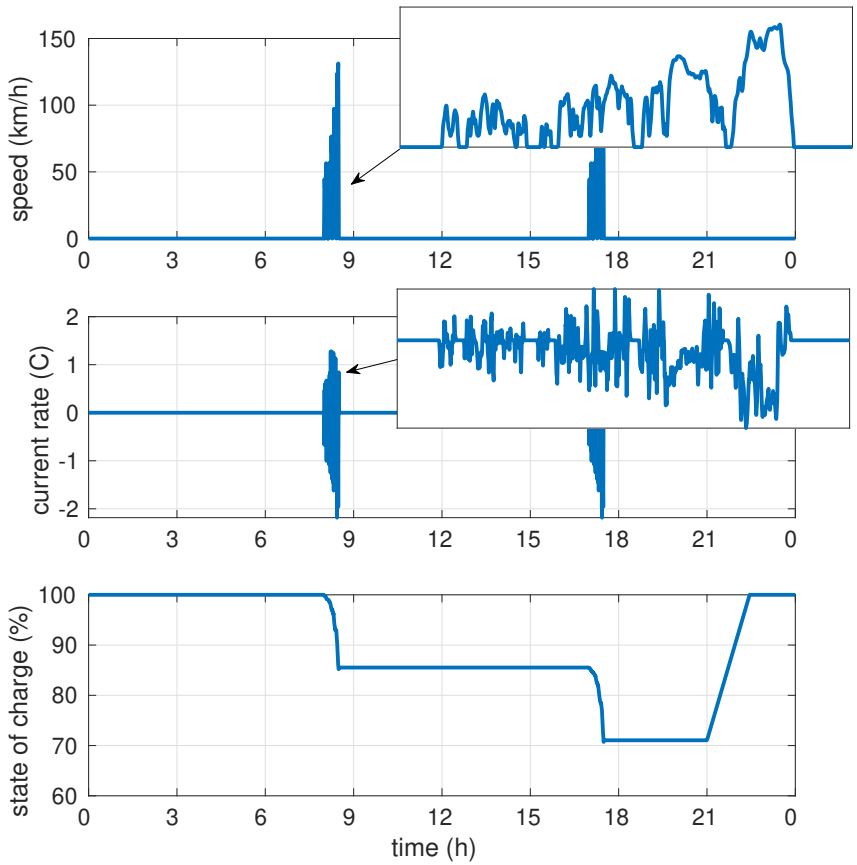
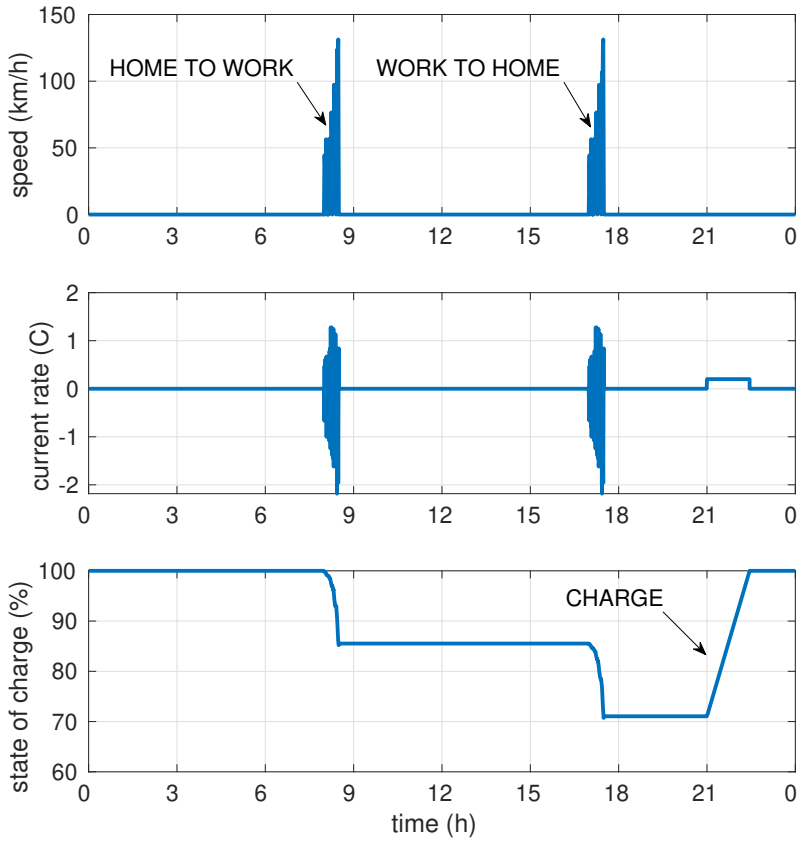


Accelerated Ageing Tests

Electric vehicle use profile

- Battery use
  - during each trip
    - $\Delta SoC \sim 15\%$
    - $I_{max} = 2C, I_{avg} = C/3$
    - $duration \sim 0.5 hours$
  - charge
    - $\Delta SoC \sim 30\%$
    - $I_{cst} = C/5$
    - $duration \sim 1.5 hours$
  - rest periods
    - $I = 0$
    - ~ 21.5 *hours a day*



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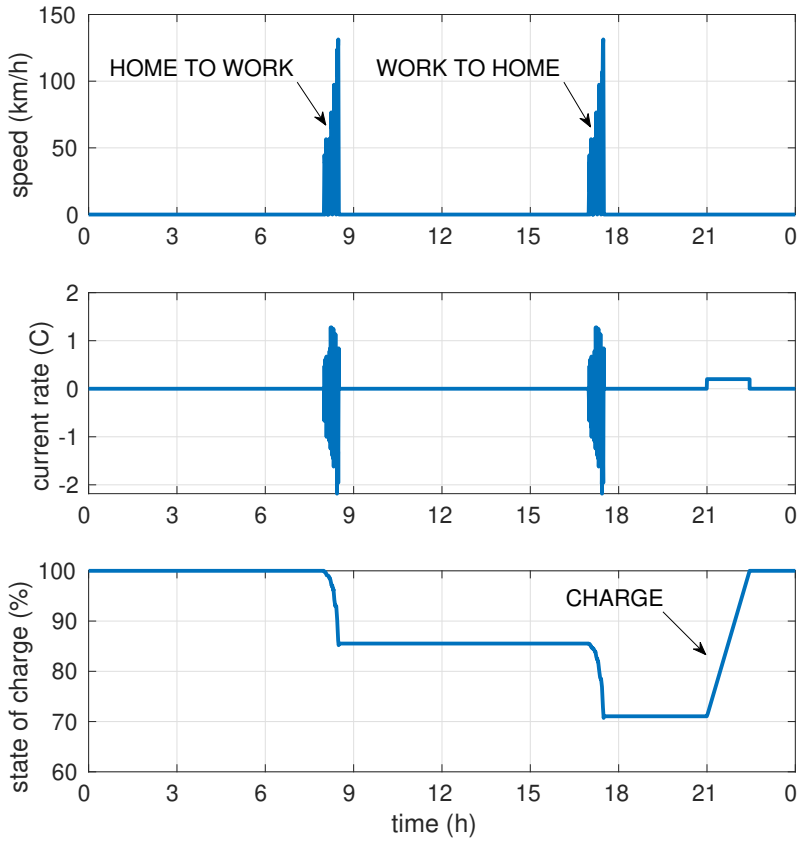

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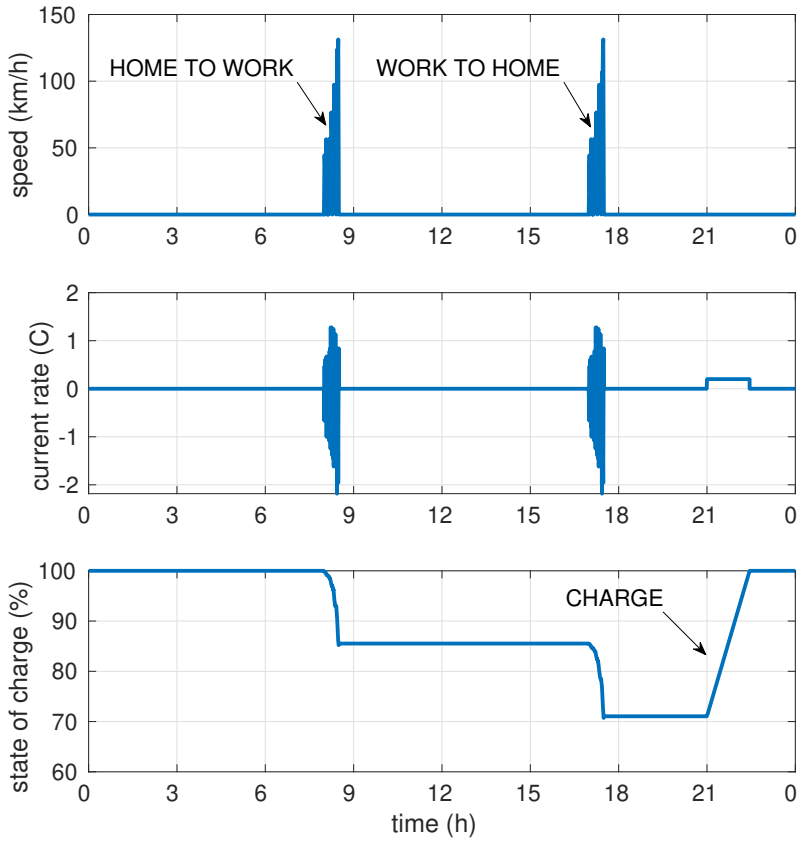

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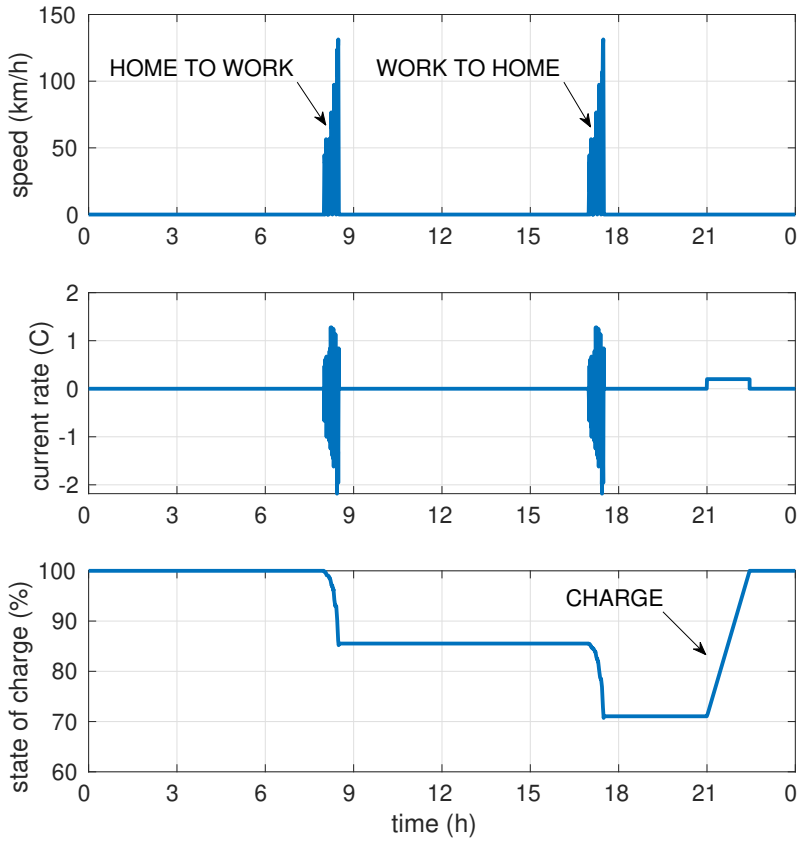

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- Are both ageing modes arithmetically cumulative?
  - Combined ageing $\simeq$ Calendar ageing + Cycling ageing ?

Accelerated Ageing Tests

Experimental setup

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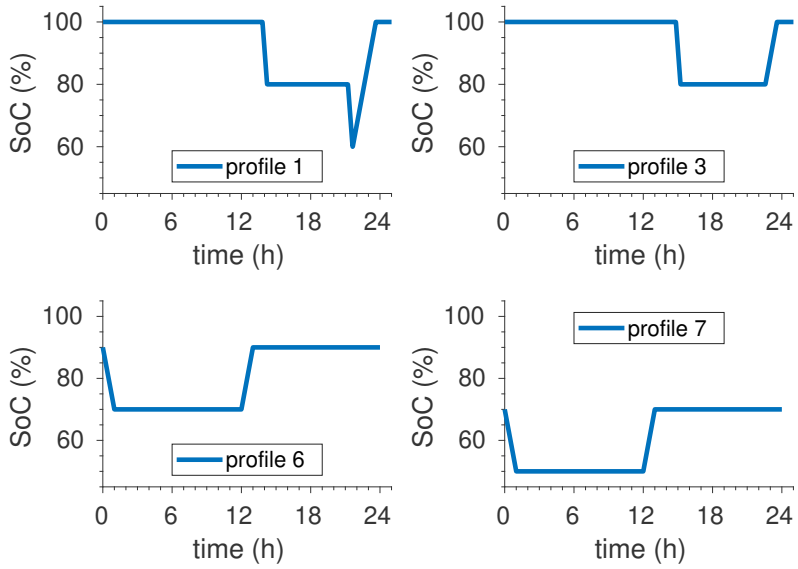

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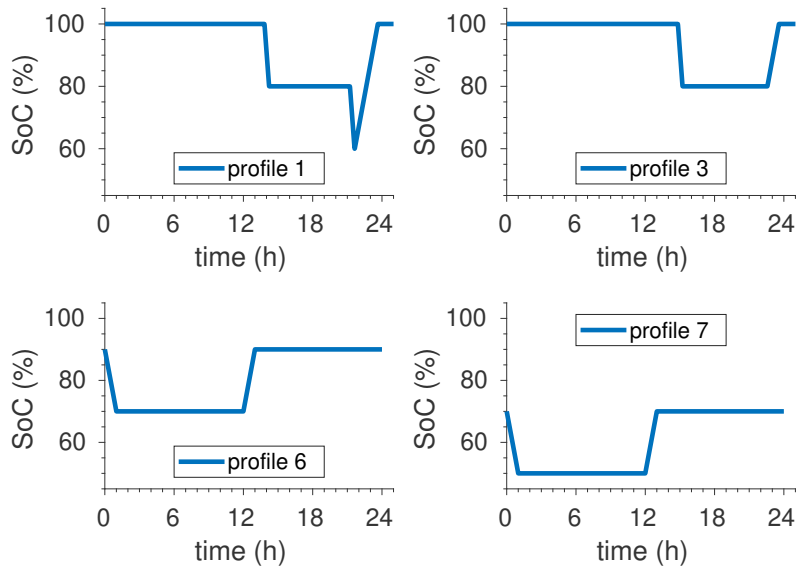


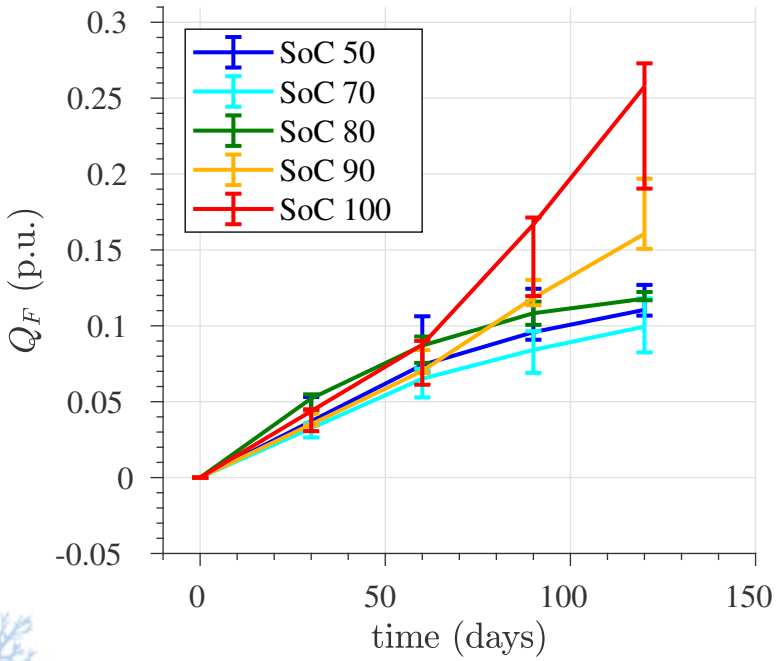
- For all ageing tests (cycling + calendar)
  - T = 60°C
  - 3 cells for each ageing condition (15 cells in calendar ageing, 21 cells in cycling ageing)
  - capacity measurements every month

Accelerated Ageing Tests

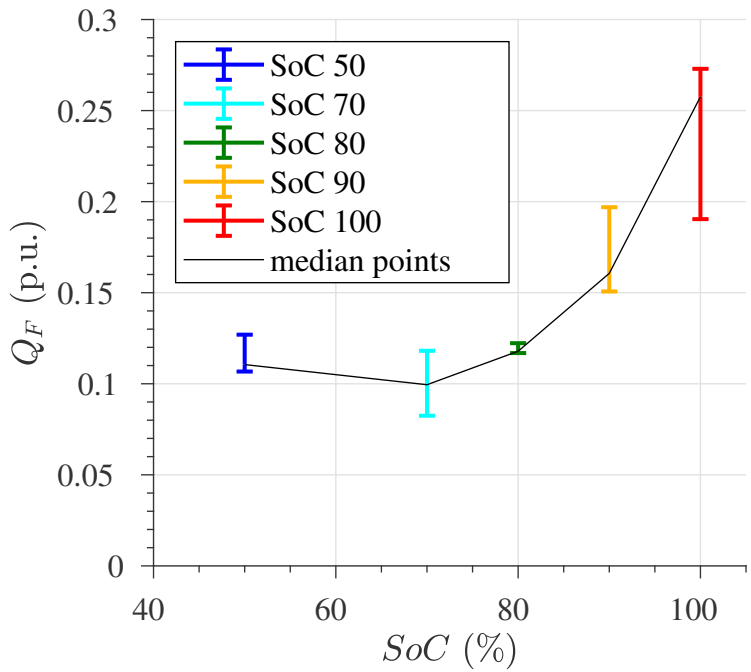
Results

Calendar ageing

- vs. time:



- vs. SoC (120 days):

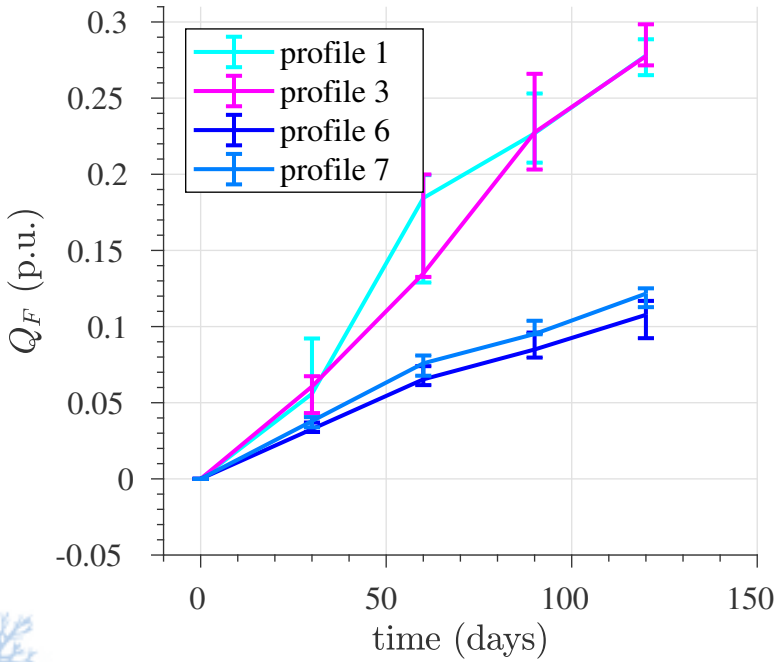


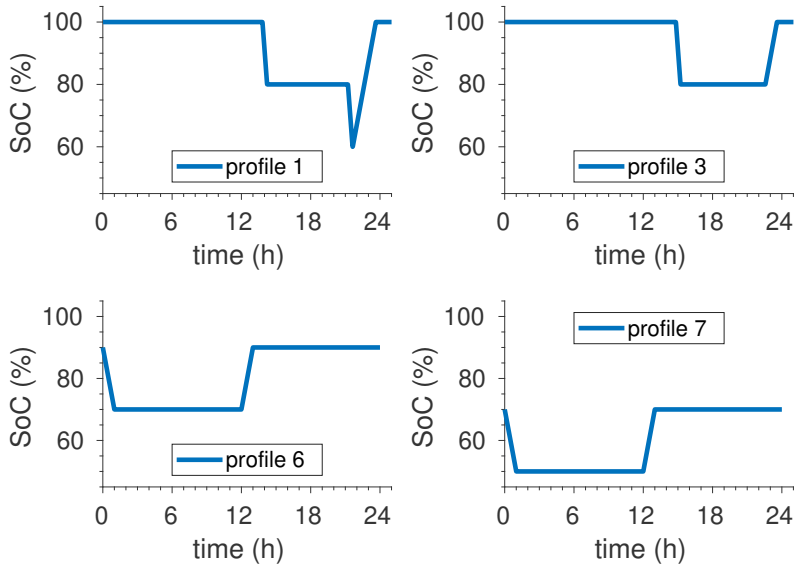
very non linear with SoC

Accelerated Ageing Tests

Results

Cycling ageing





faster degradations when charging to 100%

Analysis of results

How to separate calendar and cycling parts of ageing?

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$$Q_F = Q_{F,\,cal} + Q_{F,\,cyc}$$

- Q_F: Total capacity fade
- $Q_{F,\,cal}$: Capacity fade due to **calendar ageing**
- $Q_{F,\,cyc}$: Capacity fade caused by **cycling**

Analysis of results

Cumulative damage approach

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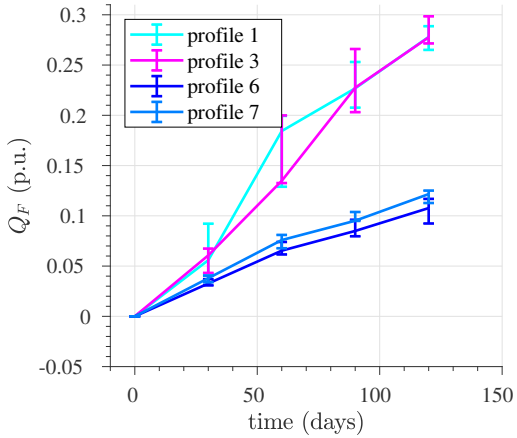
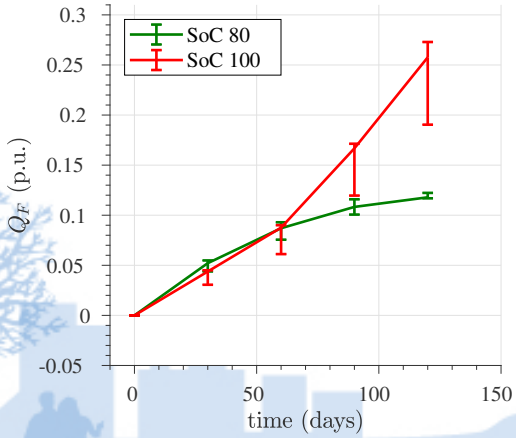
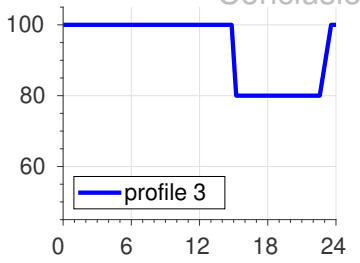


Example: profile 3

Calendar tests:





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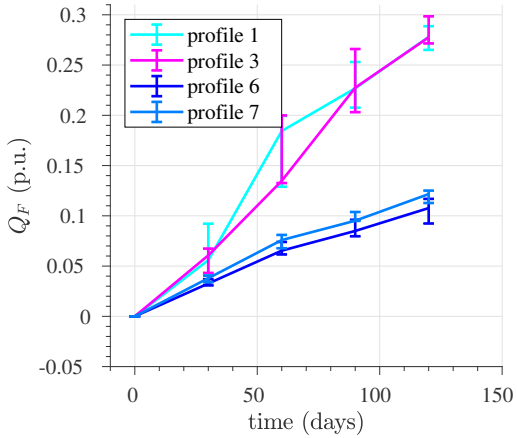

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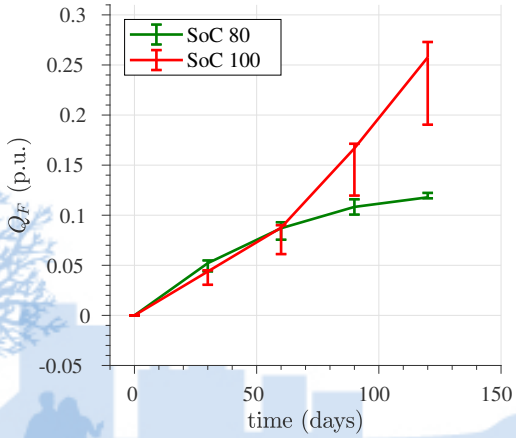

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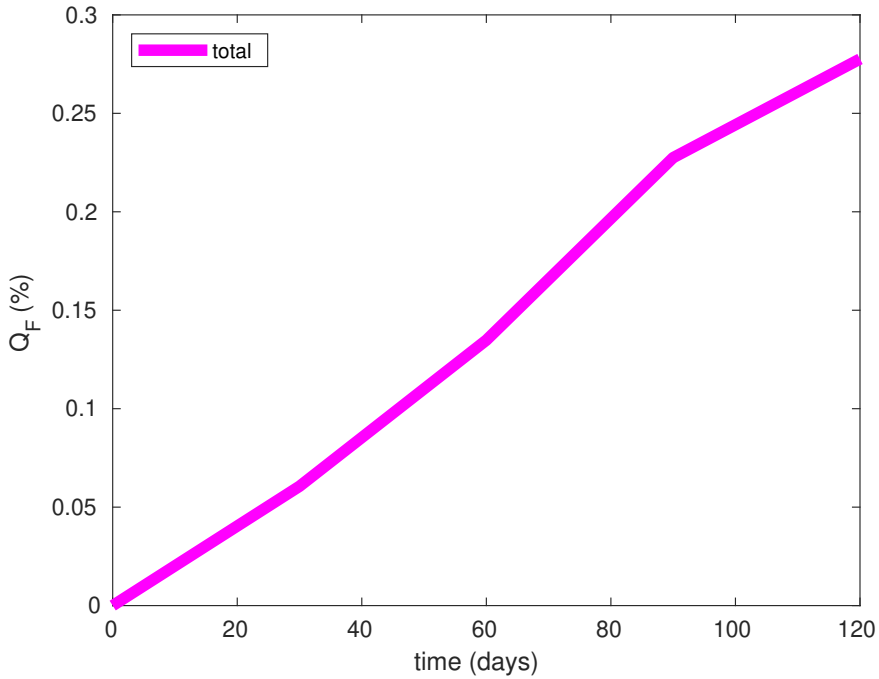

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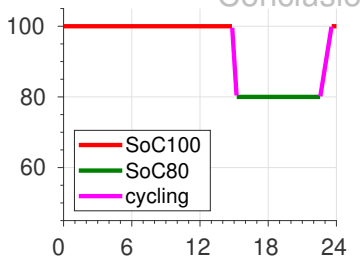

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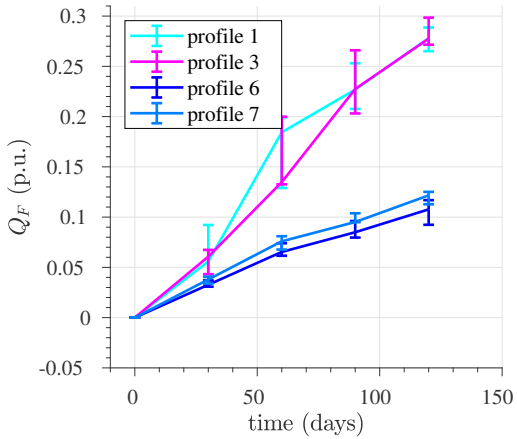

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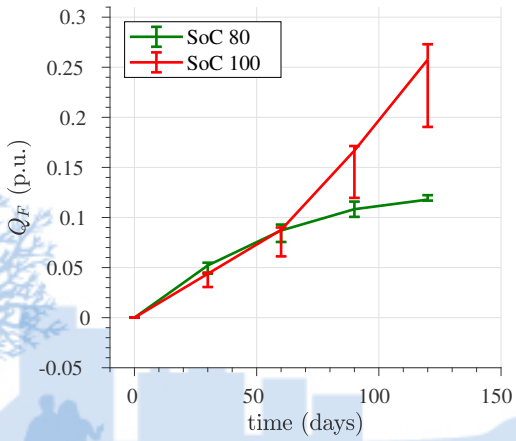

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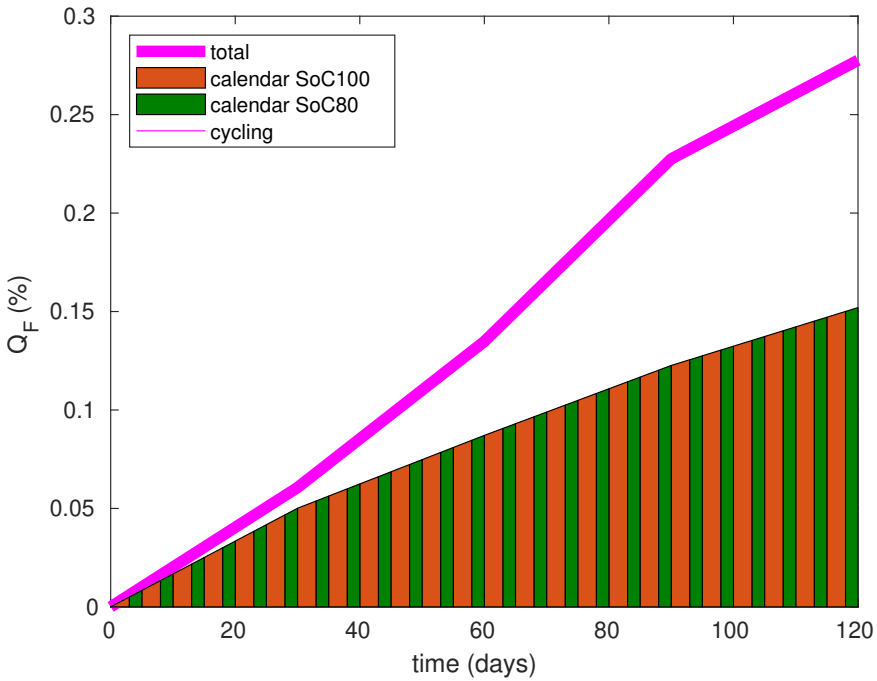

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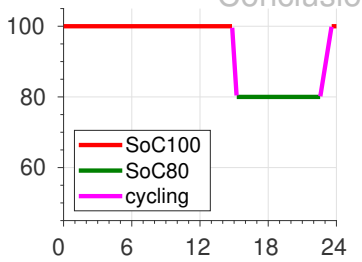
2. $Q_{F,\,cal}$: from calendar ageing tests



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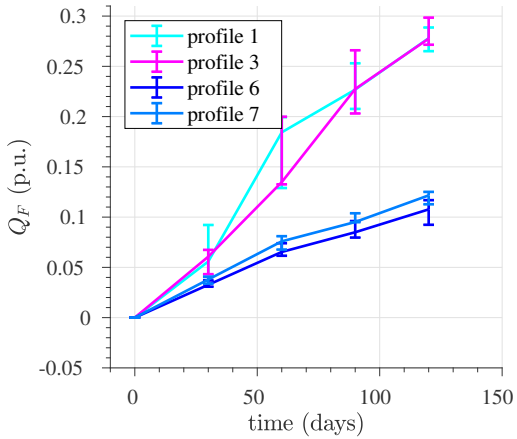

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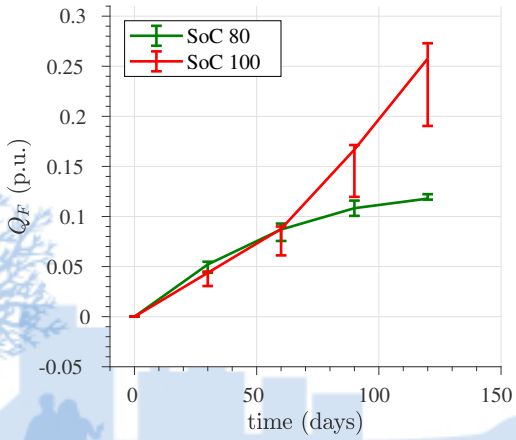

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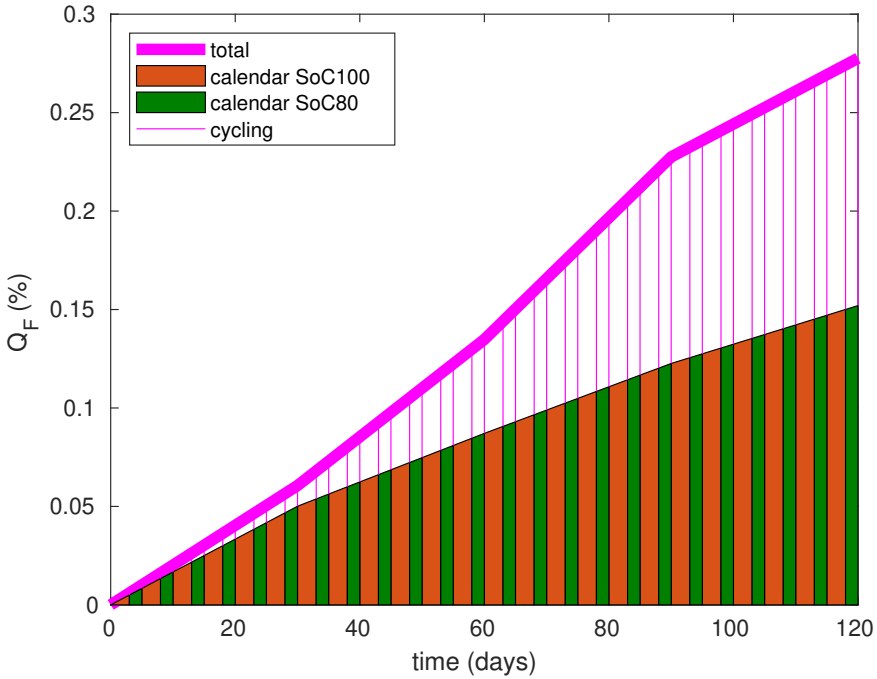

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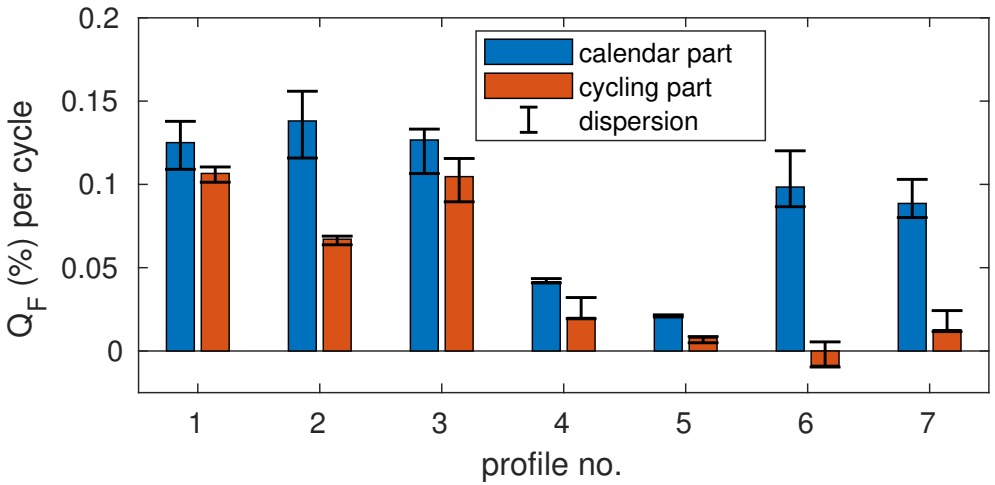
Analysis of results

Calendar and cycling parts of ageing

Capacity fade per cycle:



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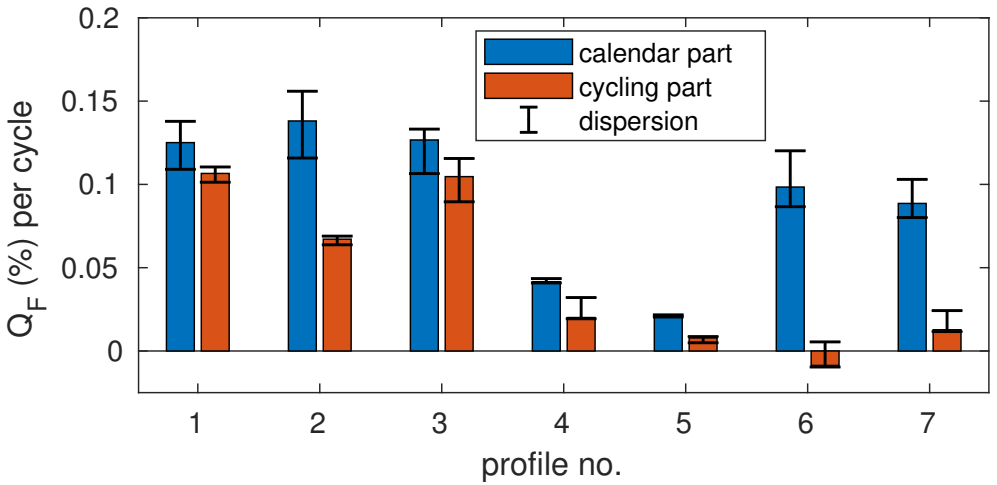

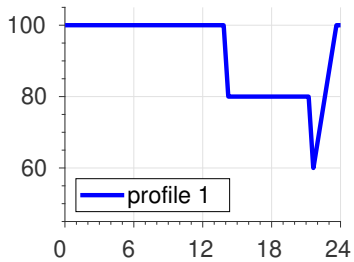

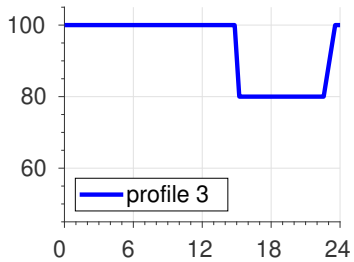

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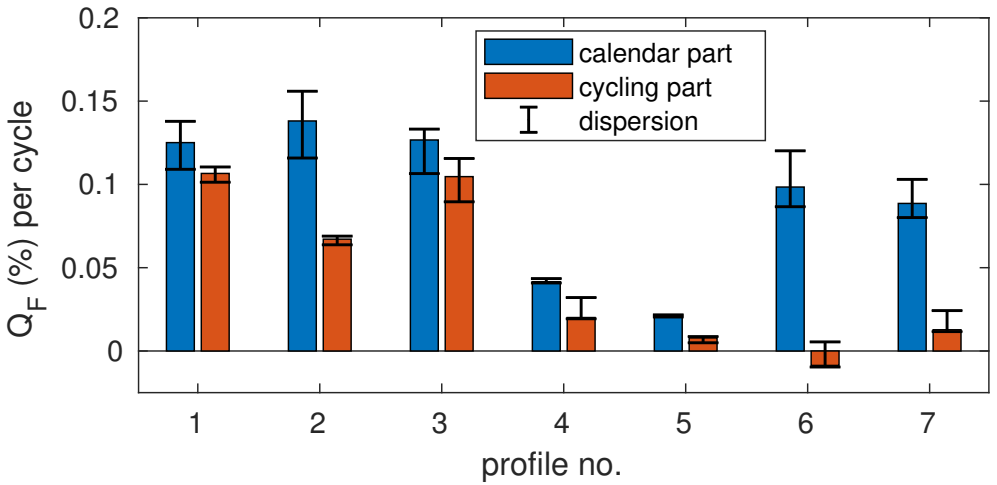

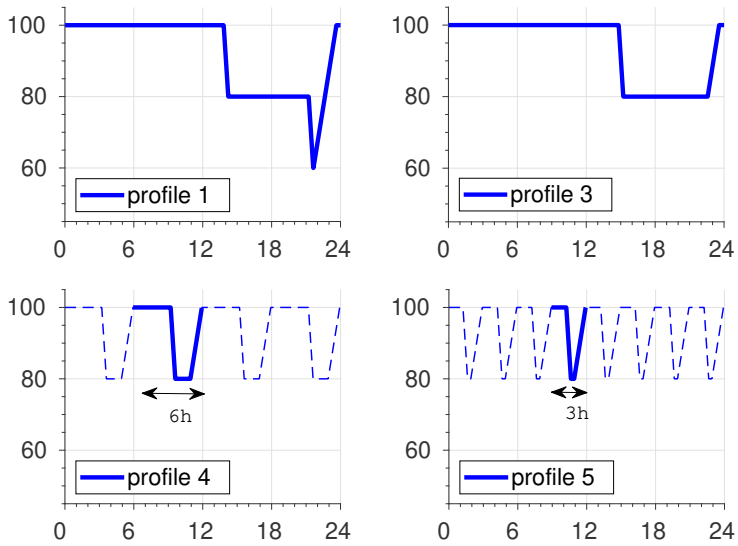

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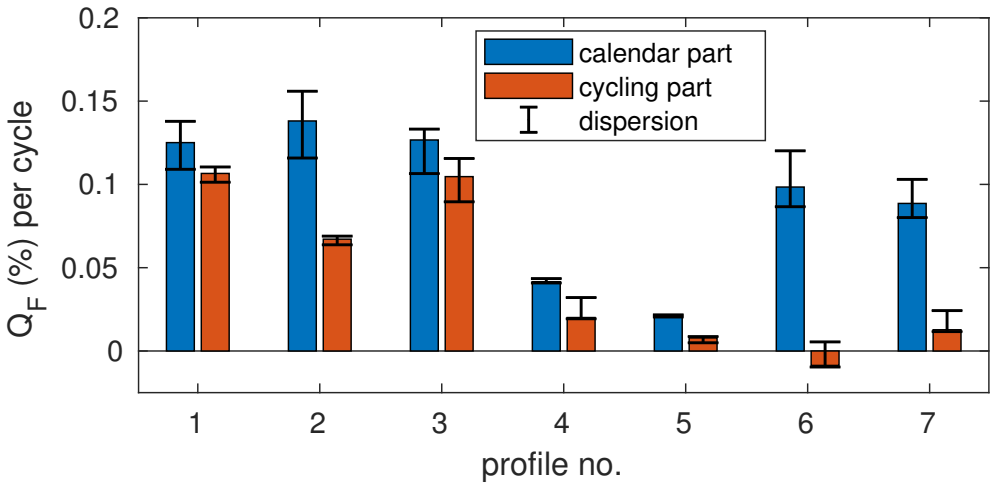

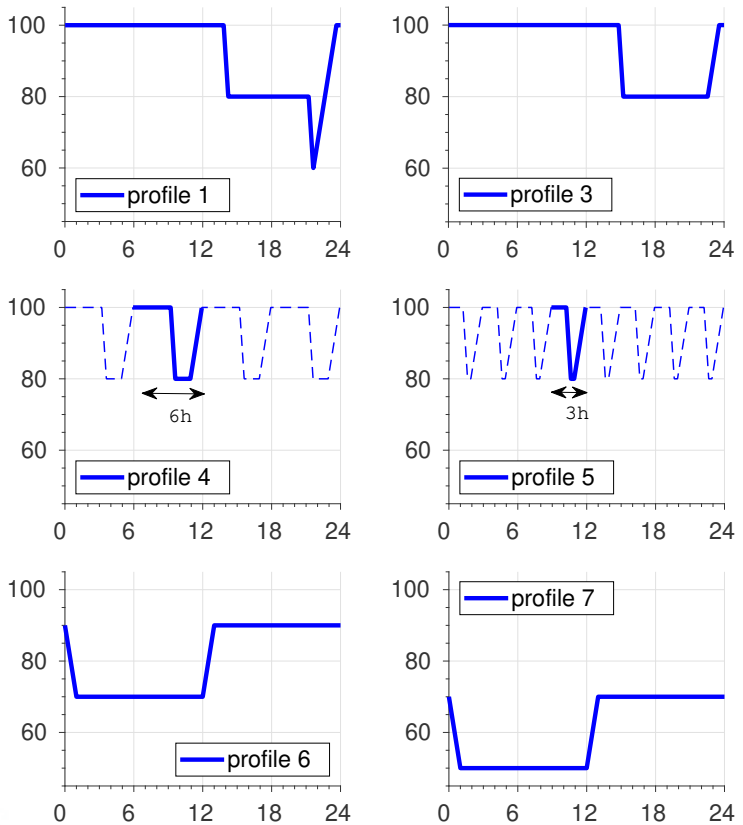

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- Profiles 6 and 7: lower SoCs $\Rightarrow Q_{F,cyc} \simeq 0$

Conclusions:

- Electric vehicle application
  - not continuous cycling (calendar and cycling combination)
  - very low current rates
- Calendar ageing is very non linear respect to SoC
- **Cycling ageing** combined to calendar ageing **may accelerate degradation**
  - very significant at full charges (100%)
  - less influence when charging at lower SoC levels (90, 70%)
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Further work:

- Incremental capacity analyses (ageing mechanisms)
- Empirical degradation model (single or multiple ageing mechanism)
- Validation tests

Thank you for your attention
Any questions?

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Ampère

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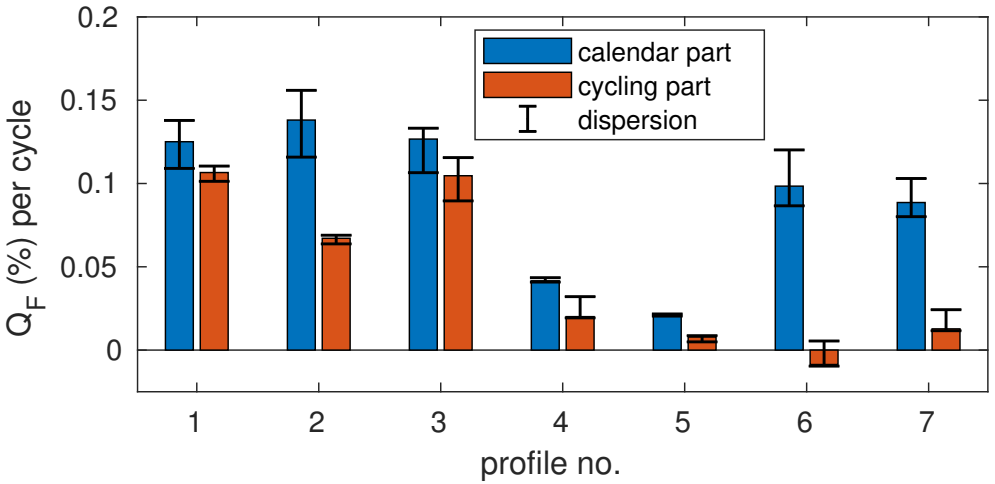
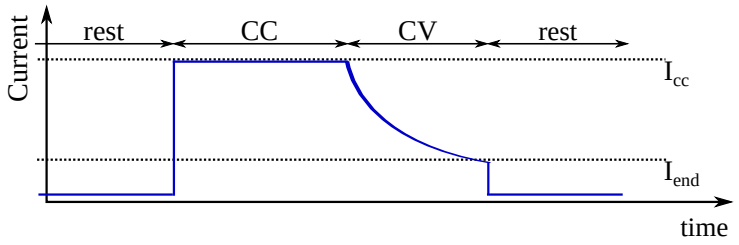
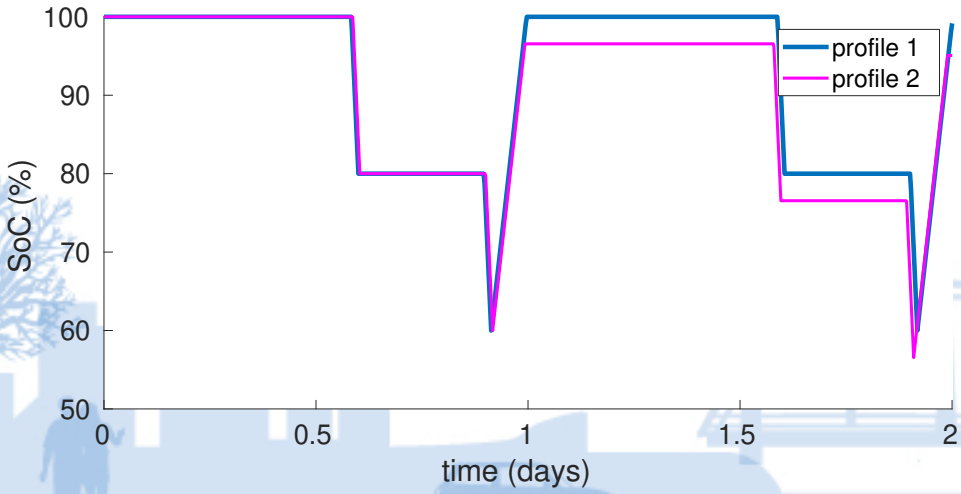
Calendar and cycling parts of ageing (profile 1 vs. 2)



CCCV charge protocol:



- Profile 2 is like profile 1 but:
  - final charge with CC 6 days/week
  - final charge with CCCV 1 day/week



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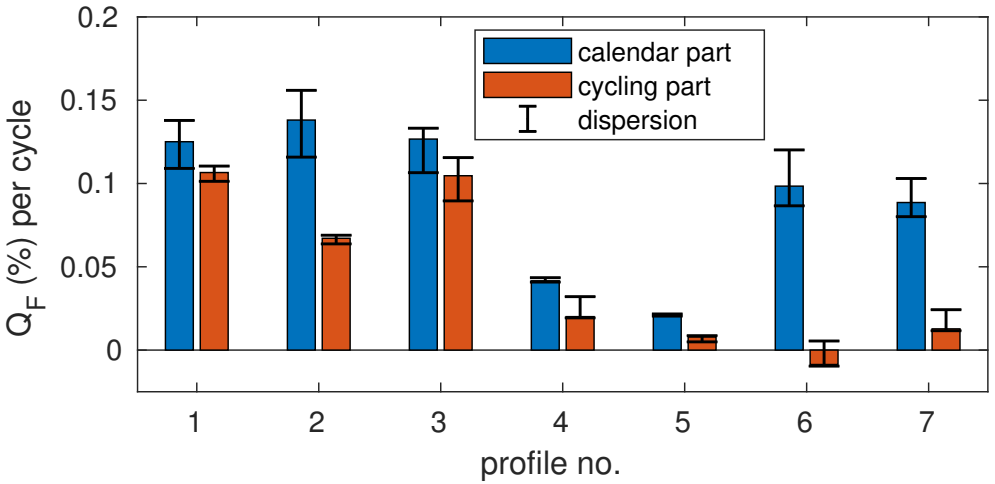

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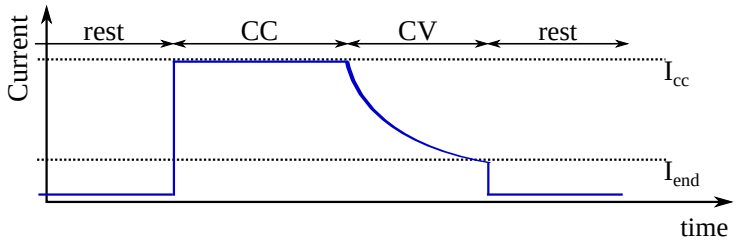

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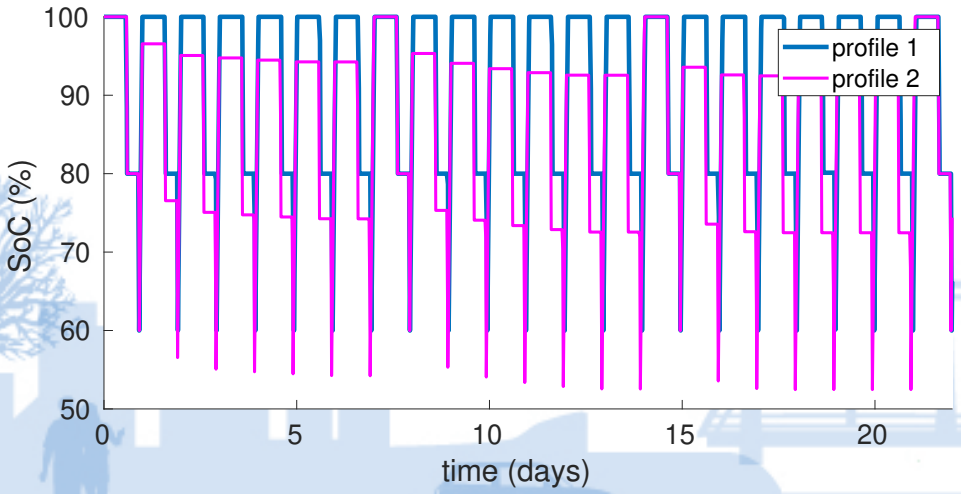
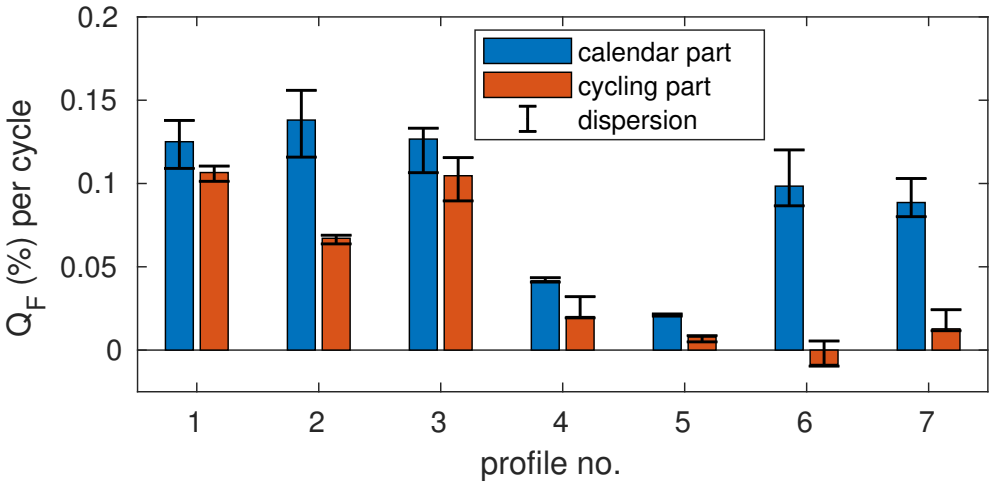
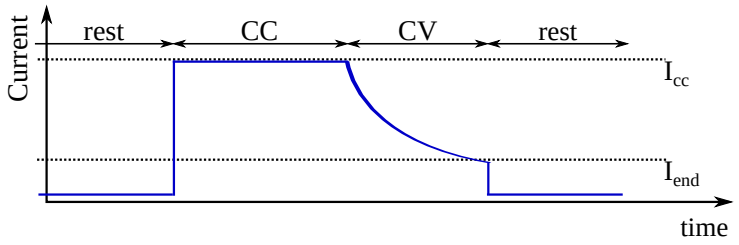
  - final charge with CC 6 days/week
  - final charge with CCCV 1 day/week



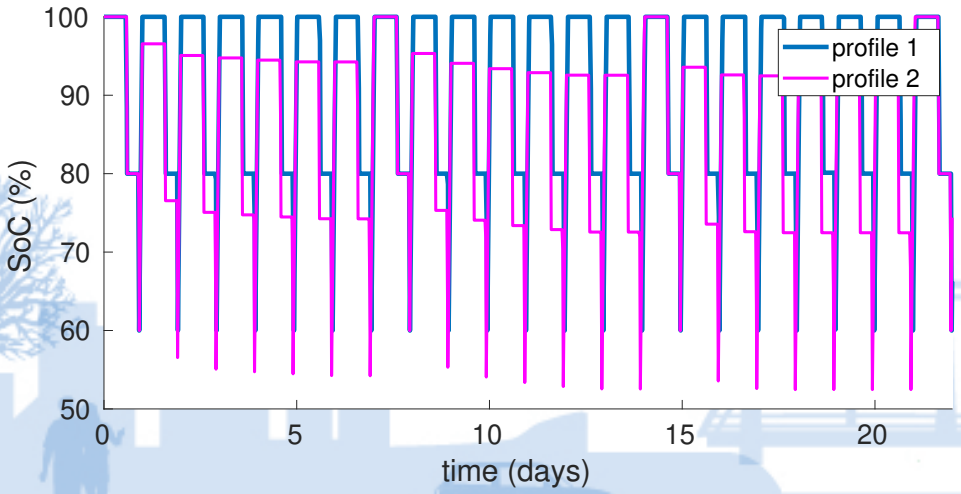
Calendar and cycling parts of ageing (profile 1 vs. 2)



CCCV charge protocol:



- Profile 2 is like profile 1 but:
  - final charge with CC 6 days/week
  - final charge with CCCV 1 day/week



Profile 1 vs. profile 2:

more CV phases $\Rightarrow Q_{F,cyc} \uparrow$