Optimizing Fault Injection in FMI Co-Simulation through Sensitivity Partitioning

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Outline

- Introduction
  - Context and fault injection
- Power window use case
  - Model and specifications
- Co-simulation
- Technique
  - Interval partitioning and sensitivity analysis
- Simulation
- Summary and next steps

Introduction

Cyber-Physical System (CPS)

- Increasing complexity
- Increasing application

Error prone and critical

- Test and simulate system

Introduction

Why?

- Understand system behavioral
- Safety
- Robustness
- Detect failure mode and errors
- Repaired

Fault Injection

What?

Testing method which aids in understanding how
[virtual/real] system behaves when stressed in unusual ways

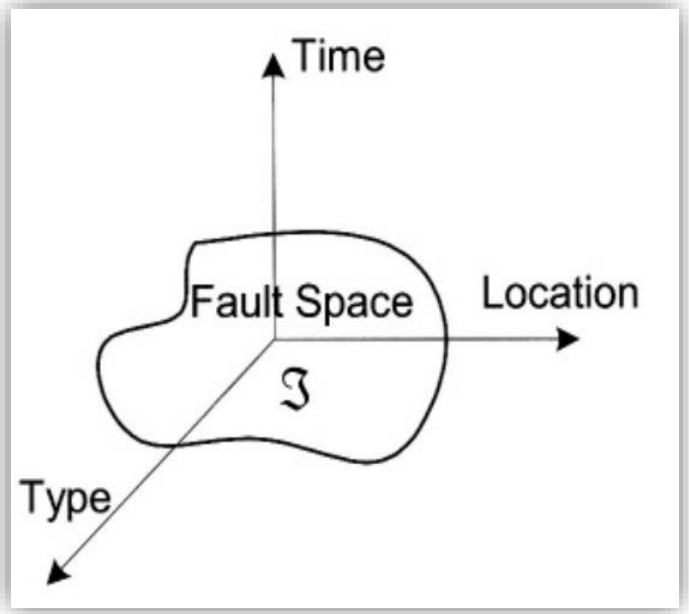
Fault injection

How?

- In the level of model
- Library of faults considering fault's nature
  - latency
  - Stuck to value

Research problem

- Faults are uncertain
- Limit fault space
  - Using sensitivity analysis
-



Benso, A. and Prinetto, P. eds., 2003. Fault injection techniques and tools for embedded systems reliability evaluation (Vol. 23). Springer Science & Business Media.

Motivating example

Power window

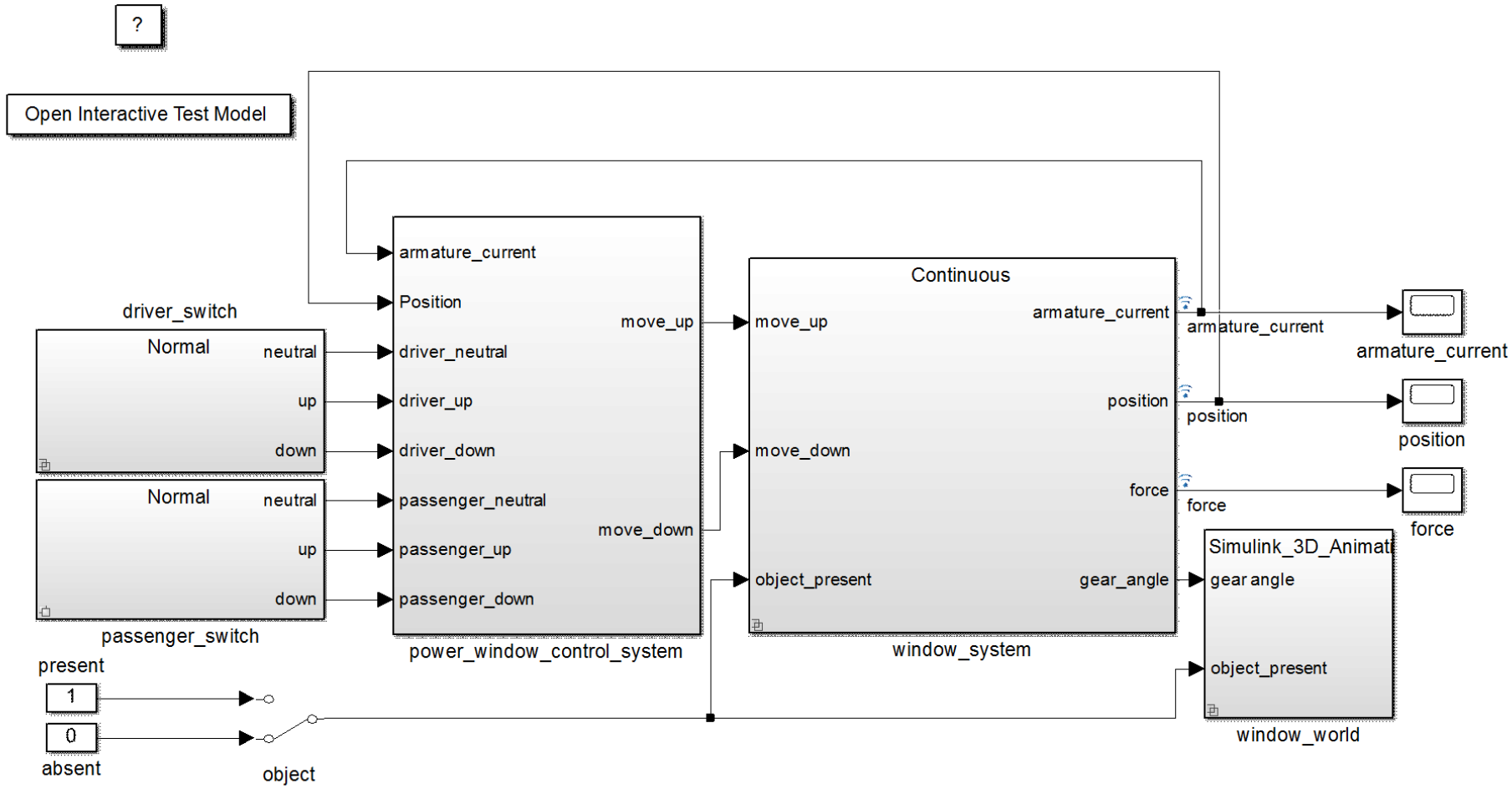
- Hybrid system

Specifications:

1. Fully opened/closed within 4s
2. Force to detect when an object is present should be less than 100 [N]

Safety-critical system due to possibility of object being crushed

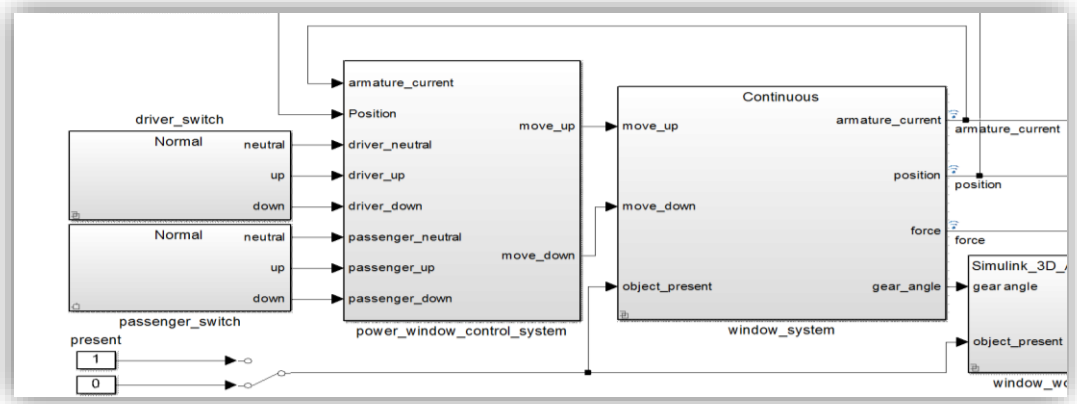
Motivating example - Structure



https://www.mathworks.com/help/simulink/ug/power-window-example-case-study.html

Motivating example – Normal behavior

Holding the up switch



Specifications:

1. Fully opened/closed within 4s
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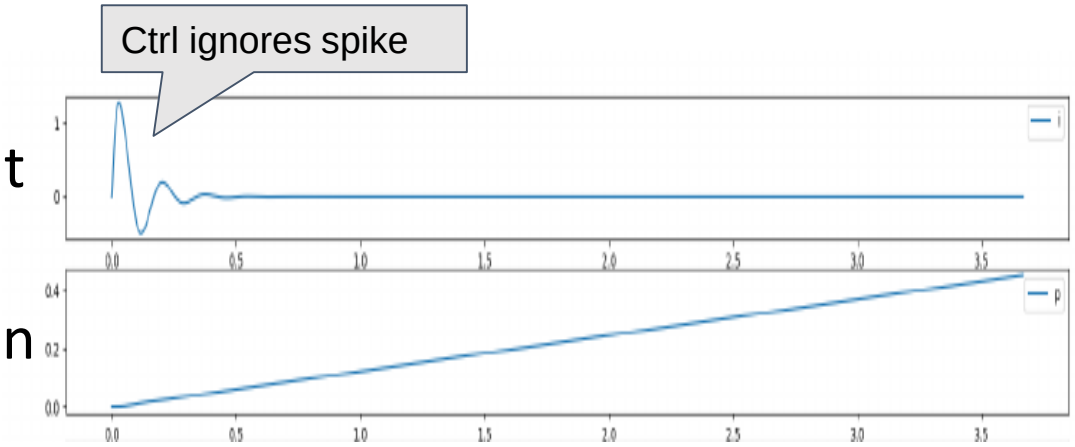
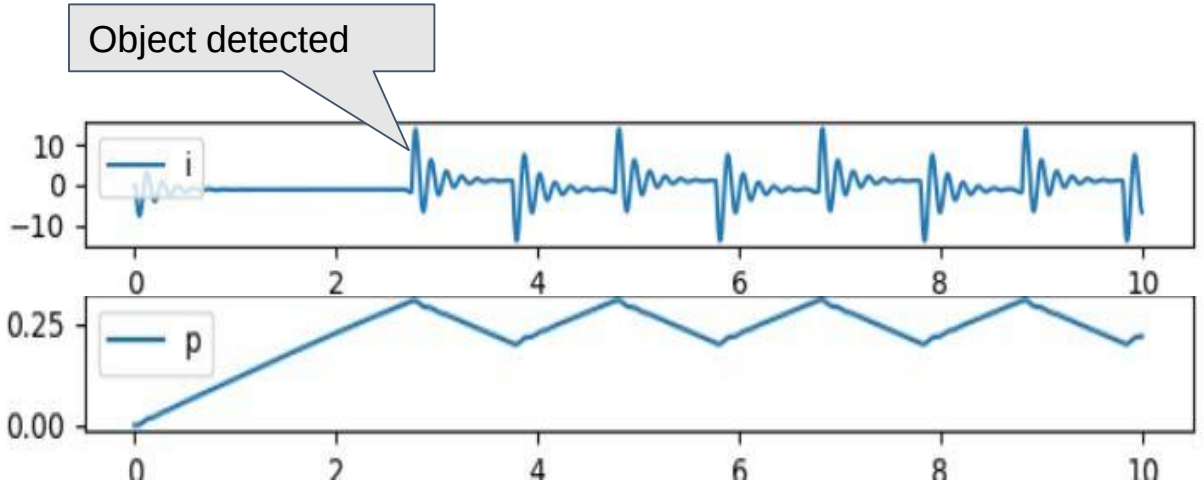
Current

Position



Without Object



With Object

Motivating Example – Fault

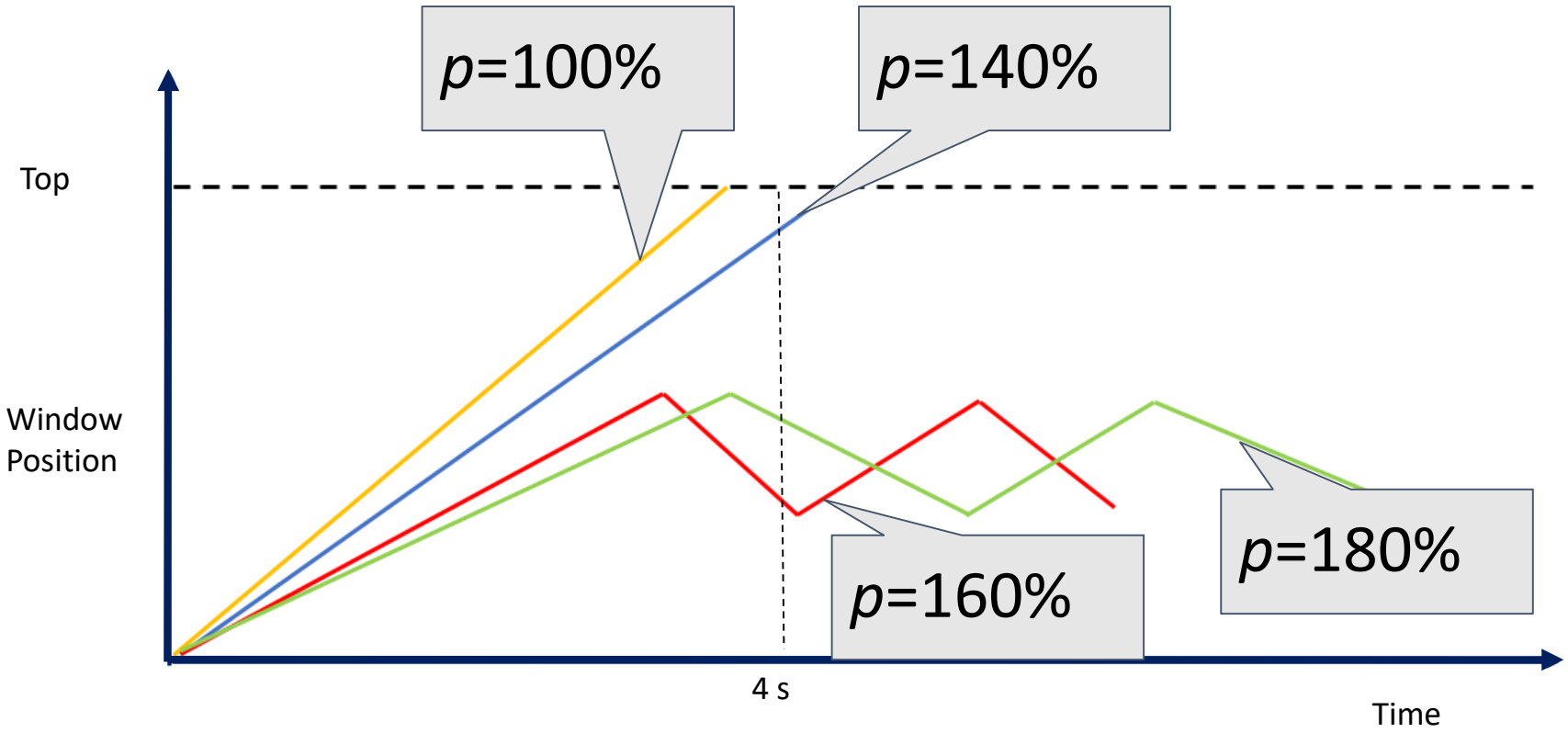
A power window is affected when the rubber slips into the window

Uncertainty in: when the rubber falls; and how much friction there is.

Example fault - Rubber friction

Friction parameter *p* is in [100%, 200%]

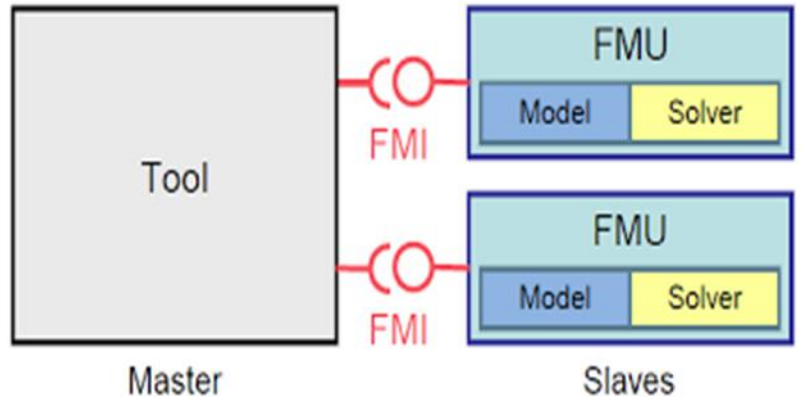
Different values of *p* lead to different behaviors of the window



Co-simulation

https://fmi-standard.org/

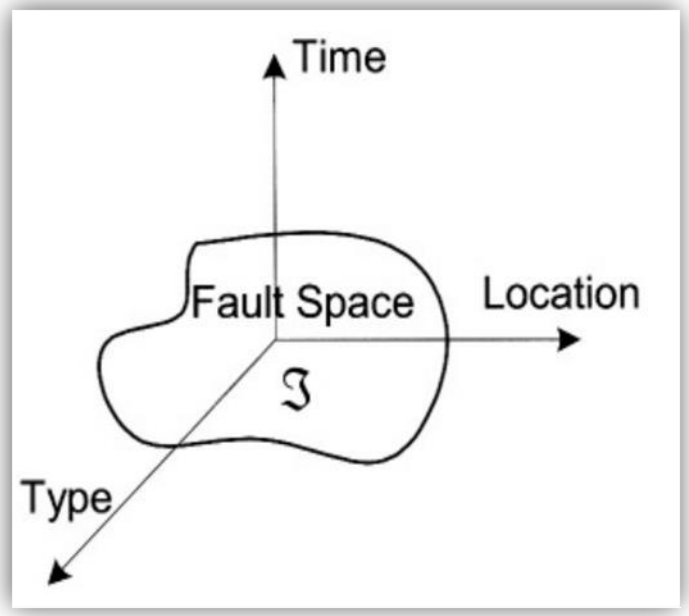
Co-simulation - defined in Functional Mock-up Interface (FMI)



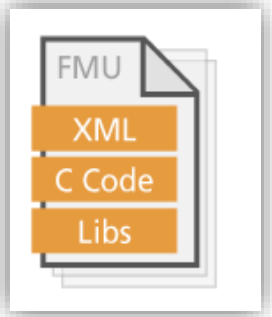
- Heterogeneous system
- High level of fidelity
- Free from IP concerns
- Increasing standardization and adoption by industry

Research problem in the fault injection

- Given a co-simulation, a library of faults, and system specifications
- Provide user with an **intuition** about how the fault parameters affect the behavior
  - Possibly violating specifications

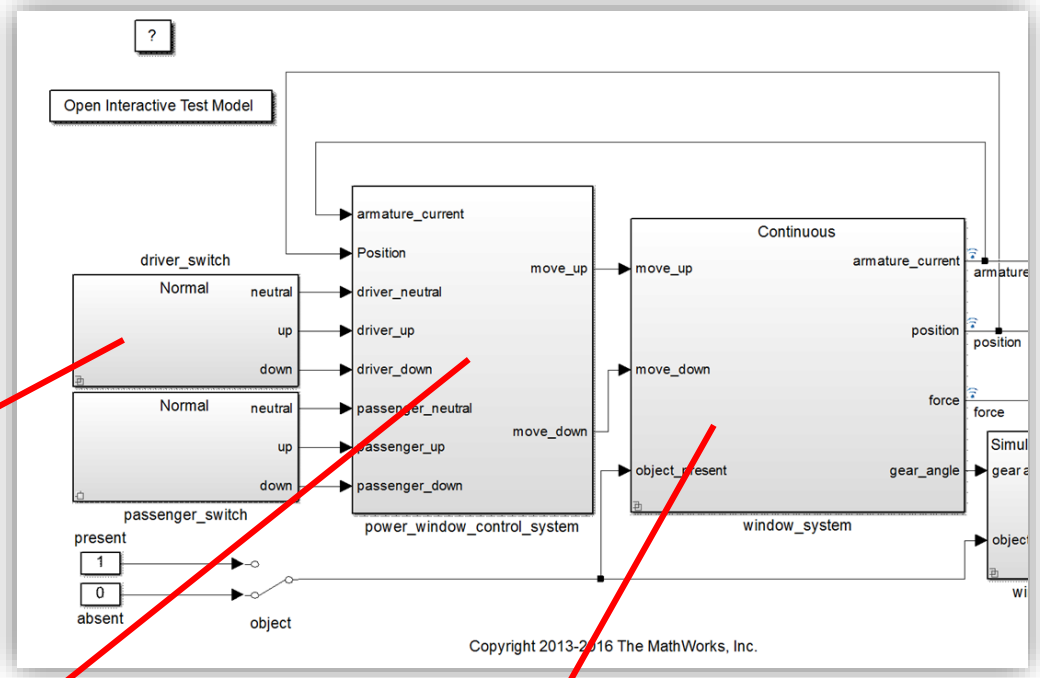


Injecting faults into co-simulation

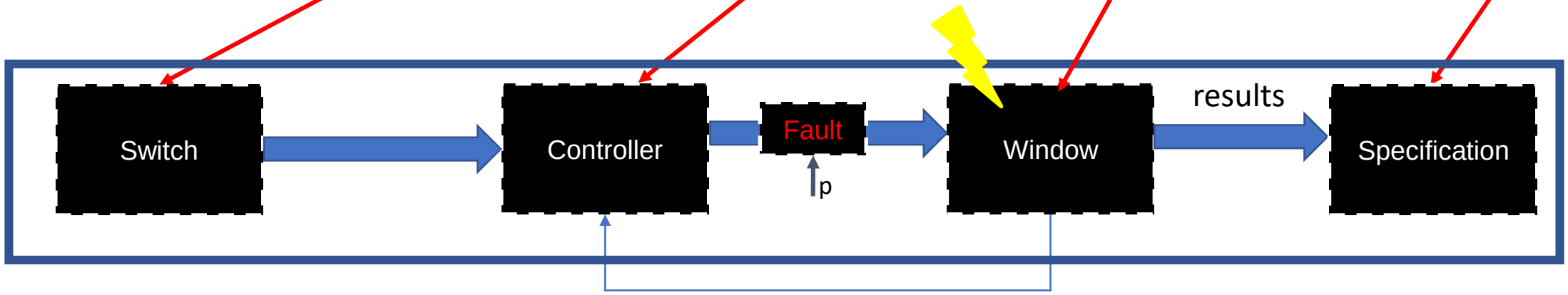


Virtual FMU

doStop()
setReal()
getReal()



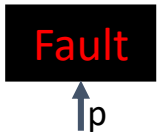
2. Force to detect when an object is present should be less than 100 [N]



Assumption: Stable and accurate master algorithm

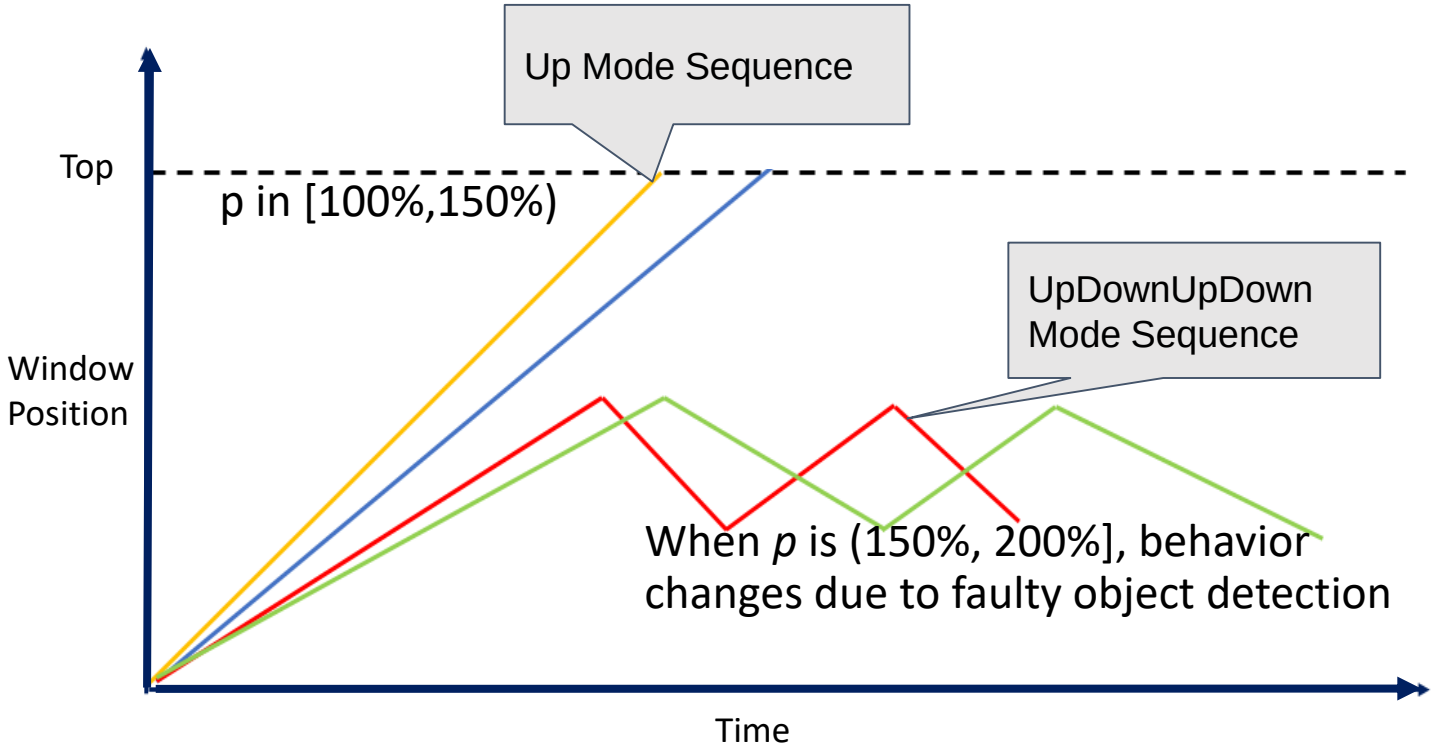
Interval partitioning → Sensitivity analysis

Parameter interval partitioning



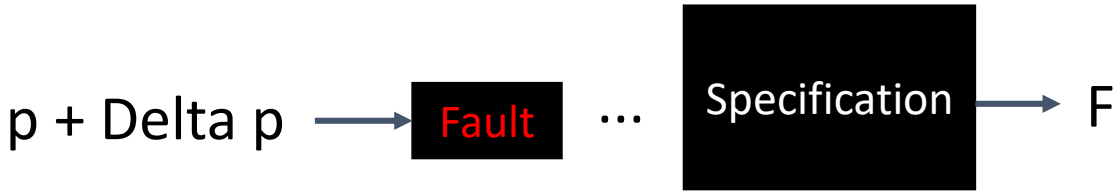
Example naive procedure:

1. Let fault parameter *p* in interval [100%,200%]
2. Partition the interval into N points,
   - run a co-sim per point,
   - store sequence of modes
3. Group adjacent points with same sequence of modes to form equivalence classes of continuity
4.

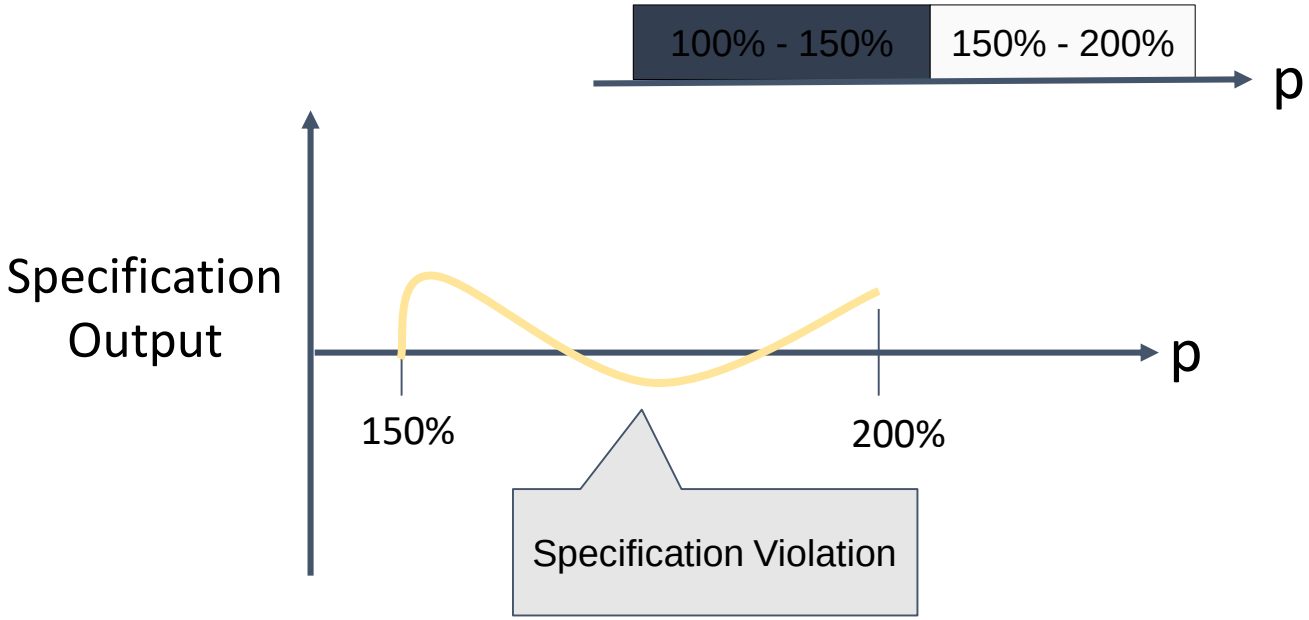


Sensitivity analysis

Want to determine how a change in our fault parameter affects the output of the specification



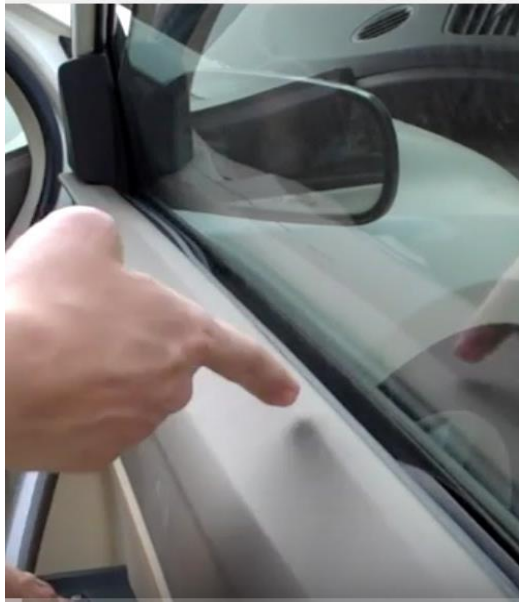
Within the same equivalence interval



Simulation

- Object is present
- Change of the rubber slip out’s time

- Causes the window to:
  To crush the object

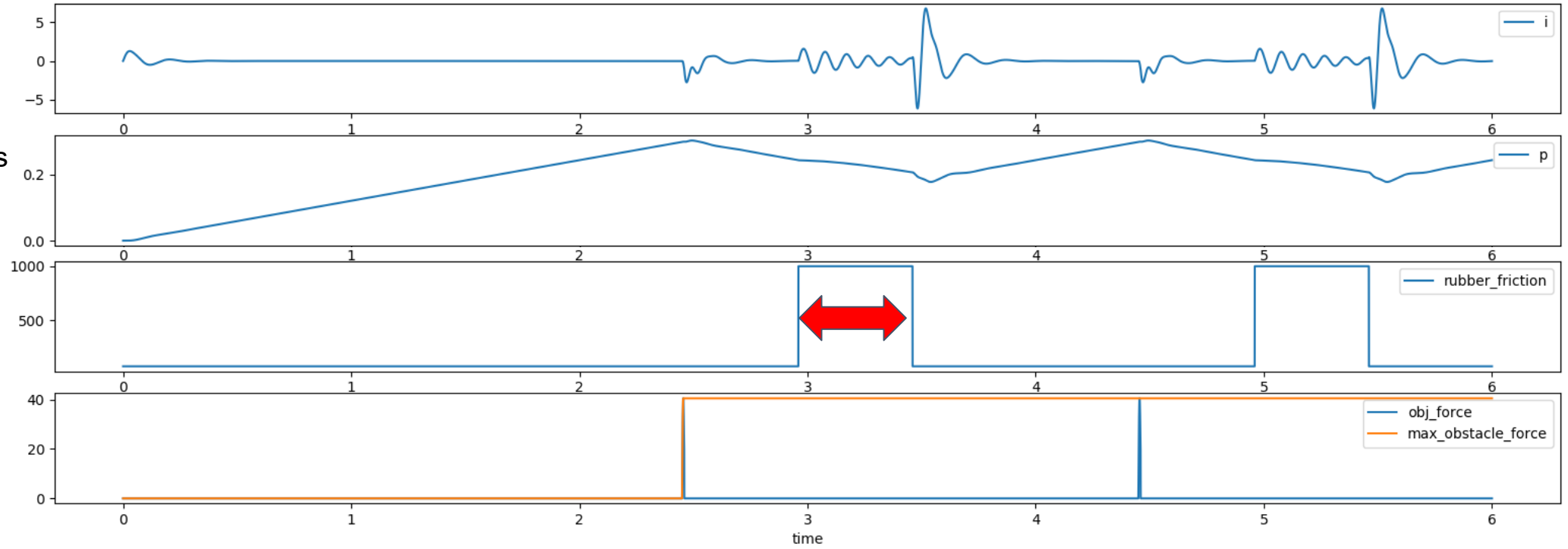


Armature current

Window's position

Rubber friction

Force



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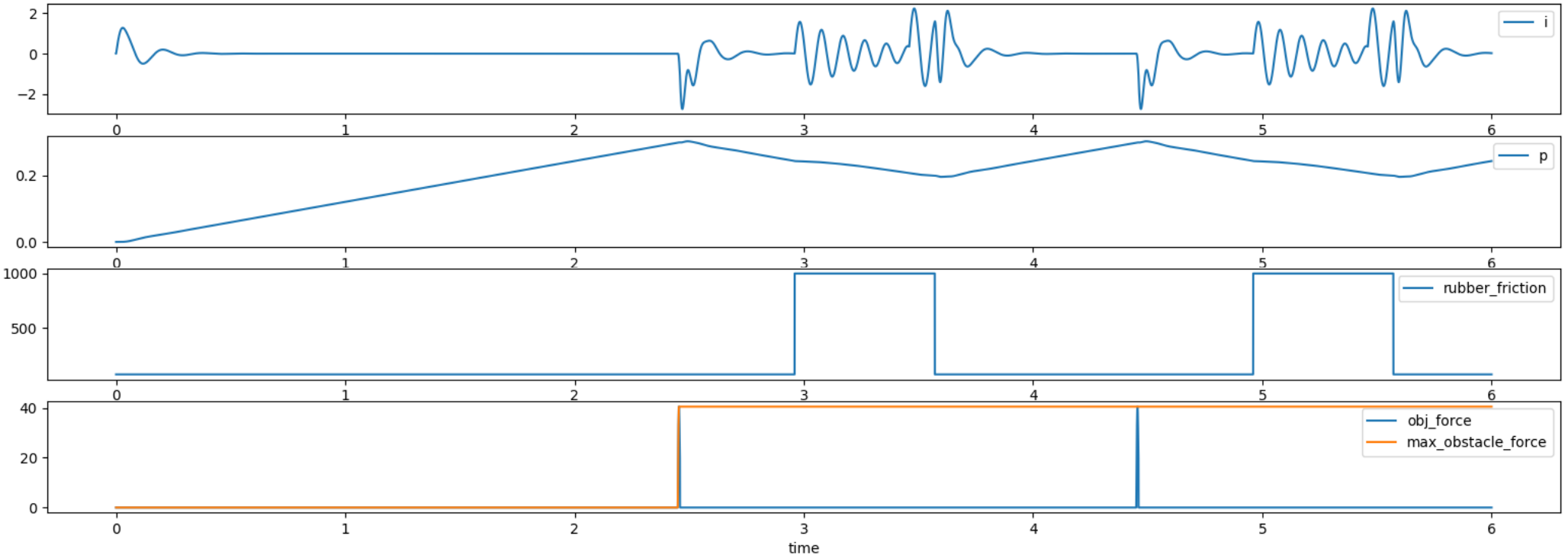

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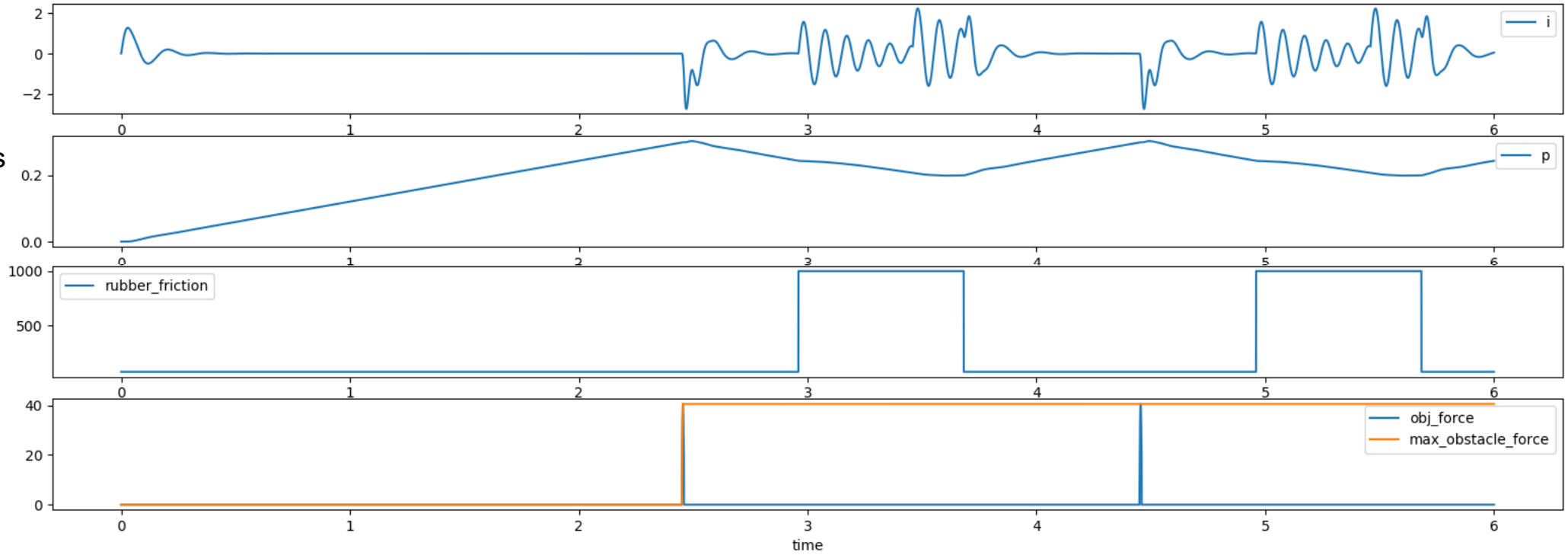

Armature current

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Rubber friction

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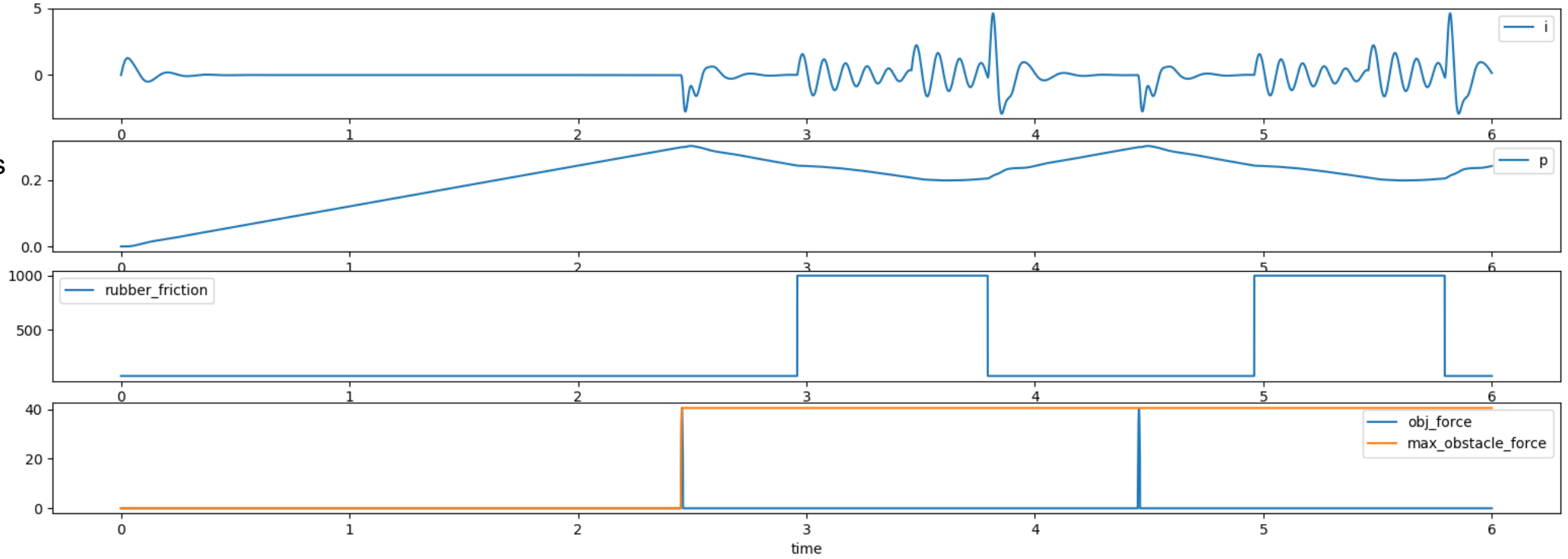

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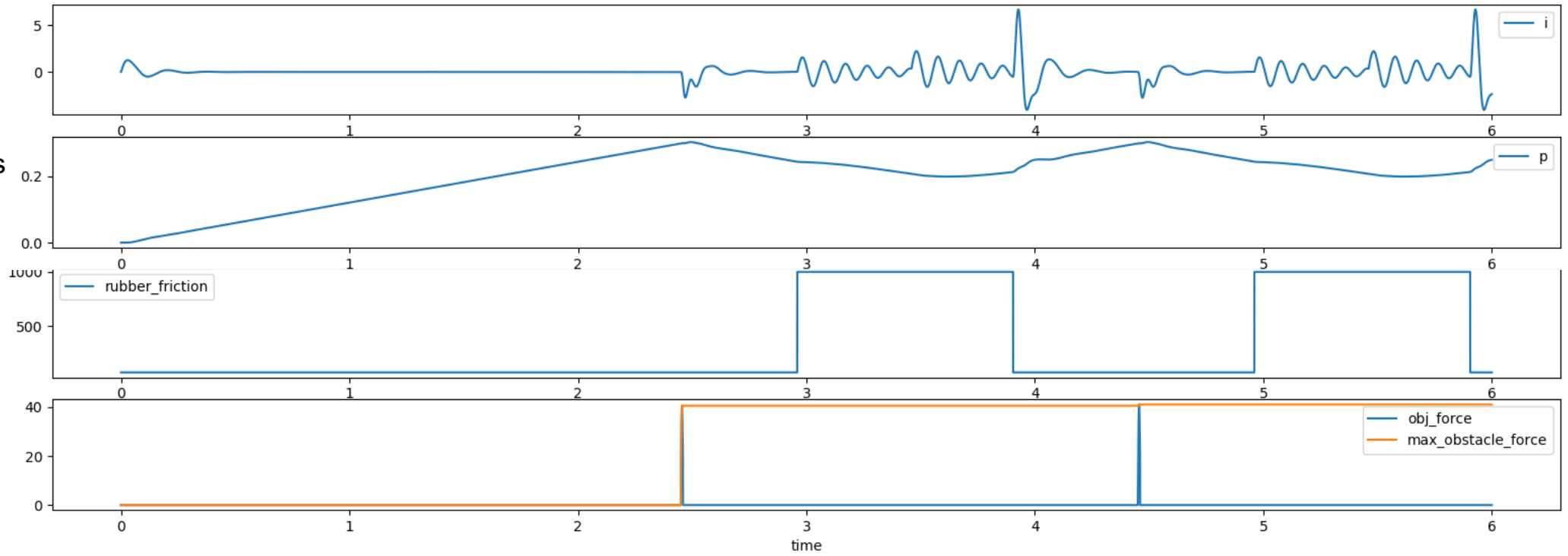

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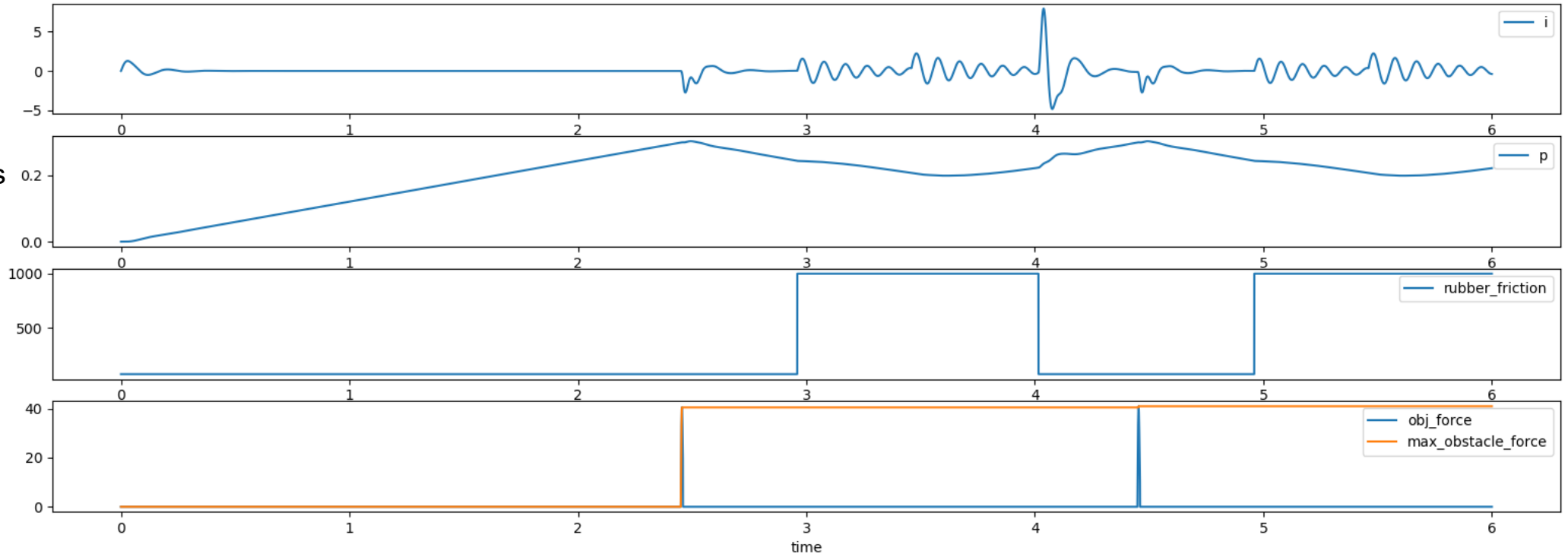
Rubber friction

Force



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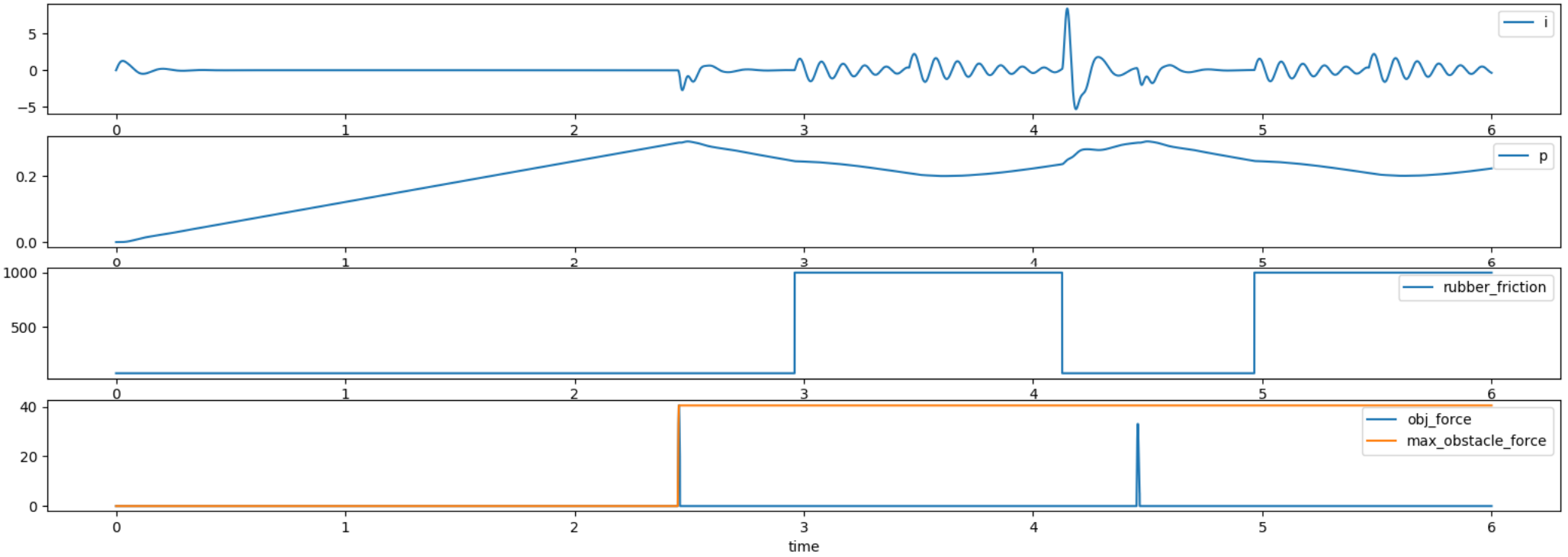
Window's position

Rubber friction

Force

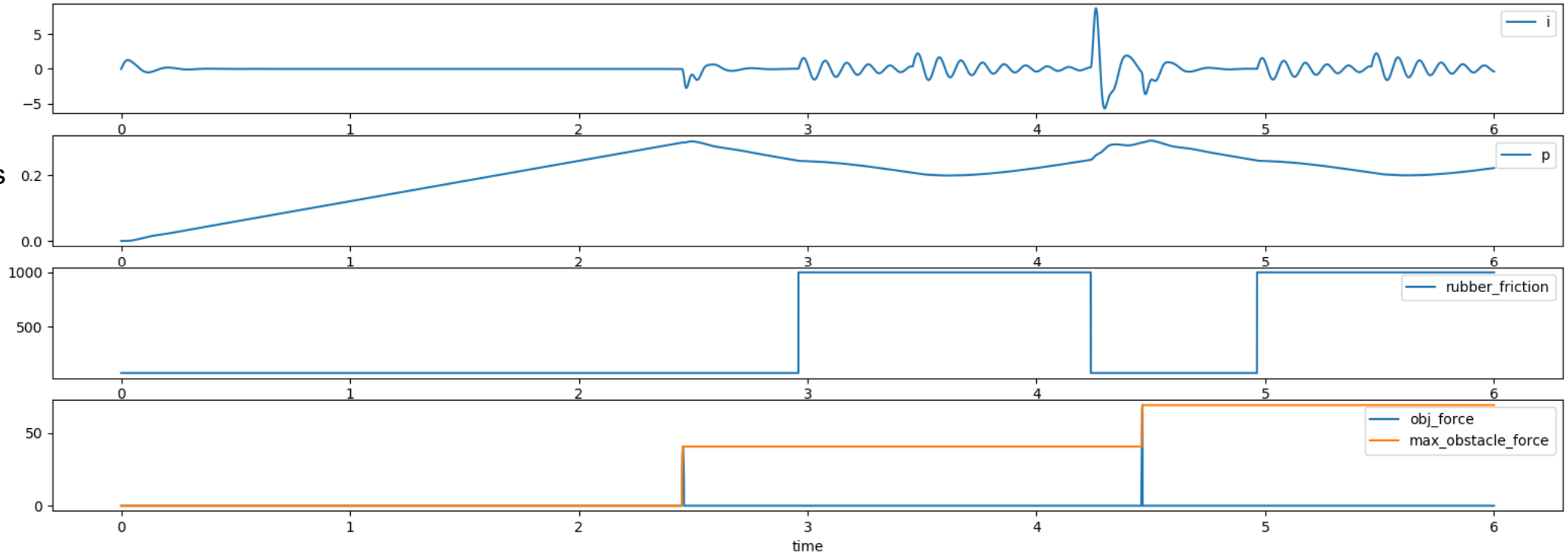


Armature current

Window's position

Rubber friction

Force



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Rubber friction

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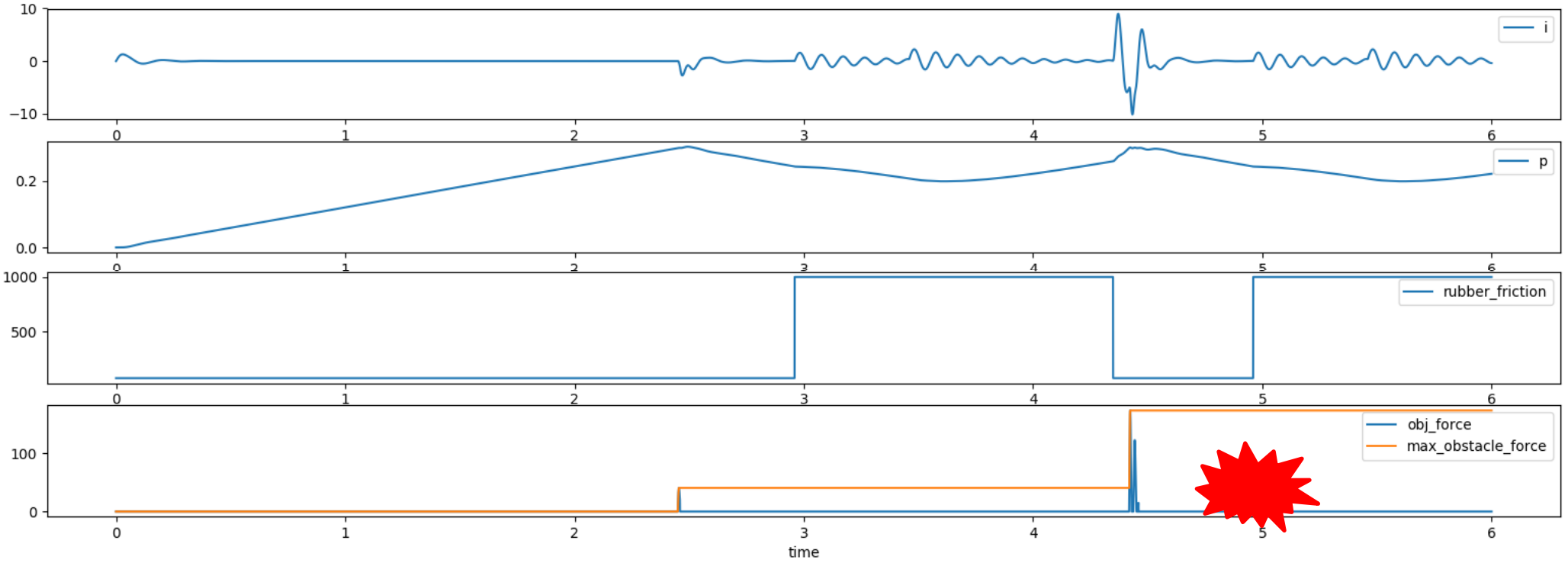

Armature current

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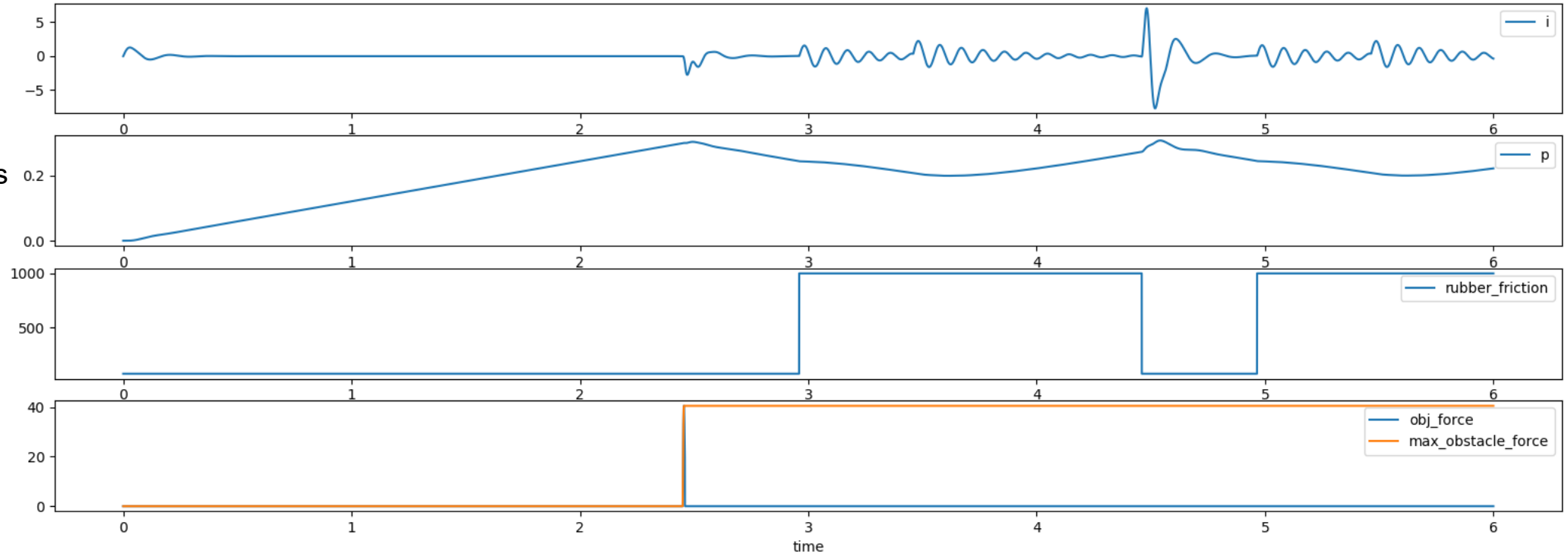

Summary

- Applying fault injection to FMI
- Using sensitivity analysis to relate system trajectories to fault parameters

Next steps

- Co-simulation effect
  - Delay due to step-size
- How to **observe discrete** modes of the hybrid system in FMI standard
- How to **compute intervals** more effectively
  - Sensitivity equations

Thank you for your attention