Design of a PID Controller for a Molten Salt Microreactor

A Thesis
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by
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Abstract

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Acknowledgements

This work and my coursework was completed under a Graduate Fellowship funded by Nuclear Regulatory Commission (NRC). I would like to thank Dr. McKellar...

Dedication

To my mother, Tammy, who planted and nurtured my love of science. To my father, Paul, who taught me how to design and build, and showed me that I am an engineer. To my cats, Babe and Bunyan, who stayed up with me all those late nights studying and writing. Thank you for your endless support.

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Acronyms

LWR Light Water Reactor.

MSNB Molten Salt Nuclear Battery.

NRC Nuclear Regulatory Commission.

PID Proportional-Integral-Derivative.

Chapter 1

Introduction

1.1 Background

The Molten Salt Nuclear Battery (MSNB) is a self contained design for a liquid fueled molten salt microreactor [1, 2]. It is fueled by an inorganic form of uranium, UF_4, dissolved in a coolant salt such as $FLiNaK$ (a eutectic mixture of three alkali fluorides) or $FLiBe$ (a mixture of LiF and BeF_2) [3]. Heat is generated in the core by fission, is transported by the natural circulation of the coolant/fuel salt, and rejected to a secondary working fluid in an integrated heat exchanger. Criticality is manipulated using axial control drums, which may be rotated to aim either a neutron reflecting material or a neutron absorbing material towards the core.

Micro Reactors

Its like a reactor but smol. This is a test from CAES.

Molten Salt Reactors

Light Water Reactor (LWR)

1.2 Scope

As a developing design, work has been done on neutronics [2], thermal-hydraulics and autonomous load following [1], and corrosion concerns [4]. However, until now, little to no work has been done on the control system. First and foremost, this work details a multiphysics characterization of the MSNB required to design a feedback controller capable of matching the core power generation to the secondary power demand. In addition to the main control mode of following power transients during normal operation, specific discussion is centered around more dynamic time periods, namely: 1) initial start-up; 2) shutdown, both planned and emergency; and 3) restart;

Chapter 2

Process Control Engineering

2.1 Feedback

2.2 Feedforward

The term 'Feedforward' can be used to refer to any element in the control block diagram that exists outside of the feedback loop.

Disturbance Feedforward

Not that useful since disturbance transport delay is on the order of minutes and disturbance dynamics are on the order of milliseconds

Pre-Filter

This could be electronic (less ideal) or physically realized by decoupling

2.3 Time Variance

Fissile depletion - time function parameters or look-up table to gain-schedule and turn the time variant system into a shift invariant system.

In addition to the relatively slow time variance of fissile fuel depletion during steady-state critical operation, there are specific times in a MSNB's expected operational life-cycle that exhibit a higher degree of time variance: 1. Start-up; 2. Shut-down; and 3. Re-start.

Start-up

Black-start may need to deal with thawing salt - main concern is fission product neutron poison build-up (discuss the burnable poison stuff)

Shut-down

Planned shut-down

Emergency Shutdown/SCRAM(must be passive)

Decay heat and keeping the salt liquid for restart

Re-start

^{135}Xe stripper

Chapter 3

Reactor Characterization

3.1 Reactor Design selection

3.2 Neutronics Modeling

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Chapter 4

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4.2 Tuning Methodology

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References

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[2] Peterson, John, 2019 8. An Analysis of the Nuclear Characteristics of a Molten Salt Microreactor. Master's thesis, University of Idaho.

[3] Roper, Robin V., Sabharwall, Piyush, Christensen, Richard, 2019. Chemical overview of molten salts. ANS Annual Meeting.
URL `https://www.ans.org/pubs/transactions/article-45524/`

[4] Roper, Robin, 2022. The Effect of Impurities and Geometry on the Corrosion and Thermodynamic Behavior of Molten Salts. Ph.D. thesis, Univesity of Idaho.

Appendix A

Test

Code 1: Hello!

```
    print("Hello World") #comment
    try:
        a=2/x
    except ZeroDivisionError:
        print('undefined')
```

Inline codes like `import numpy`

Code 2: F strings

```
x = 4
print(f"The numeral four: {x}")
#comment
```

Appendix B

What

Straight Cash Homie