UNIVERSIDADE DE LISBOA

INSTITUTO SUPERIOR TÉCNICO

Università degli Studi di Padova

Tokamak Magnetic Control Simulation: Applications for JT60-SA and ISTTOK Operation.

Doménica Corona Rivera

Supervisor:Prof. Horácio Fernandes
Co-Supervisor: Prof. Nuno Cruz
External supervisor: Prof. Alfredo Pironti

Thesis specifically prepared to obtain the PhD Degree in

Technological Physics Engineering

Month 2020

ABSTRACT

The characterisation of the interactions

Keywords: Plasma-surface interactions, Liquid-metals, Tin, Deuterium retention, Spectroscopy

RESUMO

A caracterização das interações entre plasmas magneticamente

Palavras-chave: Plasma, metais liquidos, estanho, retenção de deutério, espectroscopia

SOMMARIO

Il soggetto del presente lavoro di tesi è la caratterizzazione dell'interazione tra la superficie di metallo liquido

Parole chiave:Interazione plasma-parete, Metalli liquidi, Stagno, Ritenzione del Deuterio, Spettroscopia

ACKNOWLEDGEMENTS

This work, supported by the European Communities and "Instituto Superior Técnico", has been carried out within the Contract of Association between EURATOM and IST. Financial support was also received from "Fundação para a Ciência e Tecnologia"

CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

@TODO: Review variable lists as writing the thesis

- AC - Alternating Current
- ADC - Analog to Digital Converter
- ATCA - Advanced Telecommunications Computing Architecture
- CREATE - Consorzio di Ricerca per l'Energia, l'Automazione e le Tecnologie dell'Elettromagnetismo
- DAC - Digital to Analog Converter
- IST - Instituto Superior Técnico
- LQR - Linear Quadratic Regulator
- MARTe - Multi-threaded Application Real-Time executor
- MIMO - Multiple-Input Multiple-Output
- PCS - Plasma Control System
- PF - Poloidal Field
- XSC - eXtreme Shape Controller
- WO - Wiring Offset

LIST OF VARIABLES

@TODO: Review variable lists as writing the thesis

VARIABLES:

- I_p - Plasma current
- B_p - Poloidal magnetic field
- μ_0 - Vacuum permeability

1

INTRODUCTION

1.1 TOKAMAK PLASMA CONTROL

1.2 BEHIND THE PLASMA CURRENT

1.3 THESIS OUTLINE

2

PLASMA CONTROL SYSTEMS

2.1 OVERVIEW OF CONTROL SYSTEMS

The control of plasma position, shape and current among other parameters is one of the crucial engineering problems for present and future magnetic confinement devices. The Plasma Control Systems (PCS) lead with the overall control of the fusion devices being responsible also for the plasma configuration and scenarios algorithms [1, Chapter 8].

Currently different PCS's are use in the tokamaks around the world. In this chapter will be approach the "DIII-D-like" PCS and the Multi-threaded Application Real-Time executor (MARTe).

2.1.1 *DIII-D Plasma Control System*

[3]

2.2 MARTE FRAMEWORK

MARTe was developed in order to standardize general real-time control systems for the execution of control algorithms. MARTe framework is based on a multiplatform C^{++} library. [2]

2.2.1 *MARTe architecture*

2.2.2 *Hardware containers*

2.2.3 *MARTe 2.0*

2.3 EQUILIBRIUM AND CONTROL ALGORITHMS

2.3.1 *PID control*

2.3.2 *Multiple-Input Multiple-Output control*

3

JT60-SA CONTROL DESIGN

3.1 MACHINE DESCRIPTION

3.2 CREATE TOOLS

3.3 CONTROLLER DESIGNS

3.4 QST TOOLS IMPLEMENTATION

3.5 SIMULATION RESULTS

4

ISTTOK

4.1 MACHINE DESCRIPTION

4.2 DIAGNOSTICS AND ACTUATORS

4.3 ATCA-MIMO-ISOL BOARDS

4.3.1 *Hardware layout*

4.3.2 *Real-time integration software*

4.4 RETRIEVING THE CONTRIBUTION OF PLASMA CURRENT

The methods of correction of the magnetic error fields due to inaccuracies of tokamak manufacturing and assembly are considered. The problems of the plasma position and shape reconstruction based on magnetic field measurements are discussed.

4.5 PLASMA CENTROID POSITION DETERMINATION

5

ISTTOK RESULTS

5.1 GENERAL APPLICATION MODULES IMPLEMENTATIONS

5.2 PID CONTROL IMPLEMENTATION

5.3 MULTIPLE-INPUT MULTIPLE-OUTPUT CONTROL IMPLEMENTATION

6

CONCLUSIONS

BIBLIOGRAPHY

[1] A. A. K. Valerij A. Belyakov, *Fundamentals of Magnetic Thermonuclear Reactor Design*. Elsevier, 2018.

[2] A. C. Neto, D. Alves, L. Boncagni, P. J. Carvalho, D. F. Valcárcel, A. Barbalace, G. De Tommasi, H. Fernandes, F. Sartori, E. Vitale, R. Vitelli, and L. Zabeo, "A survey of recent MARTe based systems," in *IEEE Transactions on Nuclear Science*, vol. 58, pp. 1482–1489, 2011.

[3] J. R. Ferron, A. Kellman, E. McKee, T. Osborne, P. Petrach, T. S. Taylor, J. Wight, and E. Lazarus, "An advanced plasma control system for the diii-d tokamak," in *[Proceedings] The 14th IEEE/NPSS Symposium Fusion Engineering*, pp. 761–764 vol.2, Sep. 1991.

A

DEMONSTRATIONS