COMPLEX ENVELOPE CONTROL OF PULSED ACCELERATING FIELD IN SUPERCONDUCTING CAVITY RESONATORS

L = 9·λ/2 ~ 10^{37}

particle \((z,t)\) \(E_0(z)\)

Editorial Series on ACCELERATOR RESEARCH

Institute of Electronic Systems
Publishing House of Warsaw University of Technology
Ph. D. THESIS

Tomasz Czarski, M. Sc.

COMPLEX ENVELOPE CONTROL
OF PULSED ACCELERATING FIELD
IN SUPERCONDUCTING CAVITY RESONATORS

REGULACJA OBWIEDNI ZESPOLONEJ
IMPULSOWEGO POLA PRZYSPIESZAJACEGO
W NADPRZEWODZACYM REZONATORZE WNĘKOWYM

Supervisor
Professor Ryszard Romaniuk, Ph. D., D.Sc.

Warszawa 2009
ABSTRACT

A digital control system for superconducting cavities of a linear accelerator is presented in this work. FPGA (Field Programmable Gate Arrays) based controller, managed by MATLAB, was developed to investigate a novel firmware implementation. The LLRF - Low Level Radio Frequency system for FLASH project in DESY is introduced. Essential modeling of a cavity resonator with signal and power analysis is considered as a key approach to the control methods. An electrical model is represented by the non-stationary state space equation for the complex envelope of the cavity voltage driven by the current generator and the beam loading. The electromechanical model of the superconducting cavity resonator including the Lorentz force detuning has been developed for a simulation purpose. The digital signal processing is proposed for the field vector detection. The field vector sum control is considered for multiple cavities driven by one klystron. An algebraic, complex domain model is proposed for the system analysis. The calibration procedure of a signal path is considered for a multi-channel control. Identification of the system parameters is carried out by the least squares method application. The FPGA based controller executes a procedure according to the following prearranged control tables: Feed-Forward, Set-Point and Gain. The control tables are determined for the required cavity performance, according to the recognized process. Nonlinearities and deterministic disturbances are compensated by the feed-forward table for the open loop operation. The closed loop correction for the feed-back mode is performed by the complex gain of the corrector table. The adaptive control algorithm is applied for the feed-forward and feedback modes according to the recognized process. The presented method is useful for the repetitive, deterministic condition. It has been verified experimentally in the case of a pulsed mode of an accelerator operation. Experimental results, based on the field measurement, are presented for a cavity representative operation. The results of the project accomplishment can be presented and used physically by driving the real cavity module according to the given control algorithm.
CONTENTS

Abstract 4

1. Introduction 7
   1.1 Origin and subject of the thesis
   1.2 Objective and thesis of the work
   1.3 Linear accelerator overview
   1.4 LLRF system introduction

2. Cavity resonator modeling 13
   2.1 Basic physical features description
   2.2 Electrical circuit model
   2.3 RF signal modeling
   2.4 Cavity power consideration
   2.5 Cavity mechanical model
   2.6 Cavity electromechanical model

3. Cavity simulator design 32
   3.1 Discrete cavity model
   3.2 Digital simulator
   3.3 Cavity simulator control

4. Criteria of cavity model control 41
   4.1 Electrical model control
   4.2 Electromechanical model control

5. Algorithms of cavity control 56
   5.1 Adaptive Feed-Forward by direct inverse control
   5.2 Adaptive Feed-Forward by differential inverse control
   5.3 Adaptive Feedback by differential inverse control
   5.4 Complex differential inverse control
   5.5 Conventional feedback supported by feed-forward control

6. Multi-cavity modeling and control 87
   6.1 The real plant system modeling
   6.2 System model identification
   6.3 Vector sum calibration
6.4 Complex envelope detection
6.5 Multi-cavity system control

7. Multi-cavity complex controller
   7.1 Multi-cavity complex controller design
   7.2 FPGA based integrated firmware engine
   7.3 FPGA cavity simulator control

8. Summary

Appendix

References