MODELLING AND CONTROL OF AN ELECTRIC ARC FURNACE OFF-GAS PROCESS

by

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To my mother who taught me principles.

Abstract:

Title: Modelling and Control of an Electric Arc Furnace Off-gas Process
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This dissertation investigates the automation of manually controlled variables such as fan speed and slip-gap width for the electric arc furnace (EAF) off-gas process. An extensive modelling effort is conducted and results in a comprehensive plant model. The model derived in this dissertation is intended for the testing of control strategies using off-gas variables in the control of an electric arc furnace. Derivation of a multivariable non-linear state-space model for the process is handled. The assumptions that are made and the state space representation provide a comprehensive framework for the development of an electric arc furnace process model. First principles of thermodynamics are used to derive the model, ensuring behaviour consistent with physical observations. Typical operating conditions for a furnace are discussed, and a simulation is conducted with these operating conditions. In order to apply the model representing a specific industrial furnace the adjustable parameters in the model are selected such that the model responses concur with those of the actual furnace. After verification, this plant model is regarded as the process for which a controller must be designed. A linear model approximates the plant model to give a simplified mathematical abstraction of the process. The linear model is accepted as a reasonable approximation of the process for the controller design purpose, and an analysis of the linear system shows that the linear system is stable. The analysis also shows that the linear system is output controllable with respect to particular outputs, although the internal state vector is not completely observable. Qualitative control objectives are translated to quantitative control specifications.

Control design for the linear system is performed in the Matlab environment. Model Predictive Control is the preferred control design method, due to the use of an internal model and the use of optimisation. Experiments with the controller parameters are done to obtain the best nominal controller. These include the cost function multipliers for the controlled and manipulated variables, as well as the manipulation and prediction horizons. The effect of various inputs and disturbances is determined. A trade-off is made between improving electric arc furnace efficiency and ensuring environmental protection, and the nominal controller is obtained. The controller is then applied to the plant model, and tested on the process it was intended for. A final "on-line tuning" session on the plant model concluded the design. The controller was evaluated against the option of no control, and the controller improved process operation. The controller achieved good regulation, setpoint tracking and disturbance rejection.

Keywords: Electric Arc Furnace, Off-gas Process, Process Control, State Space Modelling, Model Predictive Control, Quadratic Programming, Real-time Optimal Control.

Opsomming:

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Hierdie verhandeling ondersoek die automatisasie van handbeheerde veranderlikes soos waaierspoed en sleur gapingwydte vir die elektriese boogoond afgas proses. 'n Deeglike modellering-fase word uitgevoer, en die nie-lineêre model word so verkry. Die model wat in hierdie verhandeling ontwikkel word, is bedoel vir die toets van beheer-strategieë deur van die afgas-veranderlikes gebruik te maak om 'n elektriese boogoond te beheer. Die afleiding vir 'n multi-veranderlike nie-lineêre toestand-ruimte model van die proses word behandel. Die gebruikte aannames en die toestand ruimte voorstelling verskaf 'n deeglike raamwerk vir die ontwikkeling van 'n elektriese boogoond proses model. Eerste beginsels van termodinamika word gebruik om die model af te lei, ten einde ooreenstemming te kry met fisiese waarnemings. Tipiese bedryftoestande vir 'n boogoond word bespreek, en 'n simulasie word met hierdie toestande uitgevoer. Ten einde die model toe te pas om 'n spesifieke industrieële oond voor te stel is die verstelbare parameters in die model gekies sodat die model reaksies ooreenstem met die van die werklike oond. Na model-verifikasie, is die model as 'n plaasvervanger vir die proses gebruik, en beskou as die proses waarvoor 'n beheerder ontwerp moes word. 'n Lineêre model is gebruik om die aanleg model te benader ten einde 'n vereenvoudigde wiskundige voorstelling te kry. Die lineêre model word aanvaar as 'n redelike benadering van die aanleg model vir beheerder ontwerp doeleindes, en 'n lineêre stelsel analise toon aan dat dit 'n stabiele stelsel is. Die lineêre stelsel analise wys ook dat die stelsel uitset-beheerbaar is, alhoewel dit nie volledig waarneembaar is nie. Die kwalitatiewe beheer doelwitte word herlei na kwantitatiewe beheer spesifikasies.

Beheerder-ontwerp vir die lineêre stelsel word in die Matlab omgewing gedoen. Model Voorspellende Beheer is gekies as die beheerder-ontwerp metode by voorkeur, te danke aan die gebruik van 'n interne model en optimisasie. Eksperimente met die beheerder parameters word uitgevoer om die beste nominale beheerder te bepaal. Hierdie parameters sluit die koste-funksie koeffisiënte vir die uitsette en insette, so wel as die manipulasie horison en die voorspellings horison in. Die effek van verskeie insette en steurings word bepaal. 'n Kompromie word verkry tussen die verbetering van die boogoond effektiwiteit en die voorkoming van omgewings-besoedeling. Die nominale beheerder wat gekry is, word op die aanleg-model toegepas en getoets op die proses waarvoor dit aanvanklik bedoel is. 'n Finale fyn-stelling sessie op die aanleg-model se beheerder sluit die ontwerp af. Die beheerder word vergelyk met operateur-beheer, en die outomatiese beheerder verbeter die proses bedryf. Goeie regulasie, stelpunt volging en steuring verwerping word met die beheerder verkry.

Sleutelterme: Elektriese Boogoond, Afgas Proses, Toestand Ruimte Modellering, Model Voorspellende Beheer, Proses Beheer, Kwadratiese Programmering, Intydse Optimale Beheer.

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I would like to thank the reader for undertaking the task of reading this dissertation. It is hoped that the contents were meaningful to the reader, and that it provided new insights and information.

LIST OF ABBREVIATIONS

BOF	Basic Oxygen Furnace
CV	Controlled Variable
C#	Controller number #
DRI	Direct Reduced Iron
EAF	Electric Arc Furnace
Fig	Figure
MPC	Model Predictive Control
MV	Manipulated Variable
NISE	Normalised Integrated Square Error
NILE	Normalised Integrated Limit Exceeded
NSS	Nominal Steady State
QP	Quadratic Programming

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