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ECONOMIC EVALUATION AND DESIGN OF AN ELECTRIC ARC FURNACE CONTROLLER BASED ON ECONOMIC OBJECTIVES

by

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ABSTRACT

The economic benefits of Model Predictive Control (MPC) over conventional manual control on an Electric Arc Furnace (EAF) are determined by means of a simulation study. The structure used for the MPC controller is chosen such that the objective function, which is minimised by the controller, corresponds to the cost of a tap. Minimisation of the objective function thus constitutes minimising EAF operational cost. The major factors contributing to the cost of the tap are thus determined and their contributions relative to each other quantified. The procedure of translating functional control objectives into economic objectives is discussed, as is the relative cost contribution of the feed additions to the EAF.

An existing EAF model is expanded by modelling the slag foam depth. The foam depth is useful in ensuring efficient energy transfer to the melt. Great emphasis is placed on ensuring that the simulation study is representative of operational conditions typically experienced in industry. Only continuous measurements are therefore used for continuous feedback, and measurements taken at discrete time intervals are only fed back at the time intervals indicated by plant data. The full non-linear model is used to simulate the plant, even though a linearised model is implemented as the internal plant model for the MPC controller. Disturbances are chosen based on plant data and suggestions from industry.

The process of an experimental design for controller evaluation is discussed in detail. The selection of an appropriate experimental technique, possible threats to data integrity, tools for data analysis and capital budgeting tools form part of the complete experimental procedure. A framework is presented to ensure that useful data is generated and that valid conclusions are made concerning the data. This evaluation framework forms the basis of the experimental procedure used to compare the two control strategies (manual and MPC). The simulation study represents a test conducted over a period of one month, and randomisation is used to ensure that the test data is not correlated to the disturbances. Hypothesis testing is performed to ensure that the result is statistically significant.

Simulation results indicate large potential benefits attributable to MPC control. Improved utilisation of feed materials can potentially reduce the cost per ton of steel by 0.8 %. The major portion of the potential benefits is however due to the elimination of unscheduled delays, by ensuring that steel specifications are met at tapping, and that off-gas limits are not exceeded at any stage during the tap. These factors account for potential savings in excess of 7 % due to increased throughput.

Keywords: Electric Arc Furnace, Model Predictive Control, Economic evaluation, Experimental design, Hypothesis testing, Dynamic models.

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OPSOMMING

Die finansiële voordele van 'n Model Voorspellende Beheerder is in 'n simulasie-studie bepaal, deur dit te vergelyk met konvensionele hand-beheer op 'n elektriese boogoond. Die struktuur van die beheerder is sodanig gekies, dat die doelwit-funksie wat deur die beheerder geminimeer word ooreenkom met die koste van 'n tap. Minimering van die doelwit-funksie is dus ekwivalent daaraan om die bedryfskoste van die boogoond te minimeer. Die belangrikste faktore wat bydra tot die koste van 'n tap is daarom geïdentifiseer en die relatiewe bydraes tot die totale koste gekwantifiseer. Die omskrywing van funksionele doelwitte in terme van finansiële doelwitte is bespreek en die relatiewe kostes van die toevoer-materiale bepaal.

'n Bestaande boogoond model is uitgebrei deur die skuimslakdiepte te modelleer. Die skuimslakdiepte is van belang, aangesien effektiewe energie-oordrag na die bad hierdeur beïnvloed word. Klem is daarop gelê dat die simulasie-studie verteenwoordigend moet wees van omstandigdhede wat tipies in die industrie aangetref word. Slegs metings wat kontinu beskikbaar is word daarom kontinu teruggevoer. Metings wat slegs op diskrete tydstippe beskikbaar is word slegs teruggevoer op dié tydstippe aangedui in aanlegdata. Die volledige nie-lineêre model is gebruik om die aanleg te simuleer, al is 'n lineêre model gebruik as die interne aanleg-model vir die Model Voorspellende Beheerder. Steurings is gebaseer op aanlegdata en voorstelle deur aanleg personeel.

Eksperimentele ontwerp met die doel om beheerders te evalueer is in detail bespreek. Die keuse van 'n geskikte eksperimentele tegniek, potensiële bedreigings vir data integriteit, prosedures vir data analise en projek-evaluerings tegnieke maak deel uit van die eksperimentele prosedure.

'n Raamwerk is voorgestel waarbinne verseker kan word dat bruikbare data gegenereer sal word en dat geldige gevolgtrekkings gemaak kan word oor die data. Hierdie evalueringsraamwerk vorm die basis van die eksperimentele prosedure wat gebruik is om die twee beheerstrategieë te vergelyk (Model Voorspellende Beheer en hand-beheer). 'n Toets uitgevoer oor die bestek van een maand word deur die simulasiestudie voorgestel. Ewekansige tegnieke is gebruik om te verseker dat geen korrelasie tussen die data en die steurings bestaan nie. Hipotese toetsing is gebruik om te bepaal of die resultate statisties beduidend is.

Die simulasiestudie dui op groot potensiële finansiële voordele weens Model Voorspellende Beheer. Beter benutting van toevoer-materiale kan die koste per ton staal potensieel verminder met 0.8 %. Die grootste deel van die potensiële besparing is egter vanweë die eliminasie van ongeskeduleerde onderbrekings. Dit word bewerkstellig deur te verseker dat aan staal temperatuur en -samestelling spesifikasies voldoen word wanneer getap word en dat die afgas temperatuur nie gespesifiseerde limiete oorskry nie. Hierdie faktore kan potensieel lei tot addisionele besparings van groter as 7 % danksy verhoogte deurset.

Sleutelterme: Elektriese boogoond, Model Voorspellende Beheer, Ekonomiese evaluering, Eksperimentele ontwerp, Hipotese toetsing, Dinamiese modelle.

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