CFD MODELLING AND MATHEMATICAL OPTIMISATION OF A CONTINUOUS CASTER SUBMERGED ENTRY NOZZLE

submitted in partial fulfillment of the requirements for the degree of

Master of Engineering (Mechanical)
in the
Faculty of Engineering, Built Environment and Information Technology
University of Pretoria

Compiled by: Gideon Jacobus de Wet
9701364-2

Study leader: Prof. K. J. Craig

Year: April 2005

SUMMARY

CFD Modelling and Mathematical Optimisation of a Continuous Caster Submerged Entry Nozzle

Author : Gideon Jacobus de Wet
Student number : 9701364-2
Study leader : Prof. K.J. Craig
Degree: : Master of Engineering (Mechanical)
Department : Department of Mechanical and Aeronautical Engineering

Abstract:

In the continuous casting of steel, the Submerged Entry Nozzle (SEN), in particular the SEN geometry, has a primary influence on the flow pattern: the SEN controls the speed, direction and other characteristics of the jet entering the mould. The SEN is however relatively inexpensive to change (in comparison with other continuous casting equipment). Thus; there is a feasible incentive to exactly understand and predict the flow of molten steel through the SEN and into the mould, in order to maximise the quality of the steel by altering the design of the SEN.

By changing the SEN geometry and SEN design, the flow pattern in the mould will also change: it is thus possible to obtain an optimum SEN design if (or when) the desired flow patterns and/or certain predetermined temperature distributions are achieved.

Expensive and risky plant trials were traditionally utilised to “perfect” continuous casting processes. As opposed to the plant trials, this dissertation is concerned with the Computational Fluid Dynamics (CFD) modelling of the SEN and mould, which, when used in conjunction with the Mathematical Optimiser LS-OPT, will enable the optimisation of the SEN design to achieve desired results. The CFD models are experimentally verified and validated using 40%-scaled (designed and built in-house) and full-scale water model tests.

This dissertation proves that the CFD modelling of the SEN and mould can be quite useful for optimisation and parametric studies, especially when automated model generation (geometry, mesh and solution procedures) is utilised. The importance of obtaining reliable and physically correct CFD results is also emphasised; hence the need for CFD model verification using water modelling.

Keywords: Submerged Entry Nozzle (SEN), mould, continuous casting, CFD modelling, scaled water model, CFD validation and verification with water modelling, mathematical optimisation, parametric studies.

OPSOMMING

Berekeningsvloeimeganika-modellering en Wiskundige Optimering van 'n Stringgietery se Ondergedompelde Spuitstuk

Skrywer : Gideon Jacobus de Wet
Studentenommer : 9701364-2
Studieleier : Prof. K.J. Craig
Graadbenaming : Magister in Ingenieurswese (Meganies)
Departement : Departement Meganiese en Lugvaartkundige Ingenieurswese

Opsomming:

Die ondergedompelde spuitstuk (OS voortaan) in die staal-stringgietproses het 'n primêre invloed op die vloeipatrone binne-in die gietstukvolume: die OS beheer die spoed, rigting en ander karakteristieke van die spuitstraal wat die gietstukvolume binnestroom vanuit die OS se poorte. Tog is die OS relatief goedkoop om te verander in vergelyking met ander toerusting in die stringgietproses. Gevolglik is daar 'n dryfveer om presies die vloei deur die OS tot in die gietstukvolume te voorspel, ten einde die kwaliteit van die vervaardigde staal te maksimeer, deur slegs die ontwerp van OS stelselmatig te verander.

Deur die OS geometrie en ontwerp te wysig, sal die voeipatrone ook verander: gevolglik sal dit moontlik wees om 'n optimum OS te ontwerp sodra die verlangde vloeipatrone en/of temperatuurverspreidings verkry word.

Duur en riskante aanlegtoetse (van onder andere nuwe OS ontwerpe) was die tradisionele metode om ontwikkelingswerk vir die stringgietproses te verrig. Hierteenoor, besig hierdie verhandeling hom met die berekeningsvloeimeganika (alombekend as CFD) modellering van die OS en gietstukvolume. Tesame met die Wiskundige Optimeringspakket, LS-OPT, kan 'n OS ontwerp die resultaat wees van 'n optimeringsoefening – waar sekere voorafbepaalde resultate aan voldoen sal word deur die optimum OS ontwerp. Die CFD modelle wat gebruik is tydens die optimering, word eksperimenteel bevestig met behulp van watermodeltoetse (40%-skaal watermodel wat intern ontwerp en opgerig is), asook eksterne volskaal watermodeltoetse.

Hierdie verhandeling bevestig dat CFD modellering baie handig te pas kan wees vir die optimering en parametriese studies van die OS ontwerp, veral wanneer outomatiese modelgenerasie (geometrie, maas en CFD oplossingsprosedure) gebruik word. Die belangrikheid om betroubare en korrekte CFD resultate te gebruik vir optimeringsdoeleindes word ook beaam; daarom die behoefte aan gereelde CFD model eksperimentele bevestiging (met behulp van watermodeltoetse).

Sleutelwoorde: Ondergedompelde spuitstuk, kontinue staalgietproses (oftewel stringgietproses), berekeningsvloeimeganika (CFD) modellering, eksperimentele bevestiging van CFD modelle, watermodeltoetse, geskaalde watermodeltoetse, Wiskundige optimering, parametriese studies.

ACKNOWLEDGEMENTS

EXPRESSION OF THANKS

The following persons are thanked for their individual efforts and assistance in order to realise this dissertation:

Professor Ken Craig, for his leadership, patience, and moral guidance throughout the duration of study. Apart from his excellent abilities and expertise as a technical study leader, his overall modesty made an everlasting impression on the author.

Johan Haarhoff, for his dedicated assistance enabling the author to make sense of the UNIX / Linux powered network. He is also thanked for his contribution in perfecting the parameterised 3D model, which was used in Chapter 5 (as opposed to the author's parameterised model which was not appropriate as it does not support a welled SEN design).

Danie de Kock, for his expertise concerning FLUENT and GAMBIT, and his willingness and dedication to assist users in the Department[1] at the most inconvenient of times (for him, of course).

Thomas Kingsley, for help, advice and assistance in a wide variety of (mostly electronic) tasks at hand.

Chris Pretorius, for his knowledge of C programming and his contribution in extracting information from FLUENT during automated optimisation exercises.

Johan Ackerman (from Columbus Stainless), for his persistent nagging (seen in a positive spirit) during the period to complete the 40%-scaled water model, in an effort not to miss the window of opportunity to find an optimum SEN design. He was also a key role player responsible for the commencement of the entire THRIP[2] project, of which this dissertation is a part.

Katlego Makgata, a fellow- post graduate student in the cfd-labs, MDOG, University of Pretoria, for mutual support during the more dreary times, especially when full-time studies were halted, and many computer problems persisted.

[1] Department of Mechanical and Aeronautical Engineering, School of Engineering, University of Pretoria, South Africa.

[2] THRIP: The Technology and Human Resources for Industry Programme (of South Africa)

Marius Botha, for his unique ideas and competently executed modifications (towards the end of the period) to enhance the usefulness of the 40%-scaled water model.
Petrus Mojela, for his dedicated assistance during the construction phase of the initial 40%-scaled water model, which was used for preliminary validation purposes.

FORMAL ACKNOWLEDGEMENTS

The Technology and Human Resources for Industry Programme (THRIP) of South Africa; a partnership programme funded by the Department of Trade and Industry (DTI) and managed by the National Research Foundation (NRF), supported this work. Columbus Stainless is acknowledged as the main industry partner of this THRIP project. LTM Technologies is also acknowledged as an active partner in this research.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES