COST 526

"Automatic Process Optimization in Materials Technology"

(APOMAT)

Half-Yearly Report

To be sent to **V.Tesch@access.rwth-aachen.de** until **August 30, 2003**

1. Reporting Period	**1.1.2003 – 30.6.2003**
Project title	Advanced Parameter Optimization Methods Preliminarily Used for Casting Processes (SI1)
Project leader Organization	Dr. Bogdan Filipic Jozef Stefan Institute, Ljubljana, Slovenia
Main collaborators involved	• Nova Gorica Polytechnic, Slovenia (Prof. Bozidar Sarler, Robert Vertnik) • Acroni Steelworks, Jesenice, Slovenia (Emil Subelj) • Department of Mathematical Sciences, University of Oulu, Finland (Prof. Erkki Laitinen)

2. Funding Situation	
Amount of money received specifically for COST	3 kEuros
Other resources partially used for the project	3 kEuros

3. International Collaboration

(mention group and type of work done in collaboration during the reporting period)

Participation in the Working Group Meeting in Brussels + project progress report

■ YES

□ NO

Project leader Bogdan Filipic participated in the 3rd Joint Working Group Meeting in Brussels held 26–27 May 2003. He reported on the progress of the project at the meeting of WG2, organized a session of WG4 on optimization methodologies, and gave a presentation entitled *An introduction to multi-objective optimization*.

Prof. Erkki Laitinen from Department of Mathematical Sciences, University of Oulu, Finland was on a short-term scientific mission to Slovenia from 22 to 29 June 2003. He was hosted by the Jozef Stefan Institute and Nova Gorica Polytechnic that both participate in COST 526. In contacts with project leaders of SI1 (Bogdan Filipic) and SI4 (Bozidar Sarler) the work done on both sides on the simulation and optimization of continuous casting of steel was reviewed, and possibilities for comparative studies using data from Slovenian and Finnish steel plants were analyzed. We plan to continue the collaboration by exchanging the software and data, and performing comparative numerical experiments on selected benchmark tasks.

4. Industry participation

(mention name of companies and work done in collaboration during the whole project)

For our industrial partner Acroni Steelworks, Jesenice, Slovenia, optimization of coolant flows for continuous casting of construction steel AC0113 was performed (see detailed description in *Progress within the reporting period*).

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5. Meetings, visits, exchange of scientists, short-term scientific missions	Location, date
Short-term scientific mission of Prof. Erkki Laitinen from Department of Mathematical Sciences, University of Oulu, Finland	Ljubljana, Slovenia, 22–29 June 2003

6. Progress within the reporting period

(Not exceeding 3 pages, including tables and figures)

Within the reporting period, the focus of our work was on solving a specific optimization problem appearing in continuous casting of steel at Acroni Steelworks. The task was to improve the settings of coolant flows in the secondary cooling zone with respect to empirical metallurgical cooling criteria in order to ensure higher product quality. In particular, continuous casting of construction steel AC0113 with the slab cross-section of 1.03 m x 0.20 m was considered. The integrated simulator-optimizer environment presented in the previous reports was used, and the quality function was a weighted sum of the individual metallurgical criteria. Out of more than 20 influential process parameters, 12 spray coolant flows were subject to optimization. Table 1 shows the predefined parameter search space used in the numerical optimization procedure. As there are five values possible for each parameter, the total number of possible parameter settings for this optimization task equals to 5^{12} = 244 140 625.

Table 1: Parameter search space for spray coolant flows in continuous casting of steel AC0113

Spray number	Min. flow [l/min]	Max. flow [l/min]	Step size [l/min]
1	120	160	10
2	65	85	5
3	200	280	20
4	190	270	20
5	160	240	20
6	150	230	20
7	120	160	10
8	140	180	10
9	120	160	10
10	120	160	10
11	130	170	10
12	120	160	10

To test the simulator performance on this task as well as its interaction with the optimization module, an initial series of calculations was done using random search through parameter space. The iterative optimization procedure used. The calculations were run on a 1.8 GHz Pentium computer and the execution time to evaluate a single solution through numerical simulation was 2.5 minutes. Figure 1 shows the trace of the search procedure. Note that the task is to minimize the cost over possible parameter settings and the search results are compared with the manual setting previously used in practice. The random search results indicate that better settings can be found and can be used as a lower bound for any other optimization procedure.

Subsequently, the coolant flows were optimized with the evolutionary algorithm (EA) which is currently the core optimization technique of our simulator-optimizer environment. The EA used real vector representation of candidate solutions and operated in the steady-state mode with the population size of 20 solutions. The operators involved to select and vary candidate solutions were tournament selection, multi-point crossover with probability 0.8, and uniform mutation with probability 0.05.

The optimization procedure was tested both for the solution quality and repeatability of results. As shown in Figure 2, the resulting solutions consistently outperformed the manual setting of the spray coolant flows. Furthermore, despite its stochastic nature, the evolutionary procedure was able to find solutions with minimum deviations of both coolant flow settings and their cost values. Table 2 provides the results and compares them with the manual setting. It turns out that the resulting coolant flows are generally higher than manual settings for the first half of the sprays in the secondary cooling zone and lower in the ending section of the secondary cooling zone. The obtained settings are now under evaluation for practical use at the plant.

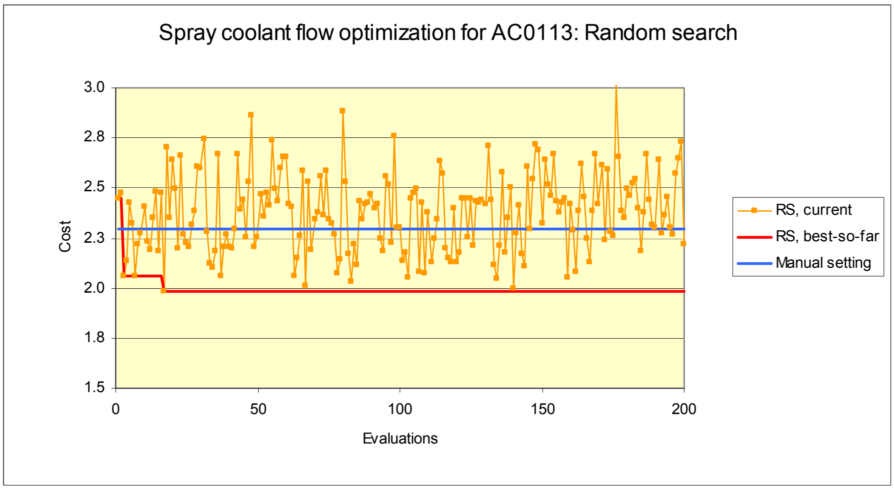

Figure 1: Random search for improved coolant flow settings

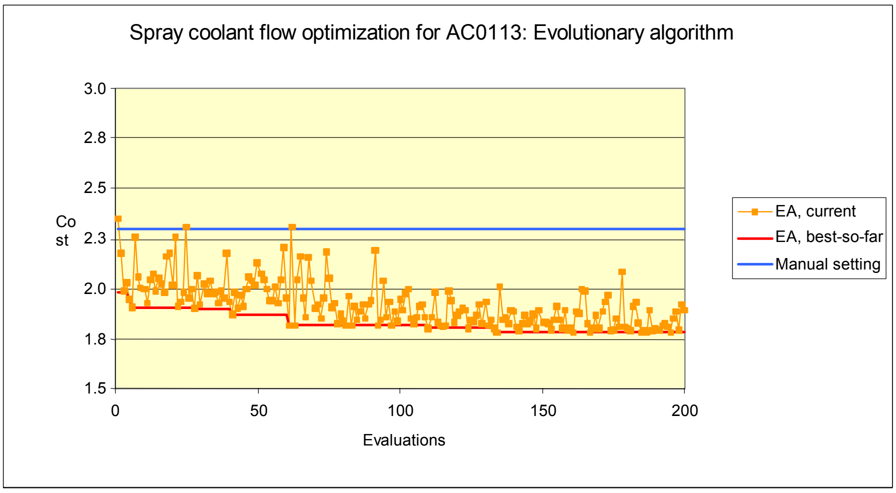

Figure 2: Evolutionary optimization of coolant flow settings

Table 2: Optimized coolant flow settings compared with manual setting

Solution	Coolant flows [l/min]											Cost (*f*)
Manual	140	80	240	230	200	190	140	160	140	140	150	140	2.3068
EA run 1	140	85	280	250	220	230	140	140	160	120	130	120	1.8587
EA run 2	140	85	280	250	240	230	140	150	150	120	130	120	1.8647
EA run 3	140	85	280	250	220	230	140	150	160	120	130	120	1.8614

This work will continue in two directions. First, additional numerical optimization algorithms will be applied and possibly hybridized in order to find near-optimal solutions and at the same time requiring the lowest possible number of time-consuming process simulations. Second, the methodology will be applied to further instances of the parameter optimization problem in continuous casting of steel relevant to our industrial partner.

7. List of publications

a) Published

B. Filipic: Numerical optimization of coolant flows in continuous casting of steel. In B. Sarler, D. Gobin (Eds.), *Heat and Mass Transfer in Solid-Liquid Phase Change Processes: Proceedings of the Seminar Eurotherm 69,* Ljubljana, Slovenia. Nova Gorica Polytechnic, 2003, pp.180–185.

b) Submitted for publication

c) In preparation

B. Filipic, T. Robic: A comparative study of coolant flow optimization for a steel casting machine.