COST 526

**"Automatic Process Optimization in Materials Technology"**

(APOMAT)

## Half-Yearly Report

| **1. Reporting Period** | **1.1.2003 – 31.07.2003** |
|---|---|
| Project title | Optimization of cooling parameters in continuous casting process |
| Project leader | **Dr. Erkki Laitinen** |
| Organization | University of Oulu, dept. of mathematical sciences<br>P.O. Box 3000<br>90014 UNIVERSITY OF OULU |
| Main collaborators involved | Helsinki Univ. of Technology, lab. of metallurgy, Finland<br>Lab. for multiphase processes, Nova Gorica Polytechnic, Slovenia<br>Josef Stefan Institute, dept. of Intelligent Systems, Slovenia<br>Banki Donat Polytechnic, Dept. of Material sci. and Tech., Hungary<br>Rautaruukki steel company, Finland<br>Outokumpu steel company, Finland |

| **2. Funding Situation** | |
|---|---|
| Amount of money received specifically for COST | 0 kEuros |
| Other resources partially used for the project | 100 kEuros |

| **3. International Collaboration**<br>(mention group and type of work done in collaboration during the reporting period) |
|---|
| Participation in the Working Group Meeting in Brussels + project progress report<br>**X** YES<br>❒ NO |
| Prof. Alexander Lapin, Kazan State University, Russia.<br>Collaboration on numerical methods for solving continuous casting problem. |

| **4. Industry participation**<br>(mention name of companies and work done in collaboration during the whole project) |
|---|
| Rautaruukki steel, Finland:<br>The new dynamic secondary cooling program for controlling cooling water flow rates is installed at casters 4, 5 and 6 at Rautaruukki steel works. The work of Rautaruukki consists of making required process communication for control program. |

| **5. Meetings, visits, exchange of scientists, short-term scientific missions** | **Location, date** |
|---|---|
| <u>Visits:</u><br>Prof. A. Lapin, Kazan State Univ., Russia<br>Prof. A. Lapin, Prof. R. Dautov, Kazan State Univ., Russia | <br>Oulu, Finland, January, 2003<br>Oulu, Finland, May, 2003 |

| | |
|---|---|
| Conferences:<br>DD15 Int. Conf. on Domain Decomposition Methods,<br>Num. meth. for Cont. Casting and Related Problems<br>EUROTHERM 69<br>STSM | Berlin, Germany, July 2003<br>Kazan, Russia July 2003<br>Ljubljana, Slovenia, June 2003<br>Ljubljana, Slovenia, June 2003 |

## 6. Progress within the reporting period

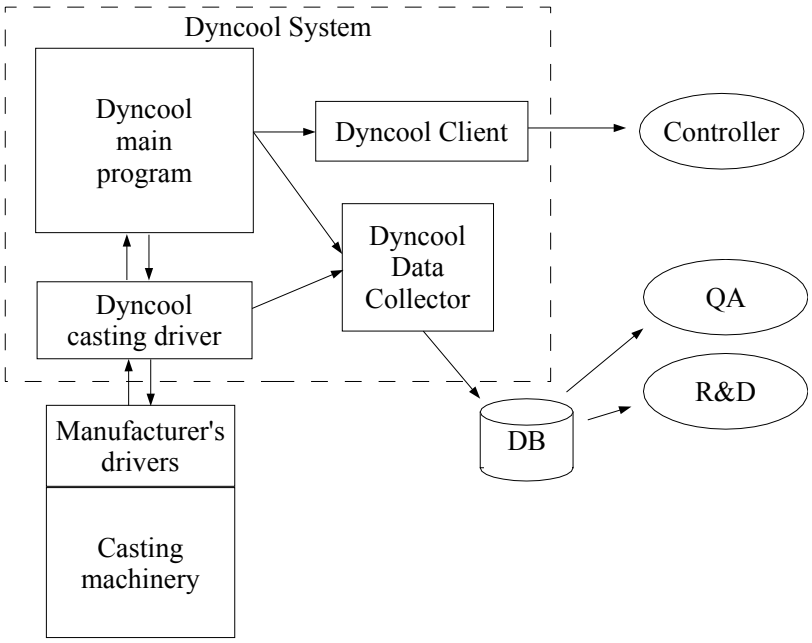
(Not exceeding 3 pages, including tables and figures)

During the last half year we have worked for developing:

- Dyncool software for controlling water cooling in continuous casting process
- 3-dimensional, real-time, simulation model for simulating temperature field of cast
- Optimization strategy and method for controlling water cooling

**The main progress of Dyncool software.**

Dyncool software is under industrial tests at Rautaruukki steel works. The interface between dyncool casting driver and manufactures driver has been determined in order to program the 3D communication between Dyncool driver and manufacture's automation driver.

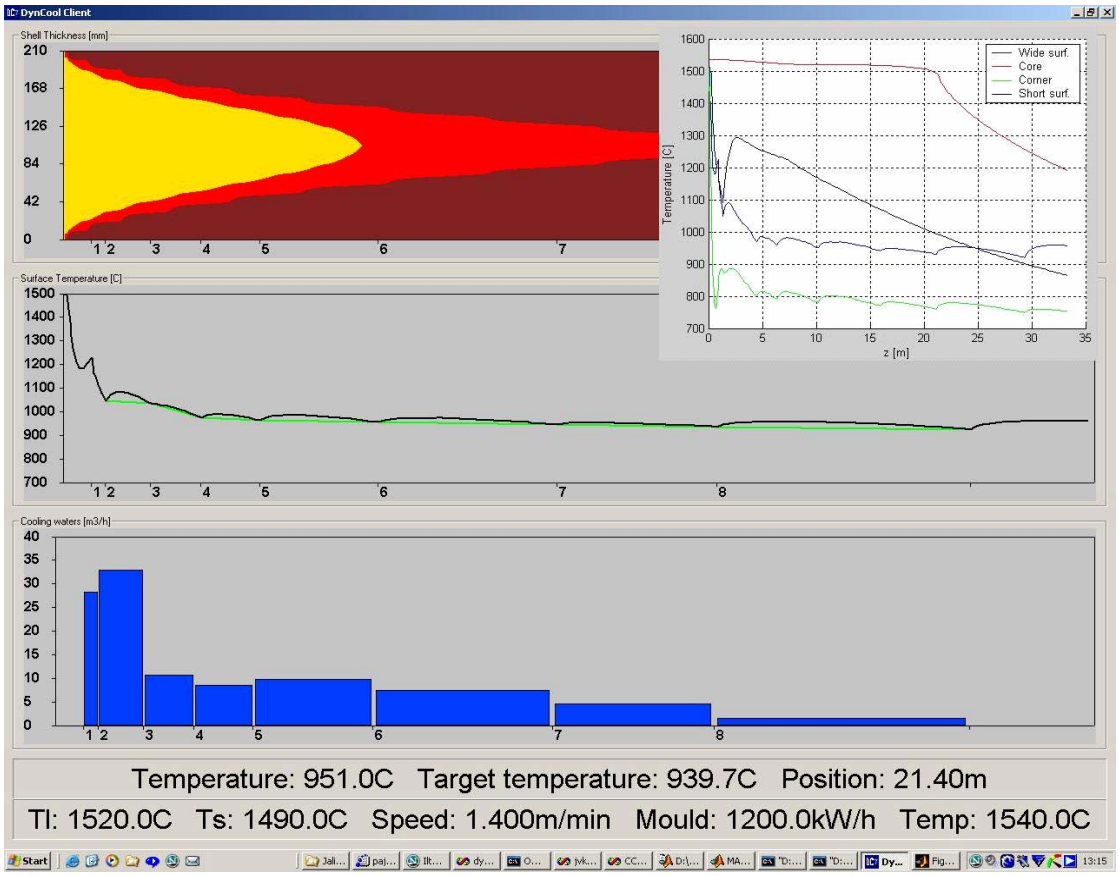



**DYNCOOL OVERVIEW**

- Dyncool analyses process and controls water cooling.
- Dyncool provides information about the state of the casting process.
- Dyncool is a tool for gathering information.
- Dyncool assists casting operator by visualizing the conditions inside the slab.
- Dyncool assists in quality assurance and development by providing data about the casting process.
- Dyncool provides flexible process control.
- Dyncool is a tool for metallurgical development research.

**The main progress of 3D simulation model**

The 3D simulation model is tested off-line. The real boundary conditions for 3D model has been defined. The interface between Dyncool main program and Dyncool client has been defined. The 3D model has not yet been tested on line.




Dyncool Client visualises the casting process.

- temperatures inside the slab, liquidus and solidus isotherms
- surface temperatures, midface and corner (3D)
- current cooling water amounts
- prosess parameters: mold cooling, casting speed, solidus, liquidus, casting temperature

**The main progress of optimization model**

The objective of quality function is to avoid surface and internal cracks of cast. The cast is sensitive for cracks near the so called A3-temperature.
The design of quality function is based on the calculation of A3-temperature for different steel grades. The quality function is designed such, that the desired surface temperature of cast don't decrease below the A3-temperaure. The work for calculating the A3-temperatures for different steel grades will be done until the end of this year at Helsinki University of Technology, dep. of metallurgy.

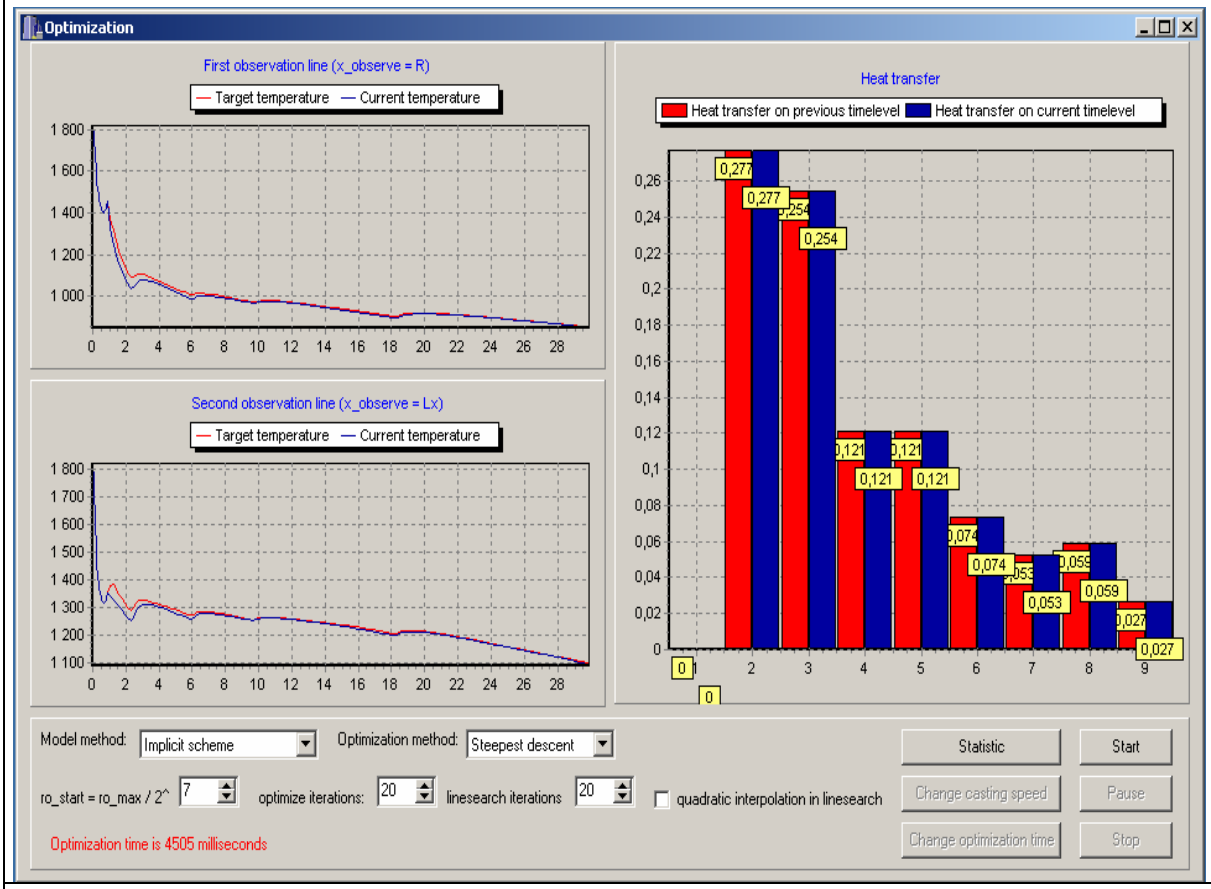
The quality function is defined mathematically as follows:

$$\begin{cases} J(T) = \frac{1}{2}\int_0^{L_z} \left(T - T^{tar}\right)^2 dz \\ J(T) = \frac{1}{2}\sum_{i=1}^{N_z} \hbar_z^i \left(T(z_i) - T^{tar}(z_i)\right)^2 \end{cases}$$

where target solution $T^{tar}$ is a vector of the desired values for the temperature field along **observation lines**.

**Two optimization algorithms has been used:**

- steepest descent method with constraints
- conjugate gradient method with constraints




## 7. List of publications

a) Published

Laitinen E., Lapin A., Pieskä J.: "*Asyncronous domain decomposition methods for continuous casting problems*", J. of Comp. and Appl. Math., 154, pp. 393-413, **2003**

Laitinen E., Pieskä J., Toivonen J.: "On 3D-Modelling and Control of Continuous Casting Process", in proc. of EUROTHERM 69, Heat and Mass Transfer in Solid-Liquid Phase Change Processes, June 25-27, **2003**, Ljubljana, Slovenia

Toivonen V., Pieskä J., Laitinen E.: "On optimal control of secondary cooling in Continuous Casting process", in proc. of Numerical methods for Continuous Casting and Related Problems, Kazan, Russia July 11-15 **2003**

Laitinen E., Lapin A., Pieskä J., *Predictor-Corrector methods for solving continuous casting problem*, Proceedings of the DD15 International Conference on Domain Decomposition Methods, Berlin, Germany July 21-25 **2003**

Lapin A., Pieskä J., On the parallel domain decomposition algorithms for time-dependent problems, Lobachevskii Journal of Mathematics, Vol. 10, p. 27-44, 2002 . http://ljm.ksu.ru/vol10/lpp.htm

Laitinen E., Lapin A., Pieskä J., Asynchronous domain decomposition methods for solving continuous casting problem, Proceedings of the DD14 International Conference on Domain Decomposition Methods, Cocoyoc, Mexico, 2002, p. 459-466

A. Lapin, E. Laitinen, J. Pieskä:"parallel solution of Stefan problem with prescribed convection", in proc. of Parallel Computational Fluid Dynamics, May 13-15, 2003, Moscow, Russia

b) Submitted for publications

E. Laitinen, J. Pieskä and V. Toivonen: ”On 3D Dynamic Control of Secondary Cooling in Continuous Slab Casting Process”, in proc. Of Moving Boundaries 2003, Seventh International Conference on Computational Modelling of Free and Moving Boundary Problems, 4-6 November 2003 Santa Fe, New Mexico, USA.

c) In preparation