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MONITORING AND PREDICTION OF THE LIQUID STEEL TEMPERATURE IN THE LADLE AND TUNDISH

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This article is focused on the description of the main features of an online system for the real time monitoring and prediction of the liquid steel temperature in the ladle and tundish. Monitoring and prediction are based on a combination of analytical and statistical methods. Thus e.g., the temperature profiles of the walls are calculated using multi-layer implicit difference scheme taking into account the current temperature of the steel, preheating of the ladle and/or tundish, properties of the refractories, etc. Liquid steel temperatures are calculated from the heat balance of the heat fluxes into the walls and other losses. The influences of all the processes in the secondary metallurgy are taken into account in this system too. The liquid steel temperature prediction is being made continuously during the processing of steel from the LD converter to the continuous casting.

Key words: *continuous casting, steel temperature, real time monitoring, prediction, control*

Provjera i utvrđivanje temperature tekućeg čelika u loncu i razdjelniku. Članak se usredotočuje na opis glavnih karakteristika online sustava za praćenje u stvarnom vremenu i utvrđivanje temperature tekućeg čelika u loncu i razdjelniku. Praćenje i utvrđivanje temperature se zasniva na kombiniranju analitičkih i statističkih metoda. Tako se npr. temperaturni profili stijenki računaju pomoću sheme višeslojne po sebi razumljive razlike koja uzima u obzir trenutnu temperaturu čelika i predzagrijavanje lonca ili razdjelnika, svojstva obzida itd. Temperature tekućeg čelika se računaju iz ravnoteže topline, fluksa topline u stijenke i drugih gubitaka. Utjecaji tih procesa u sekundarnoj metalurgiji također se uzimaju u obzir u tom sistemu.Utvrđivanje temperature tekućeg čelika se izvodi kontinuirano tijekom prerade čelika od LD konvertora do kontinuiranog lijevanja.

Ključne riječi: *kontinuirano lijevanje, temperatura čelika, monitoring u stvarnom vremenu, utvrđivanje, kontrola*

INTRODUCTION

A few decades ago the process of steel manufacturing virtually quits the melting unit, during which time the ladle was used only to transfer the steel in the cast house. Alongside the melting furnace, only some operations were performed: alloying, deoxygenation and possibly desulphurization. Recent technical progress puts high requirements on steel quality and on the stability of the useable properties of steel. The increase of quality is caused by the requirements for smaller weight and an increase in the reliability of machines and equipment. These goals are very difficult to achieve in a melting plant. An important and necessary factor for a permanent increase in the steel quality is chemical modifications of steel during and after tapping the steel from primary oven, extra-oven or secondary processing of steel in the ladle [1 - 5].

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Secondary metallurgy includes: steel mixing and homogenization, modification of chemical composition of steel, modification of steel temperature, operations at depressurization (vacuum furnace), successful casting of steel and acquisition of information on thermal status of liquid steel during all these operations.

Increasing market demand for a wide variety of steel with strict quality requirements has contributed to the development of new technologies and towards the optimization and automatization of steelmaking. The economic and technical advantages of continuous casting over other conventional procedures have established it as a leading process in the steel industry. An essential factor for the success of continuous casting regarding secondary metallurgy operations is adequate control of the casting temperature. This involves a requirement to control, alongside the composition, the monitoring and control of casting temperature within their limits as well. In previous practice, control of the steel temperature was based on the uniformity of the operations. This uniformity depended on adequate scheduling and handling of the ladle park in the steel plant and all secondary processing together with control of the steel temperature in the ladle and especially in the tundish. The introduction of new steel reheating facilities has significantly improved the flexibility of these operations. However, the target tundish temperatures may not always be achieved. In extreme cases, teeming may be terminated and steel returned back to the steelmaking vessel with consequent disruption to steel production planning. Past technical improvements were also supported by computer simulation models [6 - 10]. It culminated in the development of the on-line model for the real-time calculation and prediction of liquid steel temperature in the ladle and tundish, between the tapping and teeming [11 - 13].

PROCESS MONITORING AND CONTROL

Monitoring and control of the steel temperature requires first of all an integrated information system with all measured information from the blast furnace [14 - 16] and LD converter, through secondary metallurgy to continuous casting, and secondly, an appropriate on-line model. An extensive VAX-based computer infrastructure existed at the East Slovak Steel Works Kosice in 1997 for process

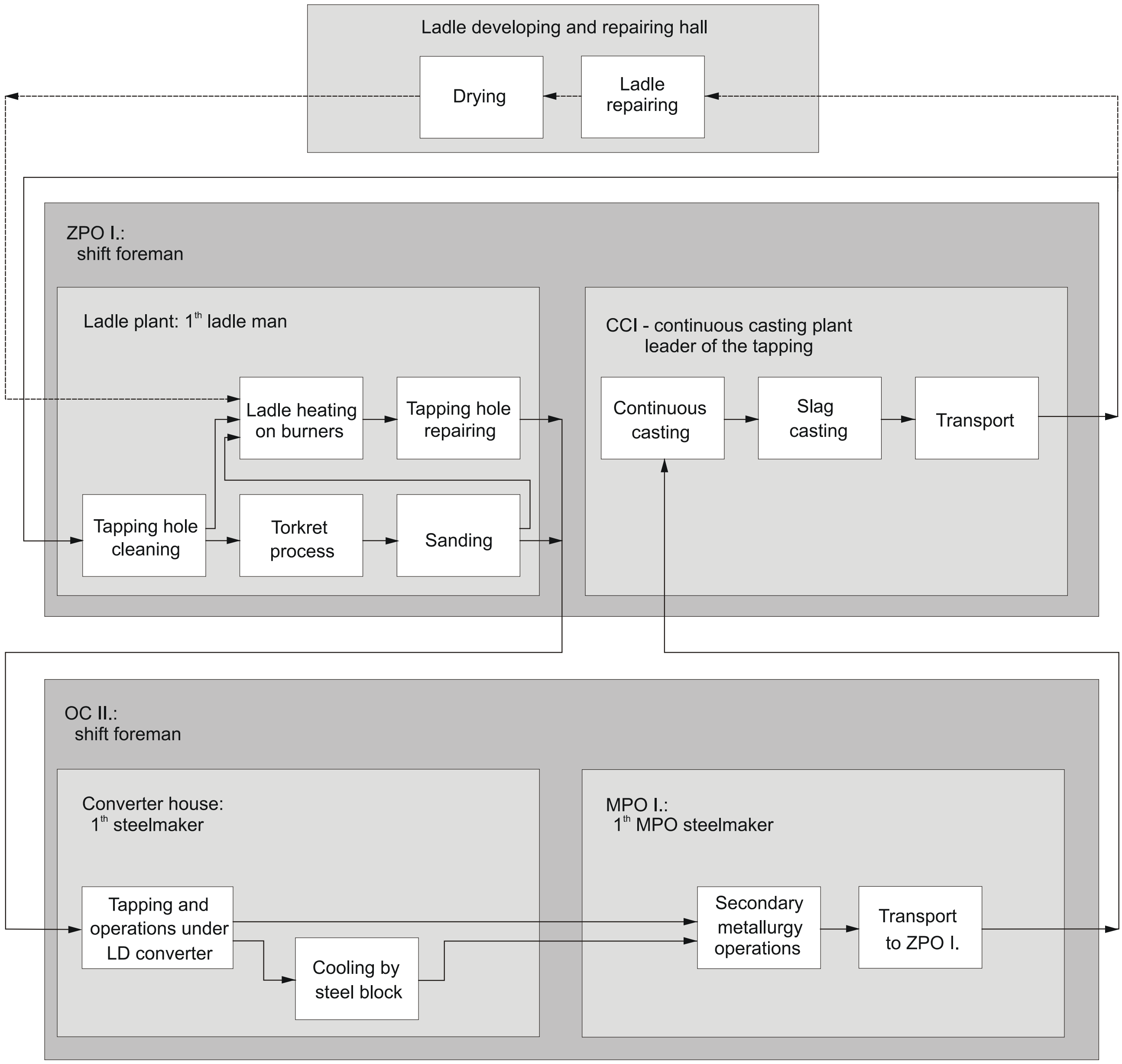

Figure 1. **Ladle life-cycle schedule**
Slika 1. **Shema radnog ciklusa lonca**

monitoring and data collection, including not only the thermal ladle history but also all their life-cycle (Figure 1.). In this environment, a fully integrated on-line system for real-time monitoring, prediction and control of liquid steel temperature in the ladle and tundish, between the tapping and teeming, has been developed.

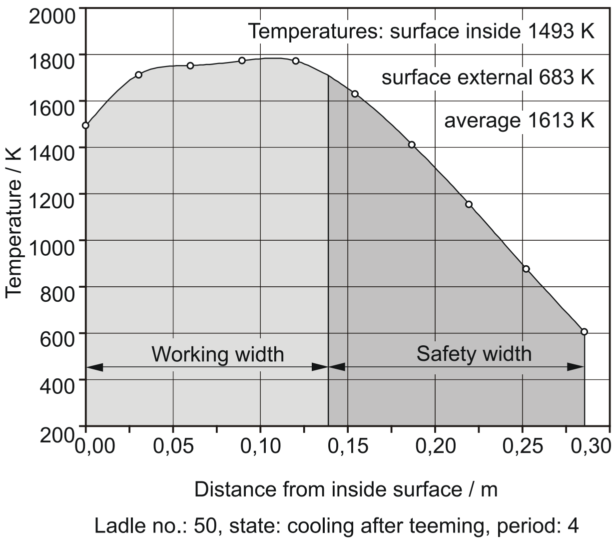

Figure 2. **Ladle lining temperature profile**
Slika 2. **Temperaturni profil obzida lonca**

This on-line system is based upon these basic components:

1. Model for calculating the thermal states of all ladles;
2. Ladle time schedule model;
3. Model for steel temperature calculation;
4. Steel temperature predicting model;
5. Tapping steel temperature predicting model.

Fundamental for all these components is the mathematical simulation model which considers all processes, such as ladle heating and cooling, liquid steel heat losses in the ladle and influences of all secondary metallurgy operations on the steel temperature. Liquid steel loses heat in the ladle however a number of mechanisms have been quantified by several workers [6 - 9, 17] and used to derive a ladle stream temperature with reasonable accuracy. A similar model of the tundish has been derived and used for the steel temperature monitoring and prediction. Further on are described the main features of the models used in this on-line system.

Ladle temperature model

This model includes ladle time schedule model and model for calculating the thermal states of all ladles in operation on plant (Figure 2.). Model takes into account the wear of the ladle refractory materials, ladle heating on burners or by steel heat and also ladle cooling. After calculating boundary conditions, using finite difference method, the heat conduction equation is solved in the multi-layer refractory linings.

Steel temperature model

From the ladle refractory temperatures, radiative [17], conductive and secondary metallurgy operations losses model calculates the resulting changes in liquid steel temperature between tapping and end of teeming (Figure 3.). Other more complex secondary steelmaking treatments are also accounted for in the model.

Predicting models

The first model evaluates the thermal state of the ladle and tundish and the time evolution of the steel temperature between tapping and end of teeming, taking into account

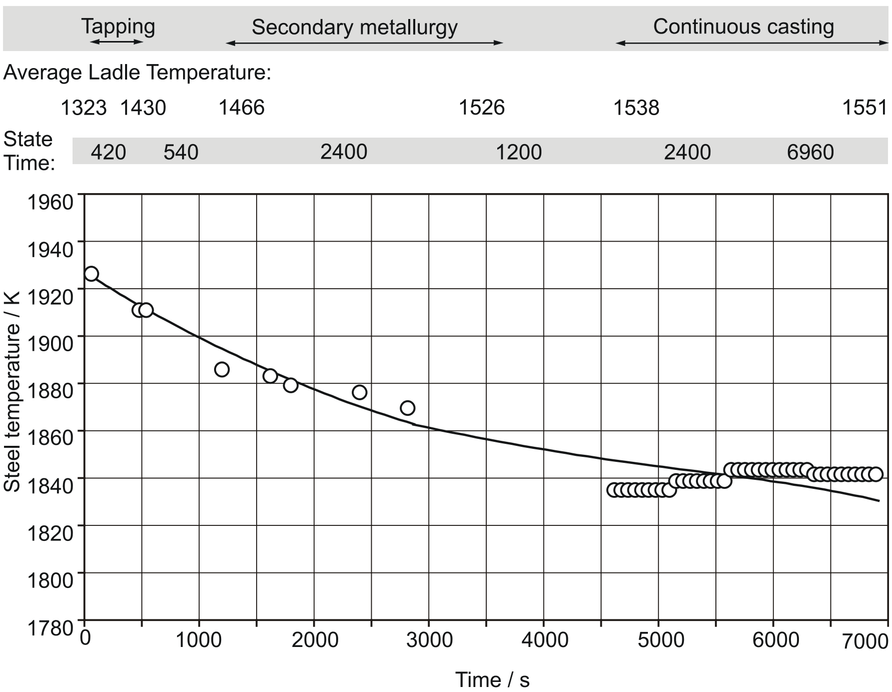

Figure 3. **Ladle and tundish steel temperature between the tapping and teeming**
Slika 3. **Temperatura lonca i razdjelnika za lijevanje između ispuštanja i odlijevanja**

planned operating conditions. Calculations are based on a combination of analytical and statistical methods. During the steelmaking process route the model receives further information about actual events which occur, e.g. argon stirring, degassing, alloying additions made to the ladle. This is used to update the predicted process route and to produce a revised liquid steel temperature flight-path for the remainder of the cast. To validate and adapt the model, predicted steel temperatures are on-line compared with in-plant measurements (Figure 3.). The second model on the basis of actual thermal state and time schedule of all the casts on plant calculates corrected tapping steel temperature for the following cast.

CONCLUSIONS

The described on-line system is still in practice with significant economic gain. The flow of steel form ladle to mould via the tundish was earlier promoted by the higher temperature but the demands of product quality and solidification rate required a lower temperature. The on-line system enabled to control such compromise which gives castability for good yield and smooth operation, good solidification and good quality of the production. Furthermore, plant operators can take any necessary corrective action to ensure the aim final ladle temperature at the start of casting is achieved.

The tundish steel temperature prediction during casting gives casting operators information on the ability to successfully empty the ladle and allows scheduling of the next ladle in the sequence. Minimised is the risk of selecting a thermally unsuitable ladle for a given cast. Optimal preheating of the ladle saves gas usage in preheater. Improving steel quality, reducing steel returns due to temperature problems, reducing tapping temperature, directly reducing the wear rates of both the converter and ladle refractories involve significant economic gain.

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