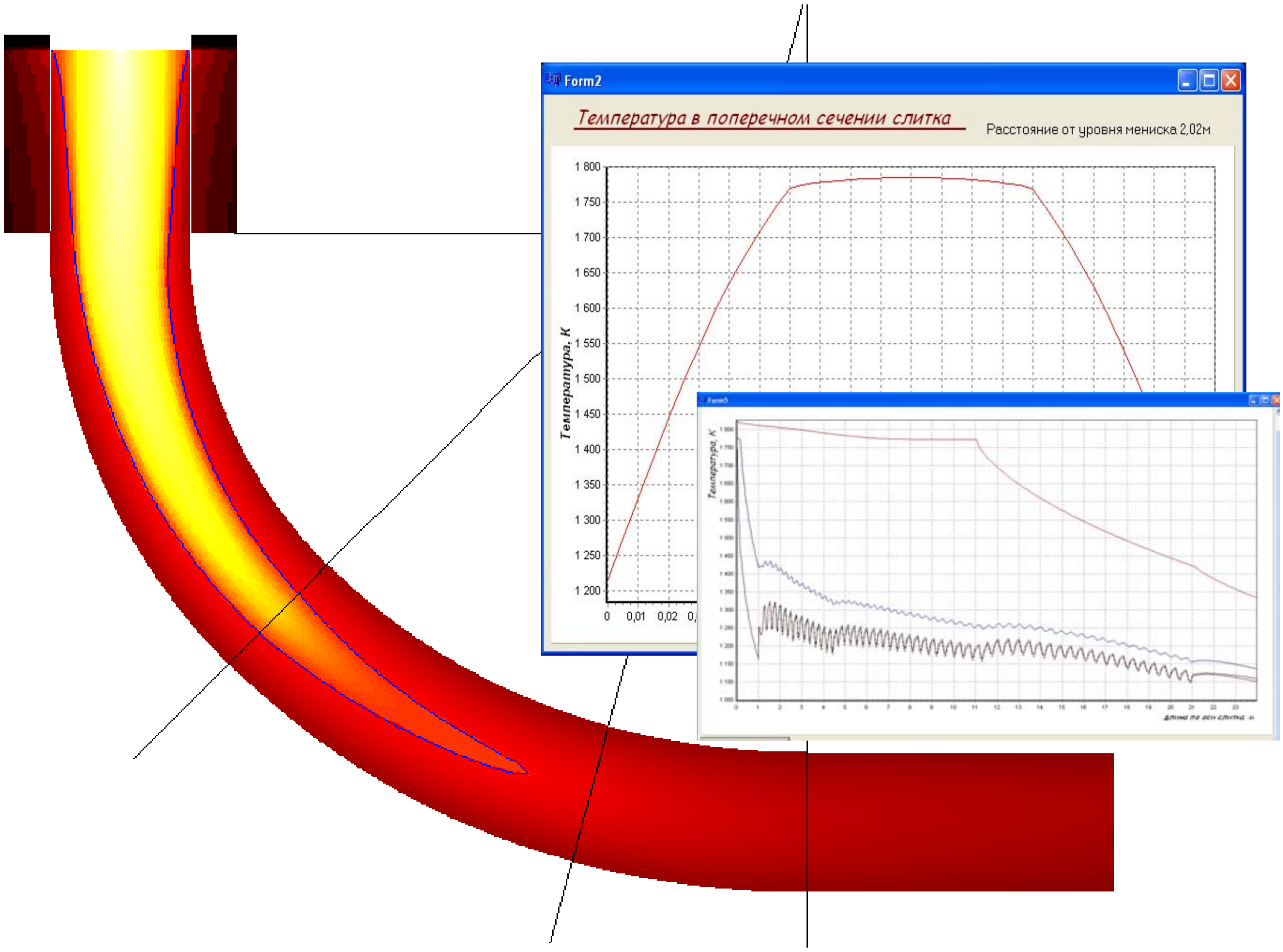
MATHEMATICAL MODELS
OF HEAT AND MASS TRANSFER PROCESSES IN STEEL INGOT
AND HEAT TRANSFER IN THE WALL OF MOLD OF CURVILINEAR CCM

The mathematical models of the quasi-stationary (steady) and the unsteady heat and mass transfer processes in the continuous ingot and heat transfer in the water-cooling walls of the mold of continuous casting machine (CCM) in longitudinal cross-section are developed.

Under given
- geometrical parameters of CCM
- thermal-physical characteristics of steel (density, specific heat, thermal conductivity, etc.),
- the speed of the ingot withdrawal,
- the rate of cooling water for mold and for each section of secondary cooling

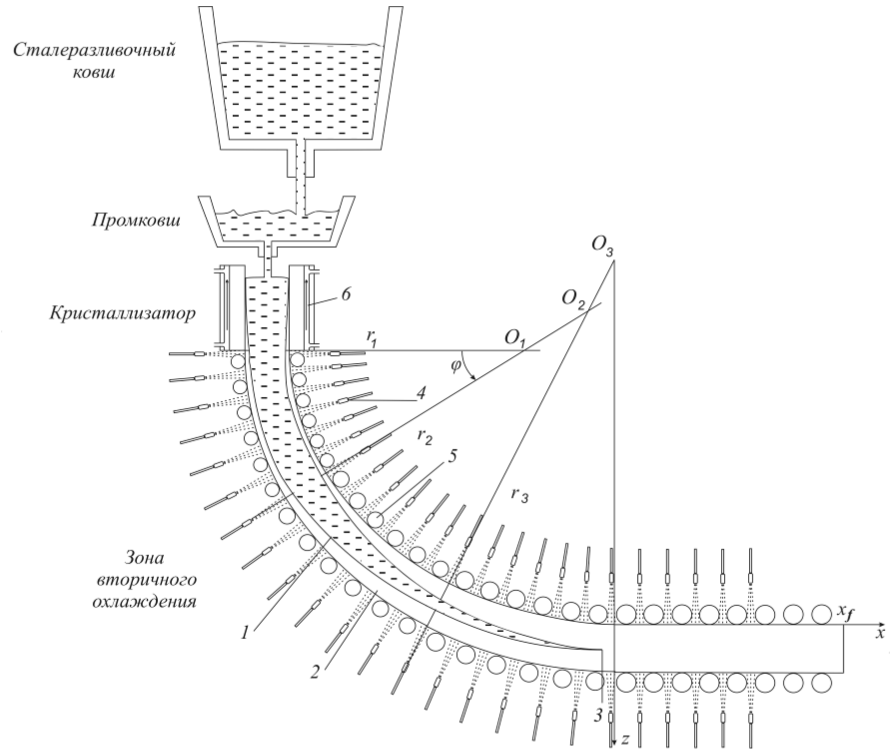
we calculate thermal field and the interface position.

The overall picture of the temperature field is displayed as a color chart. Temperatures inside and on the surface of the ingot are represented in a different graphics.



The program for nonstationary model, allows us to observe the dynamics of the temperature field, temperature gradients and form of the liquid pool under the changes of cooling water rates in the mold and/or any sections of secondary cooling, the temperature of the incoming melt and the speed of the ingot withdrawal.

The mathematical models describe the thermal field and the position of the interface in the longitudinal section of a wide slab, which is parallel to the narrow faces and passes through the middle of the wide faces. The zone of secondary cooling has a complex geometric form - it contains a straight section and curved sections of different curvature.



Since the thermophysical parameters depend on temperature of incoming cast metal and copper material of the wall of the mold, the description of processes of heat transfer and heat and mass transfer based on the nonlinear transient partial differential equations. For curved sections, these equations are written in polar coordinates for most accurately describe the geometry of the ingot. The position of unknown phase boundary is given by the conditions of equality of temperatures and Stefan conditions for the two-dimensional case.

The boundary conditions for the wide faces of the ingot in the mold take into account the air gap between the mould walls and the surface of the ingot.

The temperature of cooling water in the channel of the mold is described by the balance equation, which establishes the relationship between water temperature at the entrance of the channel of the mold, the temperature distribution in the copper wall and the temperature distribution in the channel of the mold.

The boundary conditions for the wide faces of the ingot in the secondary cooling zone take into account convective and radiant heat transfer components, as well as the dependence of the ambient temperature and heat transfer coefficients on the location of nozzles and water flow in them. The heat transfer coefficient on the surface under the torch nozzle has the parabolic law of distribution.

To solve these problems the special algorithms and software are developed. It allow to observe the temperature field of the ingot at any time and find the position of the interface directly from the of Stefan conditions.

To **adapt the mathematical models** to real conditions the problems of **initial and operative adjustment** of the coefficients of heat transfer on the surface of the ingot in the secondary cooling zone are solved.

The algorithms of **model based control of secondary cooling water rate** modes, using the ingot temperature state estimate as the feedback are developed.

The **simulation model** of control of secondary cooling water rate modes is developed. It allows estimating the accuracy of the various control methods during the CCM control system design.

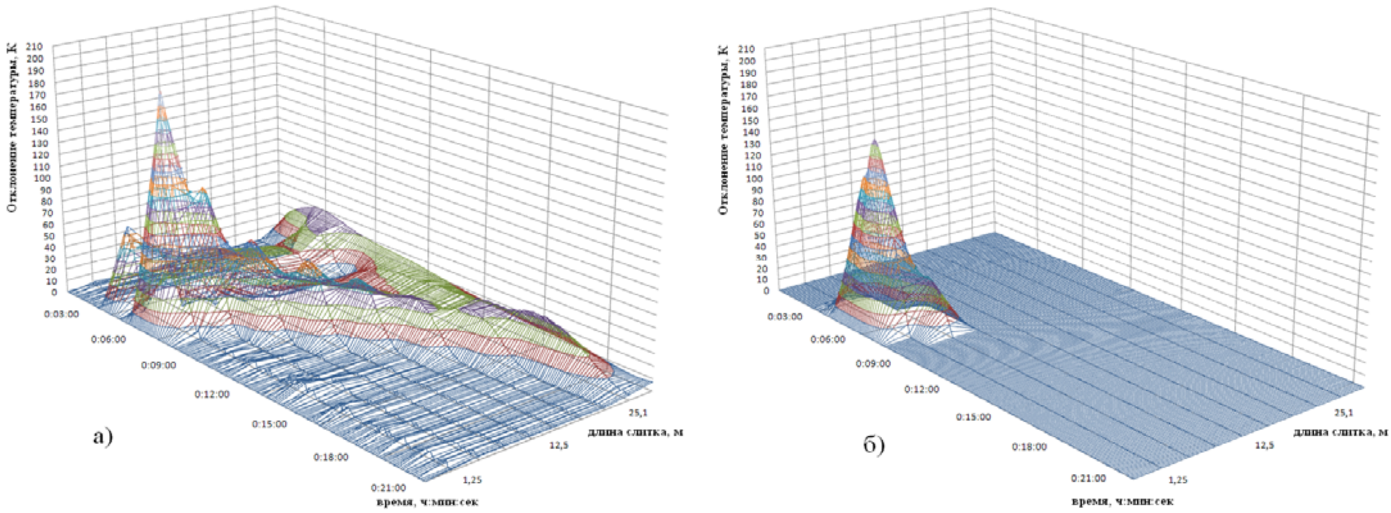


Fig. Discrepancy of the thermal regime: a) open-loop control, b) model-based control.

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