Automated Control System for the Thermohardening of Reinforcement at a 350 Mill

K. Yu. Eismondt, D. V. Zavgorodnev, E. V. Nekrasova, V. G. Lisienko, V. V. Kuchmasov, V. I. Solov’ev, and S. V. Korzhavin

OAO VNIIMT, Yekaterinburg, Russia
Ural State Technical University, Yekaterinburg, Russia
OOO Uralsoft, Russia
OAO Severstal, Russia

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In 2005, a device for thermohardening reinforcement was introduced at the 350 mill in the bar-rolling shop at OAO Severstal. The device, which was developed by OAO VNIIMT, with the assistance of the VNIImetmash design department and OOO Uralsoft, is intended for the production of reinforcement of periodic profile 25–40 (class At500S according to the STO ASChM7-93 standard) from regular steel.

The device includes a thermohardening unit, consisting of seven water-cooling sections and a water- and air-distribution system, a push-rod system, and an autonomous high-pressure pumping system. All the components have their own control systems. The cooling sections are introduced in the line of the mill only when rolling thermohardened reinforcement; section 1 is installed at cell 13, while sections 7-1 and 7-2 are introduced beyond a switch and are parallel to the exit-conveyor line. The push-rod units are between section 6 and the switch.

Guaranteed stability of the mechanical properties of the reinforcement during thermohardening by the rolling heat entails very precise maintenance of the final cooling temperature and the rate of temperature variation during accelerated cooling. In view of the high rolling rate, it is hard to satisfy these conditions in manual control. Given that the thermohardening unit must match the rhythm of the finishing group in the mill, a constant stream of information is required regarding the rod diameter, the rolling rate, the cooling conditions, and other factors. To meet the technological requirements on the thermohardening of reinforcement, the device is equipped with an automatic control system.

The automatic control system is charged with the following tasks: adjustment of cooling in accordance with the rolled product; ensuring effective operation of the unit by real-time control of the process, determining and maintaining the cooling conditions, establishing the temperature state of the rolled metal after cooling in the unit, and introducing corrections as necessary; monitoring, visualization, and storage of the technological parameters; and information support, in collaboration with adjacent automatic control systems.

The system is characterized by many input signals from the object and output control signals to the executive mechanisms (more than 750 variables); analysis of the copious input information and coordination of the unit’s operation pose considerable challenges. In addition, some functions may be performed practically independently. The brief cooling time in the thermohardening unit (5–8 s) imposes rigorous demands on control-system operation, such that all of the subsystems cannot be integrated within a single control computer. Accordingly, a two-level structure is adopted. The lower level is responsible for measurement, monitoring, and direct control on the basis of specifications from the upper level or the operator of the thermohardening unit, as well as intermediate analysis of the information obtained and information transfer with the upper level. The upper level is responsible for ongoing dispatcher control of the automated device as a whole, calculation of the specifications for the lower-level subsystems, display of information for the operating staff, the generation of warning signals, and information storage (Fig. 1).

At the lower level, a Simatic S7-400 programmable controller analyzes the monitoring and measurement signals, undertakes diagnostic and control functions, ensures data transmission in one-time or group mode, and communicates with adjacent systems of the automatic control system. Simatic ET200M multifunctional distributed input–output stations communicate directly with the executive mechanisms and the sensors. Information exchange between the controllers and the peripherals is by means of a Profibus-DP Network.
At the upper level, a PC 870 Box industrial computer calculates the specifications for the lower-level subsystems from a mathematical model; ensures display, development, and debugging of new technological conditions; and collects, analyzes, and archives expanded information on the technological process during research and debugging periods. Communication between the upper and lower levels is by means of a Profibus-DP network, which also ensures communication of the automatic control system for the thermohardening unit with adjacent and higher-level control systems.

Problems solved at the lower level of the automatic control system include temperature measurement of the rolled metal before and after accelerated cooling; tracking of its position between the last operating cell, the thermohardening unit, and the roller conveyer of the cooling unit; measurement and adjustment of the water flow rates; switching on and off of the water supplies and the air and water supplies in localized cooling sections; diagnostics and warnings regarding emergencies; and information exchange with the upper level and with adjacent automatic control systems. Tasks at the upper level include real-time operation of the mathematical model of cooling and parameter correction; display of the technological process; the formation of control commands for the lower-level systems; analysis and storage of information on the operation of the thermohardening unit and cooling of the rolled metal; and the formation of a database of cooling conditions.

The automatic control system is adjacent to the rolling control system and the pumping control system and is below the control system for rolled-metal production in the shop. (Provision is made for the supply of information from this higher control system on the range of rolled products to be supplied to the thermohardening unit, by means of a network at the controller level.) Information on the speed of the rolled metal in cell 12 and transportation by the push-rod units may be obtained from the rolling control system.

The control board is equipped with an industrial computer, which displays the process parameters and information on the current state of the equipment in the thermohardening unit. In the General View window of the monitor (Fig. 2), information regarding the selected cooling conditions and the results of cooling is displayed: information on the rolled metal; the numbers of the operating sections; the actual speed of the rolled part; the metal temperature and maximum temperature before and after cooling; and the readings of the sensors
detecting the presence of metal. Other windows provide information on the specified and actual water flow rates in the sections, the operation of the equipment in the thermohardening unit, the temperature variation over time and over the length of the rolled part, and so on.

The modeling software permits the prediction of the parameters of accelerated rod cooling from the specified initial data. The following calculation results are shown on the monitor of the control board: the technological speed of the reinforcement through the thermohardening unit; the cooling rate of the rolled reinforcement; and its surface temperature in the pyrometer-viewing zone ahead of the thermohardening unit, which is in the immediate vicinity of the last operating cell, and also in the zone beyond the thermohardening unit, at a distance of 30 m from the last section of the device.

The system may operate in various modes. In automated direct-control mode, the automatic control system acts on the executive mechanisms of the thermohardening unit; these actions are displayed on the operator monitor. The information required for the generation of control signals is sent to the automatic control system of the thermohardening unit from adjacent automatic control systems or is input by the operator. In this mode, control of the thermohardening equipment and calculating of the cooling conditions may proceed independently. In direct control, the proposed flow rates are sent automatically as specifications to the controller. In automated operator mode (startup and adjustment mode), the automatic control system supplies information regarding the thermohardening unit, but the operator selects and implements the control actions. In operator mode, specifications, flow-rate values determined by means of the mathematical model, or the actual values of these parameters may be transmitted to the controller.

Direct and operator control may be divided, in turn, into preliminary and working stages. The preliminary stage includes all the operations associated with adjusting the thermohardening unit for processing a specified batch of metal. The working stage encompasses control of the cooling process. Simultaneous implementation of both stages is impermissible.

The automatic control system employs standard Step7 (V5.3) and WinCC (V6.0) software for upper- and lower-level equipment and FoxPro database control software. The mathematical model is written in the programming language C++ and activated by means of WinCC functions.

Before processing the batch of metal, information on the rolled parts, the final cooling temperature, and other parameters is supplied by the rolling control system. Depending on the technological requirements, the thermohardening control system selects the particular sections to be switched on and determines the water flow rate for each. The calculation is based on an algorithm developed at OAO VNIIMT, which implements a mathematical model of cooling.

The accelerated-cooling conditions are determined by means of the one-dimensional differential heat-conduction equation, with boundary conditions of the second and third kind. The conditions are specified on the basis of formulas for the heat-flux density as a function of the irrigation density on cooling; these formulas are derived at the startup and adjustment stage. In operator control, the basic control parameter is the water flow rate in the sections operating during thermohardening.

After the reinforcement leaves the thermohardening unit, the actual final cooling temperature is measured. If this value differs from the specified value for five successive rods, a correction to the water flow-rates in the sections is calculated and introduced. At the end of thermohardening, a file describing the treatment profile, with all the necessary information, is added to the database.

The technological staff has the option of using the mathematical model of cooling in Consultation mode. This permits staff training, preliminary estimates, and calculation of the heat-treatment parameters for accelerated cooling, quenching, and experimental treatments. The initial data for the calculation are specified by the technological staff; the results are shown on the display screen.

CONCLUSIONS

An automatic control system has been developed for the device used to thermoharden reinforcement in the line of the 350 mill at OAO Severstal’s bar-rolling shop. The automatic control system permits monitoring and control of the thermohardening process and the equipment. The system consists of two levels, each of which performs particular functions. The system may operate
in two basic modes. In automated direct control, the operator only intervenes in exceptional cases; in operator mode, some tasks are performed automatically, and the remainder by the operator. For maximum flexibility of control, the list of tasks to be performed may be adjusted by the operator.

The autonomous thermohardening control system is integrated into the overall control system for the rolling-mill line and exchanges information with higher-level and adjacent systems. Display of the process and equipment parameters permits control of the thermohardening unit as a whole and each of its executive mechanisms. The mathematical model operating at the upper level of the thermohardening control system permits real-time implementation of the cooling systems for each batch of reinforcement. Operation in Consultation mode permits simulation of the cooling process in any specified conditions.
OJSC Scientific-Research Institute of Metallurgical Heat Engineering (VNIIMT) established in 1930 as Ural Division of All-Union Heat Engineering Institute is widely known in Russia and the CIS. The Institute focuses on development of high-technology heat engineering units, energy efficient and ecologically friendly technologies in ferrous and non-ferrous metallurgy, machine-building and other fuel-consuming branches of industry.

Highly-qualified academic researchers, unique experimental and production facilities and own research and design centre enable efficient scientific-and-research, design-and-experimental, engineering and project works, delivery of equipment, designer's supervision and commissioning works including execution of turnkey contracts in the following areas:

**Sintering:**
- development of techniques and modes of metal raw material heat treatment;
- design of energy-efficient agglomeration hearths and agglomeration gas heat recovery circuits allowing to reduce energy consumption and dust and gas emissions.

**Pellet production:**
- optimal traveling grate pelleting furnaces for heat treatment of iron-ore pellets from various concentrates (hematite, magnetite, etc.) with optimal automatic process control system.

**Preparation of metallic and nonmetallic raw materials:**
- technique of iron-ore raw material dephosphorization by roasting and leaching;
- installations for drying high-moisture dispersive materials of various designs;
- efficient techniques of magnetizing roasting and subsequent dressing;
- technique of rare-earth element extraction (for example, germanium from germanium iron ores).

**Blast-furnace ironmaking:**
- explosion-proof near-furnace systems of blast furnace slag granulation giving a high-quality product for cement production;
- optimal control system for hot blast stoves;
- an innovative bench for drying hot metal and steel-smelting ladles;
- copper coolers and tuyeres of blast furnaces.

**DRI (direct reduction of iron)**
- improvement of the reduction technique in shaft furnaces for radical improvement of technical and economic indicators of their operation (productivity is increased twice);
- technique of raw material reduction in rotary furnaces using coal as the reductant.

**Lime production:** development of the technique and increase of lime production process efficiency:
- in shaft furnaces;
- in double-shaft furnaces;
- in rotary furnaces;
- in “stacked-tower preheater - rotary furnace” installations;
- in “shaft calciner - rotary furnace” installations (VNIIMT innovative technology).

**Granulation of metal melts:**
- development of technologies and designs of explosion-proof plants for near-furnace granulation of metallurgical slag, molten metal, etc., including heat recovery;
Reheating furnaces:
• development of new and update of the existing designs of furnaces for stock heating;
• high-performance systems of reheating furnace firing with recovery and regeneration firing systems based on the innovative burner units designed by VNIIMT;
• switching the furnace firing systems to cheaper fuel types;
• development and implementation of optimal furnace operating parameters.

Heat-treatment furnaces development of techniques and equipment for heat treatment of roll stock and metal products including those with protective atmospheres:
• thermochemical treatment conditions ensuring retention or directional change in chemical composition of metal surface;
• gas dampers for heat-treatment furnaces;
• spray quenching units and other elements of convective cooling systems;

Furnaces with protective atmosphere and gas treatment units:
• development of the furnace structure, design, manufacture, delivery and commissioning works;
• development of a technology for treatment of articles and devices for protective gas generation;
• calculation, development and manufacture of endogas and exogas atmosphere generators for metal product thermochemical treatment units;
• gas analysis systems for monitoring and control of physico-chemical properties of protective process atmospheres.

Reheating, heat-treatment and drying furnaces with convection heat transfer:
• development, design and manufacture using industrial heat-resistant (up to 900 °C) furnace fans designed by VNIIMT.

Rolled products:
• techniques and units for controlled high-speed air-to-water cooling (quenching) of rolled ferrous and non-ferrous metal products including thick plate on mill 5000;
• replacement of oil quenching technology with VNIIMT's eco-friendly air-to-water technique;
• innovative technique of oily mill scale processing;
• line of wire rod accelerated air cooling with process improvement.

Manufacturing manufacture and delivery of:
• high-performance burner units;
• heat-resistant (furnace) fans (up to 900 °C);
• copper coolers for blast furnaces and nonferrous furnaces based on VNIIMT technology;
• Pitot tubes for measuring flow rates and pressures.

OJSC VNIIMT developments are widely used in metallurgical enterprises of Russia, Ukraine, Kazakhstan, China, India and others.
For detailed information on institute developments, please visit OJSC VNIIMT site at www.vniimt.ru