COOLING CONTROL FLAT-ROLLED PRODUCTS

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Received 07 July 2016
Accepted 15 December 2016

ABSTRACT

Results of the comparative analysis of two ways of flat rolling products cooling control are presented: water nozzle and roller contact cooling.

Keywords: ingots, sheets and strips, continuous casting machine, hot rolling mill, roller cooling of flat metal, controlled cooling.

INTRODUCTION

Hot-rolled flat-rolled products include sheets and strips. The production of sheet and strip at modern metallurgical plants begins in continuous casting machines (CCM), which continuously cast slabs produced. Further rolling of the slabs is carried on hot strip mills (HSM). The rolled sheets and strips are heat-treated in roller-hardening machines. All three stages of metal processing combine the need for cooling to obtain various properties of finished products [1 - 4].

In this paper we present the qualitative results of the comparative analysis of different methods of cooling metal control - both taking place in practice and promising (perspective).

Cooling in the production of continuously cast slabs in CCM

In the process of casting in continuous caster, molten steel is poured into a water-cooled form called crystallizer. The mold harden only the surface layers of the metal ingot to form a solid shell that retains the liquid phase along the central axis (Fig. 1). Receipt of the liquid metal into the mold is continued, and the ingot is continuously increasing. For the mold is a secondary cooling zone, also called the second crystallization zone. In this area the result of the forced surface cooling, the workpiece is solidified along the entire cross section. This process is a method for producing ingots of unlimited length. The main trends in the development of CCM used to increase the casting speed, improving the quality of continuously cast slabs, reduction of costs. The basis of the continuous casting control optimality criteria are realizing these trends.

The quality of continuously slab ultimately determines the quality of the finished hot-rolled strip, but continuous casting of steel currently is the least informative and the controlled process in the production chain. This is due, primarily, to the difficulty of getting into the production environment of reliable information about the heat and the phase state of the ingot in the zone of secondary cooling of CCM and largely due to imperfection of adopted means of cooling the ingot, namely the nozzle of the water cooling system. It should be noted that the cooling nozzle undoubted advantage – the possibility of significant heat removal from flat metal surfaces, followed by a number of disadvantages, the main of which are:

- uncontrolled and uneven heat, different refrigerant behavior at small and large radii CCM;

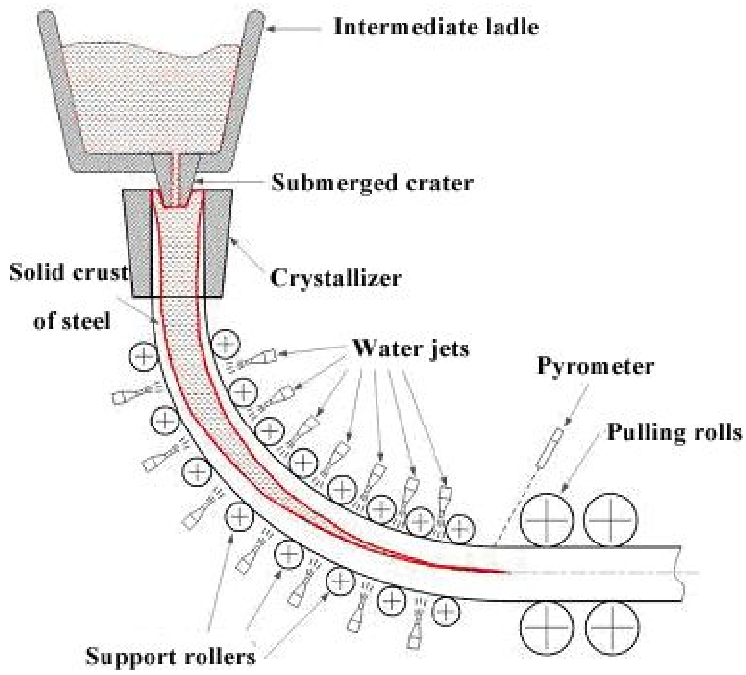

Fig. 1. Scheme cooling the ingot in a continuous casting machine.

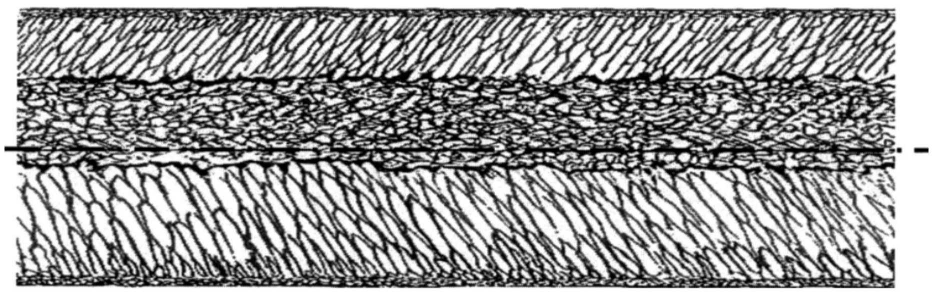

Fig. 2. The cross-section of continuously cast slabs, the cast on radial CCM.

● intensive evaporation, difficult to control the state of the ingot and lead to significant pollution of the working area with steam, dust and scale;

● permanent non-renewable loss of refrigerant, pollution of its by salts and dust, the need for treatment facilities;

● ineffective control of refrigerant flow;

● inability to control the quality of the individual nozzles, the lack of timely information about what is dirty or clogged nozzles.

The main drawback of the world used the nozzle cooling remains ambiguous laws of heat removal from the surface of products from small and large radius of CCM.

As a result of heat treatment of continuously cast slabs with cooling nozzle often occurs axial asymmetry and non-uniformity of the crystalline structure of the metal (Fig. 2). This is because, in accordance with the law of gravity, the jets of water fall on the lower surface of the cast and cooled slab unevenly and bounce off it. At the same time, while cooling the top surface of the slab jets of water merge to form water and steam film.

Obviously, the use of jet cooling of the ingot leads to unevenness in the crystalline metal structure in the cross section of the slab, significant pollution working zone vapor, dust and mill scale. The effective functioning of the process equipment and automation means in such an aggressive environment is unlikely. In addition, to ensure sustainability of production become difficult to achieve.

Cooling the flat metal in line rolling and heat treatment

In the production of rolled sheet the controlled cooling of metal takes place on the roller conveyors of the process line metal processing: interstand, intermediate and exit rolling table, as well as during subsequent heat treatment of hot-rolled products. The optimal control problem of hot rolling strips and heat treatment regime, along with the intensification of production, is to ensure the required level of quality indicators and stabilization of rolling: uniform temperature and rheological properties of the metal, as well as the geometric parameters (thickness and shape) of strip.

Nozzle supply of water or other coolant to upper and lower surface of strip also underlies techniques cooling of metal known in rolling and heat treatment line. At the same disadvantages of such cooling, similar to the nozzle metal cooling in continuous casting machines, are increased costs of water and electricity for its pumping and low metal temperature control due to the unsteadiness of the refrigerant thermal characteristics. The need to eliminate these drawbacks is particularly relevant in connection with the fact that the use of forced interstand cooling can control not only the temperature and rheological properties of the metal, but also the shape and profile of the hot strip [3]. Accordingly, the spray nozzle can not provide the cooling requirements for increased metal temperature control accuracy.

Advanced methods for cooling the flat metal

In order to eliminate the above drawbacks of the nozzle cooling in CCM, HSM and metal heat treatment area there are alternative proposals for the use as a tool cooling steel rollers, outwardly similar to the supporting roller table rollers. The constructive difference is that the roller is hollow inside and filled with water. However, initially arriving in these rollers the water was intended solely for cooling the walls of the roller.

It should be noted that the diameter of the cavity within the roller is limited due to the possible reduction of its “rigidity”, so the “power” of such cooling is only enough to prevent overheating of bearings assemblies supporting a roller. Therefore, such a roller can rather be called a water-cooled, but no water-cooling, as it cools itself but it is not cooling the strip metal.

Currently, a team led by prof. Z.G. Salikhov [2, 4] implemented a fundamentally new method of heat removal device by passing the turbulent flow of coolant through the «hollow» metal rollers in contact with the surfaces of the flat metal. The essential difference between this proposal from the above is that the «cavity» rolls filled with elements that provide both a high thermal conductivity, stiffness rollers and turbulence of coolant [5]. The proposed roller cooling method by replacing the conventionally used rollers of roller tables in production of steel products at the hollow rollers with fillers (Fig. 3), the geometric dimensions of the hollow rollers coincide with replaceable rollers or roller conveyors. In connection with this roller replacement operation can be performed at any preventive stop rollers of CCM, HSM or roller-hardening machine.

Preliminary studies have shown that the filler should

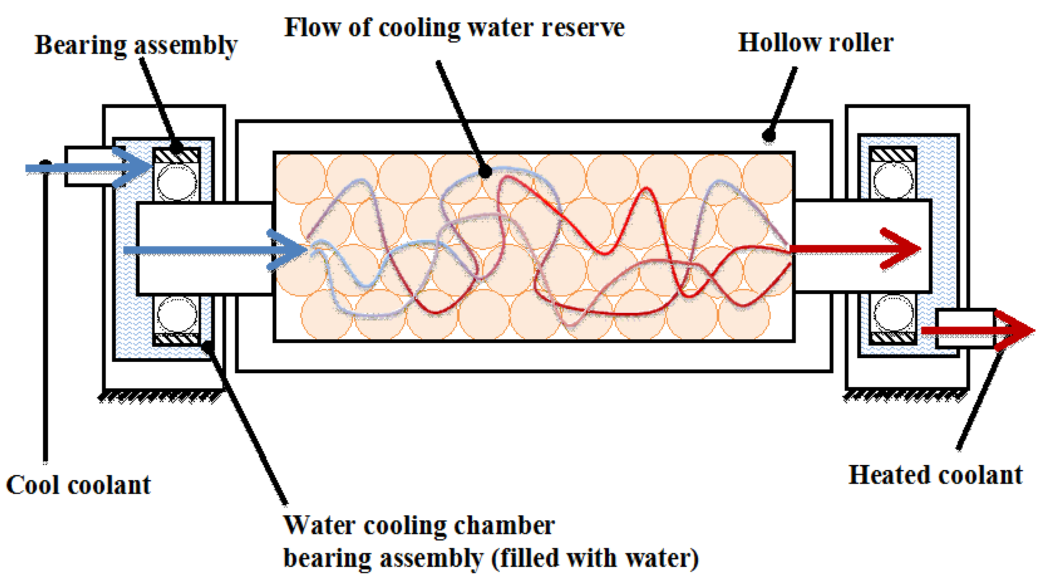

Fig. 3. Scheme heat sink roller (longitudinal section).

be used copper balls having a high coefficient of thermal conductivity [5]. Gets the ball filling the cavity of the roller and the high thermal conductive filler is provided rigidity roller and high heat its contact surface to the water passing through the roller. Direct measurement of cooling water temperature at the inlet and outlet roller provides a significant increase in the accuracy of the rolled metal control parameters [2].

In view of the above, the major advantages of the cooling roller (relative to the nozzle) may include:

- full control of the value of each waste heat roller and the control of this value of each roller – it is more opportunities in supporting a given cooling path;
- high precision control of the magnitude of the heat losses from the workpiece; a uniform heat removal across the width of the workpiece cooling rollers, the identity of their work on small and large radii CCM;
- no vaporization – improvement of operating conditions of the equipment, a significant improvement in working conditions;
- closed refrigerant circuit – a reduction of its losses, there is no need for large wastewater treatment plants with a large consumption of reagents.

The analysis of the known automatic control systems and metal heat treatment control with continuous his casting in CRM, rolling in a rolling mill and a finishing treatment in roller-hardening machine showed that they operate in the space of probability estimates, which are based on computer calculation model predictive parameters of the process, virtually receiving no information about the amount of heat withdrawn refrigerant. This is due to the fact that the vapor-dust veil, which is an integral part of the nozzle cooling, control distorts the accuracy scanning the workpiece surface – rolled or slab products. Therefore, when heat-treated cast or rolled pieces on their surfaces in reality there are considerable temperature gradients, thermal stresses, cracks and other defects, and the operator sees only the results of the abstract computer model predicting the flow of metal heat treatment process, and hence the work virtual automatic control system. Obviously, in this control action by system or fed by hand do not correspond to actual conditions and only exacerbate the situation that eventually leads to the production of nonstandard hot rolled product to 20 %.

The proposed new principle of management of the flat metal heat treatment process uses a fundamentally new method of heat removal and the regulatory body, realized by passing the turbulent coolant flow through hollow metal rollers that come in contact with the surfaces of flat metal. A refrigerant supply (water) under pressure through the cylindrical rollers, by copper balls filled, provide intense cooling of rollers walls and hence the strip surface, and the degree of cooling is adjusted by changing the coolant flow rate. The difference in the

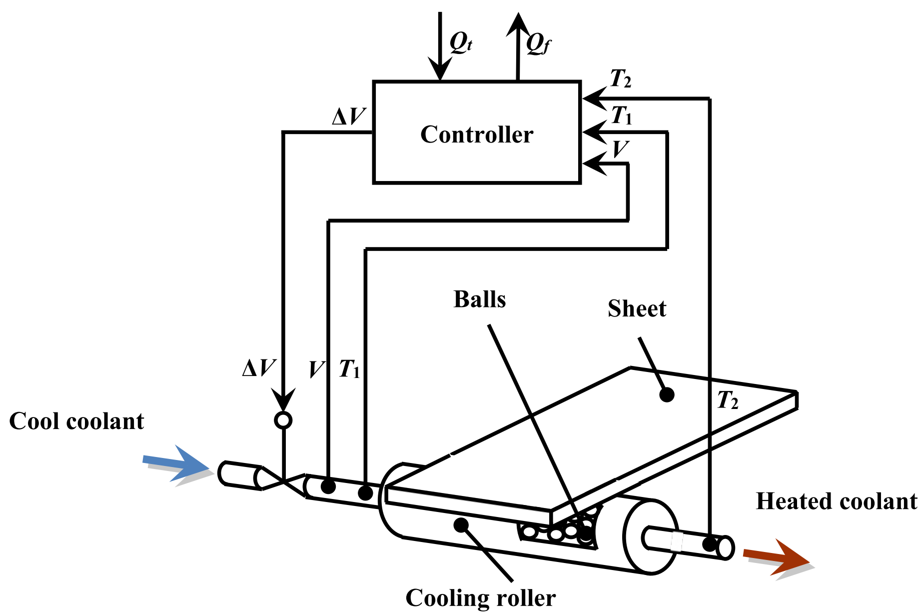

Fig. 4. ACS cooling module for roller table sheet rolling mill.

direct, i.e. accurate, measuring the temperature of the coolant inlet and outlet streams determines the real value of heat removal rates, which significantly improves the accuracy of the control parameters of the metal, and hence the crystallization processes and recrystallization of the rolled metal product or the continuous casting slab.

On the basis of the results of simulation a multi-circuit system of automatic control roller cooling slab, sheet (strip) in different parts of the metal processing is developed. The simplest cooling circuit sheet rolling mill roller conveyor discussed in Fig. 4.

Under the present scheme, the top-level reference systems formed on the task of thermal energy $Q_t(\tau)$, which roller should withdraw from the strip (or sheet) per unit time. Automatic control system implements $Q_t(\tau)$ by changing the V flow of refrigerant flowing through the cooling roll filled with copper or aluminum balls. Factual quantity heat sink $Q_f(\tau)$ from a moving cooled steel product (sheet or strip) is calculated based on the measured temperature values of inlet T_1 and output T_2 from the roller, and the refrigerant flow rate.

Aggregate of solutions presented for the first time makes it possible to organize the direct control of cooling sheets and strips, not based on a probability of (theoretical or empirical) models, and the results are accurate, straight and fast measurements of process parameters that both simplify and reduce the time calculations are not previously monitored parameters.

The problem of automatic control system (ACS) for each cooling roll is to stabilize the set value heat sink by each roller. High accuracy is achieved by closing the circuit of the local ACS negative feedback on actual value of the heat sink. Thus, we get not only a high-precision actuating mechanism, totally controlled and managed, but also new means of accurate continuous measurement of the amount of heat withdrawn from the workpiece. Since the refrigerant is not in direct contact with the metal and is circulated in a closed loop cooling off, the heat sink refrigerant properties remain unchanged.

Prospects for the development of the roller cooling for flat rolled products

The preliminary testing of the proposed roller cooling metal, conducted in simulation mode [2], affirmed:

- simplicity of its implementation;
- the possibility of changing the metal surface temperature on 30 - 40°C smoothing thus most of the temperature perturbations;
- the possibility of not less than 2 times more efficient use of the refrigerant flow (water).

This creates favorable conditions for the continuation of the life of the equipment by reducing humidity and dust, which, of course, increases the reliability of the electrical and automation equipment.

The purpose of the further development of the roller cooling - modernization of methods and means of automatic control of process parameters and process control cooling of rolled steel, providing a reduction of off-grade metal, coolant flow rate and energy, improvement of sanitary conditions of service of the rolling equipment and increase its productivity by handling and controllability of the process cooling metal.

Closing the system provided in Fig. 4 an identification contour on quality of metal (it agrees to the estimates accepted on production by results of metallurgists examination) we will receive the self-organized intellectual system with a kernel in the form of the associative neuro structured knowledge base. This will allow the system to self-organize by building in the structure of knowledge base the new cooling circuit modes with estimates of their effectiveness to achieve the necessary consumer properties of the metal. Taking into account the latest achievements of the theory of building high-quality adaptive automatic control systems, the advantages of the proposed new method of cooling and the appearance of observability most of the parameters, the system should have multiple paths for control considered the process.

According to the technicians of the metallurgical enterprises implementation of roller cooling of metal will reduce the refrigerant flow rate (water) to 500 m^3/h, allow to reduce the power consumption (by 30 - 40 %), and to reduce the amount of off-grade metal of 20 %.

CONCLUSIONS

The comparative analysis of the water nozzle and the roller contact cooling methods of flat rolled products (continuously cast slabs, hot-rolled sheet and strip) showed clear advantages in the latter part of the ease of implementation, improve the observability and controllability, economy of resources.

REFERENCES

1. R.L. Shatalov, T.A. Koinov, N.N. Litvinova, Automation of metal and alloy rolling and heat treatment, Moscow, Metallurgizdat, 2010, 368, (in Russian).
2. Z.G. Salikhov, R.T. Gazimov, A.V. Demin, Structure ACS roller cooling hot metal, Automation in Industry, 5, 2012, 60-63, (in Russian).
3. A.L. Genkin, Modelling and optimization of hot strip rolling process, Moscow, LENAND, 2012, 168, (in Russian).
4. Z.G. Salikhov, R.T. Gazimov, A.L. Genkin, I.V. Nikulina, New Solutions for Thermal Treatment of Flat Products Using Self-Adjusting Mathematical Models with Partly Observable Parameters, IFAC-PapersOnLine, 48, 3, 2015, 1242-1247.
5. Z.G. Salikhov, R.T. Gazimov, A.V. Demin, D.S. Kapralov, Engineering principles of calculations of ball filling of cooling rolls for fast cooling units on continuous casting machines and rolling mills, Tsvetnye Metally, 3, 2014, 77-80.