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Improvement of Cooling Technology through Atmosphere Gas Management

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The production of advanced high strength steels requires the improvement of cooling technology. The use of high cooling rates allows relatively low levels of expensive alloying additions to ensure sufficient hardenability. In classical annealing and hot-dip galvanizing lines a mixing station is used to provide atmosphere gas containing 3-5% hydrogen and 97-95% nitrogen in the various sections of the furnace, including the rapid cooling section. Heat exchange enhancement in this cooling section can be insured by the increased hydrogen concentration. Drever International developed a patented improvement of cooling technology based on the following features: pure hydrogen gas is injected only in the rapid cooling section whereas the different sections of the furnace are supplied with pure nitrogen gas; the control of flows through atmosphere gas management allows to get high hydrogen concentration in cooling section and low hydrogen content in the other furnace zones. This cooling technology development insures higher cooling rates without additional expensive hydrogen gas consumption and without the use of complex sealing equipments between zones. In addition reduction in electrical energy consumption is obtained. This atmosphere control development can be combined with geometrical design improvements in order to get optimised cooling technology providing high cooling rates as well as reduced strip vibration amplitudes. Extensive validation of theoretical research has been conducted on industrial lines. New lines as well as existing lines, with limited modifications, can be equipped with this new development. Up to now this technology has successfully been implemented on 6 existing and 7 new lines in Europe and Asia.

Keywords *: cooling technology, hardenability, atmosphere gas, flow control*

1. Introduction

Weight reduction and increase of safety are key parameters in the development of the automotive industry, with major consequences on the processing of steels with the increased production of high-strength steels. However the production of these new steel grades requires improvements of both processes and equipments. Two complementary routes can be used: addition of several alloying elements and/or annealing cycle modification with increased cooling technology performances. The chemistry route can generate additional problems for strip processing such as alteration of zinc adhesion and poor welding ability. The rapid cooling process therefore represents a strategic way that has large potential to enhance annealing and galvanizing lines. Taking advantage of high cooling rates allows low levels of expensive alloying additions to ensure the aimed hardenability.

In classical annealing and hot-dip galvanizing lines a mixing station is used to provide atmosphere gas containing 3-5% hydrogen, the balance nitrogen, in the various sections of the furnace, including the rapid cooling section. Heat exchange enhancement in this cooling section can be insured by increased hydrogen concentration. This paper presents a patented improvement of cooling technology developed by Drever International: this technology is based upon an original gas atmosphere management providing high hydrogen content in the rapid cooling section. The characteristics and advantages of this technology are presented. The performances of hydrogen confinement in the rapid cooling and gas management in the furnace are illustrated by the interesting results obtained on two new lines built in China.

Drever International obtained high advances in rapid cooling performances, with the development of the Ultra Fast Cooling System. This optimised technology is the re-

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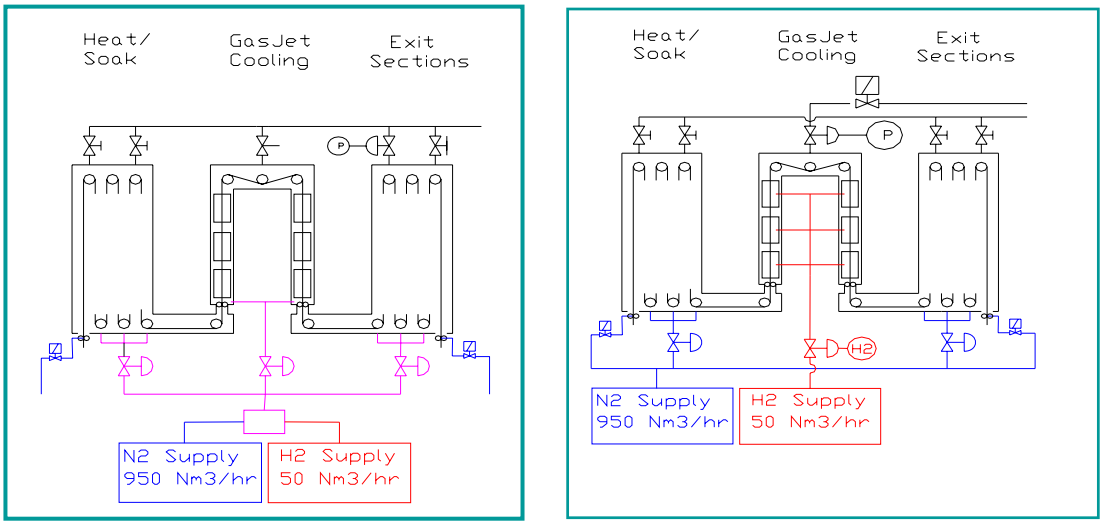

Fig. 1. (left) Classical injection of HNx mixture in the furnace
(right) Drever International patented atmosphere gas management with unique hydrogen supply in cooling zones

sult of R&D activities realized during several years, providing high cooling rates as well as control of strip vibration amplitudes. Strip cooling performances obtained on the new lines in China are also presented.

2. Furnace atmosphere gas management

The thermal annealing process of the steel is performed in a complete gastight furnace under positive pressure with reducing atmosphere gas composed of a mixture of 3-5% hydrogen and 97-95% nitrogen. The hydrogen and nitrogen gas are mixed in the proper proportions in an automatic mixing station. The mixed gas is injected in the various sections of the furnace, as presented in the Fig. 1 (left).

A new furnace atmosphere gas management is patented by Drever International. In this invention, pure hydrogen gas is injected in the rapid cooling section only, whereas nitrogen is provided in the different sections of the furnace. The rapid cooling equipment insures intense re-circulation of nitrogen and hydrogen gas through heat exchangers and plenums. The design of free opening for the strip, at the entry and exit zones of the cooling chamber and the control of flows between furnace sections result in higher concentration of hydrogen in the rapid cooling section, whereas usual hydrogen concentrations are obtained in the heating, soaking and exit furnace sections.

Fig. 2 (left) gives the advantages linked to the increase of hydrogen content in cooling areas. For a defined heat transfer coefficient, the plenum pressure reduces as a function of the hydrogen concentration. As a consequence, lower gas speeds impacting the strip are required for the same cooling power, resulting in lower strip vibration amplitudes. In addition increase of hydrogen content reduces fans electrical power consumption.

Fig. 2 (right) presents typical transition from the use of mixing gas with 3.5% hydrogen in the entire furnace to the injection of hydrogen only in the rapid cooling section. The hydrogen content in this section increases up to 15%, whereas H_2 concentration in heating and exit sections remains below 5-6% during the transition. Gas pressure and fan power are reduced in relation with the hydrogen increase.

This innovation presents multiple benefits:

- No complicated sealing equipment at the entry and exit of cooling section;
- No additional hydrogen or nitrogen consumption is required (at the end of the transition phase);
- Reduction of gas pressure and electrical energy consumption;
- Limited modification of existing lines;
- Installation possible in new and existing lines.

3. Cal and cgl atmosphere gas management

Extensive validations of Drever International's theoretical research have been conducted on industrial lines. New lines as well as existing lines, with limited modifications, can be equipped with this new development. This chapter presents a continuous annealing line (CAL) and a hot-dip continuous galvanizing line (CGL) recently built in Shougang Cold Rolling Mill, near Beijin (ShunYi District) in China.

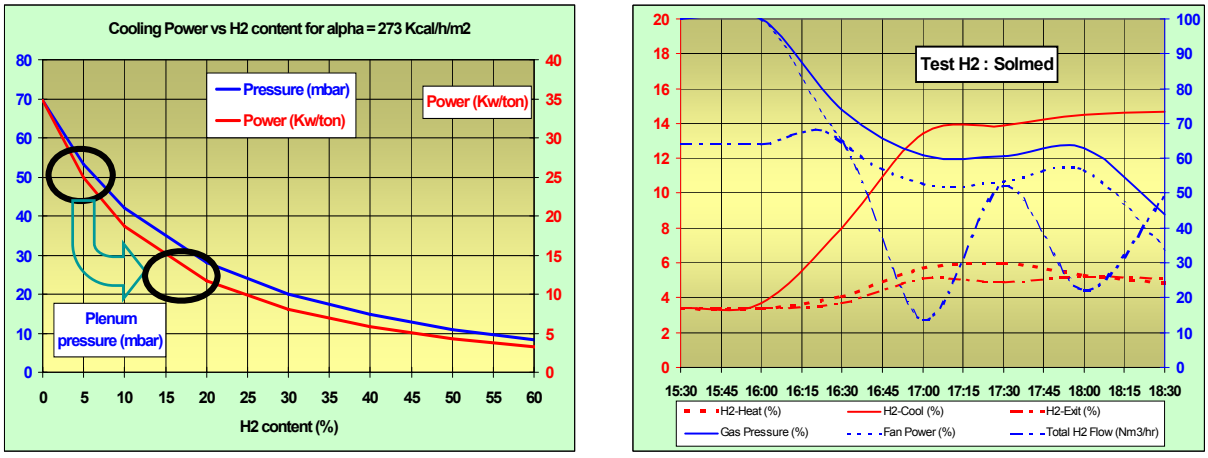

Fig. 2. (left) Effect of hydrogen content on plenum pressure and fan power
(right) Transition between use of mixing station gas and injection of hydrogen in rapid cooling zone only

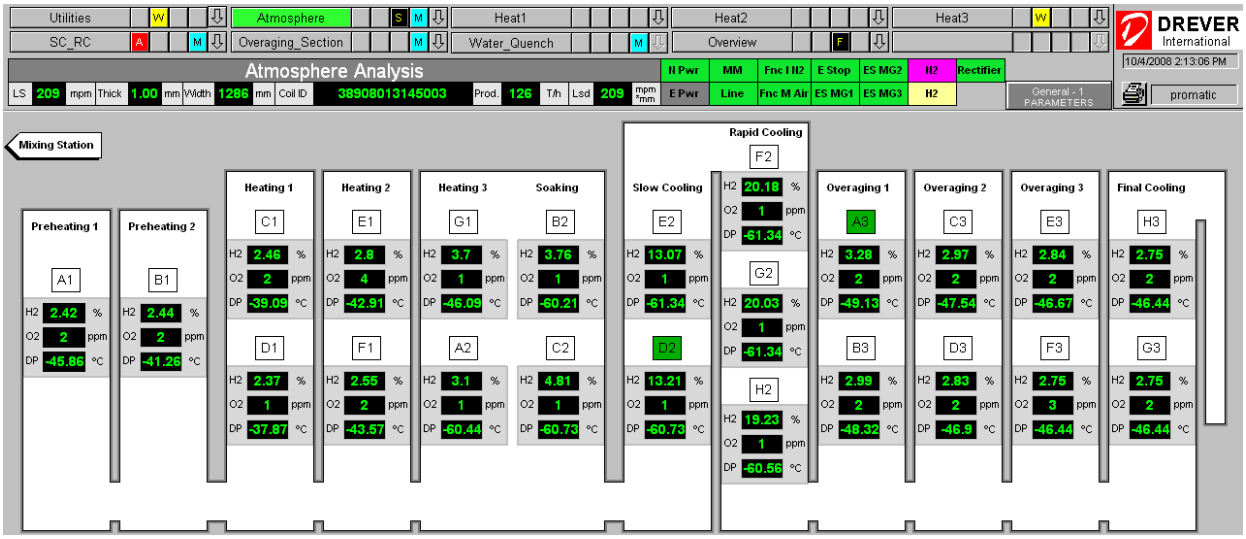

Fig. 3. Rapid cooling high hydrogen confinement in Shougang ShunYi CAL N°1

3.1 The Shougang ShunYi CAL N°1

The Shougang ShunYi CAL N°1 is equipped with a vertical furnace designed to process cold rolled strips made from low carbon steel, ultra low carbon steel or interstitial free steel for the production of steel qualities from CQ to DP-HSS 780 and TRIP-HSS 780. The strip width range is 800 - 1870 mm and the thickness range is 0.3 - 2.5 mm. The maximum line speed is 420 mpm. The annual production is 950 000 tons. The strip travel in the furnace is 2.3 km. The line was started in October 2008.

This CAL N°1 is equipped with the separated hydrogen injection in cooling zones. Fig. 3 presents typical results for hydrogen confinement in cooling zones obtained through atmosphere gas management.

The hydrogen concentration of 20% is reached in the rapid cooling section and this value is maintained constant. Hydrogen concentration is also increased in the slow cooling section, reaching 13%. Hydrogen content varies from 2.4 to 4.8% between preheating and soaking zones and from 2.7 to 3.3% in overaging and final cooling sections. Limited gradient is observed from soaking to preheating and from overaging to final cooling, but the concentration are far below the values obtained in the cooling zones. These results illustrate the excellent hydrogen confinement obtained through the developed atmosphere gas management.

Fig. 4 shows that the hydrogen concentration in the rapid cooling is well maintained constant to 20% (left part of the figure) even if large, quick and frequent line speed variations occur. The middle part of the figure presents

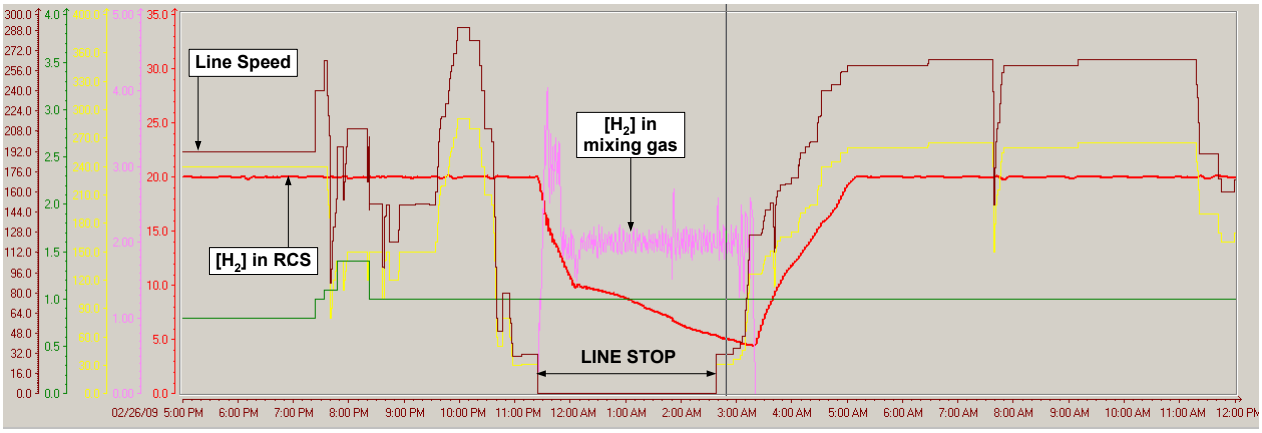

Fig. 4. Rapid cooling hydrogen concentration versus line speed in CAL N°1. Line stop induces the return to the use of classical HNx mixing gas

Fig. 5. The Shougang ShunYi CGL N°1

the return to use of mixing station with 2-3% H_2, after line stop. This sequence has a duration of 4 hours to come back to classical HNx mixture furnace filling. Hydrogen injection stop in the rapid cooling is combined with large injection of nitrogen to purge efficiently the cooling zone. New hydrogen injection is presented in the third part of the figure, after the line restart. H_2 concentration reaches 20% without overshoot after 90 minutes only and is maintained constant despite an additional quick line speed change.

3.2 The Shougang ShunYi CGL N°1

The Shougang ShunYi CGL N°1 is equipped with a vertical annealing furnace, galvanneal soaking furnace, after pot cooling, final cooling and water tank. This line is designed to process cold rolled strips for the production of galvanized sheet for the automotive industry (steel qualities from CQ to DP-HSS 780 and TRIP-HSS 780, both GA and GI). The strip width range is 800 - 1870 mm and the thickness range is 0.4 - 2.5 mm. The maximum line speed is 180 mpm. The annual production is 475 000 tons. The line was started beginning of 2009. A photograph of this CGL1 is given in Fig. 5.

The Shougang ShunYi CGL N°1 is also equipped with the separated hydrogen injection in cooling zones. Atmosphere gas management allows the confinement of hydro-

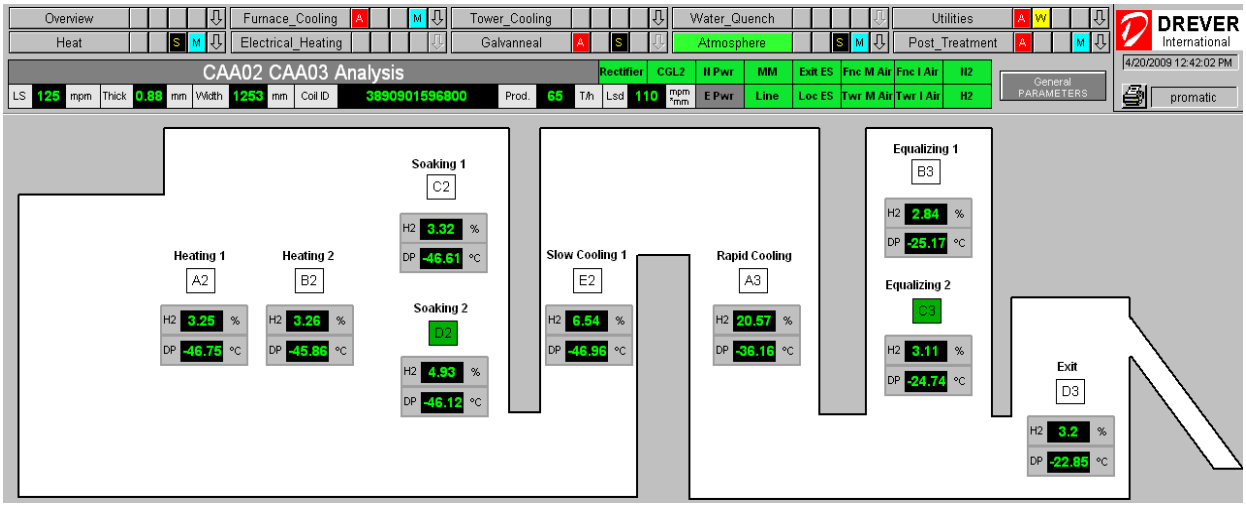

Fig. 6. Rapid cooling high hydrogen confinement in Shougang ShunYi CGL N°1

gen gas in cooling zones, as presented in typical results of Fig. 6. The hydrogen concentration obtained in the rapid cooling section amounts to 20% and this value is maintained constant. Hydrogen concentration is also slightly increased in the slow cooling section, reaching 6.5%. Hydrogen content in the heating and soaking zones amounts to 3.3%, with a limited gradient observed in the soaking area closed to the cooling zones, where H_2 value is 4.9%. Limited gradient is also obtained in the equalizing and exit sections, with hydrogen concentration between 2.8 and 3.2%. Hydrogen content in the furnace zones surrounding the cooling sections is significantly lower than the 20% maintained in the rapid cooling: this demonstrates again the excellent hydrogen confinement obtained through the developed atmosphere gas management.

Numerous hydrogen confinement tests are performed with 15% and 20% concentration in rapid cooling, as well as with more than 20%.

Numerous validations of theoretical research on innovative furnace gas confinement have been conducted on several industrial lines. Up to now Drever International has successfully implemented this technology on 13 lines - 6 existing and 7 new lines - in Europe and Asia.

4. Ultra fast cooling (UFC) performances

During several years, Drever International performed extensive R&D activities to improve cooling performances. Convective heat transfer in multiple-jets cooling systems is studied by laboratory tests on reduced-scale models and CFD simulations, in collaboration with the von Karman Institute.[1)] Investigations on strip vibration behaviors are conducted on laboratory scale[1)] as well as with a pilot line, within an industrial partnership with ArcelorMittal Maizieres Research.[2)]

Table 1. Ultra Fast Cooling performances for Shougang ShunYi CAL N°1 and CGL N°1

Line		CAL N°1	CGL N°1
Strip thickness	mm	1.8	1.48
Strip width	mm	1260	1253
Steel grade		DP590	CQ
Line speed	m/min	90	95
Production	T/h	96	83
LSD	mm*m/min	162.0	140.6
RCS hydrogen content	%	22.0	20.0
Cooling length	m	10.6	5.35
Entry temperature	℃	700	714
Exit temperature	℃	301	457
Cooling rate for 1mm thick	℃/s	101.6	112.4

R&D studies are also performed on detailed design improvements of multi-jets cooling equipments. These activities ensure Drever International to develop optimized technology, the Ultra Fast Cooling (UFC) System, combining high cooling performances and control of strip vibrations. The best cooling performances are obtained with the high hydrogen rapid cooling technique presented above. The two new lines built for Shougang ShunYi are equipped with this new Ultra Fast Cooling technology.

The CAL N°1 and CGL N°1 rapid cooling sections contain three zones, the two last zones having a shorter length than the first one. To get the highest cooling performances,

only the two short-length zones are used. Table 1 gives the characteristics of the production, the hydrogen content in the rapid cooling section, the cooling length and the strip cooling temperature range. The cooling rate is expressed in °C/s for a strip thickness of 1 mm. The table presents the excellent cooling performances of the Ultra Fast Cooling System: 101.6 °C/s mm for the CAL N°1 and 112.4 °C/s mm for the CGL N°1.

4. Summary

A new and patented furnace atmosphere gas management is presented. In this invention, pure hydrogen gas is only injected in the rapid cooling section. The atmosphere management ensures to get high hydrogen content in cooling zones and classical hydrogen concentration in the other furnace sections, without additional hydrogen nor nitrogen consumption and without complex sealing equipments. Limited modifications are required in the case of existing lines. This innovation insures high cooling rates as well as reduction of strip vibration amplitudes. In addition large reduction of electrical energy consumption is obtained. Up to now this new technology has successfully been implemented on 13 lines (6 existing and 7 new lines) in Europe and Asia.

Drever International developed the Ultra Fast Cooling (UFC) System, optimized technology combining high cooling performances and control of strip vibrations.

The paper presents the excellent results obtained on two new lines built for Shougang Group Co, China. High hydrogen confinement in rapid cooling zones as well as cooling rates higher than 110 °C/s for a strip of 1 mm thickness are demonstrated.

Acknowledgements

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