

# Strip Annealing Furnaces for New Galvanizing Lines

D. Astesiano, D. Ghira, C. Leoncini

*Constant improvements to continuous annealing process technology are necessary for the production of both new and traditional steel grades to provide good formability and ductility and also gives higher mechanical properties when combined with correctly tuned steel chemical compositions.*

*One vertical and one horizontal type furnace are to be started up at Acciaieria Arvedi S.p.A. (Italy) in 2011, these furnaces form part of the Continuous Galvanizing Line (CGL) in the Danieli Cold Mill Complex, this complex also includes a six-high Tandem Coil Mill and Push-Pull Pickling Line.*

*The furnaces will be able to match any market requirements for different annealing cycles, thus combining high performance with low investment and transformation costs. Short heat-up, long soaking, both slow and rapid cooling have all been included in equipment design to give any type of annealing curve and include a large group of steel grades commonly required by the market. Planned expansion will allow for additional slow cooling and extended over-aging time. High performance direct flame burners and radiant tubes fed by natural gas are the key to guarantee strip quality and low maintenance costs. Flexible rapid jet cooling performs different cooling rates to accommodate the metallurgy of several different steel grades.*

## Keywords:

steel, heat treatment, process control, numerical simulation, automotive, energy

## INTRODUCTION

Chemical steel compositions are constantly improved through the design of metallurgical modelling and laboratory and industrial trials for the production of non-alloyed and alloyed steels in hot pickled and cold rolled coils for the cold forming application of Low Carbon steel, High Strength Low Alloy steel (HSLA) and Advanced High Strength steels (AHSS).

Special attention is paid to high strength dual-phase (DP) and transformation induced plasticity (TRIP) steels which have become increasingly important over the last few years, especially in the automotive industry where, for example a progressive reduction in vehicle weight and increased passenger safety is required and market requirements are geared towards competitive costs and savings in fuel consumption.

Coating surface quality has also become progressively more stringent: coated steels considered good quality products for applications in the construction industry may not receive the same feedback from the automotive industry where coating defects could arise from carbon contamination or surface oxidation. Also incorrect in-line heat treatment or improper strip surface cleaning from all kinds of surface contaminants could occur.

## ANNEALING FURNACES CHARACTERISTICS

### Basics

Design of the horizontal and vertical furnaces and the final cooling tower accommodate the required uncoated strip tonnage (350,000 t/y with 7,400 h as direct operating time) and is also in line with the Customer's product mix and thermal cycles. The

furnaces mainly consist of:

1. recuperative section,
2. free flame section (non-ox type),
3. gas fired radiant tube section (final heating and soaking),
4. slow jet cooling section (future installation, in vertical furnace only),
5. rapid jet cooling section,
6. electrical extended over-aging section (future installation),
7. electrically heated post-heating (induction for vertical furnace) and equalizing section,
8. hot bridle section and snout,
9. after-pot air cooling section.

### Steel Strip Dimensions and Grade

- Thickness 0.25-2.5 mm (hot and cold rolled)
- Width 700-1570 mm (edge width 1550 mm)
- Speed 30-180 m/min (max. 200 mechanical)
- Steel grade low carbon, HSLA, HSS, AHSS
- Coating GI (Zn > 99%), thickness range 50-600 g/m<sup>2</sup> (both sides)

### Process Cycles and Reference Production

- i. Strip pre-heating in the recuperative room.
- ii. Strip heating to 700-730°C in the free flame section.
- iii. Completion of heating in the first part of the radiant tube treatment chamber (according to different requirements) and maintaining the strip at cycle temperature for metallurgical transformation (designed for max. speed) in the second part of the section.
- iv. Slow cooling when required (in the future, below AC1) and rapid cooling (below MS for AHSS) as per cycle requirements in the relevant dedicated sections.
- v. Over-aging (future) and post-heating up to zinc bath temperature.

D. Astesiano, D. Ghira, C. Leoncini  
Danieli Centro Combustion - Genoa, Italy

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For vertical furnace									
Cycle	Temp. [°C]	Soaking [sec]	Cooling [°C]	Cooling rate [°C/sec]	Post heating [sec]	Snout [°C]	Max. speed [m/min]	TV [m/min *mm]	Prod. [t/h]
CQ	730	23	460	No requirement		460	180	108	78.8
DQ / HSLA	780	28	460	No requirement		460	150	90	65.7
DP600/800	800	31	320-400	(*)	1.5	460	140	84	61.3
TRIP	820	31	400	(**)	1.5	460	140	84	61.3
For horizontal furnace									
CQ	730	11	460	No requirement		460	180	108	78.8
DQ / HSLA	780	15	460	No requirement		460	120	72	52.6
DP600/800	800	16	400	(***)	7.0	445	100	60	43.8
(*) 100°C/s from 800 320°C for 1 mm strip thickness									
(**) 87°C/s from 800 400°C for 1 mm strip thickness									
(***) 57°C/s from 800 400°C for 1 mm strip thickness									

TAB. 1 Reference process cycles.

Dati di produzione.

- vi. Strip transfer to the snout at bath temperature.
- vii. Galvanized coated strip after-pot-cooling from approximately 460°C (GI) to a max. temperature of 280°C in the vertical up-pass and below 150°C in the vertical down-pass.

Rapid heating and soaking in the continuous annealing cycle aim to attain the desired grain structure and growth after recrystallization and simultaneously control annealing texture to accomplish formability. Consequently, slow and rapid cooling and over-aging promote solute carbon precipitation dissolved during the earlier steps and complete the required microstructure transformation.

### Recuperative Room and Free Flame Section

The free-flame solution in the horizontal and vertical furnaces reduces investment costs (furnace costs, building costs, etc.) even further compared to an all radiant tube furnace, final product quality is in no way compromised.

Costs and risk factors are cut even further through reducing the capability of the upstream cleaning section. A lower hydrogen content may also be used for the protective atmosphere of the downstream chambers to finish strip cleaning before the pot.

This free-flame section is designed to heat the strip to max. temperature in the first part of the thermal cycle and, considering the reducing atmosphere of this area, the incoming strip surface is also cleaned in this section.

This system heats the strip to a maximum temperature and keeps exposure time minimum: strip temperature is first increased in the recuperative chamber which acts as a heat recovery system through the convection of un-burnt combustion

products fired by post-combustion air injection inside the furnace if the temperature is above 750°C (auto-ignition condition), otherwise outside the furnace in the waste gas duct. Strip heating is then completed in reducing and non-oxidizing conditions in the free-flame section: this section is equipped with mixing nozzle type burners with an automatic flame and ignition control system which are grouped in different zones, and arranged in a staggered pattern at an appropriate distance from the strip. Burners are fed with hot air heated through a centralized recuperator arranged in the waste gas duct before the final exhaust fan and stack to improve specific consumption. The length and volume of this section allows various strip widths and gauges to be produced without the risk of edge overheating and also provides the best temperature uniformity across the strip.

Free-flame section degreasing efficiency can be assessed in terms of maximum rolling oil residue and iron fines acceptable for coating adhesion (max. 1000 mg/m<sup>2</sup> on both sides): this operation cleans the strip by sweeping its surface with reducing atmosphere achieved by burning gas at an under stoichiometric combustion ratio set via the PLC (3-5% CO+H<sub>2</sub> and 0% O<sub>2</sub> in the flue gas), depending on the type of rolling mill and operating practices used in the galvanizing plant.

The last zone only of the vertical furnace is equipped with a firing system to perform efficient heating and cleaning in complete safety: two panels of small burners facing the strip guarantee high turbulence of impacting waste gas onto the strip. Burners are premix type and fed by a separate gas line, cold air is blown by a separate fan: air and fuel mix takes place at each single burner entry to assure perfect combustion and avoid dan-

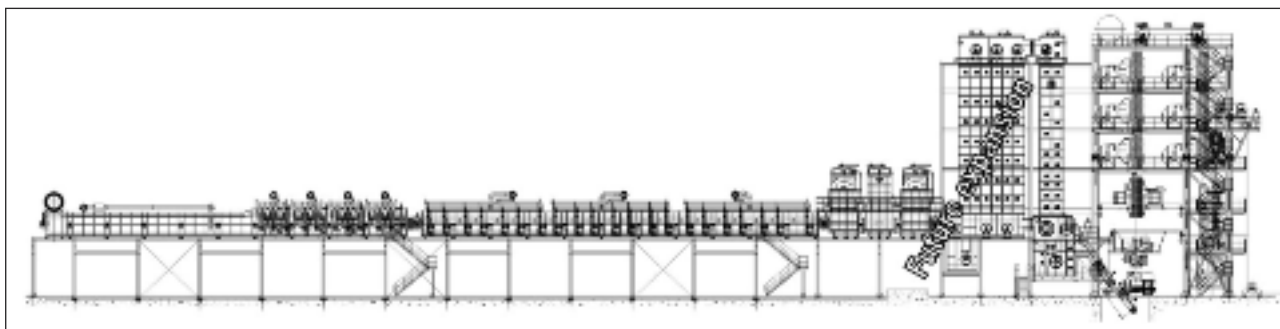


FIG. 1 Horizontal furnace arrangement.

Forno orizzontale.

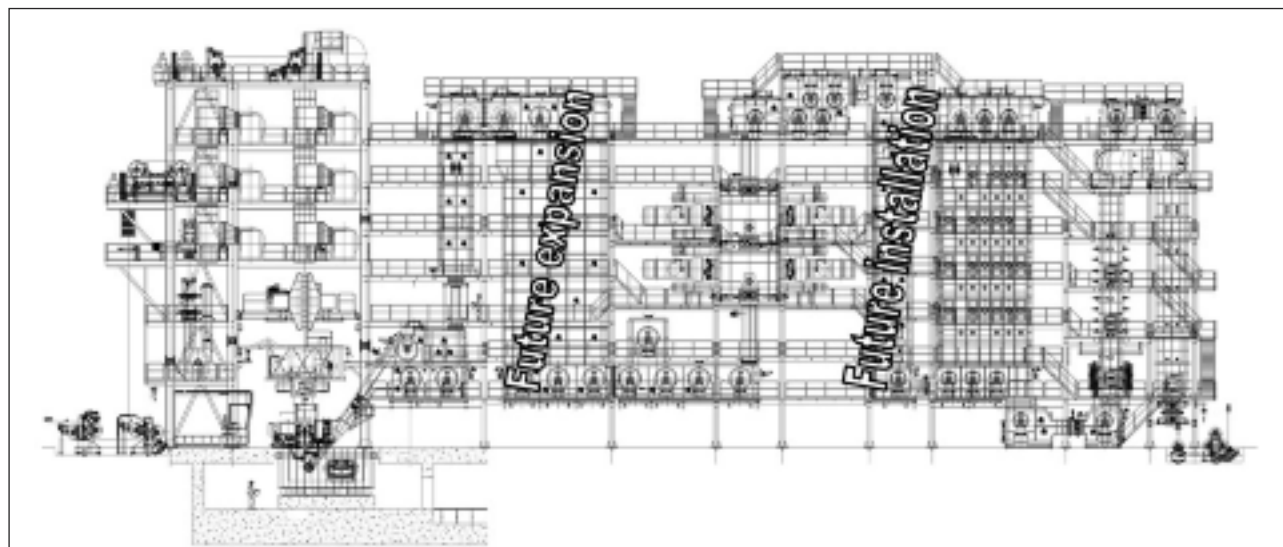


FIG. 2 Vertical furnace arrangement.

Forno verticale.

	Horizontal furnace	Vertical furnace
Unfired recuperative length	4½ modules	1 pass and by-pass
Fired recuperative length	4 modules	1 pass
Number of zones	4 (10 burners each)	3 (12 burners each, and 2 flame doors)
Number and burner type	40 lateral (LAT HG4S)	24 radiant (RAD HG4) 160 premix (RAD MIX 6)
Installed power capacity	17.000 Mcal/h	14.500 Mcal/h

TAB. 2 Reference thermal cycles.

Cicli termici di riferimento.

gerous situations which usually occur when mixtures are handled on board the plant. Waste gas impacting the strip surface assures rapid thermal heating and chemical cleaning: with this process a dirtier strip (up to 1500 mg/m<sup>2</sup>) may be accepted at furnace entry further reducing the upstream cleaning section's capability. A perfect radiant surface is obtained and transversal temperature discrepancies are avoided thanks to many small burners. To match any possible narrow strips, a trimming system is foreseen to switch off the lateral burner rows and reduce the likelihood of the strip edge overheating.

Exit strip temperature is optically controlled by a pyrometer to adjust the working zone's thermal input; chamber temperature and gas and air temperature parameters are correctly coordinated to achieve the requested strip exit temperature and surface quality.

Zones are proportionally controlled by the automation system, which regulates accurate heating, and sequenced to lower the firing rate according to line speed, or for narrower widths or thinner gauges, selected chamber temperatures and atmosphere are maintained. An ambient temperature up to 1300°C is permitted to provide maximum strip heating rate and minimum strip exposure.

### Radiant Tube Chamber

After leaving the free-flame chamber the heating process is completed in a section equipped with gas fired radiant tubes: here cycle temperature is achieved in a reducing HNX protective atmosphere (15% as max. H<sub>2</sub> content). Thanks to extended residence time (designed for the max. foreseen speed in both the horizontal and vertical furnaces) soaking and metallurgical transformation take place.



FIG. 3 Flame door.

Porta corazzata con bruciatori.

The design uses a radiant tube lay-out with dimensions allowing strip production without the risk of edge overheating and to meet requirements for different widths and gauges, considering a max. chamber temperature of 930°C.

The surface heat load of each radiant tube is always within a safe value range ensuring reasonably long service life above all for the vertical furnace where thermal stress is typically higher. Radiant tubes are fired by burners grouped into zones and controlled in both proportional and on-off modes. Burners are mixing nozzle type and equipped with an automatic flame and ignition control system. They are fed by air preheated through a cast plug-type recuperator which leads to a gain in fuel.

Combustion system control and efficiency and maintenance problems are frequently encountered in strip annealing furnaces equipped with radiant tubes: incorrect ratio control and local tube overheating constantly occurs, and may seriously represent premature failure.

### Radiant Tube Burner Enhancement

The radiant tube burner is normally designed to achieve a long and stable flame pattern without waste gas recirculation, this improves the tube temperature uniformity by reducing the hot spot effect and also gives a significant reduction in NO<sub>x</sub> pollution.

The horizontal furnace is equipped with a U-shaped radiant tube which is centrifugally cast in heat resistant alloy (25Cr-20Ni), this design is more than acceptable in terms of reliability, life and performance. Similar configurations have demonstrated excellent results even after 7 years.

Robust design coupled with a mixing nozzle type burner fed by air preheated through a cast recuperator (up to 400°C max), leads to fuel gain and gives satisfactory thermal uniformity along the tube surface tested during experimental activities at approximately 80°C.

More severe and different thermal cycles occur in the vertical furnace therefore double P-shaped radiant tubes manufactured with 3 mm gauge Inconel 601 sheet and combined with a new self-recuperative burner have been selected. They represent the best solution in terms of efficiency, temperature uniformity, low inertia and reduced maintenance time if compared with the traditionally cast W-shaped radiant tubes.

The new burner comes complete with a high efficiency recuperative metallic heat-exchanger and is developed with combustion techniques apt at reducing NO<sub>x</sub> pollution without compromising flame stability and minimizing un-burnt production in light up phase: the burner head divides the combustion air and gas into different stages (commonly known as fuel and air staging combustion).

Research activities have commenced to define and develop a new self-recuperative burner (150 kW with natural gas) to be combined with the double P tube: final tests have shown excellent temperature uniformity along the tube surface: the difference between the hottest and coldest point is less than 40°C, less than 30°C on the central leg. Air pre-heated to a high temperature (max. 650°C) means reduced fuel consumption compared to burners with a plug-in recuperator, or cold air burners.

The following pictures shows test results considering a constant furnace temperature of 930°C: temperature uniformity is drastically reduced considering the total length of the tubes when comparing a double P with W radiant tube: the double-P tube is slightly shorter with a similar radiant surface (37500 cm<sup>2</sup> for double P tube and 42000 cm<sup>2</sup> for W tube) since there are fewer pipes with larger diameters. Double P tube temperature uniformity combined with the new self-recuperative burner is considerably superior compared to W tube temperature uniformity

where the ΔT is reduced from 150°C (measured during old tests) to 40°C.

NO<sub>x</sub> emissions are less than 180 mg/Nm<sup>3</sup> @ 3% O<sub>2</sub> in dry waste gas (0,1 lb/MMBTU) with the furnace at 930°C and preheated air up to 600°C. NO<sub>x</sub> emissions are also drastically reduced in the flameless mode, a value near 50 mg/Nm<sup>3</sup> (0,029 lb/MMBTU) has been recorded, corresponding to a reduction of 70%.

### Ratio Control Enhancement

Negative pressure inside the radiant tube and pressure fluctuations on account of exhaust fan regulation are essential in galvanizing line applications but lead to high fire operations and low oxygen content in waste gases due to air/gas ratios and flame patterns.

This condition rapidly damages the radiant tube causing deformation and creeps by large amounts of carbon deposits which also clog the recuperator.

Another unpredictable situation for both the horizontal and vertical arrangement which could damage the radiant tube could be the difficulty to achieve even gas and air distribution along the furnace leaving to incorrect ratios.

An extremely efficient Push-Pull system feeds the radiant tube burner and maintains the correct oxygen content in the waste gas also during burner power modulation or any pressure fluctuation.

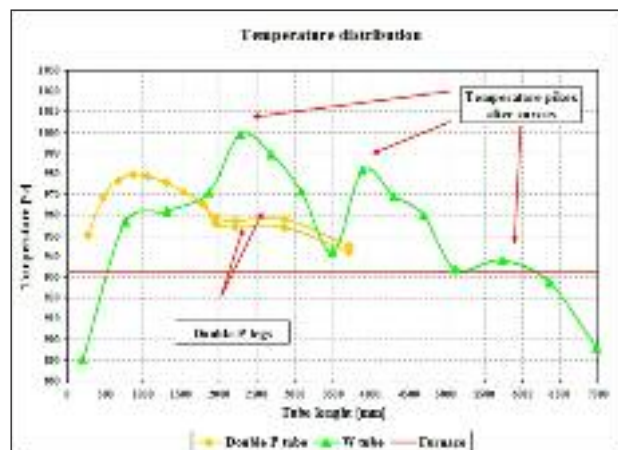


FIG. 4 W and double P radiant tube: temperature distribution along length.

Tubi radianti a W e 2P: distribuzione di temperatura sulla superficie.

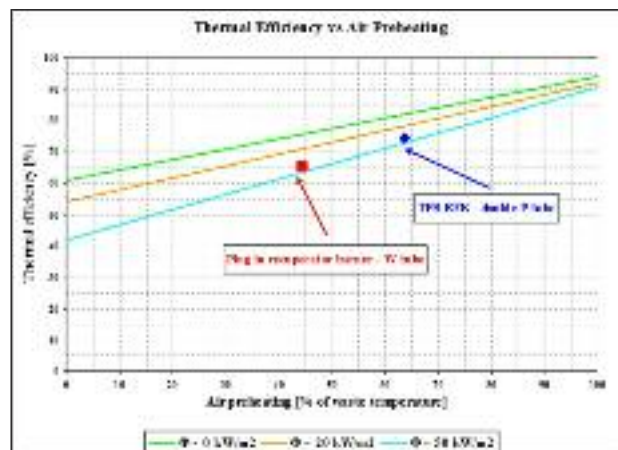
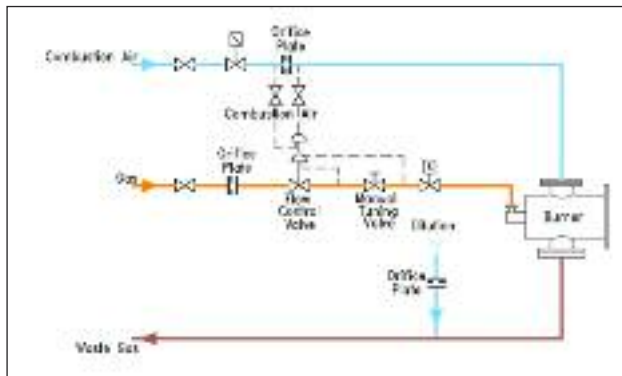


FIG. 5 Thermal efficiency of burners for radiant tube.

Efficienza termica dei bruciatori per tubi radianti.



**FIG. 6 FCR control scheme.**  
*Schema di controllo FCR.*

tuation. A dedicated blower feeds combustion air to the burner using positive pressure while an exhauster maintains negative pressure inside the radiant tube and sucks away the waste gas. To ensure the correct combustion ratio is always achieved during any thermal throughput (i.e. from 1,25 to 1,10 respectively at min. and max. firing power) a pressure differential produced by an orifice plate installed in the combustion air line controls a special self-regulating valve. An FCR valve (Flow Control Regulator) installed on the fuel gas line before each burner constantly monitors gas flow at the burners.

The FCR is also equipped with connections for fuel gas pressure balancing: pulse pipes are linked upstream and downstream the burner gas calibration valve to balance any pressure fluctuations produced by exhauster regulations inside the radiant tube. The FCR also compensates any pressure fluctuations in the fuel gas feeding line or any preheated air temperature change without modifying fuel flow at the burner: the furnace's basic automation system only adjusts the air flow-rate of each zone according to thermal requirements: the correct fuel ratio is guaranteed by the FCRs, while a flow-meter will check the global zone ratio. The FCR allows each burner to be individually adjusted without interference between different burners during fine tuning of the system thus ensuring a correct final operation.

Using this technology the zones are controlled both proportionally and in the on-off mode by the automation system, a precise heating effect is regulated by acting on the combustion air flow valve only.

Exit strip temperature is optically controlled by a dedicated pyrometer; this value adjusts the thermal input of the working zones while parameters such as chamber temperature and reducing atmosphere are properly co-ordinated to achieve the desired exit strip temperature and surface quality.

The zones are sequenced or trimmed so that narrower widths, thinner gauges or reduced line speed cause the firing rate to automatically lower while maintaining selected chamber temperatures and atmosphere. The system allows an operating temperature up to 930°C.

	Horizontal furnace	Vertical furnace
Slow cooling length	-	1 pass
Number of jet coolers	-	5 x 37 kW
Capacity of heat exchangers	-	2.300 Mcal/h

**Tab. 4**

### Slow Jet Cooling Section (future installation of jet coolers)

As a basic solution and only for the vertical furnace, this section transfers the strip at a constant temperature. It will also slightly decrease strip temperature from the cycle temperature up to AC1 where rapid cooling takes place equipped with jet coolers. Apart from the metallurgical advantages, this solution also allows downstream equipment performance to improve and reduce the temperature drop. Cooling is through impingement of cold HNX facing the strip surface through transversal plenum holes and the flow is re-circulated by single VVVF driven fans that suck HNX from a lateral opening in the casing to re-direct to a water-finned heat exchanger and deliver to the above mentioned plenum chambers. The jet coolers are controlled by a downstream infrared pyrometer. Electric heaters (270 kW) will be provided to compensate for heat loss and for pre-heating during start-up.

### Rapid Jet Cooling Section

Both horizontal and vertical furnaces are equipped with a rapid cooling section, where jumbo power fans are installed. The key point of the process occurs in rapid cooling from cycle temperature or AC1 temperature with performances up to or greater than 100°C/s (based on actual cooling length)

with 1 mm gauge strip: the quicker the process, the shorter over-aging, consequently final mechanical characteristics are superior. The target temperature is the bath temperature or lower (< MS) with HSS material grades.

This section is divided into portions. Each portion works as follows: rapid cooling is realized through high speed impingement of cold HNX protective atmosphere with a hydrogen content up to 15% facing the strip surface after exiting special profiled nozzles welded on a couple of plenum chambers. One single VVVF driven fan sucks HNX from lateral openings in the casings, re-circulates gas flow and re-directs it to a water-finned heat exchanger for delivery to the above-mentioned plenum chambers via large ducts. Each section is equipped with an infrared pyrometer positioned immediately downstream to measure strip temperature, but unless special cooling rates have been requested only the last pyrometer (scan type) in the last section controls the entire jet cooling system.

A trimming system is provided to reduce blowing and avoid different strip width edges over-cooling: this system allows to divide HNX flow and adjust the temperature profile along the

	Horizontal furnace	Vertical furnace
Unfired recuperative length	11 modules	6 pass
Number of zones	3 (14 burners each)	3 (14 burners each)
Number and burner type	42 long flame (RT 3)	42 long flame (TFB-REK)
Recuperator	Plug-in radiant tube	Self-recuperative burner
Radiant tube type	Cast U-shape (25Cr-20Ni)	Double P-shape (Inconel 601)
Installed power capacity	3.400 Mcal/h	6.800 Mcal/h

**Tab. 3**



**FIG. 7** Compact design for horizontal jet cooling.

*Compact design for horizontal jet cooling.*

	Horizontal furnace	Vertical furnace
Rapid cooling length	3 modules	1 pass
Number of jet coolers	3 x 280 kW	2 x 1020 kW
Capacity of heat exchangers	6.000 Mcal/h	7.000 Mcal/h

**Table 5**

strip width by closing HNX flowing onto the portion facing the strip. This operation is performed by actuators which are fine tuned by the automation system via the downstream scan-type pyrometer.

To stabilize the strip through this high turbulence section in the vertical furnace two devices have been foreseen:

- intermediate helpers (3 x 11 kW) to increase strip tension,
- anti-vibration rolls (6 x 2,2 kW) to avoid strip fluttering.

To increase cooling the two cooling boxes facing the strip can be positioned very close to the pass line (min. 40 mm) by screw jack driven mechanics, thus heat transfer coefficient, with an additional local increase of hydrogen content of approximately 25%, allow to achieve an extremely high cooling gradient: up to 130°C/s cooling rate with 1 mm gauge strip.

#### Over-aging Chamber (future expansion)

This chamber, foreseen in both furnaces, works as a HNX equaliser to promote the precipitation of solute carbon dissolved during the annealing steps and to finely control the grain structure. The chamber also maintains strip temperature after rapid cooling for 40 seconds at max. speed.

Electric heaters (540 kW) are provided to compensate for heat loss and to pre-heat during start-up.

#### Equalising Equipment and Post-Heating

This section is designed to maintain strip temperature for further homogenising after cooling or, to heat the strip as close as possible to bath temperature when producing DP. The horizontal furnace is equipped with electric heaters (630 kW) necessary to heat the strip from 400°C to 460°C at max production at less than 12 m. The vertical furnace is equipped with an induction booster (2000 kW) which will heat the strip from 320°C to 460°C at max production at less than 2 m. Electrical heaters (540 kW) are also foreseen.

#### Hot Bridle complete with Snout

The strip is dipped into the zinc pot and then despatched to the final cooling tower. The snout is equipped with electric heaters (180 kW), and with the AISI 316L dipping part. To increase strip tension through the down-chute a hot bridle (45+75 kW) is provided: both rolls are coated offering a higher friction coefficient and a wear resistant surface.

#### After Pot Cooling Tower

To reduce the free distance between the sink roll and the top roll a high efficiency open air cooling system is provided. In the up-pass fixed open air coolers (3 x 110 kW) deliver air sucked from outside in long plenum chambers, and finally through slots onto the strip surface. To cut down exposure time at temperatures above 400°C (in case of DP cycle) even further, a horizontally movable in or off-line 110 kW air cooler starts the cooling process immediately after the air knives. An additional 45 kW pre-cooler is provided just above the air knife to stabilize the strip to eliminate fluttering, which could damage the strip surface.

Before contacting the top-turn roll, strip temperature is reduced to below 280°C to avoid pick-up: an infrared pyrometer is installed on the top roll controlling the downstream system for this purpose. After the top roll, other coolers of the same type and arrangement as above continue strip cooling until the strip reaches a max. temperature of 150°C before final water-quenching.

#### Strip Conveyor System

Individual variable speed roll drives are supplied in both vertical and horizontal furnaces to avoid strip skidding, and where the vertical furnace is concerned, to give a tension variation through the entire furnace. In the horizontal furnace strip handling is mainly achieved by small flat support rolls, a steering and hot bridle rolls.

The entire vertical furnace conveyor system uses coated and crown deflector rolls to avoid roll pickup: roll diameter is large enough to prevent damage by plastic strip deformation where tension is applied for self-centring upon the same rolls. Strip steering equipment and load cell are foreseen in different positions all along. The crown profile decreases from heating zone to cooling zone and the relevant flat table increases from heating zone to cooling zone. All rolls are single driven and variable, this allows for single tension variation through the furnace.

#### Refractory and Insulating Materials

Strip exposure to damage, dew-point, oxygen levels and chemistry compatible with the atmosphere's integrity were considered. Materials have been selected to minimise low thermal inertia heat loss required for rapid furnace start-up, to prevent oxidation in the direct fired section (line stoppage) and to save fuel.

In both the horizontal and vertical furnace the lateral walls and roof are lined with ceramic fibre and stainless steel cladding when in contact with the protective atmosphere. The hearth is constructed with refractory bricks and insulating boards.

In all cases refractory material temperature limitations exceed the actual furnace temperature by a sufficient margin to assure long life.

#### CONCLUSIONS

Acciaierie Arvedi S.p.A. CGL-2 and CGL-3 are new galvanizing lines producing approximately 700.000 t per year of high quality coated steel strip for cold forming applications, such as low carbon steel, high strength low alloy steel (HSLA) and advanced high strength structural steels (AHSS).

CGL-2 (horizontal furnace) was started-up at the beginning of

2011; both production rates and quality are high. CGL-3 (vertical furnace) shall enter the commissioning phase at the end of 2011.

Design of both furnaces includes "heavy-duty" equipment of an appropriate standard for this service and can easily be operated by the maintenance staff.

New improved burner technology studied and tested by DCC for direct flame and radiant tube heating gives not only lower fuel consumption figures, extremely low NOX (< 250 mg/Nm<sup>3</sup> for horizontal, < 120 mg/Nm<sup>3</sup> for vertical, with 3% O<sub>2</sub> in dry waste gas) and CO pollution requested by European legislation for the entire furnace. Strip quality is also excellent.

Thanks to an efficient direct flame section a reduction in upstream furnace strip cleaning is achieved, hence reduced hydrogen consumption in the thermal treatment chamber is expected.

To increase efficiency, new low maintenance time double P radiant tubes are foreseen in the vertical furnace giving improved temperature uniformity along the tube surface and lower thermal inertia, leading to further savings in fuel consumption.

Finally, a new flexible ultra rapid jet cooling has been developed and arranged enable the performance of a large group of cooling rates to accommodate the metallurgy of several steel grades.

## Abstract

### Forni per ricottura nastro continui per nuove e moderne linee di galvanizzazione a caldo State-of-The-Art, tecnologia e concetti

**Parole chiave:** acciaio, trattamenti termici, controllo processi, simulazione numerica, automotive, energia

La produzione di nastri di acciaio al carbonio con proprietà meccaniche elevate, assieme ai materiali tradizionali, richiede il costante sviluppo e miglioramento sia del processo di ricottura che la tecnologia dei forni stessi.

A partire dal 2000, Danieli Centro Combustion (DCC) si è proposta come uno fra i leader nella progettazione e realizzazione forni continui per linee di zincatura nastro, completi di fornitura, montaggio e supervisione durante la messa in marcia.

Le risorse dedicate da DCC per evolvere ed innovare il proprio know-how specifico sono state strategicamente mirate alla ricerca di soluzioni impiantistiche e di processo progressivamente più performanti ed economicamente competitive.

Solo in Italia, nel 2011, sono in fase di avviamento o di produzione, quattro (4) impianti che ricalcano questa filosofia progettuale. In particolare due (2) di questi, uno orizzontale ed uno verticale, fanno parte delle nuove linee di zincatura CGL2 e CGL3 (ciascuna capace di 350,000 tpy) nel Cold Mill Complex installato da Danieli & C. presso la Acciaieria Arvedi S.p.A. In Tabella I sono elencati i principali dati di configurazione impianto.

Le sezioni di riscaldamento, mantenimento e raffreddamento in atmosfera controllata (HNx), sono state progettate tenendo conto anche di future espansioni e potenziamenti.

Il riscaldamento rapido, soaking prolungato, raffreddamento lento/rapido e post-heating finale, permettono di eseguire svariati cicli di ricottura, adatti sia per gli acciai commerciali (CQ) e a medio / profondo stampaggio (DQ, DDQ) che coprono una grande fascia di mercato, sia per gli acciai microlegati e strutturali (HSLA, HSS), sia per quelli complessi di ultima generazione come Dual Phase, Bake-Hardening e TRIP (AHSS), con applicazioni finalizzate al settore automotive, determinando di fatto un impianto che permetta al Cliente utilizzatore la massima flessibilità di impiego ed al contempo consentendo l'ammortamento dell'investimento in termini molto rapidi seppure in condizioni di mutevoli esigenze di mercato.

L'impianto di combustione e distribuzione gas per alimentare i bruciatori dei forni, così come quello utilizzato per la generazione ed utilizzo delle atmosfere protettive, sono stati sviluppati da DCC in accordo con gli stringenti requisiti di processo e con gli standard locali di sicurezza e certificazione impianto.

La sezione a fiamma libera prevede l'utilizzo di bruciatori laterali a fiamma lunga (forno orizzontale) e frontali a fiamma piatta (forno verticale) di ultima generazione, studiati e sviluppati per garantire uniformità di riscaldamento nastro, senza locali ossidazioni o depositi carboniosi.

La notevole efficacia di questa sezione in termini di sgrassaggio, rimozione polveri metalliche e riduzione dell'ossido dalla superficie del nastro, è tale da richiedere una sezione di pulizia nastro a capacità notevolmente ridotta prima del forno, limitando i consumi di idrogeno nella sezione seguente di trattamento termico e raffreddamento.

Il forno verticale è equipaggiato con una coppia di porte corazzate, fronte nastro, con alloggiati bruciatori premix particolarmente adatti per massimizzare sia lo scambio termico che la capacità meccanico-chimica di pulizia del nastro, con ulteriore riduzione nei consumi di idrogeno.

La sezione di riscaldamento finale e mantenimento ad alta temperatura del nastro è di tipo a tubi radianti, gestiti con schema push-pull, equipaggiati con un regolatore bilanciato di rapporto aria/gas a doppia membrana e controllati con logica ibrida on-off / proporzionale.

Nel forno verticale sono installati tubi radianti 2P di ultima generazione, costruiti in lamiera calandrata di lega speciale resistente al calore (Inconel 601), e quindi di ridotta inerzia termica, e sono accoppiati ai bruciatori DCC auto-recuperativi, sviluppati per questo specifico utilizzo, e che garantiscono un'eccellente uniformità di temperatura sulla superficie del tubo stesso ed allo stesso tempo aumentano l'efficienza di combustione.

Le particolari tecniche di combustione utilizzate e testate da DCC nella messa a punta dei bruciatori qui utilizzati per la sezione a fiamma libera e a tubi radianti hanno permesso di diminuire i consumi gas, ed allo stesso tempo limitare le emissioni inquinanti a valori particolarmente bassi per il tipo di applicazione, in termini di NO<sub>x</sub> (< 250 mg/Nm<sup>3</sup> per il forno orizzontale, < 120 mg/Nm<sup>3</sup> per quello verticale, con il 3% O<sub>2</sub> su base secca) e CO, ed in accordo con gli ultimi standard Europei.

Il raffreddamento rapido del nastro dalla temperatura prevista dal ciclo termico a quella di vasca zinco, oppure inferiore in funzione del ciclo termico richiesto, viene ottenuta in una sezione a raffreddamento rapido con l'utilizzo di potentissimi ricircolatori di atmosfera controllata.

In particolare il sistema è dimensionato per raggiungere un gradiente massimo di raffreddamento di 100°C/sec, con spessore nastro pari a 1 mm.

Un sistema meccanico parzializza il ricircolo per evitare il sovra-raffreddamento dei bordi nastro, in funzione della larghezza dello stesso ed in cascata rispetto alla misura di uno speciale pirometro a scansione.

Il forno verticale, che in futuro sarà equipaggiato di una sezione di raffreddamento lento a monte di quello rapido indispensabile nella produzione di acciai alto-resistenziali complessi (AHSS), è equipaggiato con distributori mobili ad ugelli di profilo speciale che possono essere avvicinati al nastro, e con un sistema di arricchimento locale di idrogeno per massimizzare il gradiente di raffreddamento, parametro fondamentale per ottenere strutture metallurgiche mirate.

Il forno orizzontale è invece in grado di ridurre la lunghezza effettiva di raffreddamento per migliorare la flessibilità della curva di raffreddamento, soprattutto con nastri ad alti spessori.

Una camera a resistenze elettriche mantiene il nastro in temperatura o ne controlla un lento raffreddamento per un certo periodo, con la possibilità di una futura espansione su entrambi i forni per un esteso overaging.

Un sistema ad induzione, previsto nel forno verticale, aumenta la temperatura del nastro con un gradiente massimo di 130°C/sec in presenza dei cicli termici più complessi, fino a quella di vasca, in spazi molto contenuti.

Il raffreddamento del nastro dopo la vasca e le lame d'aria, prima della quench finale ad acqua nebulizzata, è effettuato con aria ambiente soffiata attraverso ventilatori centrifughi e speciali diffusori, di design tale da evitare dannose oscillazioni del nastro appena zincato.

Un pre-cooler ed un raffreddatore mobili sono installati a bordo della struttura di sostegno per un controllo più accurato della stesatura e lucentezza del rivestimento, inoltre consentono un pre-raffreddamento del nastro, quando richiesto in presenza dei cicli termici più complessi.

Il nastro viene movimentato meccanicamente dentro e fuori il forno attraverso l'utilizzo di rulli di centraggio, tensiometrici ed antivibranti, oltre a quelli normali di supporto e deflettori.

Inoltre, le "briglie calde" sono fondamentali per gestire il passaggio del nastro dal forno al raffreddamento finale, e, nel forno verticale, per separare zone a diversa tensione nastro.

I materiali utilizzati per realizzare il rivestimento interno sono perfettamente compatibili con il tipo di atmosfera protettiva utilizzata all'interno del forno, altamente riducente data la presenza di incombusti nella sezione a fiamma diretta e di idrogeno in quella di trattamento e raffreddamento a ricircolo chiuso.

Si è massimizzato l'utilizzo della fibra ceramica dovunque in tutte le camere del forno, ad eccezione della suola, per minimizzare l'inerzia termica del sistema.

Strumentazione di campo, architettura e automazione di controllo sono entrambe di ultima generazione e rappresentano lo State-of-The-Art per questo tipo di applicazione.

Una particolare attenzione è stata dedicata per creare un sistema operativo affidabile e di tipo User Friendly.

Tutte le funzioni di controllo processo, per entrambi i forni, sono implementate nell'automazione di Livello 1 / HMI, connessa con l'automazione di controllo linea, e capace di gestire l'intero ciclo di ricottura nastro in termini di riscaldamento, mantenimento, raffreddamento, etc.

Il Livello 2 interviene per ottimizzare il controllo del processo, affiancando l'operatore nella scelta e settaggio delle ricette di ricottura, o nella gestione del forno durante i transitori di produzione (cambio rotolo, dimensioni, materiale, ciclo ricottura, rallentamenti linea, etc.), a garanzia di alta e costante qualità del prodotto finale, minimizzando lo scarto o declassamento.

La massima attenzione è stata prestata riguardo alla sicurezza impiantistica, in accordo con la Direttiva Macchine CE e Normative attualmente in vigore. Una articolata logica interbloccata di tipo cablato provvede alla rapida messa in sicurezza dei forni durante gli avviamenti e gli arresti e fermate programmate o accidentali.