ISSN 1611-616X VULKAN-VERLAG · ESSEN

1
2003

HEAT
PROCESSING

INTERNATIONAL MAGAZINE FOR INDUSTRIAL FURNACES · HEAT TREATMENT PLANTS · EQUIPMENT

http://www.heatprocessing-online.com

Continuous heat treatment of floatingly guided copper alloy strips

Prof. Dr.-Ing. Carl Kramer, WSP GmbH, Aachen (Germany)

Published in HEAT PROCESSING 1/2003

Vulkan-Verlag GmbH, Essen (Germany)

Editor: Dipl.-Ing. Stephan Schalm, Tel. +49 (0) 201/82002-12, E-Mail: s.schalm@vulkan-verlag.de

Continuous heat treatment of floatingly guided copper alloy strips

High quality production of cold rolled copper alloy strips requires continuous heat treatment. Only a continuous furnace followed by a sufficiently fast cooling guarantees the desired material properties as hardness, grain size, electrical conductivity, etc. with the necessary uniformity over the strip width and length. Copper alloy strips are mainly heat treated in horizontal floating furnaces. The present technology of strip floatation, however, allows only the save floatation of strips up to 1.5 mm, max. 1.8 mm thickness. Because of limited floatation capability the heat treatment of strips in this upper thickness range is restricted to temperatures of 650 °C to 700 °C which is not enough for solution heat treatment of modern alloys. For the same reason strips after the first cold rolling with a thickness between 2 mm and 3.5 mm are heat treated in coils, mostly in bell-type furnaces, or, if continuous annealing is required, in vertical furnaces, regardless all the problems as rather high cost, difficulties of the strip threading, and enormous operation problems in case of a strip rupture in the heating part. In the following some new developments are described which overcome the present limitations of such plants and widen the possibilities of continuous copper alloy heat treatment.

Prof. Dr.-Ing. Carl Kramer
WSP GmbH,
Aachen (Germany)

Phone:
+49(0)241/8797030
Email:
info@wsp-aachen.de

New floatation nozzle system

The core piece of a continuous heat treatment plant for floatingly guided metal strips is the floatation nozzle system. The floatation nozzle system cares not only for the contact less guidance of the strip through the heat treatment plant but also provides the convective heat transfer. A lower and an upper floatation nozzle system stabilise the strip like between air springs. The heat transfer must be convective because of the low absorption coefficient of heat radiation of about 0.05.

The force due to a jet impinging perpendicularly on a flat surface in a distance h from the nozzle exit plane is equal to the momentum of the jet.

$$F_a = \rho \cdot \dot{V} \cdot c$$

ρ…. gas density, $\dot{V}$ … jet volume flow, c… jet exit velocity

If the plate has the distance $h = 0$ no flow is discharged and the force is

$$F_{h=0} = \Delta p \cdot A_N$$

A_N is the nozzle exit area and Δp the nozzle pressure

$$\Delta p = \frac{\rho}{2} c^2$$

With $\dot{V} = c \cdot A_N$ it follows

$$\frac{F_h}{F_{h=0}} = \frac{\rho \cdot A_N \cdot c^2}{\frac{\rho}{2} c^2 \cdot A_N} = 2$$

This simple calculation shows that in the vicinity of a nozzle field the force generated on a flat surface or on a strip will increase with increasing distance by a factor of 2. In floatation plants or in vertical furnaces with forced convection two of such nozzle systems are positioned on both sides of the strip. Therefore, a strip never can be stabilised by such simple nozzle systems. This is well known from vertical furnaces in which strips not strongly stretched experience a twisting around the longitudinal axis and take the shape of a ”fly-paper” stripe.

The stabilising effect of nozzle fields in order to float the strip in a stable position must be obtained by other means. This consists in a choking of the flow which is blown by the nozzle fields on the strip when leaving the strip. The choking effect must increase with decreasing distance between strip and nozzle field and thus generate a static pressure zone, the pressure of which increases with decreasing distance similar to the pressure cushion underneath a hoover-craft. Conventional floatation nozzles, c.f. [1], therefore consist of nozzle arms with slot nozzle at both longitudinal edges. Because round jets have a significantly higher heat transfer than comparable slot jets, mostly round jet orifices are arranged between the slot jets.

The floatation force which can be characterised by the floatation pressure coefficient

$$c_{p,\mathrm{float}} = \frac{F_{\mathrm{float}}}{A_{\mathrm{strip}} \frac{\rho}{2} c^2}$$

increases with an increasing ratio of nozzle arm area related to the total area of the nozzle hearth. For the conventional floatation nozzles, **Fig. 1** on the left, the nozzle arm area is rectangular and $c_{p\ \mathrm{float,\ max}} \cong 0.3$.

Because the returning flow increases from zero at the strip centreline linearly to the maximum at the strip edges, the free space available for this returning flow between the nozzles arms can be reduced in the centre of the nozzle field and should increase symmetrically to both sides. The result are nozzles arms with a plane view similar to the longitudinal section of a barrel [2], Fig.1 on the right). Now the ratio between nozzle arm area and total area is significantly increased and the max. floatation pressure coefficient is about twice the value for conventional rectangular nozzles.

$$c_{p,\ \mathrm{float,\ barrel\ nozzle}} \cong 0.62$$

Because the area portion with round jet nozzles is increased, too, the heat

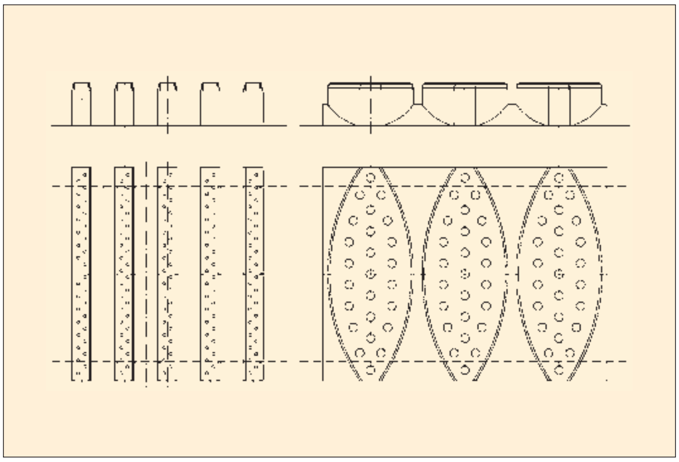

Fig. 1 Conventional floatation nozzles with rectangular nozzle area (left) and novel floatation nozzles with nozzle areas of “barrel shape“ (right)

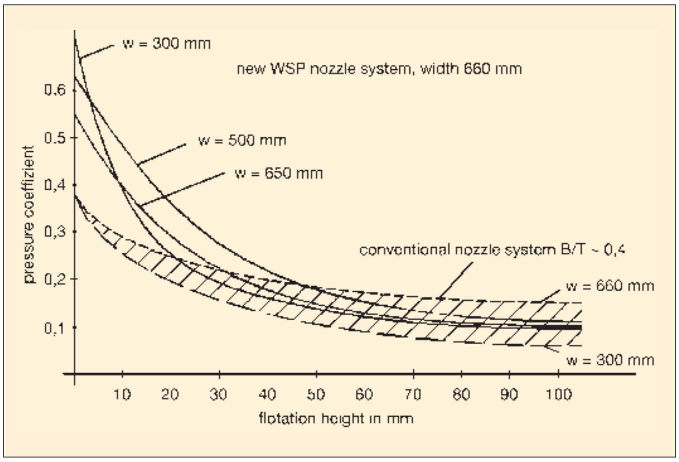

Fig. 2: Floatation pressure coefficient $c_{p\ float}$ vs. floatation height h

transfer is also significantly higher, for the same nozzle exit velocity 20 % and more. In **Fig. 2** the floatation pressure coefficient is plotted vs. the floatation height. In the mainly interesting range close to the nozzles the $c_{p,\ float}$-value for the new system is about twice the value for the conventional rectangular nozzle arms. So now strips from copper alloys of about 3 mm thickness can be heat treated floatingly with the usual protective atmosphere N_2 96 %, H_2 4 % even at temperatures of 750 °C to 800 °C. This is more than sufficient for the intermediate soft annealing, after the first cold rolling, which, according to the state of the art, today is executed in bell or chamber furnaces.

Fig. 3 shows an example of the novel nozzle system.

New flow circuit concepts

The gas flow in strip floatation plants is enormous. This has the advantage that the mass flow of the gas transferring the heat to and from the strip is much higher than the mass flow of the strip. In other words: a lot of kilograms of gas will be circulated in order to heat 1 kg of copper strip throughput. In modern floatation furnaces this ratio is up to 20. Because of the high gas circulation the heating part as well as the cooling part are subdivided in several zones. This subdivision in zones is in addition of advantage for the temperature control. **Fig. 4** shows schematically two conventional floatation furnace zone designs. The design Figure 4a has two fans per zone, one for the top part and one for the bottom part. This has the advantage of an additional control possibility of the floatation force by fan speed control. Figure 4b shows a system with only one fan at the side which is less expensive but does not allow a floatation control by fan speed

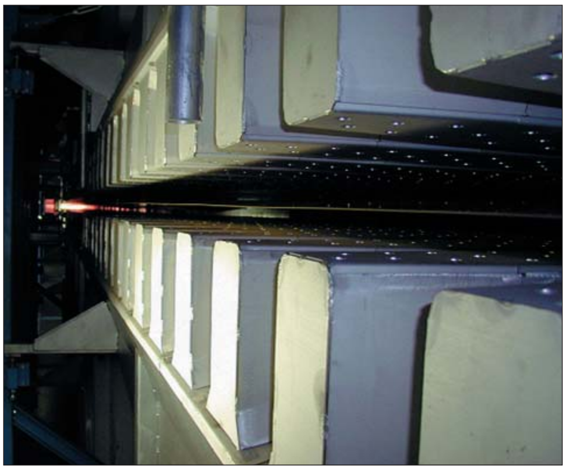

Fig. 3: New nozzles system

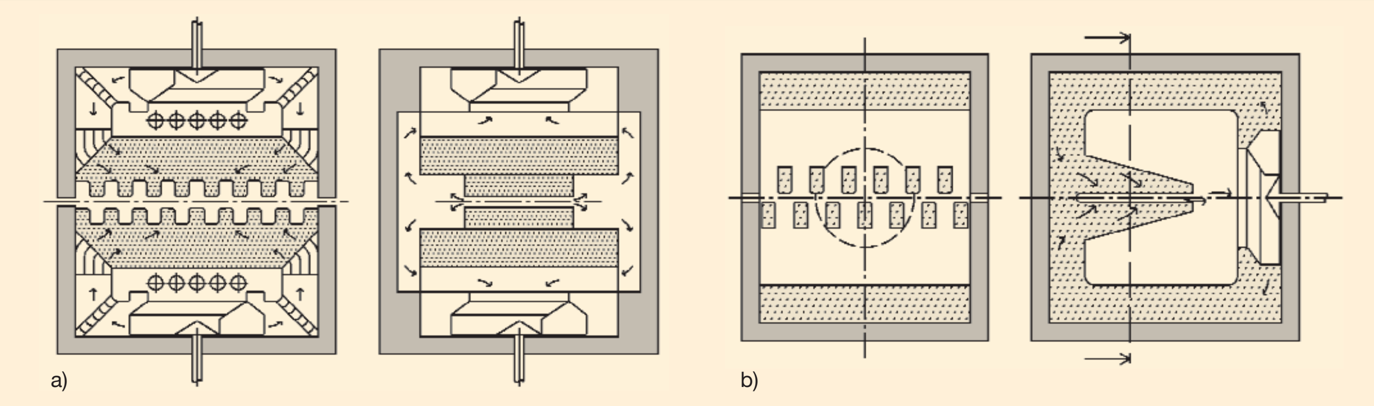

Fig. 4: Conventional flow circuit design for floatation furnace zones

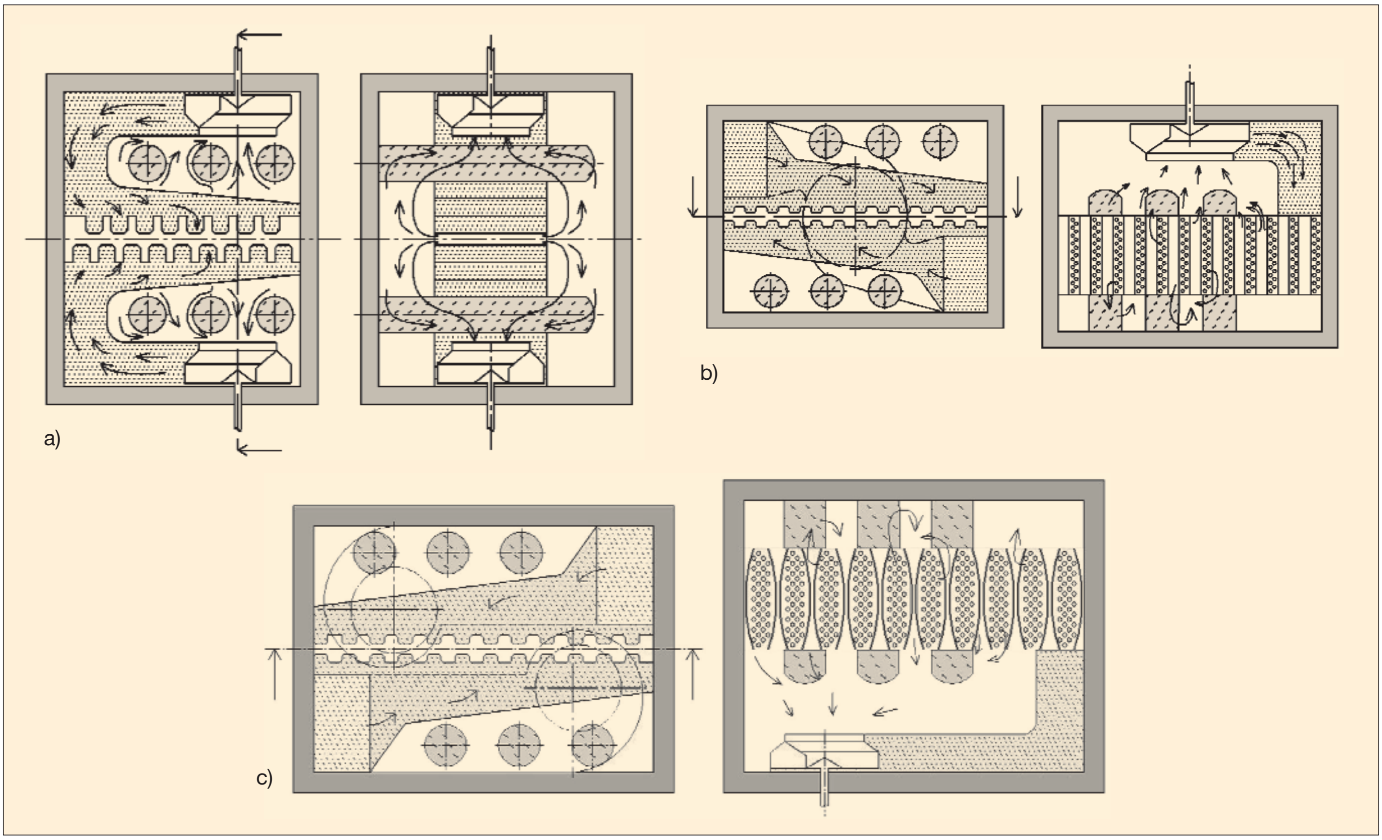

Fig. 5: New design of flow circuits for floatation furnaces zones

variation. A further disadvantage of this system is the non-symmetrical flow situation which is the reason for problems with non-uniform heating over the strip width.

Two novel designs are shown in **Fig. 5a and b**. The flow duct of the system Figure 5a is comparable to a horizontally positioned U with one fan for the upper and one fan for the lower nozzle system. The flow situation in the cross section is absolutely symmetrical and no un-symmetrical heating over the strip width can occur. The heating elements - gas fired or, if desired electrically heated radiant tubes of relatively large diameter - are positioned in the back-flow area. The radiant tubes are straight and therefore much better suited for high temperature operation than the conventional P- or U-tubes.

Figure 5b shows a similar system with one fan at the side. This design is especially suited for the replacement of old floatation furnaces with fans at the side which are at the end of their lifetime. A special design feature is the connection between the fan housing and the nozzle plenum box. This connection is designed such that it can move freely which is necessary because of the significant thermal elongation. A further advantage of this new circuit design is that the flow system is a completely welded stiff structure and that the functions of lining the internal surface of the furnace walls and forming flow ducts are now separated, so a leakage of these ducts does not lead to an entry of hot gas with fan pressure into the furnace's thermal insulation. The thermal elongation cannot cause problems because the flow ducts can move freely and the radiant tubes which are connected to the outer shell of the furnace cannot interfere with the flow ducts. **Fig. 5c** shows a design with two fans positioned in a furnace side wall, one for the upper and one for the lower nozzle system.

The flow circuit design Figure 5a has an additional advantage. The fan housing can be a conventional 360°-spiral. Therefore, the installation of a squirrel cage impeller fan is possible. These fans have a significantly higher volume flow and produce a significantly higher pressure than comparable centrifugal hot fans with the same diameter.

New strip entry sealing

In order to reduce the protective gas consumption of heat treatment lines for copper alloy strips the entry and the exit of the strip must be sealed. At the strip exit behind the cooling section a water lute with an immersed turning roller provides this sealing. The strip is guided into this water lute by a turning roller at the end of the cooling section which has in addition the function of a strip

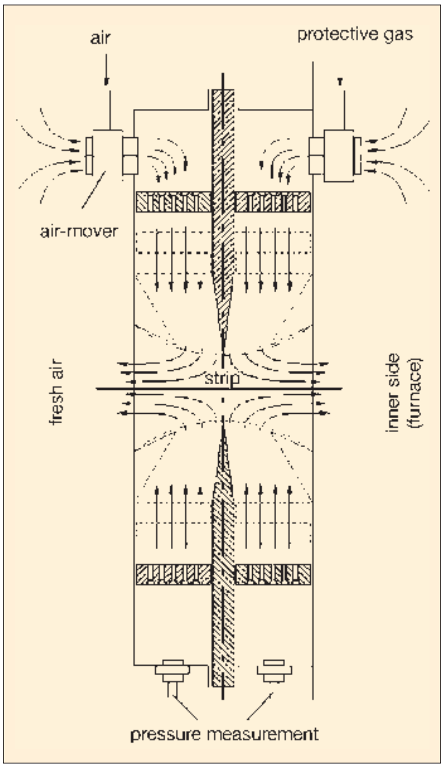

Fig. 6: "Aerodynamic lock" for the strip entry

centring control. At the entry usually sealing rollers are installed. A better solution for highly sensitive strip surfaces is a contact less seal by an aerodynamically designed jet system. The principle of this seal is illustrated in **Fig. 6**. Two adjacent slot jets - the external jet operating with air and the internal jet with protective gas - impinge vertically onto the strip surface [3]. Because both jets have nearly the same flow velocity from above and from below there is no significant mixture in the separation plane between the two jets. Therefore, from the stagnation line formed by the jets on the strip the internal jet, consisting of protective gas, is deflected into the furnace and the external air jet is deflected to the ambient atmosphere. The mixture is so marginal that the usual partial pressures of 10^{-20} bar and less will be obtained with the same consumption of protective gas than for an usual, well operating mechanical seal.

New high temperature annealing concept for copper alloy strip under hydrogen

The recent development of copper alloys require annealing at extreme temperatures with rather high heat up rates. Such fast heat up rates can only be achieved convectively because the heating by radiation is very questionable due to of the very low heat radiation absorption of these strips. An effective possibility is the convective heating by hydrogen as protective atmosphere. Hydrogen allows at the same flow speed an increase of the heat transfer coefficient of about 2 in comparison to the conventional nitrogen atmosphere with only some percent of hydrogen. The price for this advantage is the effort for a reliable safety technique which is mandatory when operating with combustible gases. The convective heat transfer even at 950 °C ... 1000 °C can reach 150 W/(m^{2}K) due to nozzle, flow circuit, and fan design. The safety of the fan operation is guaranteed by a new fan lifetime monitoring system which sums up the creeping of the hot fan impellers depending on fan temperature and speed. If a certain creep length is consumed, the PLC gives an alarm message. Due to the very low density of hydrogen in comparison to usual convective atmosphere a floatation of the strip is not possible. Therefore, the strip must be guided by the action of the gravitational force. A simple solution is a vertical furnace. In such vertical furnaces, however, problems arise because of the effect of the turning roller underneath the cooling section. If - due to any reason - the strip run stops the continuous cooling of the strip in the cooling zone will cause a nearly sudden reduction of the strip length. So a tension is build up which can cause a strip rupture, especially for thin strip which must be annealed close to the solidus temperature, what is the case for low-alloyed copper materials. Therefore, the new design (patent pending) refrains from using a turning roller in the water lute. Instead of this turning roller the strip is deflected by means of efficiently working floatation nozzles which are operated with the liquid in the lute. In this floating strip turn so much strip length is “stored“ that a sudden length shrinking of the strip is no longer a problem. An advantage of this concept is that there are no moving parts and that an automatic centring of the strip is achieved by the novel design of the floatation system. Because the floatation nozzles in the water lute provide an intensive and uniform flow impingement the strip can enter the water with a significantly higher temperature of 150 °C to 180 °C. Therefore such a new plant is very flexible concerning the length of the gas operated cooling zone. This plant therefore can cover a wide range of heating curves with long or short soaking times in combination with fast heating up in the first furnace zone. So the metallurgist may design by means of this new plant the heat treatment according to his needs. Because of the vertical strip path and the efficient stabilisation of the strip in the water lute the nozzle to strip distance can be decreased which is important for a further augmentation of the heat transfer. The new plant for operation under hydrogen has a double roller seal at the entry. This double roller seal operates by opening and closing the roller seals like a lock chamber when the stitch is passing. Because of the rather large length of this lock chamber which is only limited by the height of the furnace, the strip stitch can pass the roller seals with a rather high speed.

Plants for copper alloy strips

Fig. 7 shows a furnace zone of a plant for copper strip, width 600 mm ... 1300 mm, thickness 0.2 mm ... 1.5 mm, operating at max. 800 °C with non combustible protective gas (N_2 97 %, H_2 3 %). The strip entry has a jet seal described in chapter 4. The flow circuit design corresponds to Figure 5a. The hot fans and the straight radiant tubes,

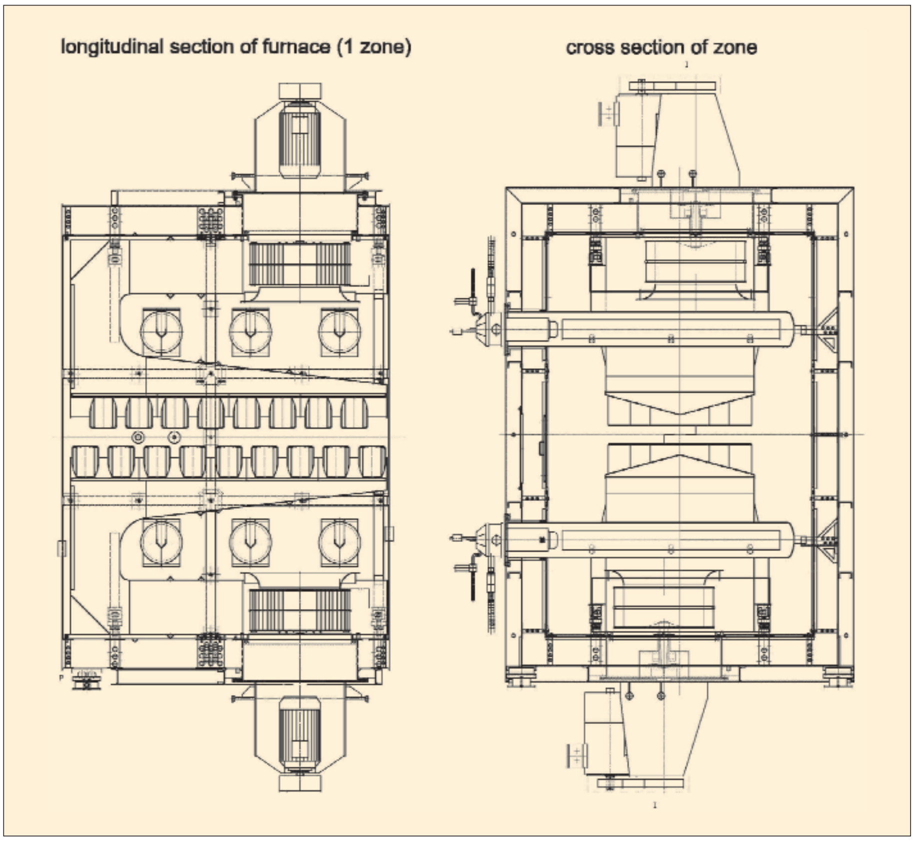

Fig. 7: Floatation furnace zone for max. 1300 mm strip width

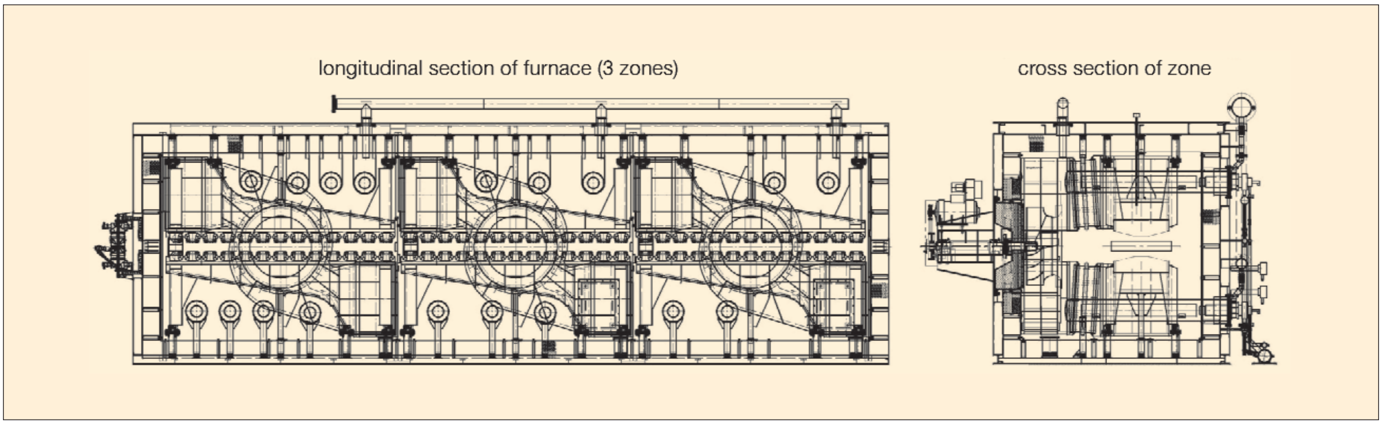

Fig. 8: Floatation furnace zone for ~ 750 mm strip width with on hot fan in the side wall

Table 1: v_{strip} x *s* for different annealing processes

	heating to material temp. 550 °C	soft annealing material temp. 650 °C	solution annealing material temp. 750 °C
$v_{strip} \cdot s \left[\frac{m \cdot mm}{min}\right]$	38	23	18
throughput in kg/hr for strip width 1200 mm	25000	15000	12000

heated by gas fired recuperative burners, have round, insulated plugs and round flanges perfectly protective gas tight by O-ring-type seals.

The throughput of a continuous strip heat treatment plant is determined by the product

strip speed v_{strip} x strip thickness *s*

For a plant with 5 heating zones and 4 cooling zones of 3.3 m length **Table 1** gives v_{strip} x *s* for different annealing processes.

In order to reduce the space requirement and the number of rolls of the strip accumulators the furnace can operate dynamically. By a reduction of the heat transfer (at constant gas temperature) and keeping the floatation height constant due to an co-ordinated PLC-controlled change of the fan speed of the upper and lower fans, the strip obtains the same final material temperature when reducing the strip speed for up to 50 %. Of course the dynamic operation is not possible for strips which require a soaking time. But these strips are running slower and are not the limiting cases for the line speed.

By using two coilers with belt-wrappers and a moving shear, the strip accumulator at the exit can be avoided. This reduces the number of rolls in the strip run behind the heat and surface treatment, what contributes to an improvement of surface quality and material properties.

Fig. 8 is a schematic drawing of furnace zone out of a furnace which replaced a conventional floatation furnace. In the furnace side wall one fan for the upper and lower nozzles is installed, c. f. Figure 5b). The new concept allowed for strips up to ~ 750 mm width as well an increase of the safely floated maximum strip thickness from 1.5 mm to 1.8 mm as an increase of the factor *v* x *s* for at least 15 %. Furthermore the furnace can now operate at a max. temperature of 850 °C instead of 750 °C ... 800 °C and thicker strips can be solution heat treated at this higher temperature.

Conclusion

The well based knowledge about the convective heat transfer in the novel strip heat treatment plants allows the definition of a very reliable working mathematical model for the furnace. Taking into account the metallurgical process of the heat treatment this model enables the operator to define the annealing process without many trials. Depending on the degree of plant automation even a controlled and automatic annealing is possible, in order to achieve the required metallurgical properties, e. g. grain size and hardness.

Literature

[1] C. Kramer (inventor): Düsensystem, German Patent DE 3026132C2

[2] C. Kramer, E. Fiedler (inventors): Nozzle array for levitational guidance of web material, U.S. Patent no. 6,321,001

[3] C. Kramer, H.J. Gerhardt (inventors): Apparatus for contactless sealing of an opening against emerging or entering gas, U.S. Patent no. 4,894,009