Light Gauge Annealing

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Introduction

Especially for thin copper alloy strips and foils the touchless continuous heat treatment is mandatory. Therefore Cu-alloy strip producers specify their continuous AP-lines, mostly floatation strip plants, as well for the thicker gauges after the first cold rolling as for light gauges down to 100 µm and less.

This leads to strip thickness and strip cross section ratios of 20:1 and more which must be handled not only by the heat treatment part but also by the mechanical components like coilers, storage towers, bridles, etc. and by the strip surface treatment. In the following these requirements and the design consequences for a modern strip line will be discussed. Finally ideas for a simplified plant specialized on light gauge only are presented.

Strip stresses and strip tensions in AP-lines (annealing and pickling lines)

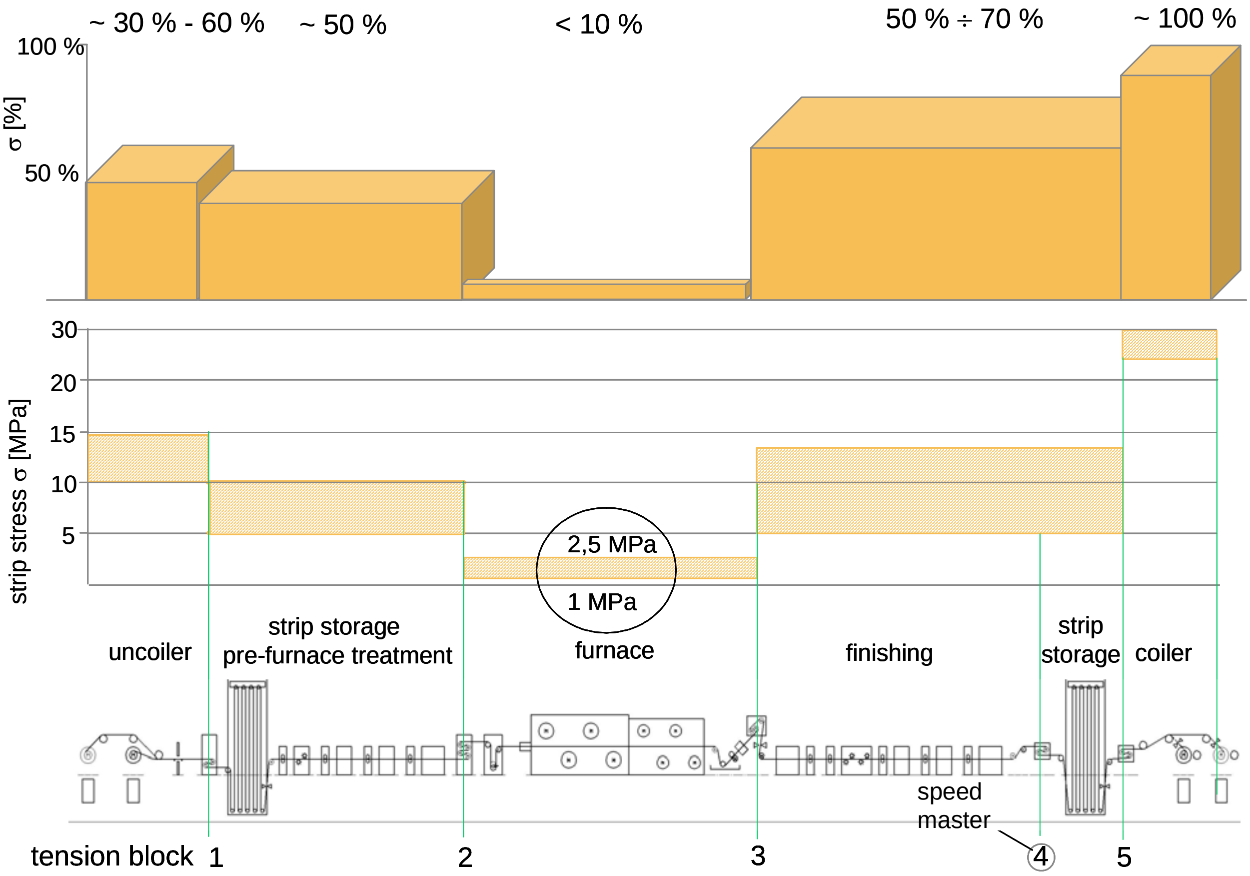
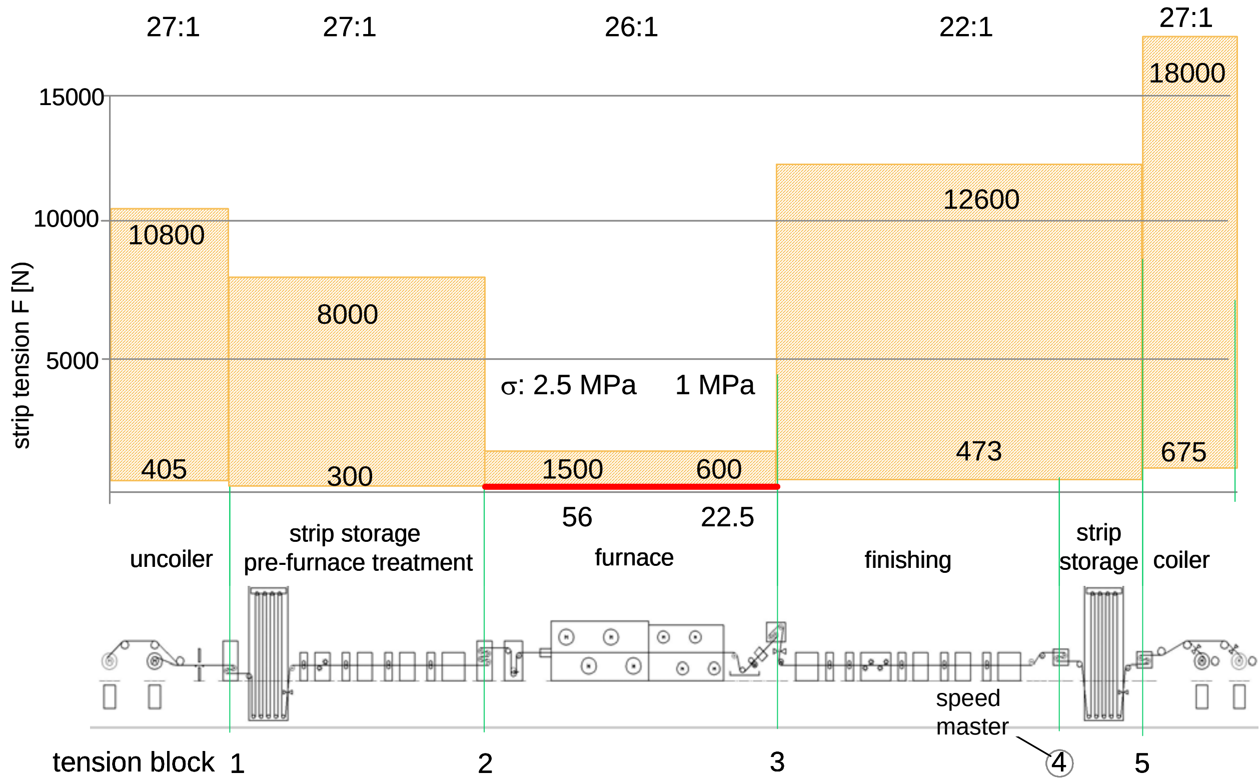


Figure 1: Strip stress in a continuous AP-strip line (the higher stress limit in the finishing part is necessary for abrasive brushing)

A survey of the strip stress in an AP-strip line is shown in Figure 1. Strip coiling and uncoiling require the highest stresses, the heat treatment section the lowest. As an example for an AP-line and strips with

strip width:	500 mm (19.68 in)	÷ 300 mm (11.81 in)
strip thickness:	1.2 mm (0.047 in)	÷ 0.075 mm (0.003 in)
strip cross section area:	600 mm^2 (23.62 in)	÷ 22.5 mm^2 (0.035 in^2)
strip cross section area range:	~ 26	

the strip tension range required to obtain these strip stresses is shown in Figure 2.



strip tension in an AP-line for strips of width: 300 mm ÷ 500 mm, gauge: 0.075 mm ÷ 1.2 mm for the stress range according to the presented stress distribution

Figure 2: Strip tension in a continuous strip line

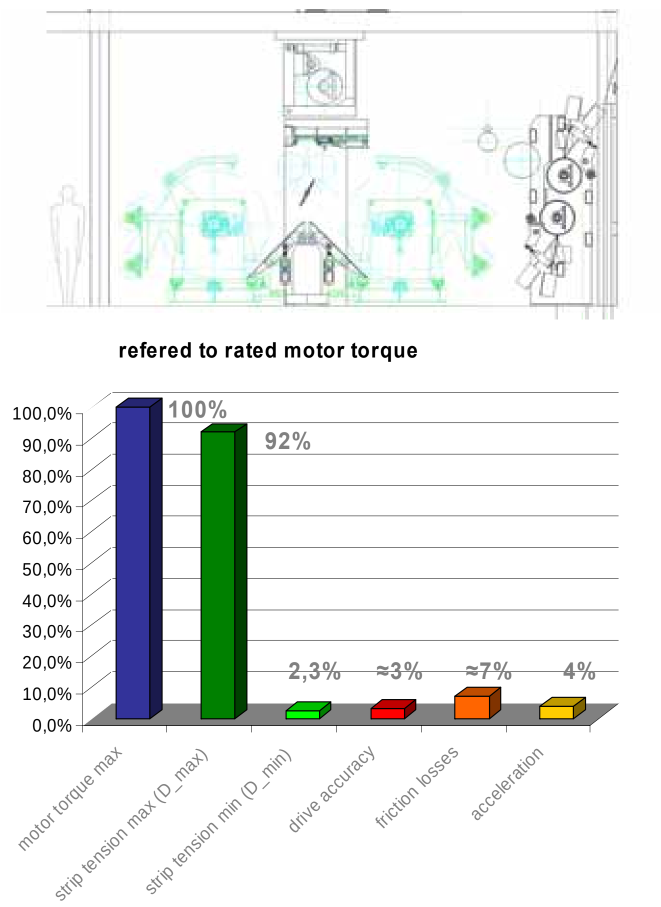
But this range cannot be covered with conventional technique even according to the best present state of the art. This is obvious from the example given in Figures 2, 3 and 4 for an AP-line coiler. The technical data are listed in Figure 3. Figure 4 shows that the max strip tension range for a coiler is limited to a factor 1:10. For the other components of the line the coil diameter ratio has no influence. Therefore the tension range is higher and should be limited to the safely obtainable value of max. 20:1 with this tension ratio the tension ranges shown in Figure 2 are not feasible.

Figure 5 gives a realistic strip tension distribution for the AP-line chosen as example. The stress $\sigma = F / A_{strip}$ is higher for small cross sections than for larger cross sections.

	max.	min.
strip width	400 mm	400 mm
coil ∅	1600 mm	400 mm
gear transmission ratio	22	
gear inertia factor	100 %	
strip tension	7500 N	750 N
strip speed	100 m/min	
acceleration time	15 s	
density	8.930 kg/m2	
motor:		
power	22 kW	
nominal speed	1500 rpm	750 rpm
tilting factor at nominal speed	2.6	
tilting tolerance	30 %	
moment of inertia	0.55	

data provided by Dipl.-Ing. E. Seekamp,
CSE Seekamp Elektroausrüstung GmbH & Co. KG, Germany

Figure 3: Typical data of an AP-line coiler

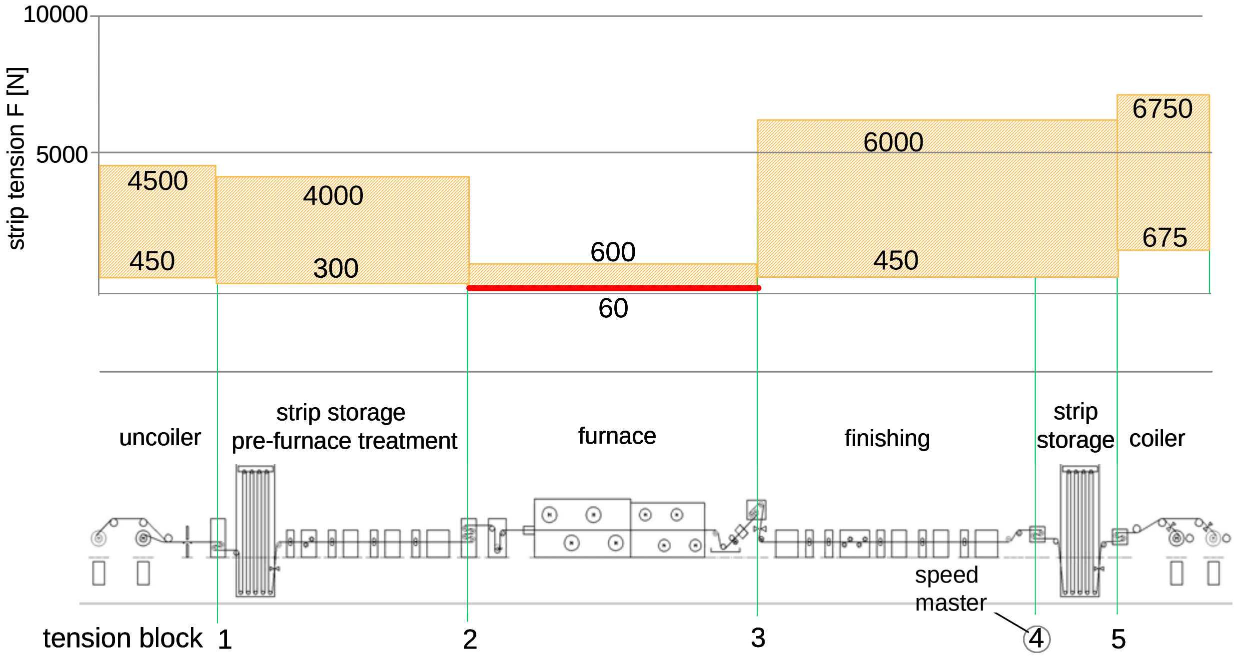


conventional technology (without dancer!) allows max. strip tension ratio

10:1

data provided by Dipl.-Ing. E. Seekamp, CSE Seekamp Elektroausrüstung GmbH & Co. KG, Germany

Figure 4: Coiler



strip tension in an AP-line for strips of width: 300 mm ÷ 500 mm, gauge: 0.075 mm ÷ 1.2 mm for the stress range according to the presented stress distribution

Figure 5: Strip tension in a continuous strip line

The lowest tension of 60 N is marked in red, because a certain minimum tension is necessary to bring the strip safely through the furnace and the cooling section. The strip must be tensioned sufficiently for a reliable operation of the strip centring unit positioned at the end of the cooling section in front of the immersed roller in the water lute.

Investigations of numerous production lines showed that a tension of 70 N to 100 N is the absolute lower limit. Higher tensions are necessary if the next strip centring unit is positioned in larger distance from the centring unit at the end of the heat treatment.

The low tension in the furnace, necessary to obtain sufficient strip planity, requires an effective tension separation between the pre-furnace strip treatment and the furnace as well between furnace and strip surface finishing. A simple turning roller with a brake or a driven turning roll with a braking motor installed behind the furnace is not sufficient for light gauge material.

Figure 6 shows a new WSP floatation furnace installed in an older strip line. In order to create the possibility for the annealing of light gauge strip a specially designed 3 roll bridle was installed above the water lute at the cooling section exit.

A further problem with thin strip, especially when soft annealed, is the start of the coiling because no folds shall occur. Here, skill and experience of the operators are required and of course a suited machinery.

Figure 6: WSP floatation furnace and special 3 roll bridle above the water lute in already existing strip line upgraded for thin strips at Diehl Metall Sundwiger Messingwerke GmbH & Co. KG, Germany

The heat treatment part

In floatation furnaces suited for light gauge material the strips must be perfectly stabilised by the floatation nozzles. The best possibility is the guidance of the strip in a longitudinal wave pattern shape. This can be obtained by high floatation force progression and an array of top and bottom nozzles staggered against each others. This so called sinusoidal wave pattern avoids a cross bow or "bird wing shaping". These deformations would be frozen in the cooling section leading to a bad planity of the annealed strip. The sinusoidal wave shape can also compensate different fibre length of the strip over the width by slightly different amplitudes of the wave.

So, even thin strips with "longer edges", e. g. split strips, can be annealed with sufficient planity. In order to keep the traversal waves in the strip the strip tension in the furnace must be low, the lower, the less powerful floatation nozzles are required to impress the wave pattern on the strip.

The effect of the floatation nozzle system on the wave pattern of the strip and the influence of the strip tension can be quantified by a simple theoretical model demonstrated in Figure 7. A half wave which corresponds to a length of half the nozzle spacing is approximated by a symmetrical catenarian curve. The self-weight of the thin strip is neglected and the constant and uniform load on the strip corresponds to the mean pressure coefficient of the floatation nozzle multiplied by the nozzle dynamic pressure. As explained in Figure 8, the amplitude of the strip wave depends on the strip tension F, the product $\overline{c}_p \cdot q_{Nozzle}$, the strip width b and the nozzle spacing t. For safely guiding the strip the amplitude "a" should be about 2 % of the nozzle spacing (= wave length). The diagram in Figure 8 gives for these assumptions the relationship between the catenarian load p = $\overline{c}_p \cdot q_{Nozzle}$ and the strip tension again for strip width 400 mm. Small nozzle spacing requires a high $c_p \cdot q_{Nozzle}$ but large spacing reduce the jet impingement onto the strip and consequently as well the heat transfer as the average pressure coefficient.

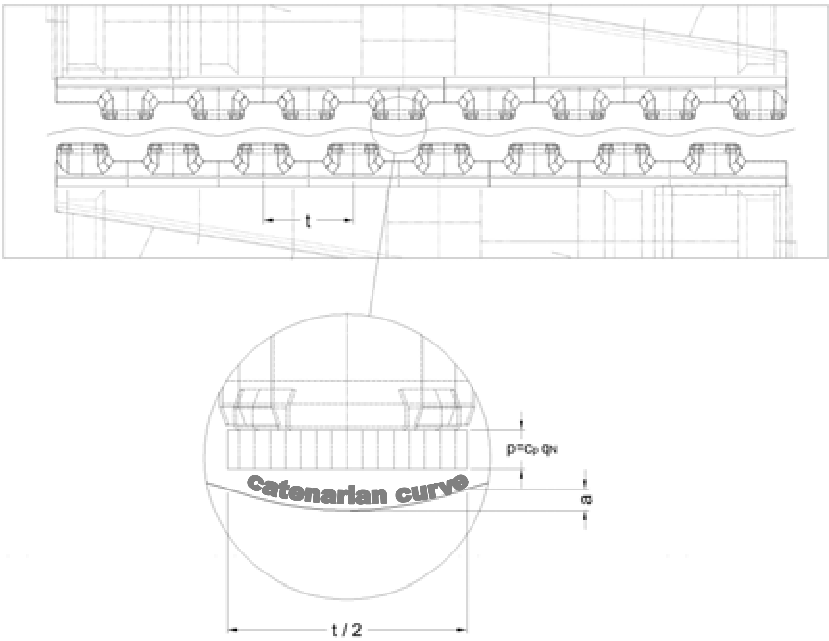
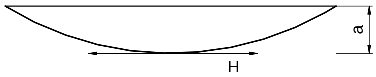
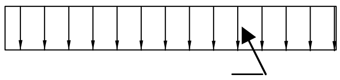


Figure 7: Strip forming a wave shape composed of "half wave" catenarian curves





$$p = \overline{c}_p \cdot q_{Nozzle}$$

$$F = \frac{\overline{c}_p \cdot q_{Nozzle} \cdot b \cdot t^2}{16\,a}$$

$$q_{Nozzle} = \frac{1}{2}\rho_{gas} \cdot c_N^2$$

$a \sim 0.02\,t$

e.g. $t = 500$ mm $\rightarrow$ $a = 10$ mm

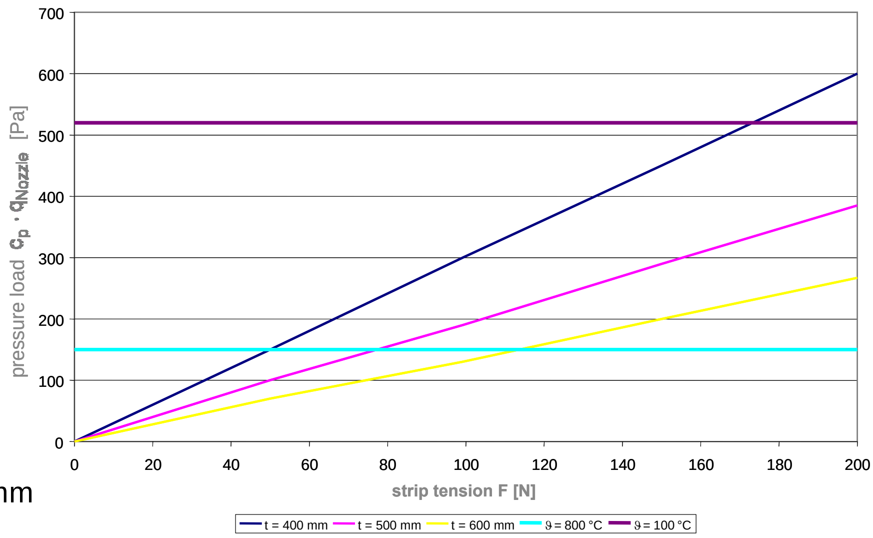


Figure 8: $p = \overline{c}_p \cdot q_{Nozzle}$ and strip tension N for various nozzle spacing t and a wave amplitude of 0.02t

To obtain the necessary load high average pressure coefficients and/or high dynamic nozzles pressures $\overline{c}_p \cdot q_{Nozzle}$ are necessary. Figure 9 shows the possible tension - again for a strip of 400 m x 0.1 mm, a 2 % amplitude a = 0.02 t for a nozzle exit velocity of 50 m/s and different $\overline{c}_p$ and nozzle spacing t. High nozzle exit velocities require high fan tip speeds which may cause stress problems at the high required temperatures. Furthermore the danger of strip edge flutter increases with increasing nozzle exit velocity. The strip flutter starts at a certain velocity which must be reduced for about 30 % to stop the fluttering again. This hysteresis effect is well known from numerous investigations dealing with flutter of freely guided webs.

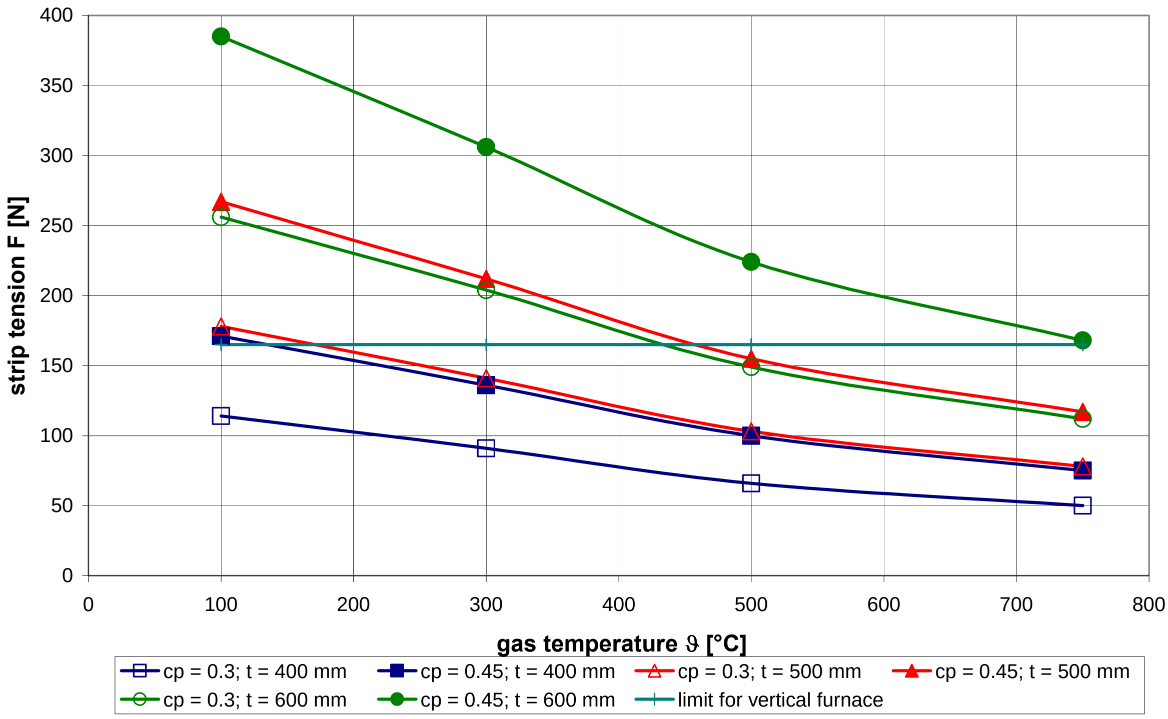


Figure 9: Strip tension for a 0.02 t amplitude vs. gas temperature (gas: 95 % N_2, 5 % H_2)

The diagrams shown give only general information because the WSP floatation nozzles are always designed according to the special requirements as heat transfer, strip thickness range, strip width range, behaviour of materials to be solution annealed, etc. It is not possible to cover all these complicated influence parameters in a short presentation.

The following items, however, are essentially:

- At the WSP nozzle systems the gap between two adjacent nozzles is completely free, no stabilising plates and other choking devices are necessary. Because of the large free area is the speed of the returning flow to the strip edge in the gap lower - about half - than in the area between the nozzles forming the bow in the strip run and the strip. This reduces the tendency of strip edge fluttering remarkably because the momentum of the returning flow differs for both strip sides by a factor 4.

- The powerful WSP-floatation nozzles do not only create a strip run like over staggered rolls but also press a cross bow in the strip according to the staggered nozzles, alternating in upward and downward direction. The straight transition between the bows in different directions acts very stabilizing.

Therefore WSP developed a floatation nozzle system with a significantly increased progression of the pressure coefficient with decreasing strip to nozzle distance, Figure 10. The barrel shape of theses nozzles reduces in addition the tendency for strip edge flutter, because the flow out of the pressure cushion between strip and nozzle is choked by this special shape and the returning flow area increases from the strip centre to the strip edges. With the WSP-nozzle system average pressure coefficients of c_p = 0.45 and more can be obtained, nozzles according to the good state of the art reach about c_p = 0.3.

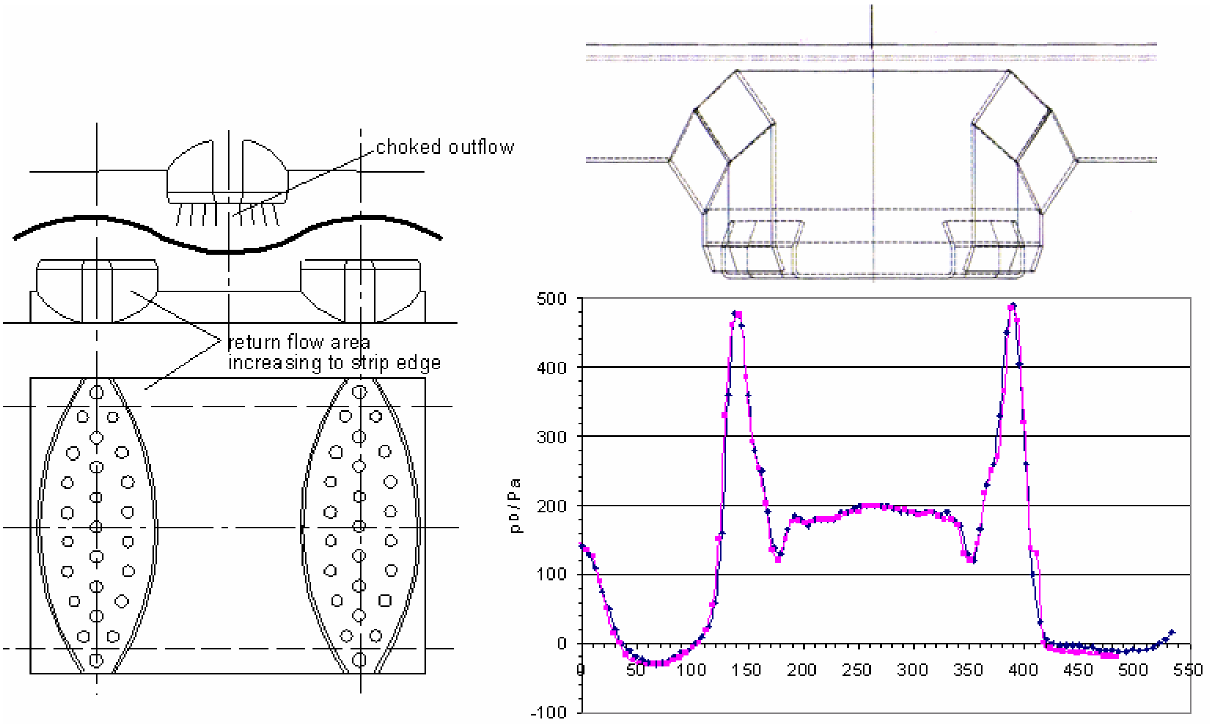


Figure 10: WSP "barrel shaped" floatation nozzles

Figure 11 Copper strip in a WSP floatation test rig

Figure 11 shows a copper strip, thickness 0.075 mm, width 320 mm, with pressure tabs on the bottom surface in the centreline forming a wave under a tension of F = 80 N and a pressure load $\overline{c_p} \cdot q_{Nozzle}$ of about 200 Pa. The strip shape confirms the validity of the simple theoretical model.

Figure 12 shows the strip tensioning situation in a vertical furnace where the nozzle system must not float the strip.

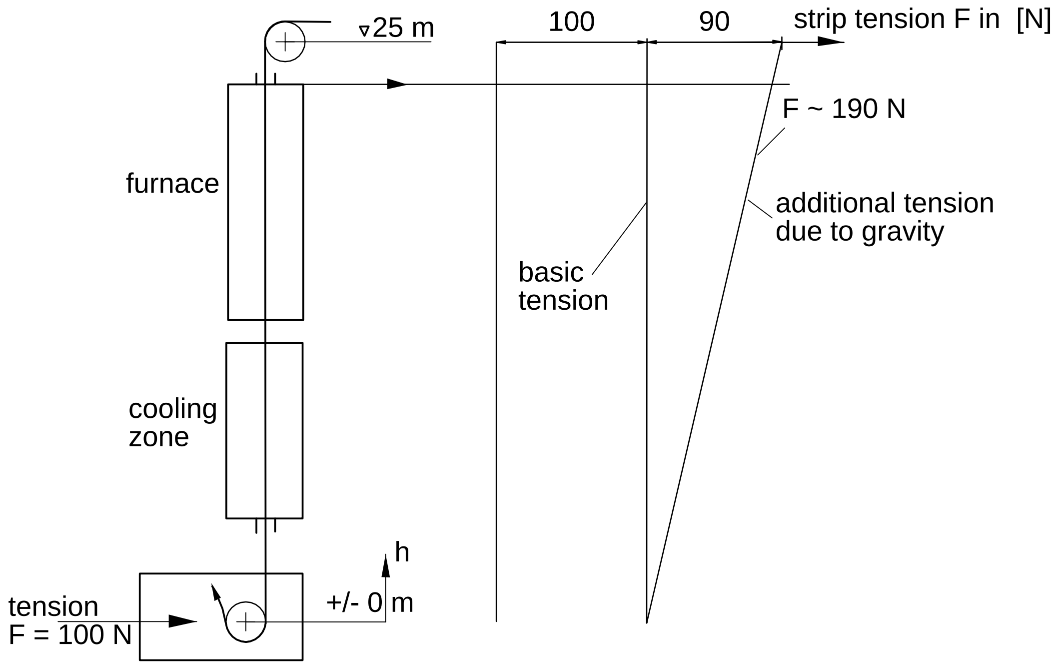


Figure 12: Copper strip 400 mm x 0.1 mm, $F = B \cdot s \cdot \rho_{Cu} \cdot g \cdot h$, additional tension due to gravity

The wave pattern of the strip, however, is necessary in order to avoid deformation of the light gauge material. Assuming a minimum tension of 100 N again for a strip 400 mm x 0.1 mm at the lower roller, due to gravity the strip tension increases additionally from 100 N to ~ 190 N at the entry of the about 25 m long heat treatment part. This tension is indicated in diagram Figure 10. At higher temperatures even a high performance nozzle system is unable to impress a sufficient wave amplitude. The assumption of the same minimum basic tension for a vertical furnace than for a horizontal floatation furnace is rather optimistic because at a vertical furnace the strip centring unit cannot be positioned at the cooling section exit, but must be situated in some distance behind the bottom turning roller. This requires a higher tension. Therefore it may be not a very good idea to anneal light gauge material in vertical furnaces.

Because the strip should be guided in the middle between upper and lower nozzles a strip floatation furnace should have separate flow circuits and separate fans (with speed control) for upper and lower nozzles.

The throughput of the heat treatment part of an AP-line is characterised by the product

(v = strip speed) x (s = strip thickness)

For existing plants and heat treatment processes, which do not require a soaking time the value range from

10 < (v m/min x s mm) < 30.

That means that thin strip of 100 µm thickness e. g. could run in a long furnace with a strip speed of 300 m/min whereas a strip of 1.5 mm thickness will run with 20 m/min only which is no problem for the heat treatment part. So the heat treatment capacity is not a problem. The limiting factors for thin strip are the capacity of the strip storage towers and the necessary residual times in surface treatment equipment.

Practical consequences for light gauge annealing

As mentioned before the tension in the furnace must be rather low. Furthermore it should not fluctuate because a high tension will flatten the longitudinal waves and the strip starts to flutter and, due to the high hysteresis effect, a very low tension is necessary to stop the flutter again. Therefore dancer rollers loaded by pneumatic cylinders, which also usually show a hysteresis effect, are not well suited for thin strip. WSP developed a "mechatronic dancer". A roller is loaded by a balance arm with a movable weight. In order to achieve different strip tension levels according to the relevant strip gauge automatically fixed weights are put on this balance, Figure 13.

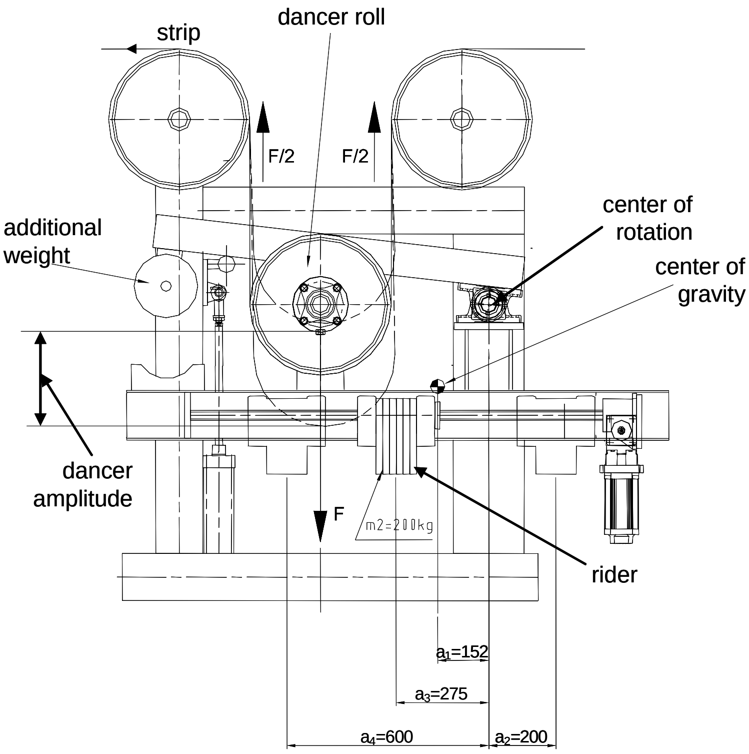


Figure 13: WSP-Mechatronic dancer (German patent DE 10 2005 059 822)

The bridles in front and behind the heat treatment unit must have enough rollers to care for sufficient stress separation between furnace and the strip treatment parts.

To avoid "aqua planning" the immersed roller behind the heat treatment must be driven and synchronised with the strip speed. Furthermore at least some of the squeegee rolls should be replaced by an aerodynamic system like a bow nozzle which does not influence the strip run. This increases the efficiency of a strip centring unit at the end of the surface treatment and reduces the work of the centring unit behind the cooling section.

The maximum roller diameter depends on the maximum strip thickness. Therefore light gauged strips run over rolls with a relatively high diameter. The inertia of these rolls should be reduced by light mass material. In addition a plant for thin strip requires of course a well engineered and effective electric control.

A plant fulfilling all these requirements will be suited to run strips with a minimum thickness lower than 0.1 mm satisfactorily.

Ideas for plants specialised for light gauge annealing

If a plant is restricted to a strip thickness range of e.g.

0.3 mm > s > 0.03 mm

it will be not necessary to guide the strip in the heat treatment in a more or less straight line.

A design shown in Figure 14 is better suited. The strip is guided - of course touchless - in a "meander shape". The strip tension is created by the nozzles floating the strip. A centring device is not necessary because the tensioned strip centres itself like a flat belt on a pulley roller of a flat belt transmission. No dancer is required.

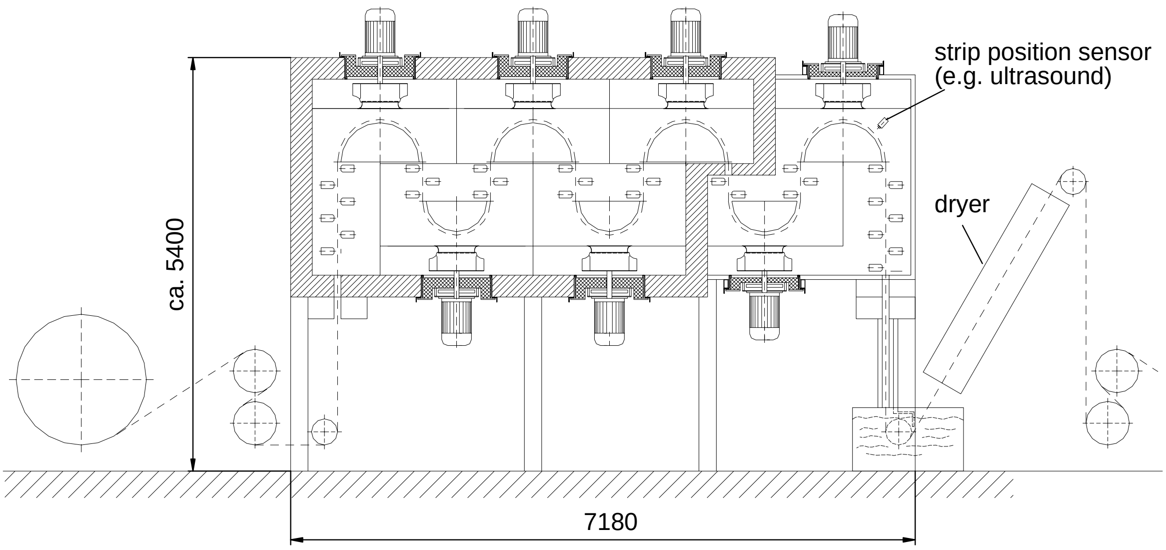


Figure 14: Floatation furnace: strip length in the furnace about 9.2 m, strip length in the cooling zone about 4.3 m. Project data: brass strip 0.1 mm x 500 mm, max. material temperature 653 °C, furnace temperature 660 °C, strip speed 130 m/min, 3.3 to/h

Bridles in front and behind the heat treatment make sure that the same strip length enters and exits the unit in a certain time. A superimposed slow monitor control corrects control deviations by mean of a strip position sensor in the cold part.

The plant is accessible at the service side by large door like openings.

Strip accumulators are not required. Because the surface of the round floatation nozzles is smooth the strip can touch the nozzles when decreasing the fan speed during a coil change.

The strip length in the furnace is about

2 x straight length,

this makes the plant more compact.

The strip speed can go up to 300 m/min with a furnace temperature only a little - within the tolerances - above final material temperature. This is important for minimising the risk of strip rupture.

Because rollers and mechanical components are designed for thin strip only, the entire line will also be less costly.

Summary

Based on the experience with numerous floatation furnaces, most of them installed in already existing strip lines, the requirements for the annealing of light gauge strips are discussed as well for the mechanical part as for the heat treatment. By an appropriate tension control and a floatation system stabilising the strip flutter free in a longitudinal wave pattern even at reasonable strip tension the production of thin strip in conventional AP-lines is possible, but requires mostly some upgrading.

For very light gauge strip, however, a special annealing facility seems to be the better solution.

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