Hot strip flatness optimisation by means of edge masking in the ROT

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The control of temperature distribution across the strip is essential for the hot strip flatness improvement. Hot strips of Arcelor in Avilès may display wavy edge defects that are generated after the finisher and are attributed to residual stresses introduced by the accelerated cooling on the run-out-table. A first approach has established that the thermal drop on the run-out-table has a significant effect on flatness, at the edges in particular. Among several systems that may control temperature at the edges, the edge masking technology has been selected, considering the previous implementation on CSP mills. Wavy edges are considerably removed or even suppressed on the operator side, while they are reduced but not eliminated on the drive side.

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INTRODUCTION

Ever more severe requirements are expressed by customers for steel strips. Concerning quality, flatness is now one of the most important factors to consider for hot coils production, although it is also one of the most difficult to handle. It has been claimed many times that the hot strip mill can roll flat products that are strictly tailored to the demands of downstream processes and final customers. Actually, there is no solution yet to ensure hot strip flatness with the standard processes.

In the case of direct supply, if the mill is not able to meet the expected requirements a further process of skin pass is needed before delivering, with the corresponding cost in time and energy consumption. When the coil is processed in downstream facilities, flatness defects are usually smoothed out through the intermediate steps, but not always removed. In some cases, the entry flatness status conditions the reliability of the following process.

The mechanical and metallurgical properties as well as the flatness may vary not only along the strip length but even across the width of the strip; they are strongly influenced by temperature changes during rolling in general and by the cooling along the run-out-table in particular. The potential degree of variation depends on material (steel grade) and strip geometry. Therefore, conventionally at hot strip mills, strip temperature is controlled by “temperature speed-up” and by strip cooling along the rolling pass and the run-out-table where the temperature target values are determined by the required metallurgical properties of the strip. To ensure a homogenous final product the temperature of the strip just before coiling should be constant and the cooling rate from head end to tail end of the strip should be uniform over the whole strip length (1, 2). In order to avoid the appearance of these defects it may be necessary sometimes to make some changes in the design, modifying parameters and the rolling conditions in the mill.

Nevertheless there occur inhomogeneities in the temperature distribution across the width direction at least at the strip edges due to the initial thermal profile of the bar and to the lateral water flow at the run-out -table, which has a major detrimental effect on strip flatness. Prerequisite for an optimized performance of the cooling with respect to the influences on strip properties and flatness is the control of the temperature in the width direction.

Optimisation de la planéité des bandes à chaud par masques de rives sur la table de sortie

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La planéité est une qualité essentielle des bandes à chaud. En effet les défauts de planéité au train à bandes ne sont pas totalement éliminés par les étapes ultérieures du process. Il est aussi parfois nécessaire de réaliser une opération de skin pass sur les bandes à chaud pour répondre aux exigences de planéité sur ce demi-produit.

Les défauts de planéité résultent d'une répartition non homogène de la température en travers de la bande, en particulier en rives. Cette répartition est introduite par le profil thermique initial de la brame et par l'écoulement latéral de l'eau de refroidissement sur la table de sortie.

La maîtrise de la température dans le sens travers de la bande est donc une condition indispensable à l'amélioration de la planéité, de mème qu'à l'optimisation des propriétés métallurgiques de la bande.

Les bandes laminées par Arcelor à Avilès présentent surtout des ondulations en rives qui apparaissent après le finisseur et sont attribuées aux contraintes résiduelles introduites au cours du refroidissement accéléré sur la table de sortie.

Des essais préliminaires ont montré que l'intensité du refroidissement sur la table de sortie a un effet significatif sur la planéité, en particulier en rives.

Parmi les différents dispositifs de contrôle de la température en rives, la technologie des masques de rives a été retenue pour ce projet, compte tenu de sa mise en œuvre antérieure sur des installations CSP.

Les résultats obtenus ont été analysés en termes de températures en rives et en termes de planéité :

- *Les ondulations de rives sont fortement réduites, voire supprimées, côté opérateur.*
- *Les ondulations de rives sont sensiblement diminuées, mais non supprimées, côté moteur.*
- *Cette asymétrie pourrait être expliquée par un décentrage de la bande.*
- *Les bandes avec masques de rives présentent en général de plus forts gradients de températures en rives.*
- *L'analyse des résultats obtenus avec un grand nombre de bandes montre que les bandes avec masques de rives ont en général un profil thermique plus uniforme, alors que les bandes sans masques de rives présentent un déséquilibre thermique plus important avec des températures plus élevées côté opérateur.*
- *Pour le moment il n'a pas été mis en évidence d'effet métallurgique des masques de rives.*

Fig. 1 - Examples of edges defects.

Fig. 1 - Exemples d'ondulations en rives.

TABLE I: Cooling tests on the run-out-table.

TABLEAU I: Essais de refroidissement sur la table de sortie.

Conditions	Results
Normal rolling	Wavy edges
Normal rolling without lateral sprays	Wavy edges
Rolling without water in the ROT	Center buckles, but no wavy edges
Rolling with +100ºC of target coiling temperature	Perfect

■ SITUATION ANALYSIS

Focusing on flatness defects, different kind of patterns may appear in rolled strip, depending on the combination of wavy edges and /or center buckles. In the Hot Strip Mill of Arcelor Spain, in Avilés, there is a problem of flatness focused in the edges as it is shown in *figure 1*.

In order to determine the origin of this problem, several tests have been carried out. It was concluded that these defects were originated after the finishing mill section and that they must be attributed to the stresses generated in the material during the cooling process of the strip on the run-out-table. Another reason to think that wavy edges are caused just by residual stresses is to be seen in the fact that wavy edges can be overcome when a slight tension force is applied during the subsequent processing of coils in the skin-pass mill.

The run-out table (ROT) is well known to deteriorate flatness in the hot strip mill. Thus, some tests with different cooling strategies were performed to confirm its effect on wavy edges on thin strips. Results are shown in *table I*.

Therefore, from experimental results, a direct correlation between flatness and cooling can be established.

The ROT of the Avilés HSM is monitored with thermal map measurement devices and flatness gauges at its entry and exit. This information has been acquired for the strips rolled during several months and it was analyzed to have a prioritization of the potential influent parameters.

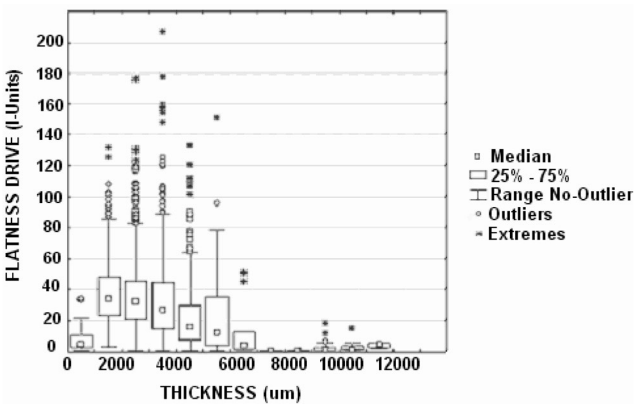

Fig. 2 - Flatness (drive side) vs thickness.

Fig. 2 - Planéité (côté moteur) en fonction de l'épaisseur.

Thickness

To confirm the operators feeling on thickness effect, some correlation with flatness values measured just before coiling have been drawn. An example for the drive side is shown in *figure 2*.

After this relation was established, three sets of strip thickness were defined for further analysis: thickness under 3 mm, thickness over 6 mm and intermediate thicknesses.

Thermal drop

The relation between water poured on the strips and the thermal drop in each parts of it (center, drive and operator side) for top and bottom cooling has been measured for the thickness groups. *Figure 3* shows an example of the different analyses done.

The effect of an increment of water flow is translated into an increment of the thermal drop in the strip, but more clearly in the center of the strip than in the edges. This can be explained by a non-uniform water distribution, having a higher flow in the edges probably due to the water coming from the center to the drainers.

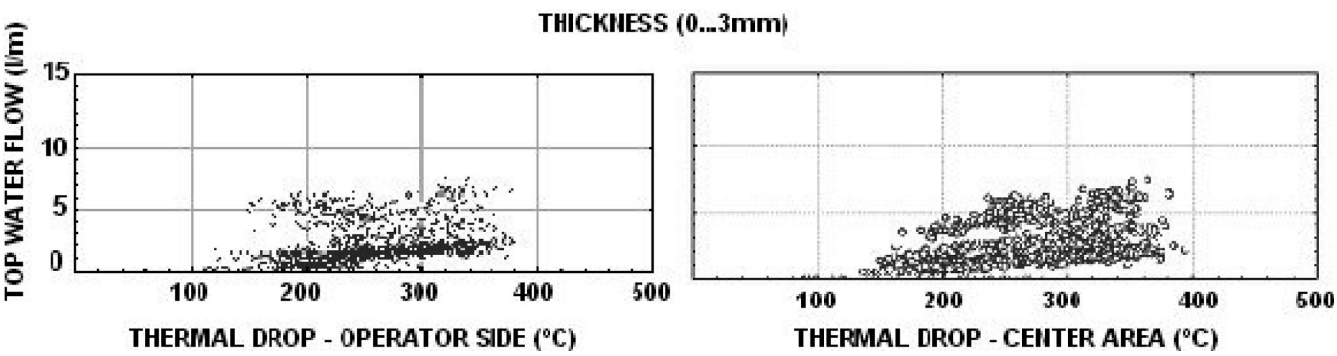

Fig. 3 - Top water flow vs thermal drop for operator side/center part for strips less than 3 mm thick.

Fig. 3 - Arrosage en face supérieure et chute de température coté opérateur et au centre pour les bandes d'épaisseur inférieure à 3 mm.

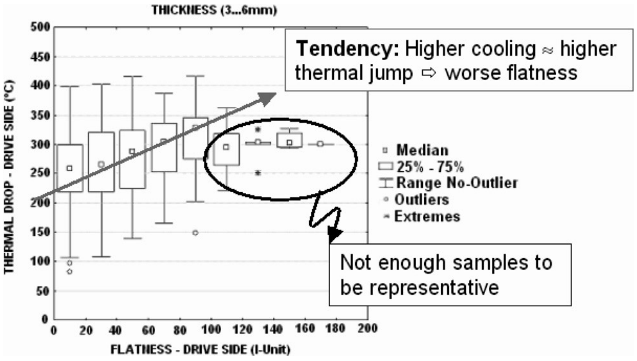

Fig. 4 - Relation of thermal drop and flatness in drive side for medium thickness strips.

Fig. 4 - Relation entre la chute de température et la planéité côté moteur pour les bandes d'épaisseur moyenne.

The influence of the thermal drop cannot be seen directly on the flatness, as it is clear that more variables are involved. Anyway, this relation is more obvious for thicker materials, as it is presented in *figure 4*.

According to these first results, the next steps of the study were based on the defined thickness classification.

Speed

Rolling speed could have some influence on the flatness, because it is directly related to thermal drop in the run-out table, modifying the water flow applied by square meter.

After considering the effect of rolling speed on the three different parts defined in the strip (center and both edges), it has been concluded that it has no significant influence, thus indicating that the cooling strategies are appropriate.

Steel grade

It was detected that there are also some differences on the frequency of appearance of the flatness defect depending on the steel grade.

Initial conclusions

After these preliminary studies, it was concluded that the thermal drop in the ROT has a relevant influence on the final flatness, especially at the edges.

■ EDGE MASKING SYSTEM

In order to control the temperature at the edges of the strip in the run-out-table, some systems have been considered:

- Induction tunnels have been installed in continuous casting to maintain the temperature in the edges of the solidified slab, but there is no such system installed in a facility with water curtains over the strip (3, 4, 5).
- Another method is based on air-pressurized blowers. The impinging air jet disturbs the laminar flow on the strip; thus the quantity of water poured on the edges can be reduced. These proposals have been investigated but there is no practical result (6, 7).
- Another approach has been reported (8) to adapt the cooling water flow to the actual strip width. This device consists of a cooling bank with a water outlet in form of a slot in transverse direction to the strip. Moving the closure plates on both sides in transverse direction the width of the slot can be altered. The cooling water outlet is then formed by those closure plates and two deflector plates. Practical experiences with this device are not known.
- The development of an Edge Masking Device (EMD) is explained in (9). This device is used on the run-out-table in order to control the transverse temperature profile and hence the uniformity of the mechanical properties, the microstructure and the strip flatness. The EMD that is movable in transverse direction prevents the temperature drop of strip edges by blocking the cooling water onto the strip edge. The amount of edge masking determines the width of the zone at the edge that is affected.

Edge masking technologies were selected because they were deemed most adequate to this facility and more experimented (10, 11). They have been implemented in the cooling section of CSP mills to compensate for the differences in temperature between the strip edges and the centerline as well as to eliminate the conditions for the appearance of stresses in the material that would give rise to wavy edges. The results in this kind of facilities were promising, but they had not been evaluated in HSM yet.

Design, installation and operation of the edge-masking system

Together with the supplier, SMS-Demag, the basic system was redesigned to be adapted to the hot strip mill, considering the location, plant restrictions, electric and control adaptations, water removal system design. Finally five edge-masking groups were installed in the first feasible cooling groups, to maximize the water flow masked, as shown in *figure 5*.

The EMD masks the same quantity on both sides which means it is a symmetrical device, considering the strip is centered in the ROT; it has three possible references for the head, body and tail.

Trials analysis

Several tests were done to check the real effect of the edge masking on the wavy edges.

Initial edge masking values had to be defined, because data used in CSP are not transferable at all, as expected from the differences in both processes.

In all the trials done, strips with similar characteristics (steel grade, width, thickness and coiling temperature) were rolled in the same program, modifying the edge masking conditions.

Fig. 5 - Edge-masking groups installation.

Fig. 5 - Installation des masques de rives.

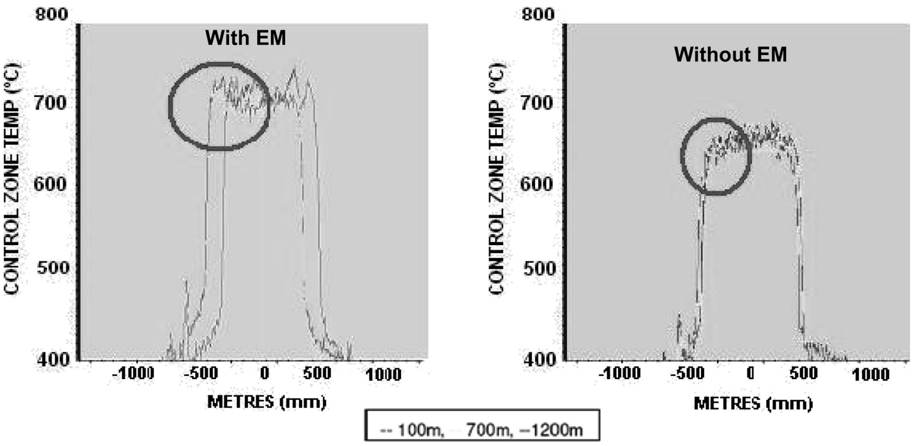

Fig. 6 - Transversal thermal profiles of the tested strips.

Fig. 6 - Profils thermiques transverses des bandes d'essais.

These experimental tests were analyzed in two different ways: checking the final results directly in the strips and also with statistical correlations to assess them.

The EMD analysis was done in two steps, addressing successively:

- The effect on temperature distribution,
- The effect on strip flatness.

The effect of edge masking on the thermal profiles was checked first. As it can be seen in *figure 6* transversal profiles at the exit of the ROT have a sharper fall down at the edges in the masked than in the non-masked strips. This means that the thermal profile is more homogeneous.

Concerning the longitudinal profile, *figure 7* shows that the edge masking reduces the global difference between edges and center temperature.

From an analytical point of view, to confirm the influence of edge masking in the temperature profile at the exit of the ROT, several variables were considered: temperature profile at the entry of the ROT, thickness, masking, water flow.

Table II shows the positive effect of the edge masking, more relevant on the operator side than on the drive side, along with the linear correlation.

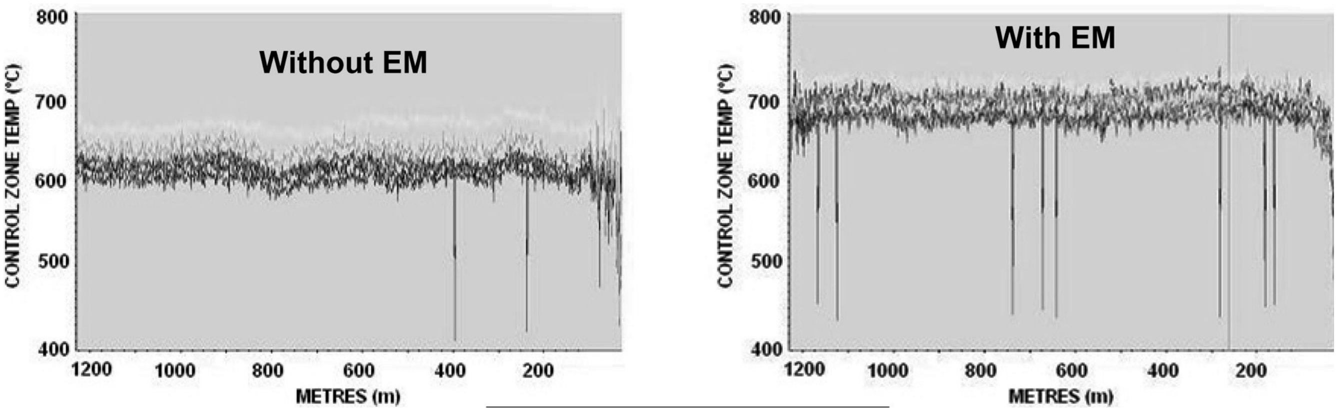

Fig. 7- Longitudinal thermal profiles of tested strips.

Fig. 7 - Profils thermiques longitudinaux des bandes d'essais.

TABLE II: Influence of edge masking on the temperature profile at the exit of the run-out-table.

TABLEAU II: Influence des masques de rives sur le profil de température en fin de table de sortie.

Input variable	Influence in Operator Output T°
Operator Entry T°	R^2 = -0.067136
Thickness	R^2 = 0.828434
Masking	R^2 = 0.347348
Top Water Flow	R^2 = -0.930702
Bottom Water Flow	R^2 = -0.208439

Input variable	Influence in Drive Output T°
Drive exit T°	R^2 = -0.068331
Thickness	R^2 = 1.001797
Masking	R^2 = 0.108963
Top Water Flow	R^2 = -0.890022
Bottom Water Flow	R^2 = -0.453721

To confirm the relation between temperature and flatness, measurements were taken in the cold state for the different tested strips. The difference is clearly shown in *figure 8*, as an example of most of the results. In general, it can be said that the wavy edge is nearly suppressed on the operator side and that it is reduced by half on the drive side.

The results of the analysis correlation done to check this influence, show that input variables considered (thickness, water flow, masking, temperature profiles,…) do not have an independent influence in the output (this is demonstrated by the lack of success with linear regression). A factorial approach is able to explain the output based on the inputs, as a result of the interaction of several variables.

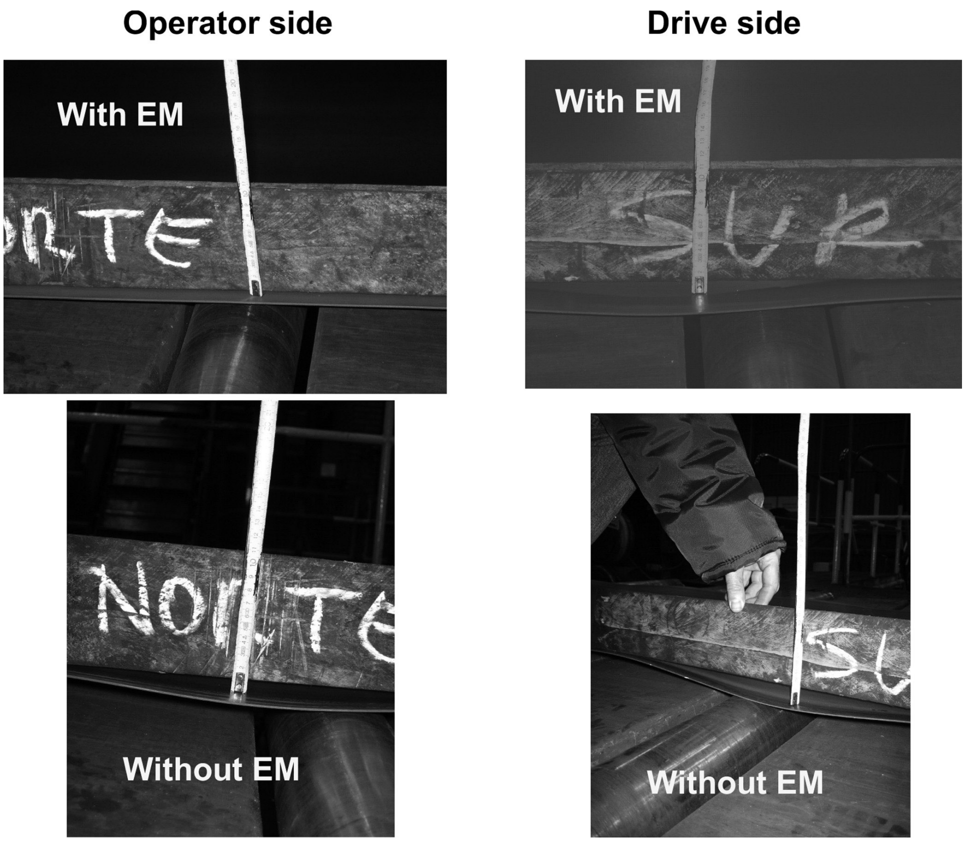

Fig. 8 - Example of strip edges with and without edge masking in similar strips (2mm thickness).

Fig. 8 - Exemples de rives de bandes avec et sans masques de rives pour des bandes semblables (épaisseur 2 mm).

The output flatness is mainly explained through the interaction of the input flatness with the other input variables, which have some influence in the rolling process, including edge masking.

■ OTHER CONSIDERATIONS

Edge masking proves to be useful to improve wavy edges, but the effect is different for both edges. Trying to find causes to explain this flatness asymmetry and as flatness is measured in the cold state, there is another important process to consider: coil cooling. Thus several coils, with similar characteristics, where cooled in different ways:

- Transported in a truck, so uniformly cooled.
- Turned on the drive edge, so that the operator edge cools quicker.
- Turned on the operator edge, so that the drive edge cools quicker.

As it happened, no relevant differences were found, as it can be seen in the example of *figure 9*. Drive edge is usually worse, from the flatness point of view.

The successful results concerning temperature incited a further analysis of the influence of edge masking on the mechanical properties. Therefore, samples were taken from the center part of the strip for mechanical testing. The aim was to assess any potential homogenizing effect of edge masking on the mechanical properties. Not enough samples have been collected yet to draw reliable conclusions on this matter.

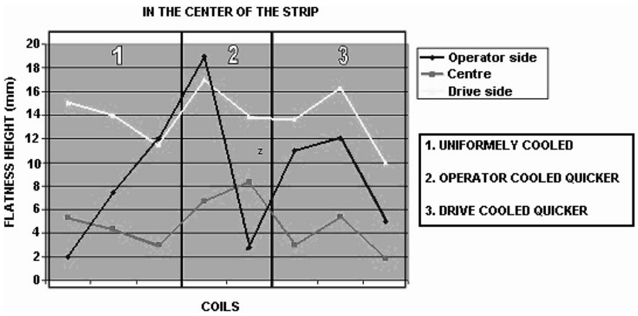

Fig. 9 - Flatness height in different coil cooling situations.

Fig. 9 - Amplitude des ondulations pour différentes conditions de refroidissement de la bobine.

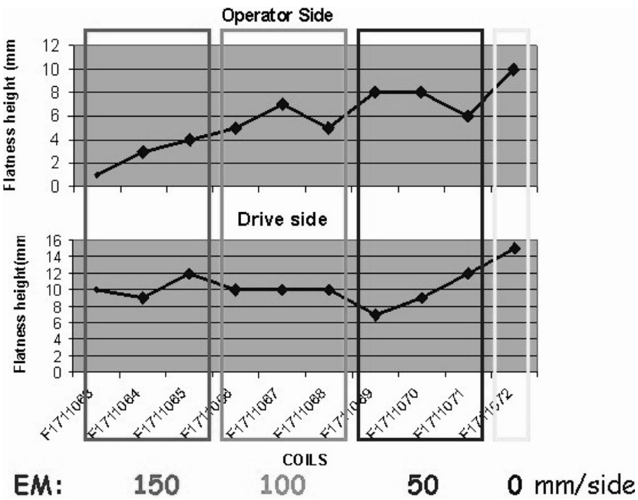

Fig. 10 - Tendency of height flatness results of masked strips.

Fig. 10 - Tendance des résultats de planéité des bandes avec masques de rives.

■ CONCLUSIONS

From all the trials performed *(fig. 10)*, it can be concluded that:

- On the operator side, wavy edge is reduced considerably by edge masking and even completely removed in some cases.
- On the drive side, the wavy edge is reduced by edge masking, although it is not suppressed.
- Some possible reasons of this asymmetrical effect might be found in the off-centering of the strip.
- Referring to thermal profiles, sudden drops of temperature at the edges are more common with masked strips.
- Considering a large number of strips, masked strips tend to display flatter thermal profiles; meanwhile in the non-masked strips there is a stronger unbalance of temperature with higher temperatures at the operator side than at the drive side.
- No relevant conclusions can be drawn from a metallurgical point of view.

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