

# Strip tracking measurement and control in hot strip rolling

L. Kampmeijer, C. Hol, J. de Roo, E. Spelbos

*Poor strip tracking is one of the notorious problems threatening process stability in a hot strip mill. These issues often lead to tail pinching and in the worst cases even to cobbles. The main pillars of the strategy set out to tackle these issues for the Hot Strip Mills in IJmuiden are rougher mill camber control and finishing mill strip steering and tail control. For such applications, a camera based measurement system has been developed in-house that is simple, cost-effective and yet both accurate and robust. Moreover, as we show in this paper, the system has proven its merits both as a finishing mill interstand centerline deviation measurement as well as a rougher mill camber measurement. In the latter application the measurement data can be used for automatic levelling in the rougher mill. The results of production tests presented in this paper demonstrate that the camber measurement in combination with a basic rougher mill tilt set-up model is sufficient to reduce the transfer bar camber significantly.*

**Keywords:** Hot Rolling - Strip Tracking - Strip Steering - Tilt Setup - Camber - Centerline Deviation - Measurement Systems.

## INTRODUCTION

It is well known that poor strip tracking can lead to reduced product quality but also to mill delays. The resulting costs for internal rejects, customer complaints and yield losses have historically been significant. Moreover, the severity of these issues increases dramatically when strips become wider, thinner and harder. Ultimately the rolling process becomes completely unstable. Hence, to reduce cost of poor quality for the current product mix as well as to enable product development it is vital that strip tracking is improved.

Most strip tracking issues arise at the head or the tail of the strip. In the rougher mill the main issue is head camber, a shape defect of the bar where the head is curved. A clear example of this shape is shown in Fig 1. Large head camber of the transfer bar may result in further problems downstream in the finishing mill and should ideally thus be prevented.

Another notorious problem closely related to strip tracking is tail pinching in the finishing mill. This is a phenomenon where the tail of the strip suddenly moves sideward's and gets damaged right after it has left the previous stand. An



**Fig. 1- Example of a bar in the rougher mill with severe (head) camber.**

*Fig. 1- Esempio di una barra in un laminatoio sbozzatore con una severa deviazione della testa.*

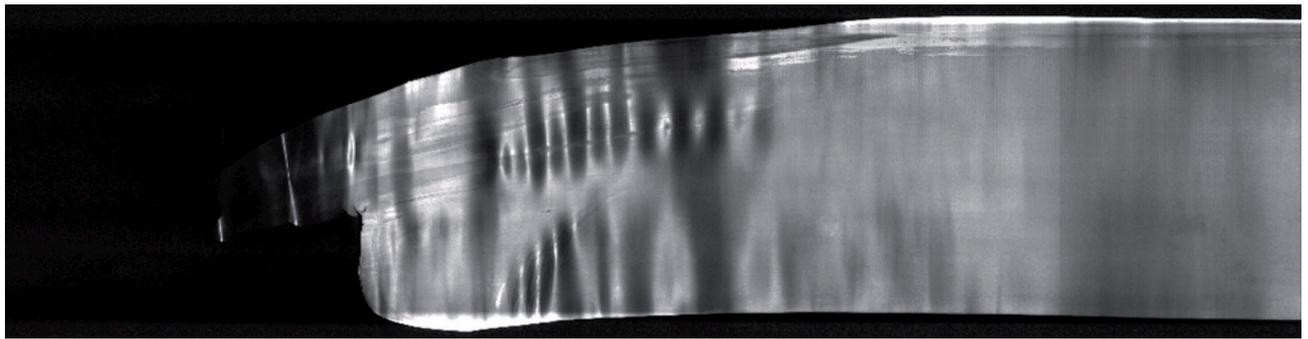
example of a pinched strip is shown in Fig. 2. Moreover the damaged strip may damage the work roll surface. If the roll is not changed, it will lead to further roll marks on consecutive strips.

Head camber and tail pinching most likely share a similar cause; in both cases there is a level error of the stand such that the profile of the gap does not match the profile of the incoming strip as illustrated in Fig 3a. Consequently, the elongation is asymmetric so that the strip becomes curved and respectively the head and the tail move sideward as

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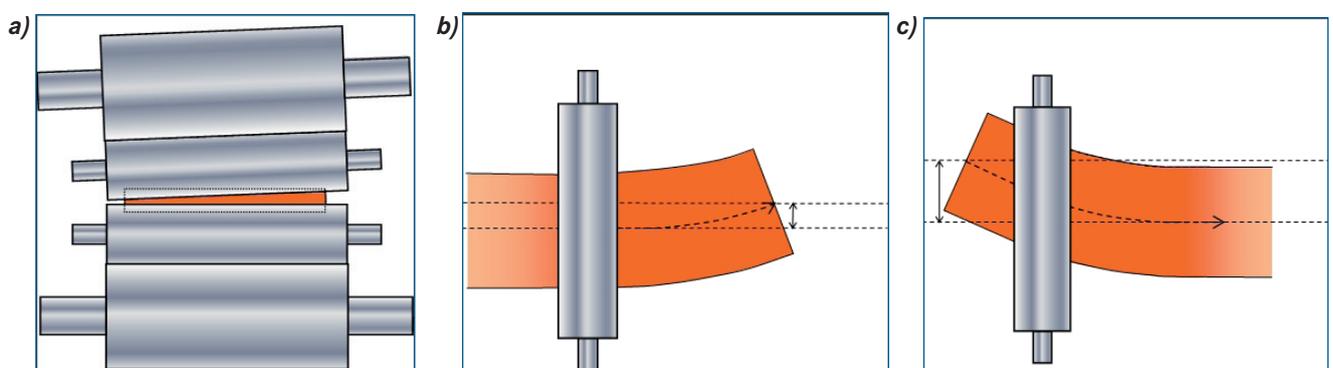
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**Fig. 2 - Example of the tail of a strip that has been pinched in the finishing mill.**

*Fig. 2 - Esempio di una coda di un nastro pizzicato nel treno finitore.*



**Fig. 3 - Example of a level error (3a) of a stand resulting in cambered head-end (3b) or cambered tail-end (3c)**

*Fig. 3 - Esempio di un errore di allineamento (3a) di una gabbia che porta a deviazioni di testa (3b) o di coda (3c)*

depicted in Fig. 3b and Fig 3c. To prevent such problems any level errors should be eliminated.

This paper describes the Tata Steel philosophy with respect to strip camber and steering control and especially concerning strip camber control results will be presented.

## ULTIMATE STRIP CAMBER AND STEERING CONTROL

As explained in the introduction the ideal situation is to prevent the camber and side way movement of the strip. The current approach is that operators act manually on the levelling of stands with visual input of what happens in the mill. The ultimate solution is an automatic control system that reduces camber and strip steering issues. In order to do so three important factors are needed:

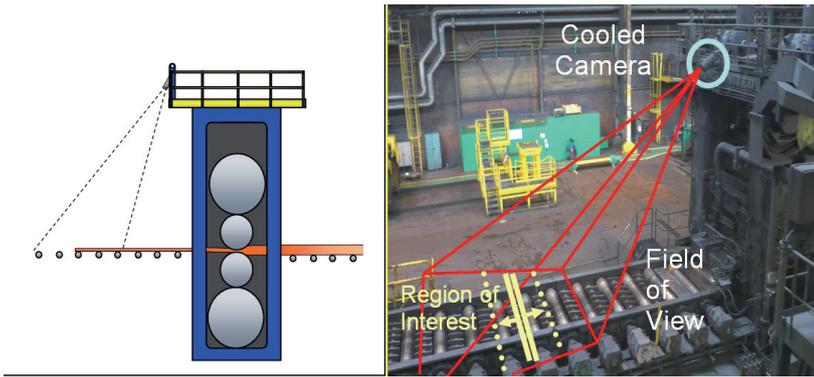
1. A measurement system to measure camber / strip position
2. Proper understanding of the causes of camber/side way movement and formulas that describe the relations
3. An automatic control of the camber and sideway movement based on measured input and the found relations.

Ad 1) The ambition to measure the camber in the roughing mill and the strip position in the finish mill translates ideally into the fact that all Roughing Mill (RM) stands are

equipped with a camber measurement system while in the Finishing Mill (FM) a strip position measurement is available after each stand. For many hot mills this ends up in the installation of typically between 7 and 11 measurement systems.

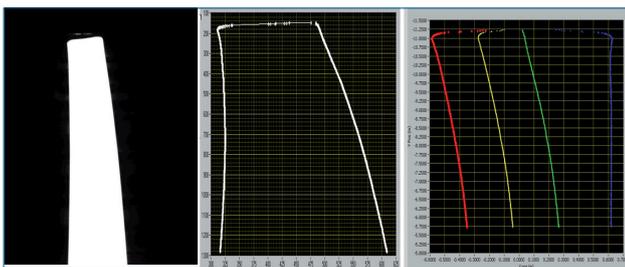
Ad 2) In order to be able to control the level position a lot of effort has been put in proper understanding on the causes of camber and strip steering issues and finding the relation between roll force difference, levelling position, strip characteristics and the effect on camber and /or possible side way movement of strips. This is done by trying to grasp the physics of the problem and convert this into a simulation models which can be validated against reality.

Ad 3) In order to tackle the strip tracking issues as discussed above Tata Steel R&D has been exploring a set of control strategies in which the level error of the stand is determined and the tilt of the stand is adjusted accordingly. For the rougher mill a control strategy has finally been chosen where the level error is computed from the measured head camber, whereas in the finishing mill the approach preferred by Tata Steel is strip steering based upon the measured centerline deviation along the body of the strip in such a way that any level errors are eliminated before tailing out. The overall approach of Tata Steel has been to develop camber control and strip steering for a single stand of respectively a rougher mill and a finishing mill and to roll this technology successively out over all stands of all hot strip mills.



**Fig. 4 - Possible configuration of a camber measurement camera positioned at the exit of a rougher mill stand with a long area of view on the slab.**

*Fig. 4 - Possibile posizionamento di una telecamera per la misurazione del profilo dei rulli all'uscita di una gabbia di laminatoio sbozzatore con una lunga area visiva sullo slebo.*



**Fig. 5 - Example of an image of a slab, the detected edges of the slab and detected edge positions (red and green) and the centreline position of the strip (yellow) relative to the centerline of the mill. In addition the detected width of the strip is indicated (blue).**

*Fig. 5 - Immagine di uno slebo: rilevamento della posizione dei bordi dello slebo (rosso e verde) e della posizione del centro del nastro (giallo), rispetto alla mezzeria del laminatoio. Inoltre viene indicata la larghezza del nastro come rilevata (blu).*

## CAMBER AND CENTERLINE DEVIATION MEASUREMENT

Given the large number of camera's needed in a single hot mill to obtain the ultimate control solution Tata Steel R&D has developed a measurement system that is simple, cheap and requires low installation and maintenance costs, but which is nonetheless accurate and sufficiently robust to withstand the harsh environment of a hot strip mill. Moreover, this system should ideally be applicable both as a rougher mill camber measurement and as a finishing mill interstand centerline deviation camera.

This has resulted in a measurement system with a single camera encased in a cooled housing that can be positioned on top of the mill stands and adjusted to the to specific requirements. The principle of the measurement system is that it collects pictures in a field view with an adjustable length (see Fig. 4). In the roughing mill this length is generally quite long (~8 m). Once the strip moves through this area the camera collects images with an adjustable sample rate of about 1-2 images per second depending on the installed computer hardware and collects the images in the computer. The images are processed to detect the edges and obviously also to correct the view for the per-

spective (see Fig. 5). This information is used to calculate the camber of the slab.

For the application of the system in a finishing mill the field view is adjusted to a range of approx. 0.5 m, this is enough to measure the strip position between the stands. The principle of the measuring system is exactly the same as in the RM.

In case the camera system is installed in a FM the situation changes such that the field of view becomes smaller. All other principles remain the same. An example of the set-up in a FM is given in Fig.6 and Fig. 7.

After developing and building the prototype by Tata Steel R&D the camera prototype was industrialised in cooperation with EMG.

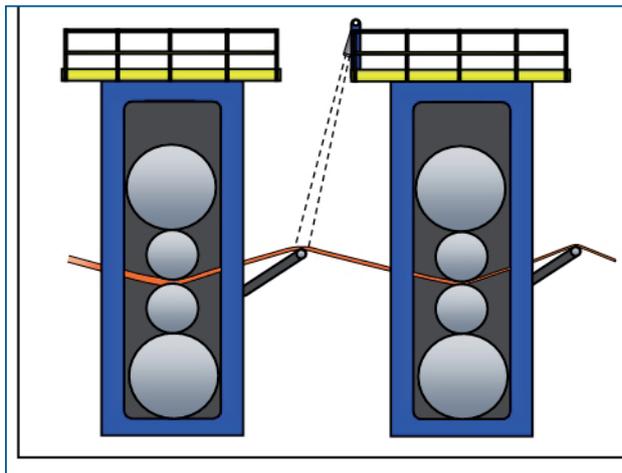
## ROUGHER MILL CAMBER CONTROL OFF-LINE DEVELOPMENT OF THE CAMBER CONTROL

One of the applications of the measurement system discussed in the previous section is rougher mill camber control: As briefly discussed and illustrated in the introduction, camber control boils down to determining the level error of a stand from the measured camber and adjusting the tilting position of the stand so that the level error is minimized for the next bar.

Camber control has first been developed offline by Tata Steel R&D and next it has been tested at the last stand of the rougher mill of Hot Strip Mill 2 in IJmuiden.

The control model is based on a transfer function which translates the tilting position of the stand into the head camber and vice versa. Note that the head-end camber can be represented in terms of the centerline deviation of the tip of the head when it has reached a certain distance after the roll gap. To determine the transfer function and to test the control offline actual measurement data has been used.

In Fig. 8 and Fig. 9 the centreline deviation as predicted by means of the transfer function is plotted against the measured centerline deviation. These figures show that there is a good correlation, illustrating the validity of this transfer function. Note that from the error in the predicted centreline deviation also the improvement of the tilt setup on the measured centreline deviation can be predicted. This prediction has not only been used in the decision on starting production trials but can also be compared with



**Fig. 6 - Possible configuration of an interstand centerline deviation camera positioned on top of a finishing mill stand with a relatively short area of view on the strip.**

*Fig. 6 - Possibile posizionamento di una telecamera di rilevamento della deviazione della linea di mezzeria fra gabbie di laminazione collocata in cima a una gabbia con un'area visiva sul nastro relativamente limitata.*

the actual results of the production trials as discussed in the next subsection.

## RESULTS OF THE CAMBER CONTROL TRIALS

The effectiveness of the camber control as developed by Tata Steel R&D can be evaluated from the measured centerline deviation at the head of the bar. In Fig. 10 the distribution of the centreline deviation measured after a stand is given for a set of bars where conventional operator control has been applied (red), as well as for a set of bars where the automatic tilt setup has been active (green). In addition the distribution is shown corresponding to the predicted improvement of the rougher mill tilt setup (blue).

Some of the statistics of the distributions for the head centerline deviation discussed above are compared in Fig 11. These figures show that automatic levelling has lead to:

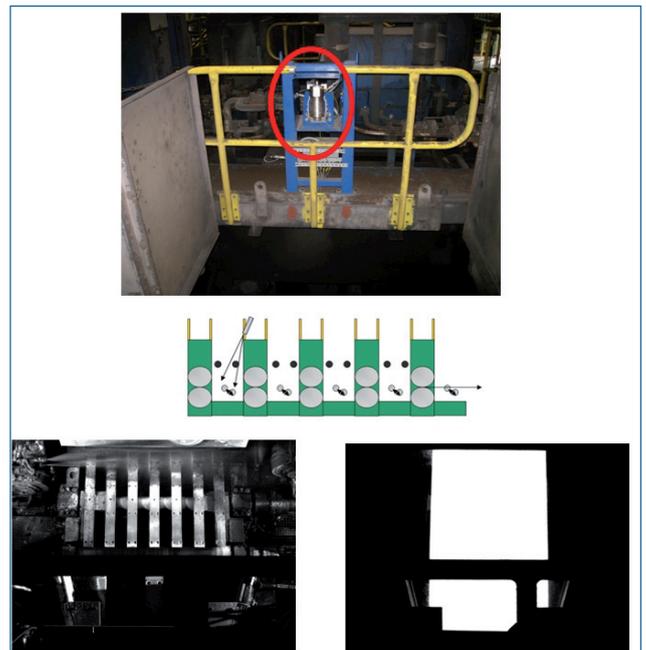
- 30% reduction in the standard deviation.
- 30% reduction in the mean absolute head centerline deviation.
- Over 50 % reduction in the number of bars with a head centerline deviation > 25 mm.
- A factor 10 reduction in the number of bars with a head centerline deviation > 75 to about 0.2%.

These results of the production tests thus clearly show that, as predicted, the rougher mill tilt setup improves the head camber significantly.

## FINISHING MILL STRIP STEERING

The measurement system described in section 2 can in principle also be used for finishing mill strip steering. This puts, however, much stricter demands on the system. First of all the measurement environment in a finishing mill is in general more challenging. On top of that, strip steering on the body of a strip requires a centreline deviation measurement with relative high accuracy.

Tests executed by Tata Steel R&D at the Direct Sheet Plant in IJmuiden show that the centerline deviation measurement system accurately detects the response to deliberately introduced tilt errors. Fig. 12 for example shows the measured change in centerline deviation measured be-



**Fig. 7 - Picture of the interstand centreline deviation camera and installed on top of one of the stands in the Direct Sheet Plant in IJmuiden and a view of the camera picture with and without a strip.**

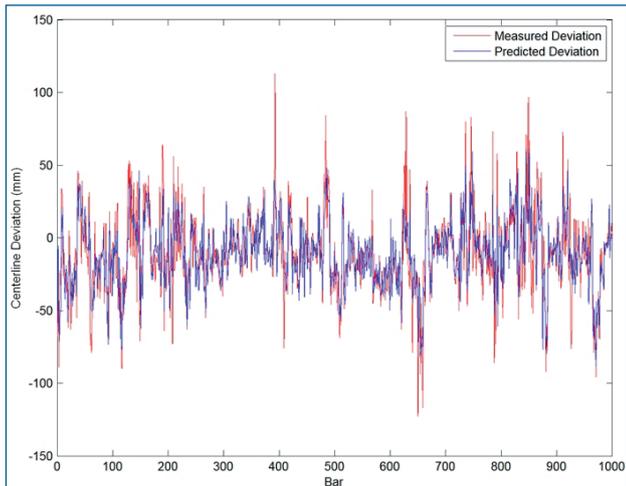
*Fig. 7 - Immagine della telecamera di rilevamento della deviazione della linea di mezzeria fra gabbie di laminazione, posizionata in cima a una di esse nell'impianto di IJmuiden e due immagini riprese dalla telecamera con e senza un nastro.*

tween the first two stands of the finishing mill caused by tilt errors at the two preceding stands and the two following stands<sup>1</sup>. This implies that the precision of the camera system is sufficient to enable strip steering, i.e. correcting the tilting position of a stand on the basis of the measured centerline deviation. However, such a control still has to be implemented and tested in production.

## CONCLUSION AND OUTLOOK

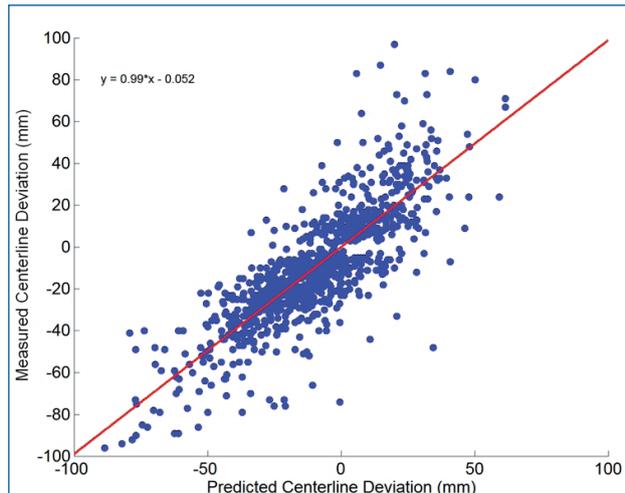
Tata Steel R&D has set out a strategy to improve strip tracking which relies on rougher mill camber control and finishing mill strip steering and tail control. For this pur-

<sup>1</sup>The layout of the Direct Sheet Plant is such that the rougher mill is directly coupled to the finishing mill and all stands together constitute a 7-stand tandem mill.



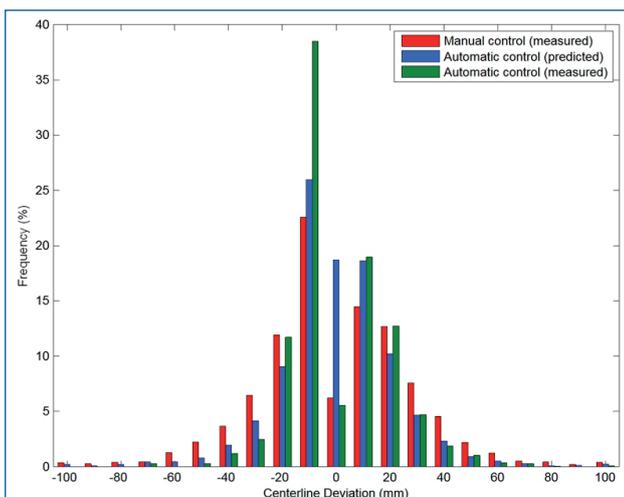
**Fig. 8 - The measured head centerline deviation (red) of the transfer bar for a set of consecutively rolled bars together with the predicted centerline deviation (blue) computed from the transfer function.**

Fig. 8 - Deviazione misurata (rosso) e deviazione prevista (blu) della linea di mezzeria di testa per un gruppo di barre laminare consecutivamente, elaborate mediante funzione di trasferimento.



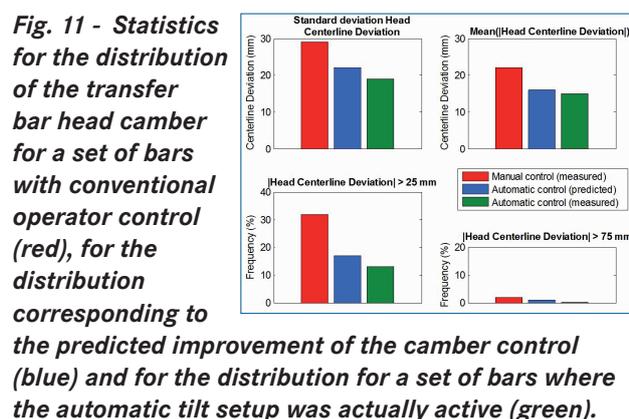
**Fig. 9 - The measured head centerline deviation of the transfer bar for a set of consecutively rolled bars plotted against the predicted centerline deviation computed from the transfer function (blue dots). Up to an error term the predicted and the measured centerline deviation are almost exactly proportional as indicated by the red line.**

Fig. 9 - Deviazione rilevata della linea di mezzeria di testa misurata per un gruppo di barre laminare consecutivamente, tracciata contro la deviazione prevista della mezzeria elaborata mediante funzione di trasferimento (punti blu). Entro un limite di errore, la deviazione prevista e la deviazione misurata della linea di mezzeria sono quasi esattamente proporzionali, come indicato dalla linea rossa.



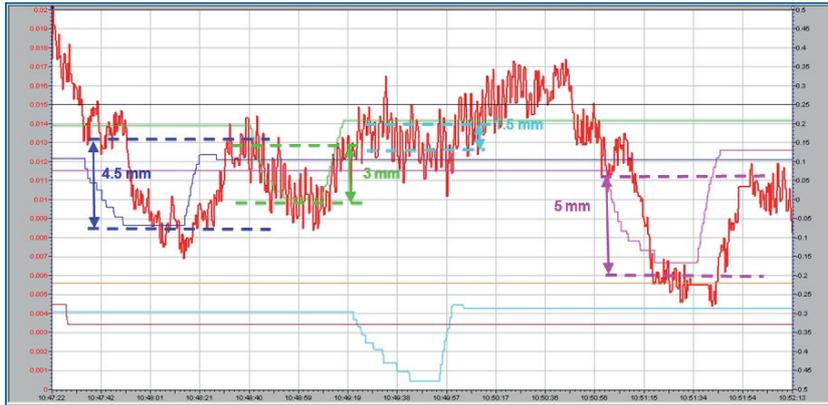
**Fig. 10 - Distribution on the head centreline deviation measured after the last stand of the rougher mill of Hot Strip Mill 2 for a set of bars where conventional operator control was applied (red), as well as for a set of bars where the automatic tilt setup was active (green). In addition the distribution is shown corresponding to the predicted improvement of the rougher mill camber control (blue).**

Fig. 10 - Distribuzione della deviazione della linea di mezzeria della testa misurata dopo l'ultima gabbia del treno sbozzatore dell' Hot Strip Mill 2 per un gruppo di barre in cui è stato applicato un controllo operativo convenzionale (rosso), e anche per un gruppo di barre in cui è stato attivato il monitoraggio automatico (verde). Inoltre viene mostrata la distribuzione corrispondente al miglioramento previsto mediante controllo della deviazione nel laminatoio sbozzatore (blu)



**Fig. 11 - Statistics for the distribution of the transfer bar head camber for a set of bars with conventional operator control (red), for the distribution corresponding to the predicted improvement of the camber control (blue) and for the distribution for a set of bars where the automatic tilt setup was actually active (green).**

Fig. 11 - Statistiche relative a: distribuzione della deviazione di testa per un gruppo di barre con controllo operativo convenzionale (rosso); distribuzione corrispondente al miglioramento previsto mediante controllo della deviazione (blu); a distribuzione per un gruppo di barre in cui è stato effettivamente attivato l'allineamento automatico (verde).



**Fig. 12 - Response of the measured F1-F2 centerline deviation (red) to the tilt errors introduced at F1 (blue), F2 (green), F3 (cyan) and R2 (magenta) at the Direct Sheet Plant in IJmuiden.**

*Fig. 12 - Risposta della deviazione della linea di mezzeria misurata F1-F2 (rosso) agli errori di deviazione introdotti in F1 (blu), F2 (verde), F3 (ciano) and R2 (magenta) presso il Direct Sheet Plant di IJmuiden.*

pose a relatively simple system to measure the lateral position of the strip has been developed which is sufficiently robust to withstand the harsh environment of a hot strip mill. Moreover, this system can be used both as camber measurement in a rougher mill and as an interstand centerline deviation measurement in a finishing mill.

A model has been developed to control the head camber after the exit of a rougher mill stand on the basis of the measured camber. Production trials at the last stand of the rougher mill of Hot Strip Mill 2 in IJmuiden have shown that camber control can reduce transfer bar camber significantly. Tata Steel is now planning to roll this technology successively out over all stands of the rougher mill of Hot

Strip Mill 2 and finally over all hot strip mills.

Initial tests at the Direct Sheet Plant in IJmuiden have shown that the centerline deviation measurement is sufficiently accurate to enable finishing mill strip steering. Tata Steel R&D is now working on the further development and implementation of this control at a single stand of the Direct Sheet Plant. Only after successful production trials this technology will be rolled out to other stands and to other hot strip mills. Finally, it needs to be shown that rougher mill camber control in combination with finishing mill strip steering is sufficient to prevent strip tracking issues such as for example tail pinching and thereby allows extension of the current production window.

## Misura e controllo della posizione del nastro nella laminazione a caldo di nastri

**Parole chiave:** Acciaio - Laminazione - Controllo processi

Lo scarso rilevamento e controllo della posizione del nastro è uno dei problemi che notoriamente minacciano la stabilità del processo di un laminatoio a caldo. Questo problema spesso porta al pizzicamento della coda o nel peggiore dei casi anche alla formazione di inspessimenti superficiali del materiale. Le principali strategie attuate per affrontare questo problema negli Hot Strip Mills di IJmuiden si basano su un più rigido controllo del profilo dei rulli e sul controllo del movimento orizzontale e della coda del treno finitore. Per tali applicazioni è stato sviluppato, un sistema di misura basato sull'utilizzo di una telecamera che si è rivelato semplice, economico, accurato e robusto. Inoltre, come si vedrà in questo documento, il sistema si è dimostrato efficace sia per la misurazione della deviazione della mezzeria fra le gabbie nel laminatoio di finitura che per la misura del profilo dei rulli nel laminatoio sbozzatore. In quest'ultima applicazione i dati di misurazione possono essere utilizzati per il livellamento automatico del laminatoio sbozzatore. I risultati delle prove di produzione presentati in questo lavoro dimostrano che le misurazioni del profilo dei rulli in abbinamento ad un modello della inclinazione nel treno sbozzatore di base sono sufficienti a ridurre in modo significativo gli inconvenienti.