

THE EFFECT OF DUAL ACTUATING STRIP GUIDANCE SYSTEMS IN A CONTINUOUS STEEL ANNEALING LINE

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ABSTRACT

In the past, Royal Hoogovens, a main primary steel and aluminum manufacturer in the Netherlands, used pre-shaped rolls and sophisticated tension tables to guarantee good strip tracking for all strip geometry's in both their Continuous Annealing lines. However: with an increasing product mix (wider range of geometrical dimensions: widths between 800 - 1200 mm and thickness' between 0.15 - 0.30 mm) in combination with high annealing temperatures of approximately 1000 K, these methods were not sufficient anymore. The steel strips became too vulnerable for wrinkles. To prevent wrinkles and tracking problems, Hoogovens Packaging Steel improved the flexibility of a processing line by partly substituting the pre-shaped rolls by flat rolls and new steering rolls. Before this process was started, a lot of time was spent, developing a suitable new steering roll type. This steering roll, it is called the **DUal** Actuating strip guidance System (DUAS), has a minimal influence on the strip tension distribution, basically consists of a flat roll and two hydraulic actuators mounted on a small frame and fits in an existing installations without large modifications. In December '95 the first system was placed in the furnace of one of the Hoogovens annealing lines and in November '96 another two.

TABLE OF SYMBOLS

K_1	setting value strip guiding controller	$m^2.s^{-1}$
K_2	setting value steering roll position controller	-
L_{opg}	size steering roll frame	m
L_{til}	pass length	m
R	Roll radius of one-roll offset pivot guide	m
s	Laplace operator	s^{-1}
t	time	s
v_s	strip velocity	$m.s^{-1}$
x	lateral strip position	m
x_{-1}	lateral position downstream roll	m
x_1, y_1, z_1	starting position of steering roll	m
$\hat{x}_1, \hat{y}_1, \hat{z}_1$	translated and rotated position of tilting roll	m
$\hat{x}_2, \hat{y}_2, \hat{z}_2$	translated and rotated position of offset pivot guide	m
x_d	desired strip position	m
ϕ_m	tracking angle caused by strip meandering	rad
ϕ_{piv}	pivot angle	rad
ϕ_{tit}	tilting angle	rad
ϕ_x	rotational degree of freedom	rad
ϕ_y	rotational degree of freedom	rad
τ	time constant geometrical tilting roll model	s^{-1}
τ_I	time constant hydraulic system	s^{-1}
τ_{opg}	time constant offset pivot guide system	s^{-1}

1. INTRODUCTION

The trends in the European steel packaging industry are: thinner food and beverage cans (weight and cost reduction of the cans) and an increase of the can production volume (cost benefits because of the scale-up). Hoogovens Packaging Steel, a major supplier of packaging steel in the world, follows this trend and delivers their customers with suitable wide (up to 1200 mm) and thin (less than 0.15 mm) tinplate coils with adequate mechanical properties. Annealing is, next to the chemical composition, mainly responsible for the mechanical properties of a strip. The production of this material sets some hard demands on the design of a Continuous Annealing line, such as:

- Tracking problems in a Continuous Annealing line generally result in damage and (partial) rejection of the steel strip, often combined with damage to the installation and delay in the production process and have to be avoided at any time.
- The tools to guarantee good strip tracking should not increase the chance of strip wrinkling. In a Continuous Annealing line, a steel strip will reach temperatures of approximately 1000 K: this makes the strip vulnerable for wrinkles.

Pre-shaped rolls (crowned or tapered) were in the past a very good solution to guarantee strip tracking, because of the satisfactory strip tracking behavior, the low initial investments costs and the low maintenance. Nowadays they are not suitable anymore. Despite the effort to alter the tension tables, the use of pre-shaped rolls in combination with the vulnerable material will

result into an unacceptable level of strip wrinkling. Within the Hoogovens research project "Strip Guidance" [1], Hoogovens Research & Development in close cooperation with Hoogovens Packaging Steel investigated the strip tracking behavior of steering rolls in a Continuous Annealing line. Steering rolls are an expensive alternative to pre-shaped rolls, but give the possibility to react fast and adequately on actual process conditions and decrease the chance of wrinkling.

In this paper, the Hoogovens solution, the "DUal Actuating strip guidance System" (DUAS), will be described to avoid tracking and wrinkling problems in an existing Continuous Annealing line without large modification. First, the preceding research project on steering rolls will be described, namely: the derivation of simple geometrical equations of the influence of two types of steering rolls (tilting and off-set pivot guide) on the lateral strip position and laboratory experiments and measurements under actual (annealing) process conditions to validate these equations.

2. STRIP TRACKING BY STEERING ROLLS

In general three different types of steering rolls are described in the literature [3, 5]: a tilting, an offset pivot guide and a triangle or swing type steering roll. Within the research project "Strip guidance" just the first two were dealt with. In this paragraph simple geometrical equations of the influence of a steering roll action on the lateral strip movement will be given.

2.1 The tilting steering roll

The steering action of a tilting steering roll is based on the rotation of the steering roll around a pivot point in the center of the roll body. The rotation of the roll and the expected reaction of the strip is exhibited in figure 1. For a top roll, the strip moves towards the lower side (in the figure towards the left side). The lateral strip velocity depends on the tilting angle and the strip velocity. Based on the geometry the lateral strip movement can be described with the subjoined equation [2]:

$$\frac{dx(t)}{dt} \approx -v_s(t) \cdot [\phi_{til}(t) + \phi_m(t)] \quad (1)$$

This approximation is allowed if the angles ϕ_{til} and ϕ_m are small. Transformation of this equation into the Laplace domain and assuming that v_s and κ_1 (see figure 1) are time-independent, results into:

$$X(s) = \frac{-L_{til}}{\tau s + 1} \cdot \Phi_{til}(s) \quad \text{with:} \quad \tau = \frac{L_{til}}{v_s} \quad (2)$$

This equation is used to determine a transfer function of a strip guiding system containing: a tilting steering roll, two proportional controllers (one for the control of the lateral strip position with a proportional gain K_1 , the other one for the control of the steering angle with

proportional gain K_2), a hydraulic system described by an integrator ($\tau_i s$) and measurement devices without any relevant dynamics:

$$X(s) = \frac{I}{\frac{\tau}{K_1 K_2 \tau_i L_{eff}} s^2 + \frac{\tau + \frac{I}{K_2 \tau_i}}{K_1 L_{eff}} s + \frac{K_1 L_{eff} + I}{K_1 L_{eff}}} X_d(s) \quad (3)$$

This is a second order transfer function. If the controllers have not been tuned well, undesired oscillation of the lateral strip position can occur.

2.2 The offset pivot guide steering roll

The principle of an offset pivot guide steering roll is very simple. Unlike a tilting steering roll, the principle of an offset pivot steering roll is based on the geometrical displacement of the roll and not on adjustments of the angle between strip and steering roll. The lateral shift of the roll equals the lateral displacement of the strip. Figure 2 is a scheme of an offset pivot guide; construction, control action and expected reaction of the strip. The lateral strip displacement depends on the tilting angle and the size of the steering frame:

$$x(t) = -L_{opg} \cdot \sin \phi_{piv}(t) \quad (4)$$

This equation can be used for offset pivot guide steering rolls which consists of a steering frame and two rolls. Dealing with a one-roll-offset pivot guide steering roll, like the DUAS (this steering roll will be discussed later on) the L_{opg} has to be replaced by $2.R$ (the roll diameter):

$$x(t) = -2 \cdot R \cdot \sin \phi_{piv}(t) \quad (5)$$

With the same assumptions as made in the previous paragraph, the transfer function of this strip guiding control system with a DUAS offset pivot guide steering roll will be:

$$X(s) = \frac{I}{\tau_{opg} s + I} X_d(s) \quad \text{with:} \quad \tau_{opg} = \frac{1}{2 \cdot R \cdot K_1} \quad (6)$$

The influence of a setpoint adjustment x_d (desired lateral strip position) can be modeled with a first order transfer function.

3. THE MULTI-FUNCTIONAL STEERING ROLL (PENTAS)

To enlarge the knowledge of strip tracking by different types of steering rolls, Hoogovens R&D developed an experimental installation containing a multifunctional steering roll. This steering roll had to be able to duplicate or simulate the two steering roll types, especially the movements or trajectories of steering rolls, discussed in the previous paragraph. The

trajectories of the two types of steering guides (tilting and offset pivot guide) can be described with the following formulas:

Tilting steering roll trajectory:

$$\begin{bmatrix} \hat{x}_1 \\ \hat{y}_1 \\ \hat{z}_1 \end{bmatrix} = \begin{bmatrix} \cos \phi_{til} & -\sin \phi_{til} & 0 \\ \sin \phi_{til} & \cos \phi_{til} & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x_1 \\ y_1 \\ z_1 \end{bmatrix} \quad (7)$$

Offset pivot guide steering roll trajectory:

$$\begin{bmatrix} \hat{x}_2 \\ \hat{y}_2 \\ \hat{z}_2 \end{bmatrix} = \begin{bmatrix} \cos \phi_{piv} & \sin \phi_{piv} & 0 \\ 0 & 1 & 0 \\ -\sin \phi_{piv} & \cos \phi_{piv} & 0 \end{bmatrix} \begin{bmatrix} x_1 \\ y_1 \\ z_1 \end{bmatrix} + \begin{bmatrix} \sin \phi_{piv} \\ 0 \\ \cos \phi_{piv} - 1 \end{bmatrix} \cdot 2R \quad (8)$$

In figure 1, the symbols used in equation (7) and (8) are explained. The steering roll simulator has five degrees of freedom: X, Y, Z, ϕ_x and ϕ_y . These degrees of freedom can be defined through five linear movement shafts. In order to move according to the described trajectories, a motion controller takes care of the synchronisation and the control of the elongation of the five linked shafts [6]. Figure 3 shows the basic configuration of the multi-functional steering roll (in reality the positions of the vertical actuators are orthogonal). The realised steering roll, the so called PENTAS, is able to cover the three trajectories with high accuracy (a following error of less than 40 μm and an end position error of 2 μm). The PENTAS is a predecessor of the DUAS system. Figure 4 and 5 show the Hoogovens experimental strip guiding installation including the PENTAS.

4. MEASUREMENTS IN THE EXPERIMENTAL INSTALLATION

During the tests in the Hoogovens experimental installation, the lateral displacement of the strip as function of the strip tension, strip velocity, shape (perfect shape and asymmetrical wavy edges of several sizes) and Young's modulus (steel and aluminum strip) was measured after imposing a tilting or pivot angle. To compare the results of the measurements, a steering factor was defined as: *the steering factor is the ratio between the lateral movement of the strip and the covered longitudinal distance*. For example if the steering factor is small, the lateral movement of the strip is also small.

Following the measurements the subjoined conclusions can be drawn:

- In case of the tilting steering roll, after a steering action, the strip moves towards the lower side (also the side with the lowest longitudinal tension). The steering factor depends on the tilting angle, but also on the process conditions, for example on the strip shape (a strip with

wavy edges acts more intense than a perfect shaped strip on a tilting steering roll action). The lateral movement of the strip can not be described with the simple geometrical equation (1). This equation overestimates the lateral strip movement [4, 7].

- In case of the offset pivot guide steering roll, the steering factor of an offset pivot guide steering roll is a linear function of the steering angle (limited to small angles), independent of the process conditions (shape, speed, tension, Young's modulus) and conform the simple geometrical equation (5).

Based on these conclusions, and the fact that in comparison with a tilting steering roll action, the mechanical load of an offset pivot guide steering roll is negligible (the strip is just twisted instead of locally elongated), Hoogovens decided that the new strip guidance device had to copy the steering principle of an offset pivot guide steering roll.

The next step was to determine the effect of an offset pivot guide steering roll action downstream the installation. This was realized by following the strip through the experimental installation after a sudden, deliberately caused, offset pivot guide steering roll action. The conclusion of this measurement was, that this process has minor dynamics (very fast first order systems) and can almost entirely be described with a delay time [8]. This makes it very easy to model the strip guidance process in a processing line containing flat rolls and offset pivot guide steering rolls.

5. MEASUREMENTS IN THE CONTINUOUS ANNEALING LINE

To validate the conclusions of paragraph 4, the influence of an offset pivot guide on the lateral strip position in a processing line was measured. First, the influence of an offset pivot guide steering roll on the lateral strip position directly after the steering roll was measured. For this measurements an additional lateral strip position measurement device was mounted at the roll upstream the offset-pivot-guide steering roll. The results were, that in accordance to the measurement in the experimental installation the lateral displacement of roll and strip is the same. Just as modeled, the control behavior of the strip guiding control system, containing an offset-pivot-guide steering roll, can be described with a first order transfer function.

The downstream influence of a deliberately caused lateral strip displacement was investigated. This measurement was executed in a Continuous Annealing line delivery looper, see figure 6. This looper contains five steering guides (offset-pivot guide steering rolls) to control the lateral strip tracking. The first delivery looper steering roll was used to create a deliberately caused lateral displacement of the strip (setpoint adjustment of the steering roll). The two following steering rolls were set out of order and were just used to measure the lateral strip displacement. The steering angle of the fourth steering roll (during the tests in action) was an indication of the lateral strip position there. We did not use the last delivery looper steering roll. The results of this test were conform the measurements in the experimental installation. The longitudinal displacement of the deliberately caused lateral displacement of the strip will move with almost the same velocity as the strip and can be described with a simple delay time.

6. THE DUAS

To avoid wrinkling and strip tracking problems in the future, Hoogovens R&D investigated solutions to control the lateral strip position with steering rolls. In the previous paragraphs two steering roll types were discussed: the tilting and the offset pivot guide steering roll. Based on production experience and the described experimental results, it was decided to design a new offset pivot guide steering roll, that could be easily mounted in a processing line and to replace the pre-shaped rolls by flat ones. In this paragraph, the DUAS (DUal Actuating strip guiding System) concept, the design and control will be discussed.

During the design of the DUAS, special attention was paid to: the possibility to replace a regular guide roll by the new steering roll without large modifications to the installation, the robustness of the chosen concept (large mean time before failure), the simplicity of the design (easy maintenance), and the size of the steering action (within the limitation of the installation and preferably as large as possible).

A good starting point was the PENTAS, described in paragraph 3. The PENTAS is a compact concept that could be installed easily in a production line, but for practical use, it is too complex and too sensitive for failures. A simplified version with only the necessary degrees of freedom to simulate the movements of an offset pivot guide would be a satisfying solution. Referring to equation (5), an one-roll offset pivot guide steering roll has only one degree of freedom: the pivot angle ϕ_{piv} . So, the PENTAS design could be simplified to a MONAS (just one horizontal actuator). However, because of safety reasons, Hoogovens chose a two actuators solution (DUAS). Figure 7 shows the final concept. In this design the vertical actuators of the PENTAS are replaced by a fixed foundation. The three horizontal actuators are replaced by two horizontal hydraulic actuators and a circular guideline. The maximum steering action depends on the diameter of the steering roll (similar to the existing ones) and the maximum pivot angle (depends on the installation), see equation (5) and is limited to ± 0.03 m.

Next, an appropriate strip guidance controller was designed. Because of the simple dynamics (a first order transfer function and a delay time) and the linear relation between the elongation of the linear actuators and the pivot angle (this linear relation is acceptable because of the limited pivot angle), either a simple feed forward or a feedback controller (with a proportional action) is possible, depending the location of the strip measurement device. A measurement device downstream implicates a feedback controller and a device upstream a feed forward controller.

In 1995 Hoogovens Packaging Steel and Hoogovens R&D implemented the first DUAS in a continuous annealing line. To achieve the desired lateral strip correction facility and avoiding wrinkles, nowadays three DUAS systems are applied in a Hoogovens Continuous Annealing line and several pre-shaped rolls are replaced by flat ones. Two of the DUAS systems are operating with a feedback controller and the other one with a feed forward controller. At this moment, it is too early to evaluate the obtained result regarding the cost benefits.

7. CONCLUSIONS

In this paper a method is described to avoid tracking and wrinkling problems in a Continuous Annealing line by partly substituting the pre-shaped rolls by flat rolls and DUAS systems. The DUAS is a new steering roll device, that combines the advantages of a tilting and an offset pivot guide steering roll. Its design is simple like a tilting steering roll (small external frame) and its steering principle is based on the offset pivot guide steering roll. So, the DUAS system, can be easily mounted in a processing line without large modifications, the steering action is independent of the strip properties and process conditions (strip shape, strip speed, Young's modulus) and the strip guidance controller is very simple and either a feedback or a feed forward type. At the present time, three DUAS systems are applied in a Hoogovens Continuous Annealing line and several pre-shaped rolls are replaced by flat ones. Two of the DUAS systems are operating with a feedback controller and the other one with a feed forward controller. At this moment, it is too early to evaluate the obtained result regarding the cost benefits.

8. REFERENCES

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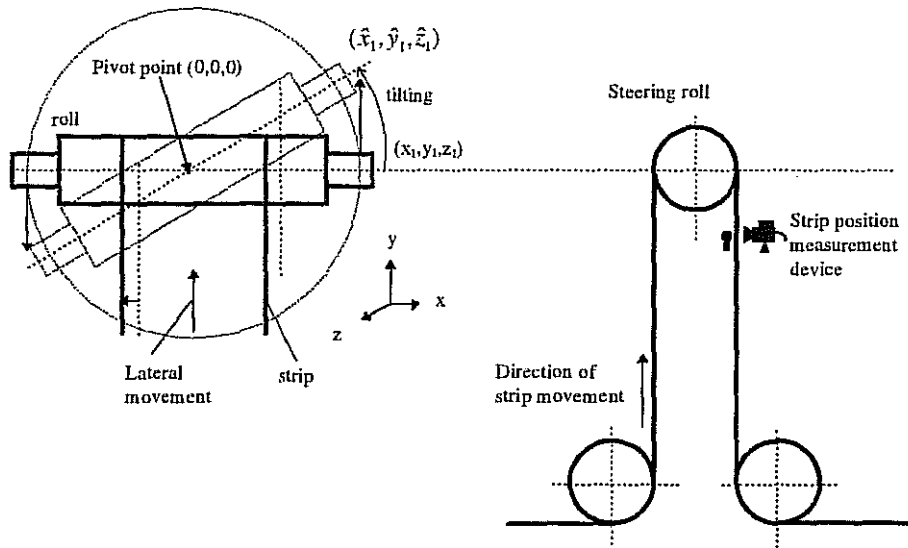


FIGURE 1: OUTLINE OF A TILTING ROLL AND ITS PRINCIPLE

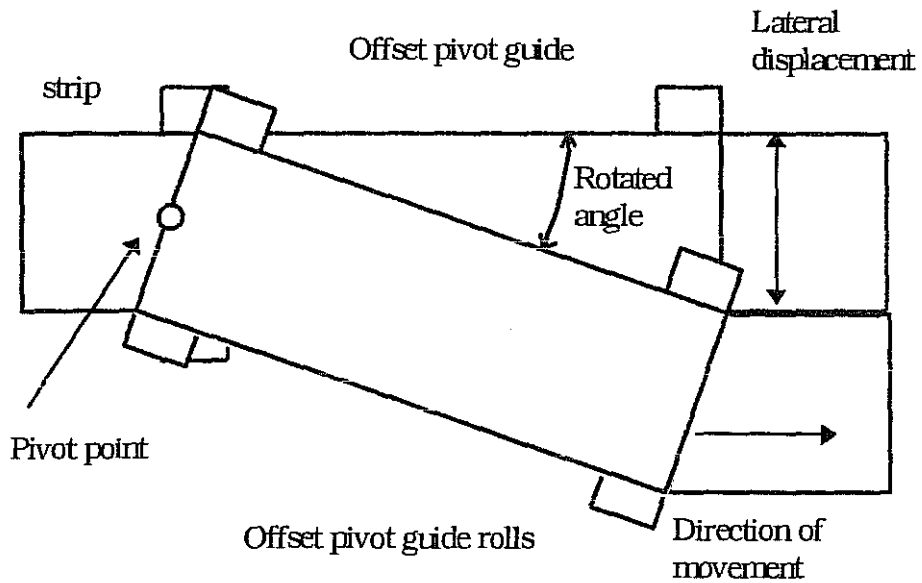


FIGURE 2: SIMPLIFIED SCHEME OF AN OFFSET PIVOT GUIDE STEERING ROLL

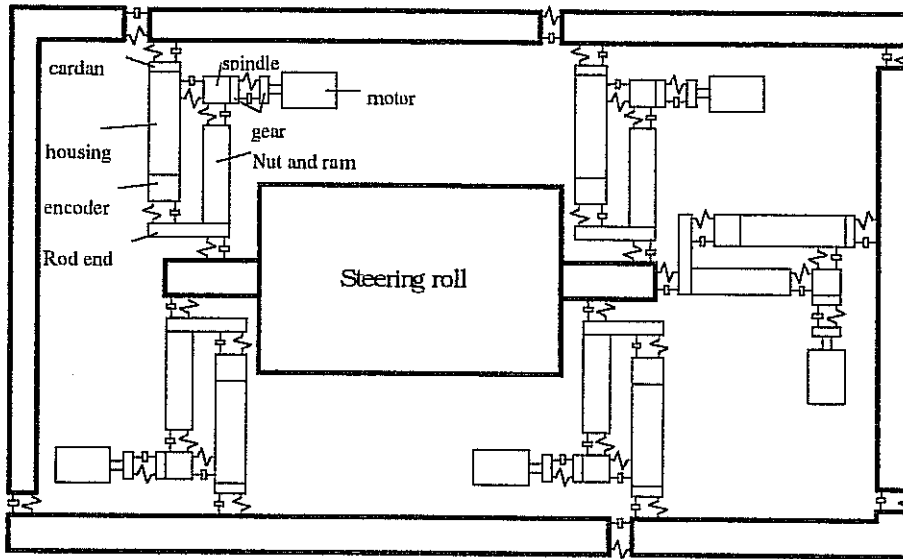


FIGURE 3: BASIC CONFIGURATION OF THE MULTI-TASKING STEERING ROLL ROBOT' (PENTAS)

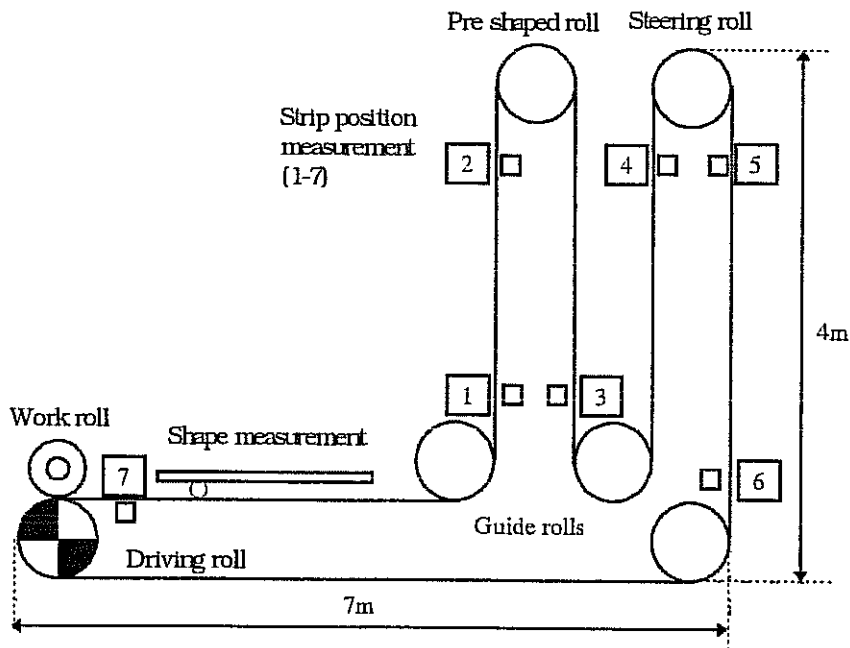
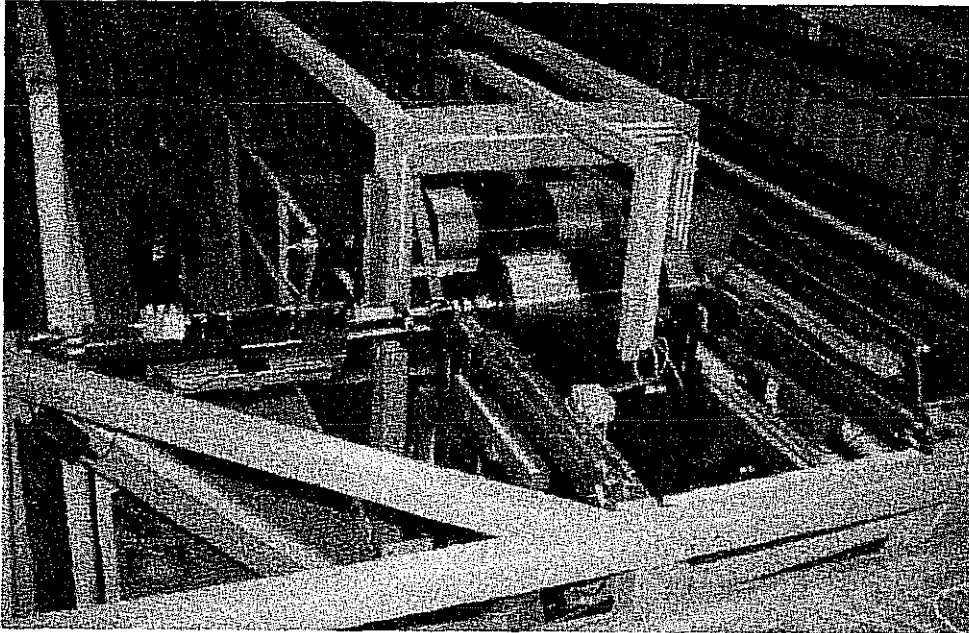


FIGURE 4: SCHEME OF THE EXPERIMENTAL STRIP GUIDANCE INSTALLATION



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FIGURE 5: PHOTO OF THE EXPERIMENTAL STRIP GUIDANCE INSTALLATION

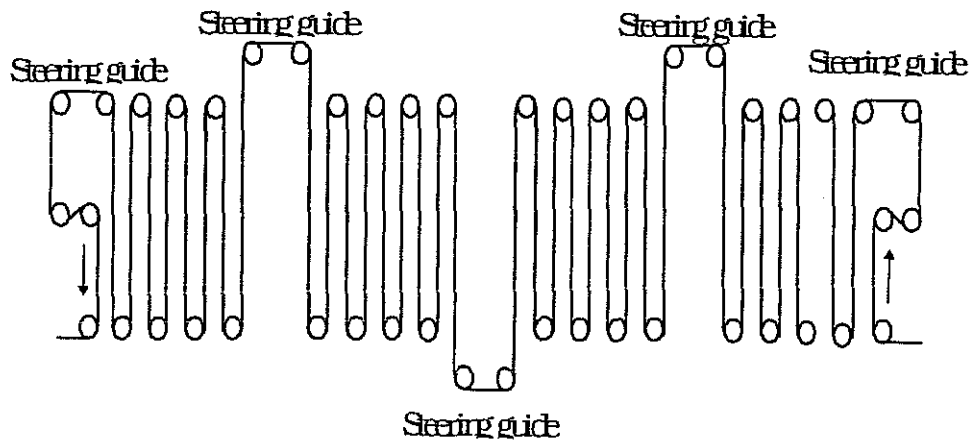


FIGURE 6: SCHEME OF THE DELIVERY LOOPER OF A CONTINUOUS ANNEALING LINE

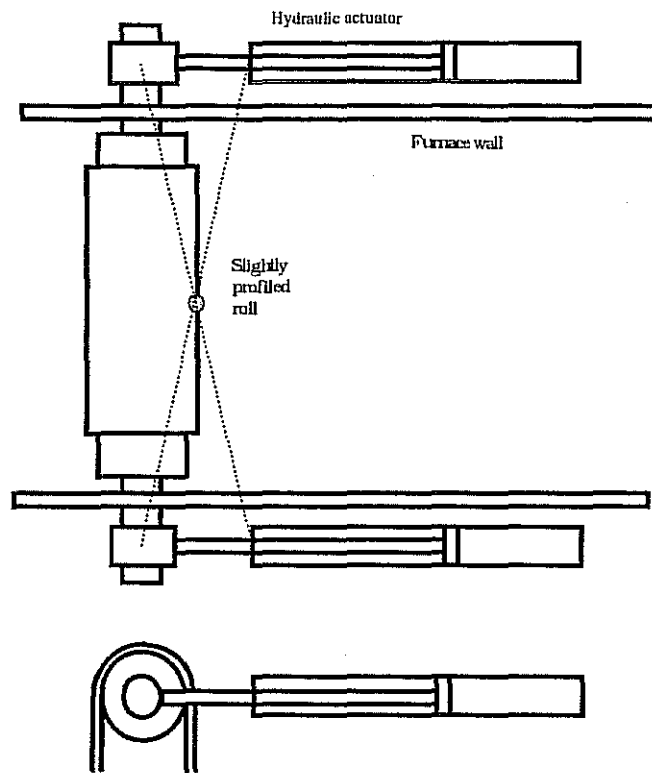


FIGURE 7: BASIC CONFIGURATION OF THE DUAS-SYSTEM

Question - What is the side board correction that you can apply and correct?

Answer - ± 2 to 3 cm on each side. This steering system is slower than a 4 roll off set pivot guide. We therefore use more of these systems, in order to make the necessary roll position correction in a short time.

Question - What are the roller diameters?

Answer - In the experimental line 375 mm, in the CA-line: 700-800 mm

Question - Why are there 2 hydraulic actuators and not 1?

Answer - 1 actuator would shift the pivot point of the roll movement. This causes our additional tension dip in the sheet. We want to avoid this.

Question - Why do you want to keep the pivot point constant?

Answer - Shifting the pivot point introduces extra tension in the sheet. This needs to be avoided. We therefore have plans to install an additional, third actuator to correct sheets that are not passing in centerline through the furnace.