Abstract

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The invention relates to a design for the model-based determination of actuator nominal values for a hot wide strip mill comprising a plurality of roll stands, by which means the application of the actuator nominal values enables the adjustment of a desired target contour of the roll gaps of the stands. In a first method step, a nominal speed conicity of the hot strip is defined after each stand. In the second step, values for the strip thickness contours at the outlets of the stands are determined by means of strip flatness models. In the third step, roll separating force distributions to be applied for each stand are distributed by means of material flow models. In the fourth step, the target contour for the strip advancement actuators is determined, while in the fifth step, the actuator nominal values are calculated, for each stand, from the target contour by means of an optimising method.

Fig:-1

We Claim

1. Iterative method for model-based determination of nominal actuator values for asymmetric actuators (22_i) of a hot wide strip mill with a number of roll stands G_i, with $i=1,\dots,n$ and $n \geq 2$, for rolling a hot strip (10), whereby each roll stand G_i, has a roll gap with a roll gap contour, and the actuators (21_i) act on the rollers (22_i) such that, for each stand G_i, a specific target contour ($K_i(z;k)$ of the roll gap is able to be set,

   Whereby, in a cycle of a process concerned k (k=1,2,...):

   1) In the first step, a nominal velocity tapering ($v_{i,soll}^{(1)}(k)$) after each stand G_i is preset,
   2) In a second step, values for the strip thickness contours $\theta_i(z;k)$ at the outlets from the stand G_i, $i=1,\dots,n-1$ are determined, whereby

   2.1)initially with the aid of strip flatness models 40_i for each stand G_i, a velocity profile ($v_i(z;k)$) is calculated at the respective outlet of the stand G_i, whereby a strip flatness model 40_i is assigned to each stand G_i and whereby a strip thickness contour $\theta_{i-1}(z;k)$ of the hot strip (10), at the point of entry of the given stand G_i, are taken into account,

   2.2)subsequently the velocity taperings ($v_i^{(1)}(k)$), obtained as parameters in the calculated velocity profiles ($v_i(z;k)$), are compared with the nominal velocity taperings specified in the first step ($v_{i,soll}^{(1)}(k)$),

   2.3)the strip thickness contours $\theta_1(z;k)$ to $\theta_{n-1}(z;k)$ are modified if the calculated velocity taperings ($v_i^{(1)}$(k)) do not lie within the tolerance range around the nominal velocity taperings ($v_{i,soll}^{(1)}$(k)), and, with this, the second step is carried out again or

2.4) the method goes to a third step if the calculated velocity taperings ($v_i^{(1)}$(k)) lie in the tolerance range around the nominal velocity taperings ($v_{i,soll}^{(1)}$(k)),

3) in a third step, with the aid of a material flow model 50_i, roll force distributions $f_i(z;k)$ to be applied for each stand G_i are determined, wherein a material flow model 50_i is assigned to each stand G_i,

4) in a fourth step, the target contour $K_i(z;k)$ is ascertained for the strip advancement actuator (22_i), wherein

4.1) first, a flattening $\Delta_i(z,k)$ of the rollers in the stand G_i is calculated for each stand G_i from the roll force distribution $f_i(z;k)$ on the basis of a working roller flattening model (71),

4.2) a residual strip thickness profile $\theta_i(z;k)-\Delta_i(z;k)$ is calculated for each stand G_i, by subtracting the flattening $\Delta_i(z;k)$ from the given strip thickness contour $\theta_i(z;k)$ at the outlet of the stand G_i determined in the second step,

4.3) the target contour $K_i(z;k)$ is calculated for each stand G_i, by filtering out a symmetric portion of the residual strip thickness profile, wherein the target contour $K_i(z;k)$ corresponds to the portion of the residual strip thickness profile remaining hereby,

5) in the fifth step, the actuator nominal values are calculated for each stand G_i from the target contour $K_i(z;k)$, with the aid of an

optimization process.

2. The procedure as claimed in claim 1, wherein, in the first step initially

- an eccentricity d_{i-1} of the hot strip(10)is measured before each stand G_i and the eccentricity d_n of the hot strip (10) is measured after the last stand G_n,
- the strip thickness contour $\theta_n(z;k)$ is measured after the last stand G_n,
- the strip thickness contour $\theta_0(z;k)$ is determined before the first stand G_1, in particular by measuring or estimation, and the predetermined nominal velocity taperings $v^{(1)}_{i,soll}(k)$ are calculated in a closed control loop from
- the nominal velocity taperings $v^{(1)}_{i,soll}(k-1)$ and the eccentricity measurement values $d_{i-1}(k-1)$ and $d_i(k-1)$ of the preceding process cycle k-1 and also
- the eccentricity measurement values $d_{i-1}(k)$ and $d_i(k)$ from the current cycle k.

3. The procedure as claimed in claim 2, wherein, in the second step, the strip flatness model 40i assigned to the stand G_i is supplied with the following data:

- an eccentricity value $d_i(k)$ at the entry of stand G_i,
- strip thickness contours $\theta_{i-1}(z;k)$ and $\theta_i(z;k)$ at entry and outlet of stand G_i,
- strip tensions at the entry and outlet of stand G_i,

- velocity profile v_{i-1} (z;k) at the entry of stand G_i,
- measured rolling force $f_i(k)$ in stand G_i,
- nominal value for strip widths, entry thickness in the strip center and reduction of the hot strip (10) in stand G_i.

4. The procedure as claimed in claim 3, wherein, in step 3, the material flow models 50i have the same data supplied to them as the strip flatness model 40i and additionally friction parameters R which describe the friction conditions in the longitudinal and transverse direction serve as input values of the material flow model 50_i.

5. The procedure as claimed in one of the preceding claims, wherein, in step 4, subsequent to part step 4.2), correction values $a_i(z;k)$, $b_i(z;k)$, $c_i(z;k)$ are additionally subtracted from the residual strip thickness profile θ_i (z;k)-$\Delta_i(z;k)$, wherein
   - $a_i(z;k)$ represents an initial contour of the working rollers,
   - $b_i(z;k)$ represents a current calculated thermal and wear convexity
   - $c_i(z;k)$ is a contour of symmetric profile and flatness actuators of stand G_i,

   and wherein subsequently, in part step 4.3), the residual strip thickness profile corrected in this way is used for determination of the target contour $K_i(z;k)$.

6. A computer program product for carrying out the procedure as claimed in claims 1 to 5.

7. With a control computer (2) programmed with a computer program product (2') according to claim 6, for a rolling train (1) with at least two roll stands G_i.

8. A rolling train (1) as claimed in claim 7 controlled by a control computer (2).

Dated this 06th Day of March, 2012

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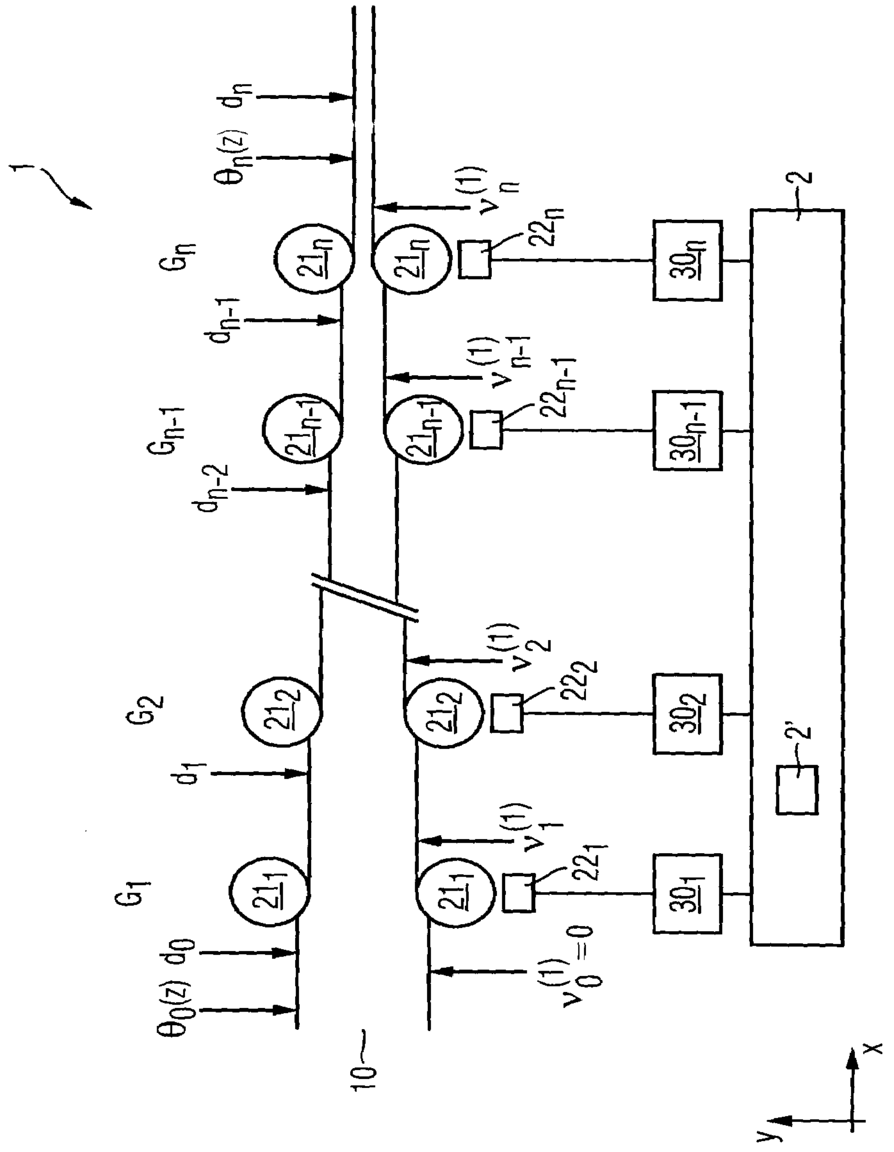

FIG 1

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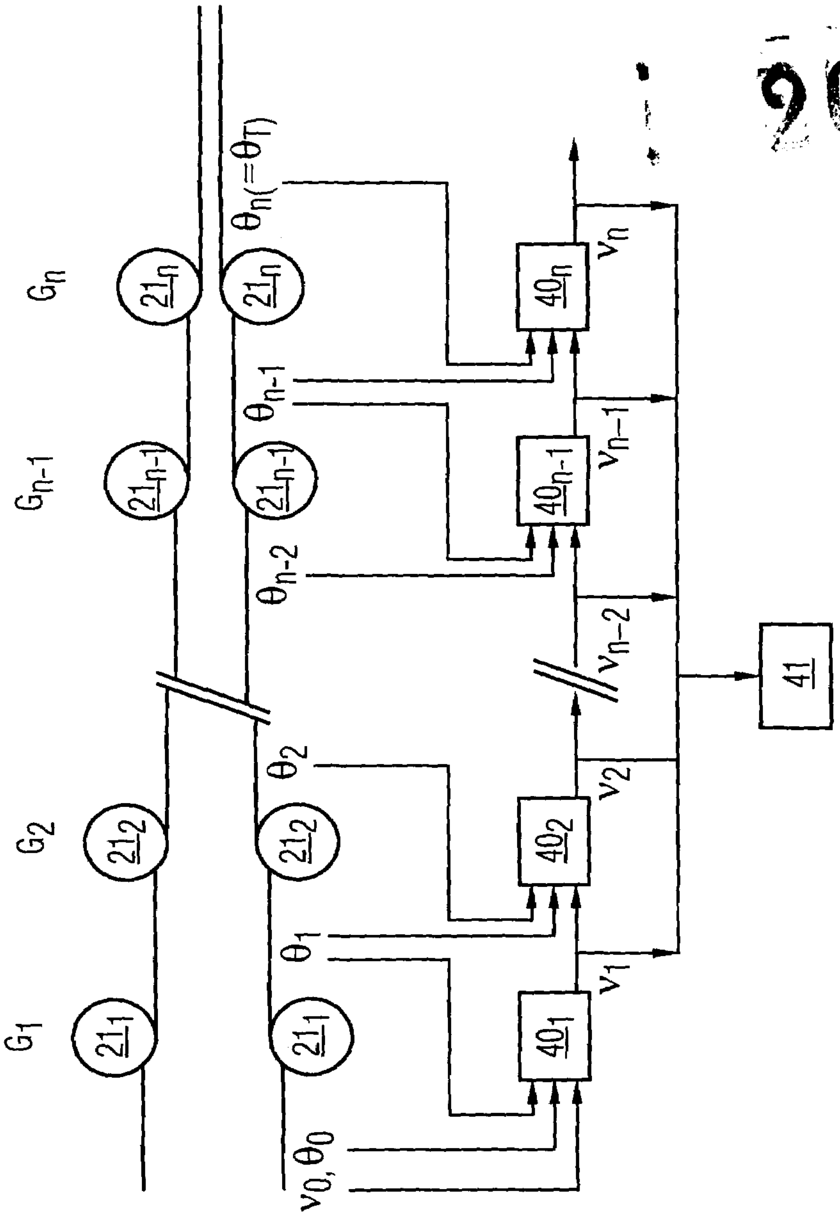

FIG 2

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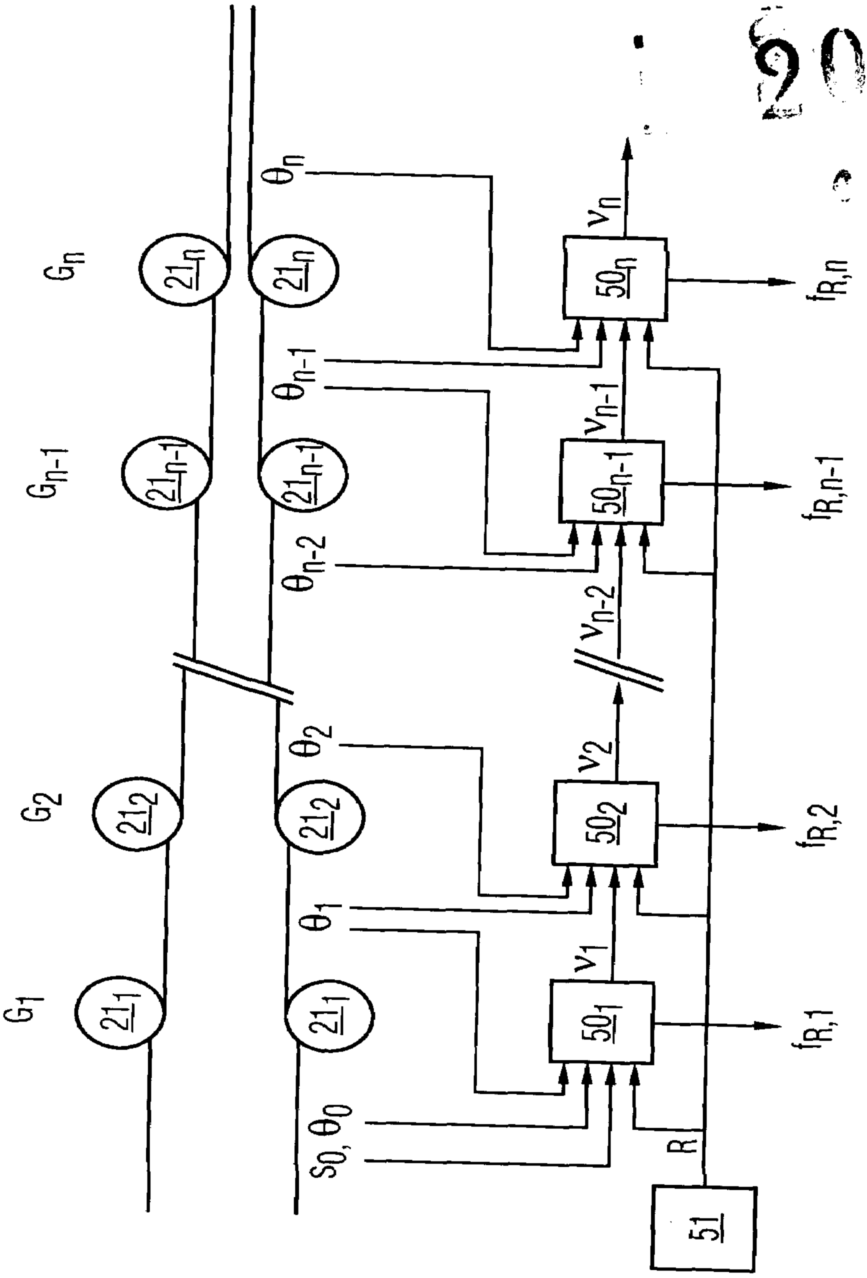

FIG 3

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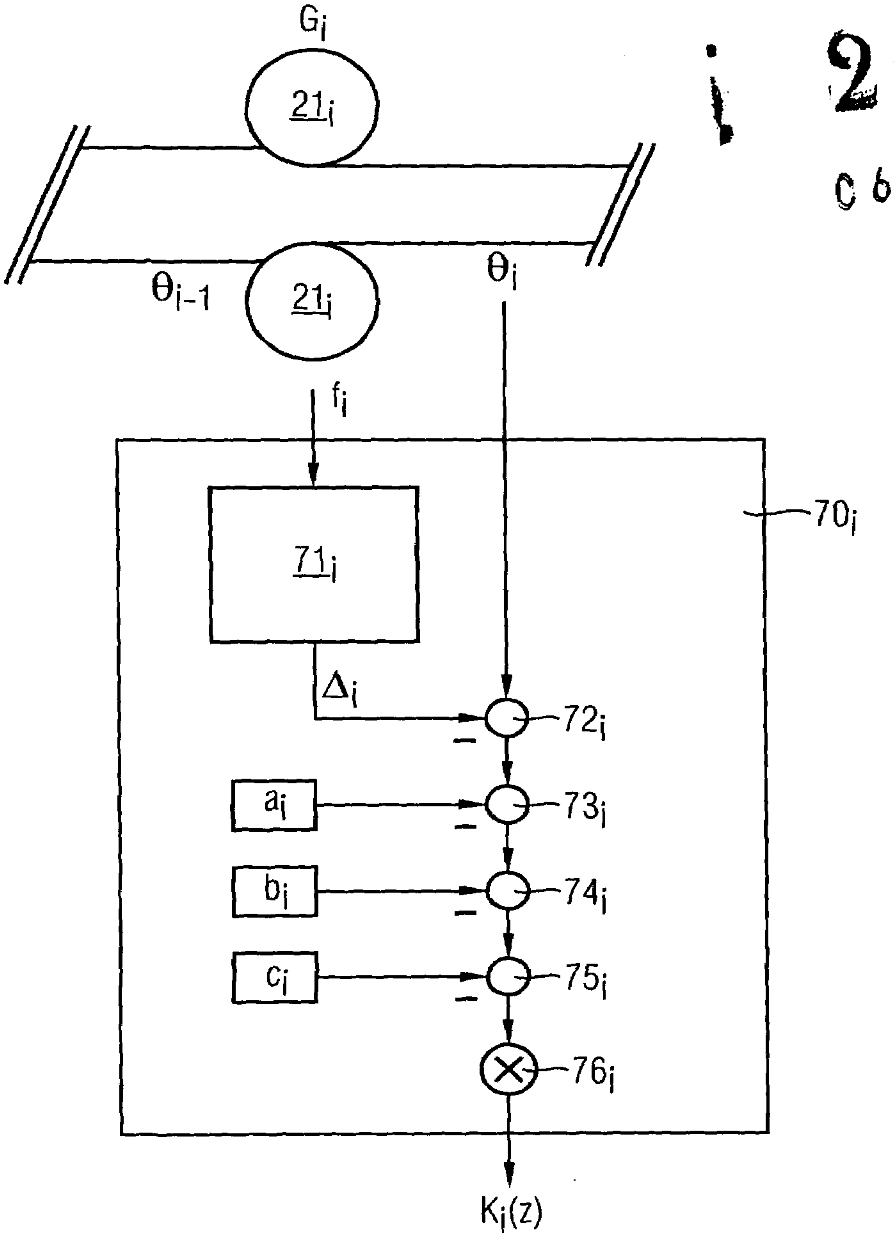

FIG 4

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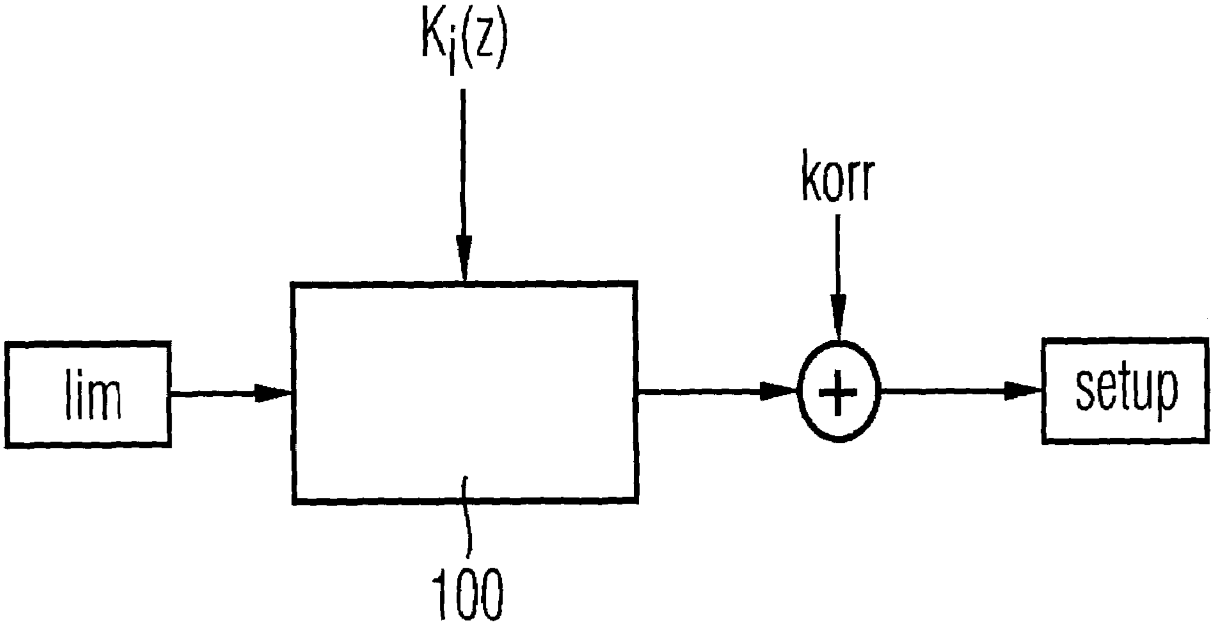

FIG 5

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Description

Method for model-based determination of actuator nominal values for the asymmetric actuators of the roll stands of a hot wide strip mill.

The invention relates to a concept for a model-based strip advancement controller for a hot wide strip mill, in particular a finishing train.

A hot wide strip mill train, in particular a finishing train, has a number of roll stands G_1, G_2, G_3,..... G_n to be traversed in turn by a strip to be rolled, typically a metal strip such as a steel, aluminum, copper, or generally a non-ferrous metal strip, wherein by means of the conventional control method and regulating method it is to be achieved that the rolled strip has a desired final temperature and a desired final thickness. Further relevant factors for assessing the roll quality are the profile, contour and flatness of the strip. In this context, the DE 102 11 623 A1 is to be mentioned, in which some of the relevant basic concepts are described in more detail. The key terms are defined here again. The "strip profile" or "profile value" of the strip indicates the deviation of the strip thickness at the strip edges from the strip thickness in the strip center. "Strip thickness contour" is to be understood as the strip thickness profile over the strip width minus the strip thickness in the strip center. The strip thickness contour can be split into a symmetric and an asymmetric part with respect to the strip center. The asymmetric part is labeled "strip thickness-wedge shape". The term "flatness" is used synonymously to the prevailing internal tensions in the strip, regardless of whether these internal tensions lead to visible distortions of the metal strip or not.

The strip is always threaded - seen relative to a rolling train center line - into each of the roll stands G_i (i = 1, ..., n) with a known respective center offset with respect to the stand center (at z = O) and with a known respective entry-side strip thickness wedge shape, so that the strip or the head of the strip outlets from the respective roll stand with the respective center offset, a respective outlet-side strip thickness wedge shape and a respective outlet-side strip curvature.

When a strip is rolled, internal tensions can be "rolled in" within the strip. Depending on the strip thickness, the strip width, the material properties of the strip and if necessary, the outer tensile stresses acting on the strip, these internal stresses lead to more or less distinct strip deformations such as corrugation or sabre effects. One of the major causes for the "rolling in" of intrinsic tensions, into a roll stand is a non-negligible strip-thickness wedge form of the strip coming into the stand. The strip thickness wedge shape can be caused by a number of different factors. For example, the strip can already have, before the rolling, strip-wide tapering. Alternatively, the strip thickness wedge shape may have been caused by it being rolled the rolling gap in an upstream roll stand. There are a number of possible reasons, for impressing a strip thickness wedge shape into the strip during the material deformation in a rolling mill. For example, the strip may have a temperature gradient across the strip width; the strip can enter the roll gap eccentrically or the roll gap can itself taper. Combinations of these (and other) reasons are also possible.

Thus, if a hot strip enters into a stand G_i with anything more than extremely slight strip-wide tapering or is anything more than slightly off-center, then the strip form will, in the ensuing, intermediate section between the stands G_i and G_{i+1}, generally not be straight, but sabre shaped. The sabre-shaped course depends on whether the strip is tensioned on one side only in a stand (when entering or exiting from the stand) or is gripped on both sides of two successive stands (during rolling of the main part of the strip, i.e. with the exception of strip head and strip foot). The influence of the strip tension on the saber form and thus on the strip course and the strip position, i.e., in particular the deviation of the strip position from the center, is clearly easy to understand: if we consider a strip edge of a strip exiting from a stand G_i and it is assumed that the speed of the plastic material flow at this strip edge is lower than that at the other strip edge, then it is clear that the strip tension over the strip width will be uneven once the next stand G_{i+1} engages. In particular, the strip tension on the "shorter" strip edge considered is higher. The higher strip tension causes a greater reduction in thickness of the strip at this strip edge and thus an increase in the speed of the plastic material flow at this edge. The velocity tapering of the plastic material flow across the strip width is reduced; the inter-stand tensions have a stabilizing effect on the course of the strip within the finishing train.

For the strip advancement controller, actuators are used on the individual stands G_1 of the rolling mill, which influence the shape of the roll gap and therefore the strip thickness profile over the strip width asymmetrically with respect to the stand center or the strip center. Such actuators are, for example, pivoting and asymmetric bending forces. Furthermore, symmetric actuators are also provided, for example, symmetric bending forces, means for axial displacement from so-called CVC working rollers (rolls with S-shaped grinding) and / or so-called "pair-crossing". These symmetrical actuators are used for profile and flatness control. An automatic model-based method or a device for profile and flatness control is disclosed in DE 102 11 623 A1.

In the prior art, it is for example also known that an operator of the rolling train, when introducing the strip, visually follows the tape head and - based on personal impressions of the strip position and strip corrugation, sets the position of the roll stand through which the strip head is currently passing (in particular a pivot position of the rollers).

The object of the present invention is to specify a control method and a control apparatus for a strip advancement controller of a rolling train having multiple stands, especially a hot wide strip mill train or a finishing train.

This object is achieved by the inventions stated in the independent claims. Advantageous embodiments result from the dependent claims.

the asymmetric rolling train actuators for controlling the tape can be calculated.

According to the invention, an iterative method for a model-based determination of actuator nominal values for the asymmetric actuators of an hot wide strip mill with multiple roll stands G_i with $i = 1, \ldots, n$ and $n \geq 2$ for rolling a hot strip is proposed, wherein each roll stand G_i has a roll gap with a roll gap contour and the actuators act on the rollers of the stands in such a way that for each stand G_i a certain target contour K_i (z, k) of the roll gap is adjustable between the rollers. The method is an iterative process, which has five separate steps for each process cycle:

1) In the first step, a nominal velocity tapering ($v^{(1)}_{i,soll}$ (k)) after to each stand G_1 is specified.

2) In the second step, values for strip thickness contours θ_i (z;k) at the outlets of the stands G_i, $i = 1, \ldots, n-1$, are identified, wherein

2.l) initially, with the help of strip flatness models, a velocity profile (v_i (z;k)) is calculated for each stand G_i at the respective outlet of the stand G_1, wherein every stand G_i is assigned to its own strip flatness model and wherein in the strip flatness model, a strip thickness contour θ_{i-1} (z;k) of the hot strip at the entry and a strip thickness contour θ_i (z;k) of the hot strip at the outlet of the respective stand G_i are taken into account, 2.2) subsequently, the calculated velocity taperings ($v_i^{(1)}$ (k)) contained as a parameter in the calculated velocity profiles (v_i (z;k)) are compared with the nominal velocity taperings given in the first Step ($v_{i,soll}{}^{(1)}$ (k)),

2.3) the strip thickness contours θ_i (z;k) to θ_{n-1} (z;k) may be modified, if the calculated velocity taperings ($v_i{}^{(1)}$ (k)) do not lie within a tolerance range around the nominal velocity taperings ($v_{i,\ soll}{}^{(1\ )}$ (k)), and thus the second step is executed again or

2.4) the process moves to the third step, if the calculated velocity taperings ($v_i{}^{(1)}$ (k)) lie in the tolerance range around the nominal velocity taperings ($v_{i,\ soll}{}^{(1\ )}$ (k)).

3) In the third step, using material flow models, applied roll force distributions f_i(z;k) are determined for each stand G_i, wherein a material-flow model is assigned to each stand G_i.

4) In the fourth step, the target contour K_i(z;k) is determined for the strip advancement actuators, wherein

4.l) initially, from the roll force distributions f_i (z;k), a flattening $\Delta_{i,}$ (z,k) of the rolls in the stand G_i is calculated for each stand G_i on the basis of a working roller flattening model,

4.2) for each stand G_i a residual strip thickness profile θ_i (z;k) - Δ_i(z;k) is calculated, by subtracting the flattening Δ_i (z;k) from the respective strip thickness contour θ_i (z;k) determined at the outlet of the stand $G_{i,}$ in the second step,

4.3) for each stand G_i the target contour K_i (z;k) is calculated by a symmetric portion of the residual strip thickness profile being filtered out, wherein the target contour K_i (z;k) corresponds to the remaining portion of the residual strip thickness profile in this case.

5) In the fifth step, finally, the actuator target-values from the target contour K_i (z;k) is calculated for each stand G_i with the help of an optimization process.

Advantageously, in the first step initially

- an eccentricity d_{i-1} of the hot strip (10) before each stand G_i and the eccentricity d_n of the hot strip (10) after the last stand G_n is measured,
- the strip thickness contour θ_n (z;k) after the last stand G_n is measured,
- the strip thickness contour θ_0 (z;k) before the first stand G_i is determined, in particular by measurement or estimation.

-

The predetermined nominal velocity tapering $v_{i,soll}^{(1)}$(k) is calculated in a loop from the nominal velocity tapering $v_{i,soll}^{(1)}$(k-1) and the eccentricity measured values d_{i-1} (k-1) and d_i (k-1) of the previous process cycles k-1 as well as the eccentricity measured values d_{i-1} (k) and d_i (k).

In the second step, the following data is supplied to the strip flatness model assigned to the stand G_i:

- An eccentricity measuring value d_i (k) at the entry of the stand G_i,

- Strip thickness contours θ_{i-1} (z;k) and θ_i (z;k) at the entry and exit of the stand G_i

- Strip tensions at the entry to and exit from the stand G_i

- Velocity profile v_{i-1} (z;k) at the entry to the stand G_i

- Measured rolling force f_i (k) in the stand G_i

— Nominal values for strip width, entry thickness in the strip center and reduction of the hot strip (10) in the stand $G_{i.}$

In the third step, the same data is fed to the material flow models, such as the strip flatness models. In addition, friction parameters R serve as input variables of the material flow model, which describe the friction conditions in the longitudinal and transverse direction in the roll gap.

In the fourth step, following the sub-step 4.2) correction values a_i (z;k), b_i (z;k), c_i (z;k) are initially deducted from residual strip thickness profile $\boldsymbol{\theta}_i$ (z;k) - $\boldsymbol{\Delta}_i$(z;k) additional. The meanings of the values are:

- a_i (z;k) an initial contour of the working rollers,

- b_i (z;k) a current calculated thermal and wear-convexity and

- ci (z;k) a contour of the symmetric profile and flatness actuators of the stand G_i.

In sub-step 4.3), subsequently the residual-strip thickness profile thus corrected is used to determine the target contour Ki (z;k).

Furthermore, an inventive computer program product for performing the inventive method is proposed as well as a control computer programmed with the computer program product for a rolling train having at least two roll stands G_i.

By comparison with a non-model-based strip advancement controller, the benefits that are obtained with the inventive solution are that, after successful piloting of a plant, shorter commissioning and service times will be needed for subsequent plants, and it becomes possible to better extrapolate the method for a new product range.

Further advantages, features and details of the invention will become apparent from the exemplary embodiment described below and with reference to the drawings, in which:

Figure 1 shows a schematic representation of a multi-stand rolling mill

Figure 2 shows a schematic representation of the rolling mill to illustrate the second process step

Figure 3 shows a schematic representation of the rolling mill to illustrate the third process step ,

Figure 4	shows a schematic representation of the rolling mill to illustrate the fourth process step,
Figure 5	shows a schematic representation of the rolling mill to illustrate the fifth process step.

In the figures, identical or corresponding areas, components, subassemblies, or process steps are identified by the same reference characters.

Figure 1 shows a side view or a section of a rolling train 1 with a strip 10 to be rolled there and a plurality of roll stands G_i (i = l, 2,... n). In the example shown, it is intended that the rolling train should have n stands, of which only the first two stands G_1, G_2 and the last two stands G_{n-1} and G_n are shown.

According to Figure 1, a rolling train 1 for rolling a metal strip 10 is controlled by a control computer 2. The operation of the control computer 2 is defined here by a computer program product 2', with which the control computer 2 is programmed.

A Cartesian coordinate system is used as a basis below, wherein the x-axis of the coordinate system corresponds to the direction of advance of the strip 10, the y-axis indicates the strip thickness direction and the z-axis is oriented in the direction across the strip 10 or in the direction of the longitudinal axes of the rollers $2l_i$ of the stand G_i. The center of the roller or stand is located at z = 0. The strip 10 is rolled in the rolling mill 1 in a rolling direction x. Each stand G_i has at least working rollers $2l_i$, and possibly (but not shown in Figure 1) supporting rollers as well.

The control computer 2, prespecifies nominal values for asymmetric actuators 22_i, or "actors", shown only in Figure 1, to stand controllers 30_i, wherein a stand controller 30_i is provided for each stand G_i, which ultimately act on the rollers $2l_i$; and thus realize the desired target form or contour of the respective roll gap. The stand controller 30_i governs the actuators 22_i, according to the specified nominal values. The basic interaction between the actuators 22_i or actuators, the rollers and the resulting roll gap can be assumed to be known.

Through the nominal values, an outlet-side roll gap path is influenced for each roll stand G_i, which is set between the working rollers $2l_i$ - in interaction with the working rollers located between the metal strips. The outlet-side roll gap process corresponds to an outlet-side contour process of the strip 10. The nominal values for the actuators 22_i must therefore be determined such that the roll gap profile, which corresponds to the desired outlet-side strip thickness contour, is obtained.

To determine the nominal values for the actuators 22_i, the input variables, which are explained below in connection with the five individual steps 1.) to 5.) of the inventive method, are fed to the control computer 2. The control computer 2 thus determines the nominal values from the input parameters supplied to it.

The strip thickness contour θ(z), which depending on the position z, specifies the thickness of the strip 10, i.e. its extent in the y direction, minus the strip center thickness, can be approximated with the exception of the strip edges in a good approximation by a second-degree polynomial:

$$\theta(z) = \theta^{(0)} + \theta^{(1)} \cdot z - \theta^{(2)} \cdot z^2 \qquad \text{(Eq.1)}$$

The coefficient $\theta^{(1)}$ here represents the wedge shape of the strip 10 or the strip thickness contour.

Furthermore, the strip thickness contour is denoted at the entry of the stand G_i with $\theta_{i-1}(z)$ and at the outlet of the stand G_i with θ_i (z) (with $1 \leq i \leq n$).

At the outlet of a stand G_i, the plastic material flow of the strip 10 in rolling or strip advancement direction has a certain speed profile v_i (z) over the strip width, which can be approximated (ignoring the average strip speed in the rolling direction) by a polynomial without a constant term:

$$v_i(z) = v_i^{(1)} \cdot z + v_i^{(2)} \cdot z^2 + O(z^3) \qquad \text{(Eq. 2)}$$

The coefficient $v_i^{(1)}$ here describes a velocity tapering or a material flow-thickness taper, which leads to the initially described sabre form of the strip 10, while the coefficient $v_i^{(2)}$) is a measure of the flatness or unevenness of the strip 10. In this equation, $v_i^{(2)} > 0$ corresponds to waves at the edge, while $v_i^{(2)} < 0$ means waves in the center.

Furthermore, a deviation of the strip center in the z direction of the center of the roller or stand at z = 0 directly in front of a stand i is denoted by d_{i-1}.

A calculation cycle k of the inventive iterative method has five individual steps 1.) to 5.), which for example, are executed with the help of a computer program on the control computer 2 (in the figures, the parameters "k" and "z" used in the text below are not shown for reasons of clarity):

Step 1)

Measurements and measurement value evaluation and nominal value specification for the material flow wedging $v_i^{(1)}$ (see Figure 1):

The following are measured, using appropriate sensors and transducers (not shown):

- the eccentricity d_{i-1} of the strip 10 before each stand G_i(where i = 1, ..., n) as well as the eccentricity d_n of the strip 10 after the last stand G_n and the strip thickness contour $\theta_n(z)$ after the last stand G_n.

The eccentricity d_{i-1} of the strip 10 before each stand G_i is preferably measured optically, for example, using a laser or camera system. For measuring the eccentricity d_n of the strip after the last stand G_n, no additional measuring instrument is required because this size can be determined by means of the (usually traversing) strip thickness contour-measuring instrument after the last stand.

In addition, the strip thickness contour $\theta_0(z)$ is either measured online before the first stand G_i or estimates can be used for $\theta_0(z)$, which are based, for example, on sporadically performed off-line or manual measurements.

In each cycle k, in the computing step 1 of the implemented tape drive control algorithm in the computer program, a (new) sepoint velocity tapering $v_{i,soll}^{(1)}$ (k) is predetermined according to each stand G_i (i = 1, ..., n). The target velocity taperings $v_{i,soll}^{(1)}$ (where i = 1, ..., n) are calculated in a control loop from the target velocity taperings $v_{i,soll}^{(1)}$ (k-l) and the eccentricity measurement values d_{i-1} (k-1) and d_i (k) of the last calculation cycle and the current eccentricity measurement values d_{i-1} (k) and d_i (k).

For the first cycle (k = 1) "start values" can be $v_{i,soll}^{(1)}(0)$, $d_{i-1}(0)$ and $d_i(0)$, for example, the values are used, which are still known from the rolling process of a pre-rolled strip. Alternatively, $v_i^{(1)}$ (0) = d_{i-1} (0) = d_i (0) = p could also be assumed, wherein p can be any numerical value including p = 0.

Step 2)

Calculation of nominal values for the inter-stand strip thickness contours

$\theta_i(z;k)$, in particular for the strip thickness wedging $\theta_i^{(1)}(k)$ after each stand G_i (cf. Figure 2):

Here suitable nominal values for the strip thickness contours $\theta_i(z;k)$, $i=1,\ldots,n-1$, are calculated at the outlets of the stands G_i, $i=1,\ldots,n-1$. With the help of a physical stock flatness model 40_i (or an approximation function ("Look-up Table") of a stock flatness model, the velocity profile $v_i(z)$ including the co-efficient $v_i^{(1)}(k)$ (refer to Eq. 2), which corresponds to the velocity tapering, is calculated for every stand G_i at the outlets of the stands G_i, wherein a model 40_i is assigned to each stand G_i. The models 40_i and also other models used below are implemented in the computer program.

The model 40_i involves the expansion of the model that is described in DE 102 11 623 A1 and is referred to there as a "flatness estimator" and its approximation function with additional consideration of asymmetric effects.

The following data is supplied to the model 40_i assigned to stand G_1:

- Eccentricity measuring value $d_i(k)$ at the entry of stand G_i,

- Adopted, calculated or measured strip thickness contours $\theta_{i-1}(z;k)$ and $\theta_i(z;k)$ at the entry of stand G_i,

- Adopted, calculated or measured tape tensions at the entry and exit of stand G_i,

- Adopted or calculated velocity profile $v_{i-1}(z;k)$ at the entry of stand G_i,
- *Measured rolling force in stand* G_i,
- Calculation of nominal values for strip width, entry thickness (in the strip center) and decrease in stand G_i.

The velocity profile $v_0(z)$, that is supplied to the flatness-model 40_1 of the first stand G_1, can generally not be measured and is assumed to be $v_0(z)=0$.

With the help of the 40_i model and the aforesaid input data, the velocity profile $v_i(z;k)$at the outlets of stand G_i is calculated for every cycle k in stage 2. The velocity tapering contained herein has been compared with the nominal velocity tapering determined in step 1) in a logic unit 41.

In the event of said comparison indicating that the calculated values for the velocity profile $v_i(z;k)$ are not within the tolerance range around these nominal values, i.e. between a maximum and minimum value, then the strip thickness contours $\theta_1(z)$ to $\theta_{n-1}(z;k)$ are modified until the comparison produces a sufficient agreement.

In the event of the comparison indicating that the calculated value for the velocity profile $v_i(z;k)$ basically falls within the tolerance range around target values, the process goes to step 3, whereby the strip thickness contours $\theta_i(z;k)$ determined in the described comparison continue to be used.

Step 3)

Calculation of roll force distribution f_i over the strip width for every stand G_i (cf. Figure 3):

Every stand G_i is assigned a physical material flow model 50_i (or an approximation function ("Look-up table") of such a material flow model), to which the same data is supplied as supplied to model 40_i in step 2). In addition, the material flow model 50_i receives friction parameters R, which describe the various friction conditions in the longitudinal and transverse direction in the rolling gap, as input values from a unit 51.

The friction parameters R are model-adaptation parameters that are defined such that the overall algorithm predicts the measured strip thickness contour and strip flatness as well as possible after the last roll stand.

The material flow models 50_i model the physical behavior of the strip 10 in the rolling gap of the stand G_i.

As in step 2), here too $v_0(z)=0$ is assumed for the velocity profile before the first stand.

With the help of the material flow model 50_i, the roll force distribution $f_i(z;k)$ is determined with the help of above input data. The respective material flow model 50_i ascertains the linear load distribution $f_i(z)$ between strip and working rollers. The integral of $f_i(z)$ over the strip width produces the rolling force in stand G_i.

The main uncertainty in the modeling of material flow in the rolling gap lies in the friction conditions in rolling gap, both in the rolling force direction and also transverse to the rolling direction. The friction parameters R are therefore the main model adaptation parameters.

Step 4)

Calculation of target contour for the strip advancement actuator elements 22_i (i.e. the asymmetric strip thickness contour for actuator elements) for every stand G_i (cf. Figure 4):

Figure 4 shows the further processing of roll force distributions $f_i(z;k)$ determined in step 3 of cycle k. These roll force distributions are provided for each roll stand G_i of the assigned arithmetic unit 70_i allocated to stand G_i, wherein the flatness $\Delta_i(z,k)$ of working rollers connected to roll separating force $f_i(z)$ is calculated with the help of a working roller flatness model 71 in stand G_i.

This flatness $\Delta_i(z;k)$ is subtracted in a subtractor 72 of the arithmetic unit 70i from the strip thickness contour $\theta_i(z;k)$ at the outlet of stand G_i, i.e. a residual-strip thickness profile $\theta_i(z;k)-\Delta_i(z;k)$ is calculated in subtractor 72_i. Correction values $a_i(z;k)$, $b_i(z;k)$, $c_i(z;k)$can be subtracted from this residual strip thickness profile in further subtractors 73_i-75_i, whereby $a_i(z;k)$is the initial contour of working rollers (i.e. the wear), $b_i(z;k)$ is the currently calculated thermal and wear convexity and $c_i(z;k)$ is the contour of the symmetric profile and flatness control elements of stand G_i. At the time of calculation of variables $a_i(z;k)$, $b_i(z;k)$ and $c_i(z;k)$ the current eccentricity $d_i(k)$of the strip is taken into consideration in each case.

Finally, the corrected residual strip thickness profile able to be obtained from the last subtractor 75_i is fed to a logic-unit 76_i, in which the symmetrical portion of residual strip thickness contour is filtered out. The remaining strip thickness contour is the target contour $K_i(z;k)$, which with the aid of strip advancement actuators 22_i, the stand G_i is to be adjusted. The arithmetic unit 70_i thus finally delivers this target contour $K_i(z;k)$.

Step 5)

Calculation of nominal values for the strip advancement actuators 22_i (cf. Figure 5):

In the last step, the correct regulatory control value is calculated for each stand G_i, with the aid of what is referred to as a "Least Squares" optimization 100 from the target contour $K_i(z;k)$ taking into account the technical, physical limits lim of the strip advancement actuators 22_i, whereby the strip advancement actuator 22_i of stand G_i is finally set. If necessary corrections korr can also be added to the setup thus determined, using manual methods for example.

In the event of there being a number of independent strip advancement actuators for a stand, for example, pivoting and asymmetric bending, the optimal combination of these actuators can be determined in optimization step 5.