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(54) STRIP VELOCITY MEASUREMENT IN ROLLING MILLS

BANDGESCHWINDIGKEITSMESSUNG IN WALZWERKEN

MESURE DE LA VITESSE D'UN FEUILLARD DANS UN LAMINOIR

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EP 1 239 979 B1

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Description

FIELD OF THE INVENTION

[0001] This invention relates to a technique for high precision estimation of strip velocities for rolling mills.

BACKGROUND OF THE INVENTION

[0002] A typical rolling mill consists of an uncoiler, one or more mill stands and a coiler. Each mill stand typically has four or more rolls, the inner pair of work rolls reduce the metal strip which passes between them, and the larger diameter backup rolls support the work rolls. Large forces are applied to the rolls so that the thickness of the metal strip is reduced as it passes between the work rolls. The exit thickness is controlled by adjusting the forces applied to, and speed of, the work rolls.

[0003] An important problem in rolling mill control is to achieve highly uniform exit thickness while maintaining highly uniform strip tension. However, direct measurement of exit thickness is often made downstream from the work rolls. This measurement is known to be unsuitable for wide-bandwidth control due to inherent transport time delay associated with the physical location of the measurement. Thus, this measurement is typically used for low-bandwidth trim control.

[0004] An early technique for overcoming the delay associated with the direct measurement of exit thickness was to combine instantaneous force and position measurements from the work rolls together with a simple spring model for the mill. This led to the so-called "BISRA" gauge for thickness estimation [UK Patent 713,105]. It was discovered later on that the eccentricity of the rolls has significant affects on the accuracy of the estimation. This led to substantial follow-up research aimed at developing an eccentricity-compensated BISRA gauge.

[0005] More recently, an alternative approach to exit thickness estimation has been proposed based on mass-flow balance across the roll gap. More precisely, the product of velocity and thickness of the strip remains constant when it passes through the roll gap assuming that the width and density of the strip does not change. This implies that the exit thickness can be estimated using the upstream thickness and velocity, and downstream velocity, if they can be measured or estimated accurately. In some schemes for tandem (multiple stand) mills, it is only necessary to measure the entry strip velocity. Typical techniques for measuring velocities are pulse-counters mounted to strip contact wheels, or laser-doppler instruments which are very expensive see for example JP-A-57-190268 and JP-A-62-114713. Strip contact wheels suffer from operational difficulties due to high levels of vibration, coolant flows on the strip, water vapour and surface modulations due to poor flatness. It is therefore desirable to provide an alternative method of implementing mass-flow balance thickness estimation.

SUMMARY OF THE INVENTION

[0006] The present invention therefore provides a method of estimating the input and exit strip velocities at the roll gap in a rolling mill of the type having an uncoiler reel, a coiler reel and at least one pair of work rolls positioned therebetween, said method comprising the steps of:

- measuring the angular velocities of the uncoiler and coiler reels;
- estimating the initial radii of the uncoiler and coiler reels; and
- applying the measured and estimated values obtained to calculate estimated velocities of the strip before and after the roll gap.

[0007] Preferably the radii of the uncoiler and coiler reels are estimated by mathematically modeling the reels taking into account eccentricity effects and inter-wrap gaps.

[0008] Preferably the model includes a procedure to estimate initial coil radii using measurements of the surface velocity of the work rolls and an estimate of the slip ratio at the work rolls.

[0009] Preferably the estimation of the reel models is formulated as a non-linear least squares problem.

[0010] Preferably the said problem is solved using a relaxation algorithm, giving an estimate of uncoiler and coiler radii.

[0011] Preferably the method includes adaptive implementation of the relaxation algorithm.

[0012] The invention further comprises a method of estimating the exit thickness of strip in a rolling mill by estimating input and exit strip velocities using the method described above, and applying the estimated velocities in a mass flow balance equation.

BRIEF DESCRIPTION OF THE DRAWINGS

[0013] Notwithstanding any other forms that may fall within its scope, one preferred form of the invention will now be described by way of example only with reference to the accompanying drawing which is a diagrammatic elevation of a strip mill incorporating coiler and uncoiler reels and a pair of work rolls.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0014] The preferred form of the invention will be described with reference to a simplified rolling mill having an uncoiler reel 1, a coiler reel 2 and a single pair of work rolls 3 positioned between the coiler and uncoiler reels. It will be appreciated, however, that the method is equally applicable to more complex rolling mills having additional rolls and multiple stands, and that the metal strip 4 can be moved in the opposite direction by reversing the roles of the coiler and uncoiler reels and reversing the drive on the work rolls 3.

[0015] The basis for the soft-sensing technique in the present invention is a simple relationship between the input strip velocity V and the angular velocity Ω and radius R of the uncoiler:

$$V = \Omega R$$

A similar relationship holds for the coiler as follows:

$$v = \omega r$$

where v is the exit strip velocity, ω and *r* are the angular velocity and radius of the coiler, respectively.

[0016] Straightforward sensitivity analysis shows that the relative error in strip velocity is equal to the sum of the relative error in reel angular velocity and reel radius. Therefore, a desired accuracy of strip velocity estimation requires higher accuracy in the measurement or estimation of angular velocity and radius. High precision measurements for the angular velocity can be obtained using, for example, standard pulse counting devices. However, accurate measurement for the reel radius is not readily available. To overcome this difficulty, a simple model for the reel radius is used. Express the instantaneous uncoiler radius R(t) as

$$R(t) = R_a(t) + R_b(t)$$

where the term R_a above contains two components: a fixed mandrel radius and a component describing the change of radius due to the reel rotation. That is:

$$R_a(t) = R(t_0) - K \int_0^t \frac{\Omega(\tau)}{2\pi} d\tau$$

where t_0 represents the initial time, *t* represent the current time, *K* represents the thickness of each layer which includes the strip thickness and inter-wrap gap. The second term R_b in the reel radius model is used to capture eccentricity effects due to mandrel and other factors. This term is approximated using Fourier components as follows:

$$R_b(t) = \sum_{i=1}^{m} C_i \cos(i\Theta(t)) + S_i \sin(i\Theta(t))$$

where $\Theta(t)$ is the reel angle, m is the number of harmonics significant to the modeling of eccentricity effects, and C_i and S_i are Fourier coefficients representing the eccentricity effects.

[0017] A key observation is that the reel radius in linearly parameterised in terms of the following parameter vector

$$\Gamma = [R(t_0), K, C_1, S_1, ..., C_m, S_m]$$

[0018] Similarly, the model for the coiler is given by

$$r(t) = r_a(t) + r_b(t)$$

with

$$r_a(t) = r(t_0) + k\int_0^t \frac{\omega(\tau)}{2\pi} d\tau$$

and

$$r_b(t) = \sum_{i=1}^{m} c_i \cos(i\theta(t)) + s_i \sin(i\theta(t))$$

The reel radius is linearly parameterised in terms of the following parameter vector

$$\gamma = [r(t_0), k, c_1, s_1, ..., c_m, s_m]$$

[0019] Using the above radius models, the prime issue in the strip velocity problem reduces to estimation of the parameter vectors Γ and γ.

[0020] The key to the estimation of these parameters is the mass flow balance at the roll gap. More precisely, the relationship between the input thickness *H*, the input velocity V, the exit thickness *h*, and the exit velocity ν at the roll gap is given by

$$H(t)V(t) = h(t)v(t)$$

[0021] Since the thickness measurements are not taken at the roll gap, transport delays need to be taken into account. Due to this, the mass flow balance equation becomes

$$H_m(t - D(t))V(t) = h_m(t + d(t)))v(t)$$

where H_m and h_m, are the measured input thickness and exit thickness, respectively, whereas D(t) and *d(t)* denote the transport delay from input measuring point to the roll gap and that from the roll gap to the exit measuring point, respectively.

[0022] Using the above mass balance equation and the models for reel radii, an entry to exit mass balance error is obtained as follows

$$e(t) = H_m(t - D(t))\Omega(t)(R_a(t) + R_b(t))$$
$$-h_m(t + d(t))\,\omega(t)(r_a(t) + r_b(t))$$

The radius estimates are linear in the parameter vectors. The following optimisation criterion can be used to estimate the parameter vectors Γ and γ .

$$\min_{\Gamma,\gamma} \int_{-T_0}^{t} \| e(\tau) \|^2 \, d\tau$$

where T_0 represents the window duration for minimisation.

[0023] Despite that the error function appears linear in the parameters, the optimisation above is non-linear because the transport delays depend on the strip velocities which in turn depend on the parameter vectors. The present invention uses a relaxation algorithm to solve the optimisation problem. This is to be detailed below.

Step 1: Initialisation of the Reel Radii

[0024] The initial reel radii are estimated by ignoring any eccentricity effects, inter-wrap gaps and transport delays between thickness measurements and the roll gap. To aid the estimation of the initial radius of the coiler, we assume that the surface velocity $V_r(t)$ of the work rolls are measured and that an estimate of average slip ratio s is also available. Using $V_r(t)$ and s, a rough estimate of the exit velocity is given by $V_r(t)(1 + s)$. The initial radius of the coiler is calculated by solving

$$\min_{r(t_0)} \int_0^t (V_r(\tau)(1+s) - \hat{r}(\tau)\omega(\tau))^2 \, d\tau$$

where

$$\hat{r}(t) = r(t_0) + \int_0^t \frac{\omega(\tau) h_m}{2\pi} d\tau$$

Once the initial radius of the coiler is estimated, the initial radius of the uncoiler radius can be estimated by balancing the input mass flow and exit mass flow over the time window from t_0 to t. This is, $R(t_0)$ can be obtained by solving

$$\min_{R(t_0)} \int_0^t \left(\hat{R}(\tau)\Omega(\tau)H_m - \hat{r}(\tau)\omega(\tau)h_m\right)^2 d\tau$$

where r (t)is given as above and

$$\hat{R}(t) = R(t_0) - \int_0^t \frac{\Omega(\tau) H_m}{2\pi} d\tau$$

Step 2: Initialisation of the transport delays.

[0025] The initial estimate for the exit transport delay is calculated using the measurement of the surface velocity of the work rolls, estimate of the average slip ratio and *l*, the distance between the roll gap and exit thickness measurement, given by

$$d(t_0) = \frac{l}{average\{V_r(1+s)\}}$$

[0026] The initial estimate for the input transport delay is given by

$$D(t_0) = \frac{L}{average\{V_r(1+s)h_m / H_m\}}$$

where L is the distance from the input measuring point to the roll gap.

Step 3: Estimation of the eccentricity parameters.

[0027] Using the initial estimates of the reel radii, the eccentricity parameters can be estimated by minimising the error function *e(t)* over the time window from $t\text{-}T_0$ to t. This is done using a standard least-squares method.

Step 4: Estimation of strip velocities.

[0028] This is done using the radius models and the measured angular velocities of the reels.

Step 5: Re-estimation of transport delays.

[0029] This is done by solving

$$L = \int_{t-D(t)}^{t} V(\tau)d\tau$$

and

$$l = \int_{t}^{t+d(t)} v(\tau)d\tau$$

Step 6: Recursion.

[0030] Repeat Steps 3-5 until the results for strip velocities converge. It is anticipated that only one repetition will be sufficient.

[0031] During the operation of the mill, the eccentricity effects, inter-wrap gaps, temperature, elasticity of the metal strip and many other factors may fluctuate, the reel models need to be frequently adjusted. If the required measurements are sampled using a common sampling frequency, it is preferred that the reel models are adjusted at each sampling point. That is, the aforementioned relaxation algorithm needs to be implemented using standard adaptive implementation techniques.

[0032] In this manner, a method of estimating the input and exit strip velocities in a rolling mill is provided which is both inexpensive to implement and robust in operation. The method does not require the use of any expensive hardware or measuring equipment, relying largely on a simple measurement of angular velocity, typically performed using pulse counting devices which are standard pieces of equipment in coilers and uncoilers and can be assumed to have extremely high accuracy. Furthermore, they are robust in use and inexpensive to provide.

Claims

1. A method of estimating the input and exit strip velocities (V,v) at the roll gap in a rolling mill of the type having an uncoiler reel (1), a coiler reel (2) and at least one pair of work rolls (3) positioned therebetween, said method comprising the steps of:

   measuring the angular velocities (Ω,ω) of the uncoiler and coiler reels (1,2) ;
   estimating the initial radii (R,r) of the uncoiler and coiler reels (1,2); and
   applying the measured and estimated values obtained to calculate estimated velocities of (V,v) the strip (4) before and after the roll gap.

2. A method as claimed in claim 1 wherein the radii of the uncoiler and coiler reels are estimated by mathematically modeling the reels taking into account eccentricity effects and inter-wrap gaps.

3. A method as claimed in claim 2 wherein the model includes a procedure to estimate initial coil radii using measurements of the surface velocity of the work rolls and an estimate of the slip ratio at the work rolls.

4. A method as claimed in either claim 2 or claim 3 wherein the estimation of the reel models is formulated as a non-linear least squares problem.

5. A method as claimed in claim 4 wherein the said problem is solved using a relaxation algorithm, giving an estimate of uncoiler and coiler radii.

6. A method as claimed in claim 5 including adaptive implementation of the relaxation algorithm.

7. A method of estimating the exit thickness of strip in a rolling mill by estimating input and exit strip velocities using a method as claimed in any one of the preceding claims and applying the estimated velocities in a mass-flow balance equation.

Patentansprüche

1. Verfahren zum Bestimmen der Eintritts- und Austritts-Bandgeschwindigkeiten (V, v) am Walzenspalt in einem Walzwerk des Typs mit einer Abwickelrolle (1), einer Aufwickelrolle (2) und wenigstens einem Paar Arbeitswalzen (3), das dazwischen angeordnet sind, wobei das Verfahren die Schritte aufweist:

   Messen der Winkelgeschwindigkeiten (Ω,ω) der Abwickel- und Aufwickelrollen (1, 2); Bestimmten der Anfangsradien (R, r) der Abwickel- und Aufwickelrolle (1, 2); und Verwenden der erhaltenen gemessenen und bestimmten Werte, um abgeschätzte Geschwindigkeiten (V, v) des Streifens (4) vor und hinter dem Walzenspalt zu berechnen.

2. Verfahren nach Anspruch 1, bei dem die Radien der Abwickel- und Aufwickelrolle bestimmt werden, indem die Rollen mathematisch modelliert werden, wobei Exzentrizitätswirkungen und Wickel-Zwischenspalte berücksichtigt werden.

3. Verfahren nach Anspruch 2, bei dem das Modell eine Prozedur zum Bestimmen anfänglicher Spulenradien umfaßt, wobei Messungen der Oberflächengeschwindigkeit der Arbeitswalzen und eine Abschätzung des Schlupfverhältnisses an den Arbeitswalzen verwendet werden.

4. Verfahren nach Anspruch 2 oder Anspruch 3, bei dem die Bestimmung der Rollenmodelle als ein nichtlineares Problem kleinster Quadrate formuliert wird.

5. Verfahren nach Anspruch 4, bei dem das Problem gelöst wird, indem ein Relaxationsalgorithmus verwendet wird, was eine Abschätzung der Abwickel- und Aufwickelradien ergibt.

6. Verfahren nach Anspruch 5, einschließlich adaptiver Implementierung des Relaxationsalgorithmus.

7. Verfahren zum Bestimmen der Austrittsdicke des Bandes in einem Walzwerk durch Bestimmen von Eintritts- und

Austritts-Bandgeschwindigkeiten, wobei ein Verfahren nach einem der vorangehenden Ansprüche verwendet wird und die bestimmten Geschwindigkeiten in einer Gleichung des Massenstromgleichgewichts eingesetzt werden.

Revendications

1. Procédé permettant d'estimer les vitesses d'entrée et de sortie (V, v) d'une bande au niveau de l'emprise des cylindres dans un laminoir du type comprenant une bobine dérouleuse (1), une bobine enrouleuse (2) et au moins une paire de cylindres de travail (3) disposés entre elles, ledit procédé comprenant les étapes consistant à :

   - mesurer les vitesses angulaires (Ω, ω) des bobines dérouleuse et enrouleuse (1, 2) ;
   - estimer les rayons initiaux (R, r) des bobines dérouleuse et enrouleuse (1, 2) ; et
   - appliquer les valeurs mesurées et estimées obtenues afin de calculer les vitesses estimées (V, v) de la bande (4) avant et après l'emprise des cylindres.

2. Procédé tel que revendiqué dans la revendication 1, dans lequel les rayons des bobines dérouleuse et enrouleuse sont estimés en effectuant une modélisation mathématique des bobines en tenant compte des effets d'excentricité et des espaces interspires.

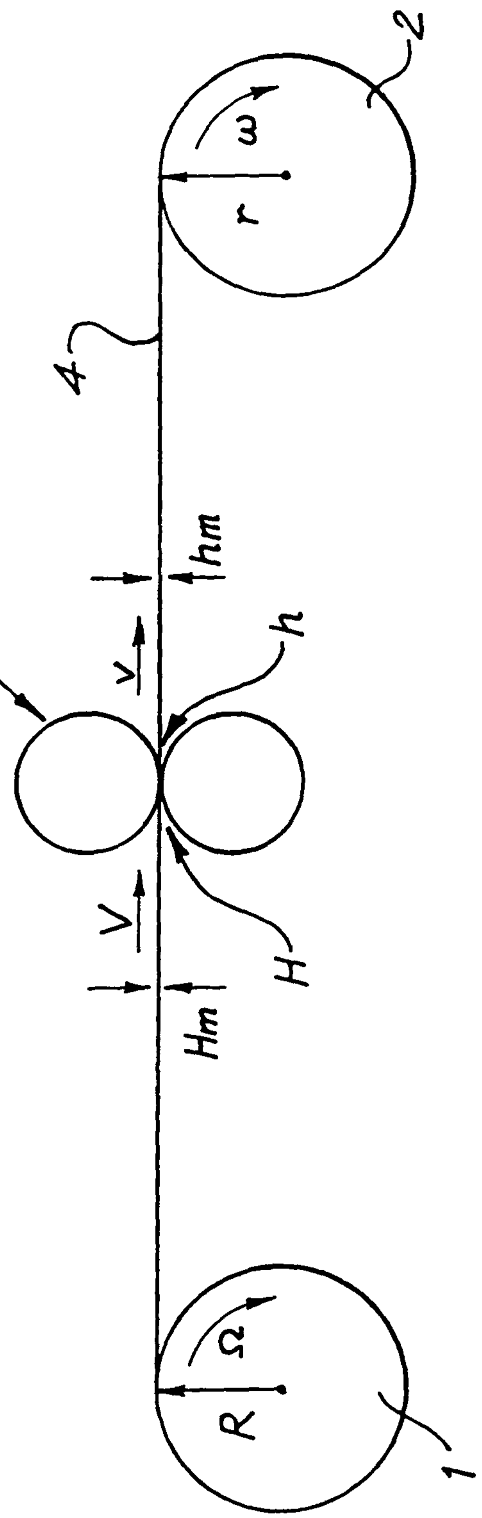
3. Procédé tel que revendiqué dans la revendication 2, dans lequel le modèle comprend une procédure visant à estimer les rayons initiaux des bobines en utilisant des mesures de la vitesse de surface des cylindres de travail et une estimation du rapport de glissement au niveau des cylindres de travail.

4. Procédé tel que revendiqué dans la revendication 2 ou la revendication 3, dans lequel l'estimation des modèles de bobine est formulée sous forme d'un problème des moindres carrés non linéaires.

5. Procédé, tel que revendiqué dans la revendication 4, dans lequel ledit problème est résolu en utilisant un algorithme de relaxation, donnant une estimation des rayons de la dérouleuse et de l'enrouleuse.

6. Procédé tel que revendiqué dans la revendication 5, comprenant une mise en oeuvre adaptative de l'algorithme de relaxation.

7. Procédé d'estimation de l'épaisseur de sortie d'une bande dans un laminoir consistant à estimer les vitesses d'entrée et de sortie d'une bande selon un procédé tel que revendiqué dans l'une quelconque des revendications précédentes, et à appliquer les vitesses estimées dans une équation d'équilibre de débit massique.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