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Method for increasing the process stability, particularly the absolute thickness precision and the installation safety during the hot rolling of steel or nonferrous materials

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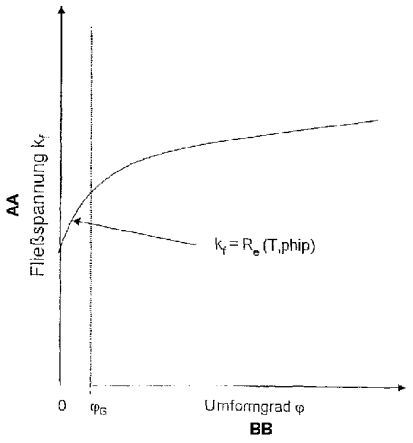
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*[Fortsetzung auf der nächsten Seite]*

(54) Title: METHOD FOR INCREASING THE PROCESS STABILITY, PARTICULARLY THE ABSOLUTE THICKNESS PRECISION AND THE INSTALLATION SAFETY DURING THE HOT ROLLING OF STEEL OR NONFERROUS MATERIALS

(54) Bezeichnung: VERFAHREN ZUM ERHÖHEN DER PROZESSSTABILITÄT, INSBESONDERE DER ABSOLUTEN DICKENGENAUIGKEIT UND DER ANLAGENSICHERHEIT, BEIM WARMWALZEN VON STAHL- DER NE-WERKSTOFFEN

(57) Abstract: The invention relates to a method for increasing the process stability, particularly the absolute thickness precision and the installation safety during the hot rolling of steel or nonferrous materials, with small degrees of deformation (*f*) or no reductions while taking the high-temperature limit of elasticity ($R_e$) into account when calculating the set rolling force ($F_W$) and the respective setting position (*s*). The process stability can be increased with regard to the precision of the yield stress ($k_{fR}$) and the set rolling force ($F_W$) at small degrees of deformation (*f*) or small reductions, during which the high-temperature limit of elasticity ($R_e$) is determined according to the deformation temperature (*T*) and/or the deformation speed (*phip*) and is integrated into the function of the yield stress ($k_f$) for determining the set rolling force ($F_W$) via the relation (2) ) $R_e = a + c^{b1 + b2 \cdot T} \cdot phip^c$, in which: $R_e$ represents the high-temperature limit of elasticity; *T* represents the deformation temperature; *phip* represents the deformation speed, and; *a, b, c* represent coefficients.




AA ... YIELD STRESS KF
BB ... DEGREE OF DEFORMATION (φ)

*[Fortsetzung auf der nächsten Seite]*

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*Zur Erklärung der Zweibuchstaben-Codes und der anderen Abkürzungen wird auf die Erklärungen ("Guidance Notes on Codes and Abbreviations") am Anfang jeder regulären Ausgabe der PCT-Gazette verwiesen.*

(57) **Zusammenfassung:** Ein Verfahren zum Erhöhen der Prozessstabilität, insbesondere der absoluten Dickengenauigkeit und der Anlagensicherheit, beim Warmwalzen von Stahl oder NE-Werkstoffen, mit kleinen Umformgraden ($\phi$) oder kleinen Abnahmen unter Berücksichtigung der Warmstreckgrenze *($R_e$)* bei der Berechnung der Sollwalzkraft *(Fw)* und der jeweiligen Anstellungsposition (s) kann bezüglich der Genauigkeit der Fließspannung *($k_{fR}$)* und der Sollwalzkraft *($F_w$)* bei kleinen Umformgraden ($\phi$) oder kleinen Abnahmen dadurch gesteigert werden, dass die Warmstreckgrenze ($R_e$) in Abhängigkeit von Umformtemperatur (T) und / oder Umformgeschwindigkeit *(phip)* ermittelt und in die Funktion der Fließspannung *($k_f$)* für die Bestimmung der Sollwalzkraft *($F_w$)* über die Beziehung *(2)* $R_e = a + e^{b1 + b2 * T} * phip^c$ integriert wird, wobei bedeuten: $R_e$ – Warmstreckgrenze, T – Umform-Temperatur, *phip* – Umform-Geschwindigkeit, a; b; c = Koeffizienten

TRANSLATION (HM-730PCT-original)

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# METHOD FOR INCREASING PROCESS STABILITY, ESPECIALLY ABSOLUTE GAGE PRECISION AND PLANT SAFETY, IN THE HOT ROLLING OF STEEL OR NONFERROUS MATERIALS

The invention concerns a method for increasing process stability, especially absolute gage precision and plant safety, in the hot rolling of steel or nonferrous materials with small degrees of deformation or small reductions, taking into account the yield point at elevated temperature when calculating the set rolling force and the given adjustment position.

Two earlier publications, "Kraft und Arbeitsbedarf bildsamer Formgebungsverfahren" ["Power and Work Requirement of Plastic Deformation Processes"] by A. Hensel and T. Spittel, Leipzig, 1978, and "Rationeller Energieeinsatz bei Umformprozessen" ["Economical Energy Use in Deformation Processes"] by T. Spittel and A. Hensel, Leipzig, 1981, describe various methods for determining the set rolling force in hot rolling as the product of deformation resistance and compressed surface area. The deformation resistance itself is determined as the product of the flow stress and a factor that takes into

account the roll gap geometry and/or friction conditions. The most frequently used method for determining the flow stress is its determination by a relation with influencing factors that take into account the deformation temperature, degree of deformation, and deformation rate, which are combined with one another by multiplication, e.g., in the following form:

$$k_f = k_{f0} \cdot A_1 \cdot e^{m1 \cdot T} \cdot A_2 \cdot \varphi^{m2} \cdot A_3 \cdot \dot{\varphi}^{m3}$$

(1)

where

$k_f$ = flow stress

$k_{f0}$ = initial value of the flow stress

$T$ = deformation temperature

$\varphi$ = degree of deformation

$\dot{\varphi}$ = deformation rate

$A_i$; $m_i$ = thermodynamic coefficients.

The thermodynamic coefficients were determined for different groups of materials; the materials within a group are differentiated by their respective $k_{f0}$ initial values.

In another treatise, "Modellierung des Einflusses der chemischen Zusammensetzung und der Umformbedingungen auf die Fließspannung von Stählen bei der Warmumformung" ["Modeling the Influence of the Chemical Composition and Deformation Conditions

on the Flow Stress of Steels during Hot Forming"] by M. Spittel and T. Spittel, Freiberg, 1996, it is additionally proposed that the initial value of the flow stress of a material be determined as a function of its chemical analysis and that the remaining parameters be used to take into account the temperature, the degree of deformation, and the deformation rate according to the material group. Basically, however, the multiplicative character of the relation according to Equation (1) is retained.

The disadvantage of the multiplicative relation for determining the flow stress is that the function tends towards a flow stress of zero MPa with decreasing degrees of deformation $\varphi < 0.04$ or reductions, i.e., the function passes through zero (shown in Figure 1 for the prior art). However, this theory conflicts with the actual circumstances. As a result, flow stress values that are too low and thus set rolling forces that are too low are determined at low reductions. The setting of the set roll gap by the automatic gage control is dependent on the rolling force and is thus subject to error. The hot-rolled products have a greater actual thickness than the desired target thickness.

The erroneous set rolling force calculation at small degrees of deformation or reductions constitutes a permanent

plant hazard during rolling at high rolling forces and/or rolling torques close to the maximum allowable plant parameters, as occur, for example, during rolling at lowered temperatures or even during at high temperatures and rolling stock widths close to the maximum width possible from the standpoint of plant engineering.

The erroneous set rolling force calculation also has an overall negative effect on process stability, since downstream automation models and automation control systems, such as profile and flatness models and control systems, determine their set values on the basis of the set rolling force.

WO 93/11886 A1 discloses a rolling program calculation method for setting the set rolling force and set roll gap of a rolling stand. This method uses stand-specific and/or material-specific rolling force adjustment elements. Stand-specific adjustments in the calculation of the set rolling force are a disadvantage with respect to transferability to other installations.

WO 99/02282 A1 discloses a well-known method for controlling or presetting the rolling stand as a function of at least one of the quantities rolling force, rolling torque, and forward slip, in which the modeling of the parameters is

accomplished by means of information processing based on neural networks or by means of an inverted rolling model by back-calculation of the material hardness in the pass with the aid of a regression model. This makes it possible to avoid errors of the type that arise in the set rolling force calculation by the multiplicative relation in the range of small degrees of deformation or reductions. However, a disadvantage of this method is that rolling results must first be available for a neural network to be trained or for an inverted rolling model. Accordingly, the application of the proposed method to materials that have not yet been rolled or to installations with different parameters is not automatically guaranteed.

A common feature of the prior-art described above is that the effect of small degrees of deformation or small reductions on the flow stress during the hot rolling of steel and nonferrous materials is not taken into account correctly or sufficiently according to the previously known methods for calculating the set rolling force and for automatic gage control, or the transferability to other installations is limited, so that there are risks for the process stability, especially absolute gage precision and plant safety.

The objective of the invention is to develop a method for increasing process stability, especially absolute gage precision and plant safety, in the hot rolling of steel and nonferrous

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materials, in which the precision of the flow stress and the set rolling force at small degrees of deformation or small reductions can be increased.

In accordance with the invention, this objective is achieved by using the following relation to determine the yield point at elevated temperature as a function of the deformation temperature and/or deformation rate, which is then integrated in the function of the flow stress for determining the set rolling force

$$R_e = a + e^{b1+b2\cdot T}\cdot \varphi p^c \quad (2)$$

by expanding a multiplicative flow curve relation by the yield point at elevated temperature as a function of the deformation temperature and deformation rate according to the formula

$$k_{f,R} = a + e^{b1\cdot b2\cdot T}\cdot \varphi p^c \cdot k_{fG}\cdot A_1\cdot e^{m1\cdot T}\cdot A_2\cdot \varphi^{m2}\cdot A_3\cdot \varphi p^{m3} \quad (3)$$

$R_e$ = yield point at elevated temperature

$T$ = deformation temperature

$\varphi p$ = deformation rate

$a$; $b$; $c$ = coefficients

Due to the fact that the invention takes into account the yield point at elevated temperature as a function of the deformation temperature and deformation rate, the method produces correct values even as very small degrees of

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deformation are approached. The starting value is the given yield point at elevated temperature of the material to be rolled as a function of the deformation temperature and deformation rate.

The advantage of using a new relation for calculating the flow stress is that the yield points at elevated temperature for the materials to be rolled are determined from measurement data of rollings with degrees of deformation smaller than a material-specific limiting degree of deformation by back-calculating the flow stresses of the given passes as a function of the deformation temperature and deformation rate from measured rolling forces and setting them equal to a yield point at elevated temperature when they are equal to the yield points at elevated temperature measured in hot tensile tests. The determined dependence of the yield point at elevated temperature on the deformation temperature and deformation rate represents the starting point of the approximated hot flow curve.

In accordance with the invention, it is further provided that the flow stress is integrated in the conventional rolling force equation for determining the set rolling force for the automatic gage control as well as for computational models and automatic control processes according to the following equation

$$F_W = Q_p \cdot k_{f,R} \cdot B \cdot (R_W \cdot (h_0 - h_1))^{1/2} \quad (4)$$

where

$F_W$ = set rolling force

$Q_p$ = function for taking into account the roll gap geometry and friction conditions

$k_{f,R}$ = flow stress, taking into account the yield point

$B$ = rolling stock width

$R_W$ = roll radius

$h_0$ = thickness before the pass

$h_1$ = thickness after the pass

In a further refinement of the invention, it is provided that a material modulus is calculated on the basis of the set rolling force, taking into account the yield point at elevated temperature as a function of the deformation temperature and

deformation rate for degrees of deformation smaller than a material-specific limiting degree of deformation, according to the formula

$$C_M = (F_W - F_m)/dh_1 \quad (5)$$

where

$C_M$ = material modulus

$F_W$ = set rolling force

$F_m$ = measured rolling force

$dh_1$ = change in the runout thickness

The invention is then developed in such a way that the conventional gage meter equation is expanded into the form

$$ds_{AGC} = (1 + C_M/C_G)dh_1 = (1 + C_M/C_G) \cdot ((F_W - F_m)/C_G + s - s_{soll}) \quad (6)$$

where

$ds_{AGC}$ = change in the roll gap setting

$C_M$ = material modulus

$C_G$ = rolling stand modulus

$dh_1$ = change in the runout thickness

$F_W$ = set rolling force

$F_m$ = measured rolling force

$s$ = adjustment of the roll gap

$s_{soll}$ = desired adjustment of the roll gap

As a result, the material flow behavior at small degrees of deformation or reductions is now also correctly represented. The adjustment position of the electromechanical and/or hydraulic adjustment for guaranteeing the runout thickness of the rolling stock is determined on the basis of the gage meter equation and the calculated set rolling force.

The figures show graphs for the flow stress as a function of the degree of deformation in accordance with the prior art and in accordance with the invention and are explained in greater detail below.

-- Figure 1 shows schematically the behavior of the flow stress $k_f$ as a function of the degree of deformation $\varphi$ with the conventional multiplicative relation (prior art).

-- Figure 2 shows schematically the behavior of the flow stress $k_{f,R}$ as a function of the degree of deformation $\varphi$ in accordance with the invention, wherein below the limiting degree of deformation $\varphi_G$, the multiplicative relation is additively expanded by the yield point at elevated temperature.

The disadvantage of the multiplicative relation for determining the flow stress (Figure 1) is that the function tends towards a flow stress $k_f$ of zero MPa at small degrees of

deformation $\varphi < 0.04$ or small reductions, i.e., the function passes through zero, as plotted in the graph.

Due to the fact that the invention (Figure 2) takes into account the yield point at elevated temperature $R_e$ as a function of the deformation temperature $T$ and deformation rate $\varphi p$, the method of the invention produces correct values even as very small degrees of deformation $\varphi$ are approached. The starting value is the given yield point at elevated temperature $R_2$ of the material to be rolled as a function of the deformation temperature T and deformation rate $\varphi p$.

It is to be understood that, if any prior art publication is referred to herein, such reference does not constitute an admission that the publication forms a part of the common general knowledge in the art, in Australia or any other country.

List of Reference Symbols

| | |
|---|---|
| $A_i$ | thermodynamic coefficients |
| $a_i$, $b_i$, $c$ | coefficients |
| $B$ | rolling stock width |
| $C_G$ | stand modulus |
| $C_M$ | material modulus |
| $dh_1$ | change in the runout thickness |
| $ds_{AGC}$ | change in the roll gap setting |
| $F_m$ | measured rolling force |
| $F_W$ | set rolling force |
| $h_0$ | thickness before the pass |
| $h_1$ | thickness after the pass |
| $k_f$ | flow stress |
| $k_{f0}$ | initial value of the flow stress |
| $k_{f,R}$ | flow stress, taking into account the yield point |
| $m_i$ | thermodynamic coefficients |
| $\varphi$ | degree of deformation |
| $\varphi_G$ | limiting degree of deformation |
| $\varphi p$ | deformation rate |
| $Q_p$ | function for taking into account the roll gap geometry and friction conditions |

| | |
|---|---|
| $R_e$ | yield point at elevated temperature |
| $R_w$ | roll radius |
| $s$ | adjustment of the roll gap |
| $s_{soll}$ | desired adjustment of the roll gap |
| $T$ | deformation temperature |

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CLAIMS

1. Method for increasing process stability, especially absolute gage precision and plant safety, in the hot rolling of steel or nonferrous materials with small degrees of deformation ($\varphi$) or small reductions, taking into account the yield point at elevated temperature ($R_e$) when calculating the set rolling force ($F_W$) and the given adjustment position ($s$), characterized by the fact that the following relation is used to determine the yield point at elevated temperature ($R_e$) as a function of the deformation temperature ($T$) and/or deformation rate ($\varphi p$), which is then integrated in the function of the flow stress ($k_{f,R}$) for determining the set rolling force ($F_W$)

$$R_e = a + e^{b1+b2\cdot T}\cdot \varphi p^c \qquad (2)$$

by expanding a multiplicative flow curve relation by the yield point at elevated temperature ($R_e$) as a function of the deformation temperature ($T$) and deformation rate ($\varphi p$) according to the formula

$$k_{f,R} = a + e^{b1+b2\cdot T}\cdot \varphi p^c \cdot k_{f0}\cdot A_1\cdot e^{m1\cdot T}\cdot A_2\cdot \varphi p^{m2}\cdot A_3\cdot \varphi p^{m3} \qquad (3)$$

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where

$R_e$ = yield point at elevated temperature

$T$ = deformation temperature

$\varphi p$ = deformation rate

$a_i$; $b_i$; $c$ = coefficients

2. Method in accordance with Claim 1, characterized by the fact that the flow stress ($k_{f,R}$) is integrated in the conventional rolling force equation for determining the set rolling force ($F_W$) for the automatic gage control as well as for computational models and automatic control processes according to the following equation

$$F_W = Q_P \cdot k_{f,R} \cdot B \cdot (R_W \cdot (h_0 - h_1))^{1/2} \quad (4)$$

where

$F_W$ = set rolling force

$Q_P$ = function for taking into account the roll gap geometry and friction conditions

$k_{f,R}$ = flow stress, taking into account the yield point

$B$ = rolling stock width

$R_W$ = roll radius

$h_0$ = thickness before the pass

$h_1$ = thickness after the pass

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3. Method in accordance with Claim 1 or Claim 2, characterized by the fact that a material modulus ($C_M$) is calculated on the basis of the set rolling force ($F_W$), taking into account the yield point at elevated temperature ($R_e$) as a function of the deformation temperature ($T$) and deformation rate ($\varphi p$) for degrees of deformation smaller than a material-specific limiting degree of deformation ($\varphi_G$), according to the formula

$$C_M = (F_W - F_m)/dh_l \quad (5)$$

where

$C_M$ = material modulus

$F_W$ = set rolling force

$F_m$ = measured rolling force

$dh_l$ = change in the runout thickness

4. Method in accordance with Claim 3, characterized by the fact that the conventional gage meter equation is expanded into the form

$$ds_{AGC} = (1 + C_M/C_G)\,dh_l = (1 + C_M/C_G) \cdot ((F_W - F_m)/C_G + s - s_{soll}) \quad (6)$$

where

$ds_{AGC}$ = change in the roll gap setting

$C_M$ = material modulus

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$C_G$ = rolling stand modulus

$dh_1$ = change in the runout thickness

$F_W$ = set rolling force

$F_m$ = measured rolling force

$s$ = adjustment of the roll gap

$s_{soll}$ = desired adjustment of the roll gap

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FIG. 1

Prior Art

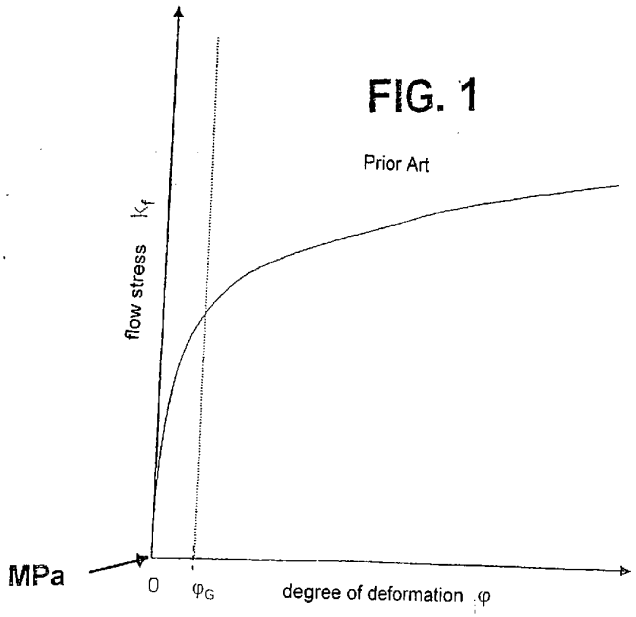



FIG. 2

