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[11] 3,600,919

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[31] 157,998

[54] **PROCESS FOR AUTOMATIC CONTROL OF THE HOT ROLLING OF METAL FLATS**
2 Claims, 4 Drawing Figs.

[52] U.S. Cl. 72/8
[51] Int. Cl. B21b, 37/00
B21b 37/14
[50] Field of Search 72/6–8, 16

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ABSTRACT: A process for automatic control of the rolling of metal flats by determination of consecutive roll nips, uses a program in the form of a sequence of intermediate thicknesses for the product devised on the basis of numerical determination of a parameter denoting the plasticity of the metal. The development of such parameter depends on product thickness and a selected rolling force. The invention finds particular, but not exclusive, application in the hot rolling of metal flats.

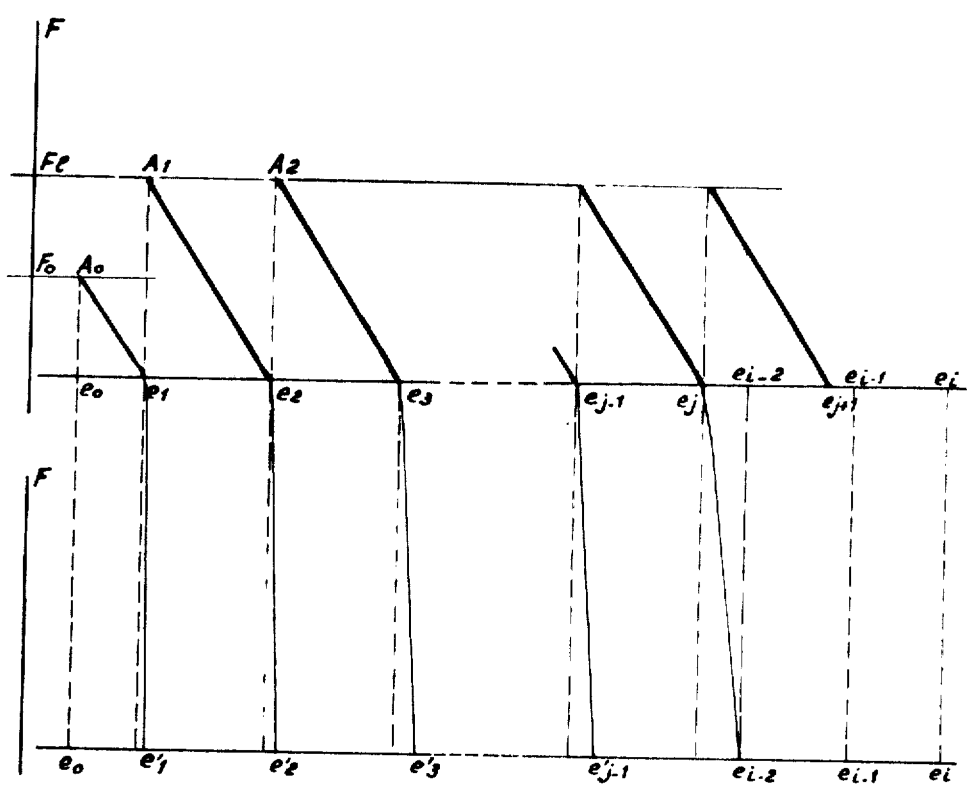

Fig : 1

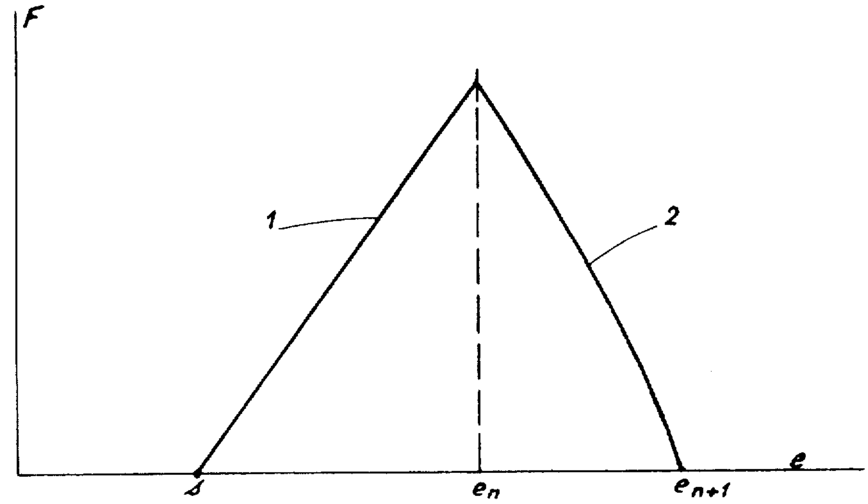

Fig : 2

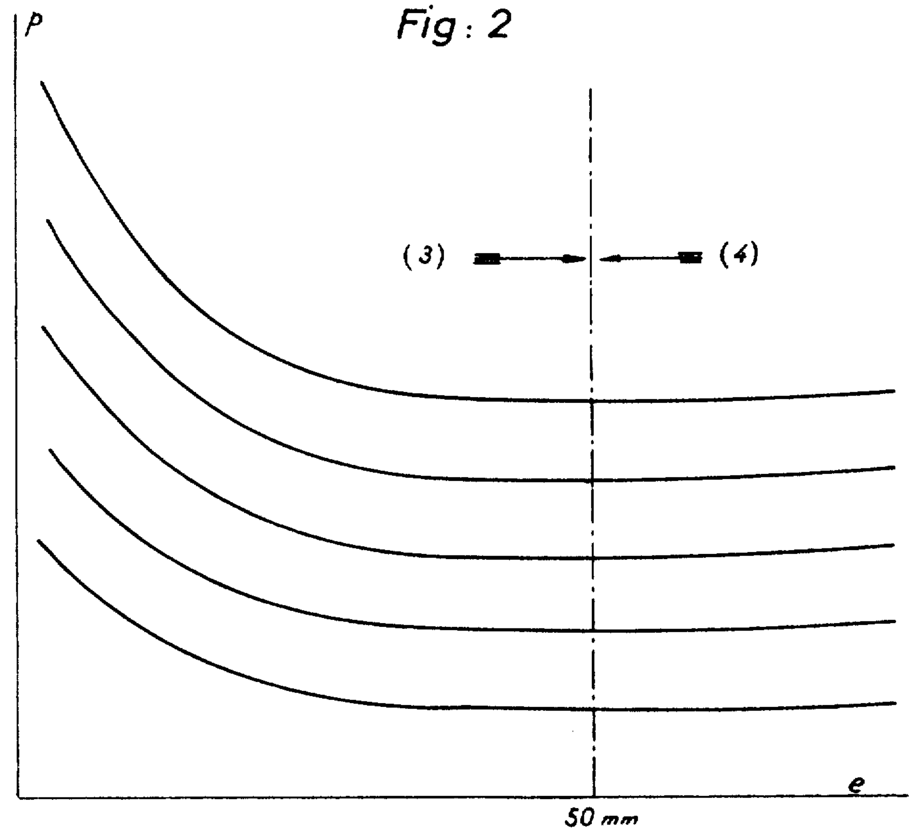

Fig: 3

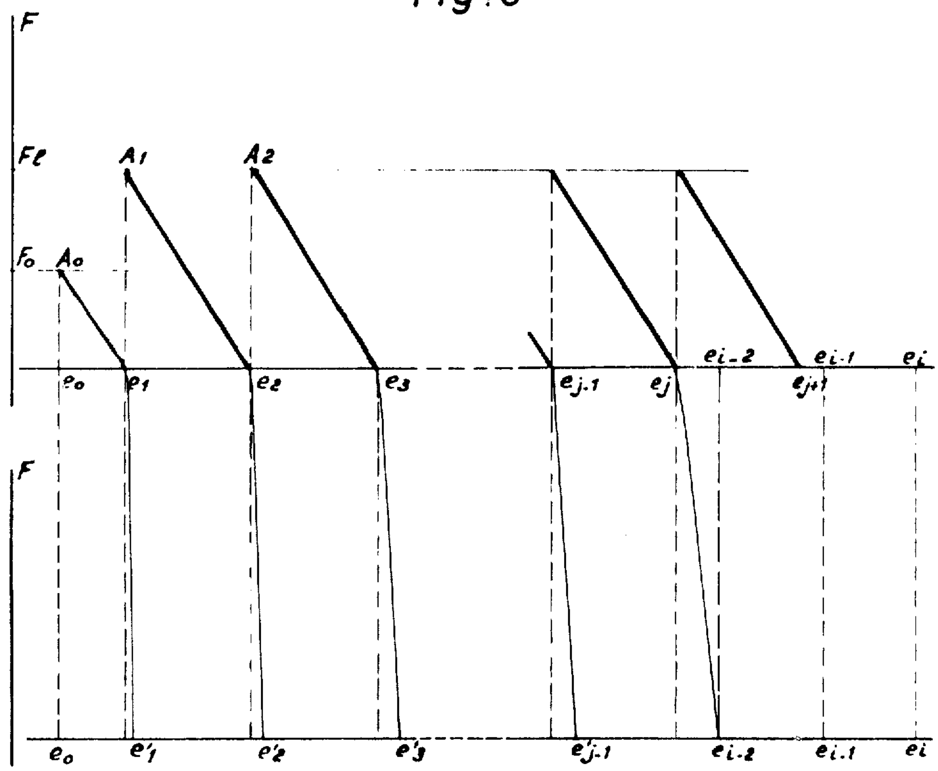
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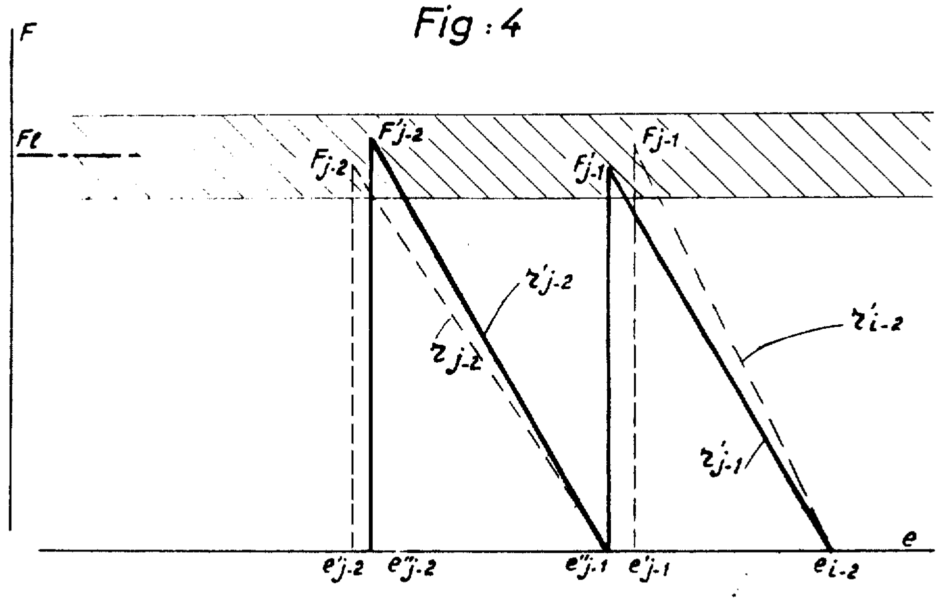
Fig: 4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PROCESS FOR AUTOMATIC CONTROL OF THE HOT ROLLING OF METAL FLATS

This invention relates to a process for automatic control of the rolling of metal flats such as heavy and medium gauge sheet metal. The invention finds particular, but not exclusive, application in the hot rolling of such metal flats.

The desiderata in this kind of rolling are:

1. To obtain an end product having the required dimensions, more particularly the required thickness, and

2. To make optimum production and economic use of existing tooling, rolling mills and furnaces.

The limitations associated with rolling mills are basically as follows:

a. A critical rolling force must not be exceeded;

b. The mechanical torque which the driving motors can provide must not be exceeded.

In rolling, condition (a) is a limitation for lesser thicknesses and condition (b) is a limitation for greater thicknesses.

Rolling right at the critical limits—of course, without exceeding them—provides many advantages, such as increased productivity, reduced electrical consumption, reduced heating, reduced roll wear, etc.

3. To obtain an end product having optimum metallurgical properties, implying in all probability programming of deformation sequences and speeds and of product temperature, all these parameters being of course interlinked, and

4. To ensure minimum expenditure on plant.

Automatic control of rolling implies automatic determination of the consecutive roll nips required to produce a product of a predetermined end thickness under optimum conditions.

There are at present rolling-mill systems comprising computing facilities working on the initial thickness and entry temperature of the product and, by calculating the temperature of the product and the rolling force at each pass, determining the sequence of product thicknesses. However, for these factors to be calculated, a system of very complex equations must be worked out. For instance, the relationship between temperature drop and time is expressed by an equation in which radiation losses and the heat introduced by the work of deformation appear. Rolling force is calculated from equations in which the product of the antilogarithm of the deformation resistance, product width, the square root of working-roll radius and the thickness reduction appear. The required calculations are therefore on such a scale as to require very extensive and costly equipment.

Another known method, used for rolling series of identical sheets, is to roll on the basis of a pattern of reductions derived from the results obtained with the first sheets of a series. This is a very special method and is of no use for everyday manufacture (which implies very small or substantially no series of sheets). Even in its own limited field this method cannot always ensure the required end-thickness accuracy.

This invention, which will be described hereinafter, overcomes the disadvantages mentioned and achieves the various stated desiderata.

According to the invention, there is provided a process for automatic control of the rolling of metal flats by determination of consecutive roll nips, wherein a Program in the form of a sequence of intermediate thicknesses for the product is devised on the basis of numerical determination of a parameter r based on the plasticity of the metal, and the development of such parameter depending on product thickness and a selected rolling force.

The invention will now be described in greater detail with reference to formulae and graphs.

Throughout the following description, thicknesses obtained consecutively during the rolling operation are given indexes in the form of decreasing numbers from the initial thickness e_i to the end thickness e_o; similar considerations apply to the rank of rolling passes, the pass of rank n being the pass which brings the product from the thickness e_{n+1} to the thickness e_n while the last pass, which has the index O, brings the product to its end thickness e_o.

In a rolling operation, the thickness e of the material leaving the rolls is of course given by the term:

$$(1)\quad e=s+c$$

in which s denotes the off-load nip of the rolls, and c denotes mill "yieldability"—i.e., the increase in nip due to resilient deformation of the complete mill stand as a result of the rolling force produced by the passage of the stock between the rolls.

FIG. 1 is a graphic representation of the phenomenon and represents the development of a product of initial thickness e_{n+1} introduced between rolls whose nip s is less than e_{n+1}. Product thickness (or roll nip) is plotted along the abscissa and the rolling force is plotted along the ordinate. Curve 1, known as the yieldability curve and passing through abscissa point s, is a characteristic of the mill and denotes the resistive force of the rolls and roll housing when endeavors are made to force the rolls apart further than corresponds to the adjusted off-load nip. Curve 2, called the plasticity curve and passing through abscissa point e_{n+1}, is a characteristic of the rolled product and corresponds to its deformation resistance in dependence upon its thickness reduction. The point of intersection of the curves 1 and 2 corresponds to the abscissa point e_n, denoting the thickness of the sheet after the pass.

According to the invention, to denote the plasticity of a product of width l during a pass reducing the thickness from e_{n+1} to e_n by means of a rolling force F_n, the parameter r_n is used; it is defined as follows:

$$(2)\quad \mu_n=\frac{F_n}{1}\,\frac{e_{n+1}}{e_{n+1}-e_n}=K[f(e_n)]$$

This parameter has the interesting feature that its variation in dependence upon product thickness, assuming working with a substantially constant rolling force, can be denoted, if product thickness is plotted along the abscissa and the parameter r along the ordinate, by a family of closely related curves relative to the ordinate axis. The family of curves as defined by the statistical method can be represented in a satisfactory approximation by a family of hyperbolae for lesser thicknesses and by a family of parabolae for larger thicknesses.

FIG. 2 shows an exemplary curve family of this kind. The family has been equated. To facilitate formulation, two forms of equation are used. For thicknesses less than 50 mm., the hyperbolic expression:

$$(3)\quad \mu_n=K\frac{\alpha_1 e_n+\beta_1}{\gamma_1 e_n+\delta_1}$$

is used in which r_n denotes the plasticity parameter for a rolling operation bringing the product to the thickness e_n; α, β, γ, δ are constants; and K denotes the affinity coefficient of the curves of the family.

For thicknesses above about 50 mm. the parabolic expression:

$$(4)\quad r_n=K[\alpha_2 e_n(e_n+\beta_2)+\gamma_2]$$

is used in which α_2, β_2, γ_2 are constants, and K is the affinity coefficient of the curves of the family.

Also, theoretical calculations show that the variation of plasticity in dependence upon rolling force, assuming a constant thickness, proceeds approximately in accordance with a hyperbolic form such that, once r_n is known for a thickness e_n and a rolling force F_n, the new value r'_n of the parameter chosen to represent plasticity can be calculated for a different rolling force F'_n. This value is defined by the formula:

$$(5)\quad \mu'_n=K_0\frac{\delta_2 K_0 F'_n+\Sigma}{K_0 F'_n+\nu}$$

in which δ_2, Σ ν are constants; and K_o is defined by the formula:

$$(6)\quad K_0=\frac{\alpha_3-F_n\mu_n+[(\alpha_3-F_n\mu_n)^2+\beta_3 F_n\mu_n]^{\frac{1}{2}}}{\gamma_3 F_n}$$

in which α_3, β_3 and γ_3 are constants.

Housing yieldability in dependence upon rolling force and product width can be satisfactorily represented by a formula of the kind:

$$(7)\ C_n = F_n(\alpha_5 l^2 + \beta_4 l + \gamma_4) + \delta_3 l + \Sigma_2$$

in which l denotes product width and α_5, β_4, γ_4, δ_3, Σ_2 are constants characteristic of the mill.

Also, of course, the selected rolling conditions must lie within the power of the driving motors, more particularly as regards their maximum permissible torque, which is usually a factor limiting the working of heavy-gauge material.

The maximum possible thickness reduction Δ_e without exceeding the permissible torque of the driving motors for a piece of sheet material of given plasticity, width and initial thickness can be determined from theoretical calculations based on observation of the term defining the rolling torque, and is determined by a relation of the kind:

$$(8)\qquad \Delta_e = \left[\frac{\alpha_4}{K1} \frac{e_{n+1}}{\alpha_2 e_{n+1}(e_{n+1}+\beta_2)+\gamma_2}\right]^{\frac{2}{3}}$$

in which α_4 is a constant characteristics of the drive motors, K is the affinity coefficient of the plasticity curve which is associated with the operation and which is taken from the family defined by the formula, l denotes product width, e_{n+1} denotes product thickness at the entry of the product into the roll nip, and α_2, β_2, γ_2 are the same constants as in formula (4).

A description of how the process can be used will now be given with reference to a product of width l and initial thickness e_i, which is brought to a final thickness e_o. A rolling force F_1 is determined by conventional operating practices. For the sake of dimensional tolerances, curvature and flatness, the rolling force F_o in the first pass is reduced, the object being to meet these requirements in optimum conditions—i.e., more particularly by using the minimum number of passes compatible with the available equipment.

For a better understanding of the calculations, the same are set forth as if performed by ordinary manual means; in fact, of course, they are performed by computers which given substantially no indication of intermediate results but indicate the results directly as consecutive nips for the mill rolls.

The first two passes are performed under manual control; during these passes data which will be used for subsequent automatic calculation are sampled. The rolling force F_{i11} developed during the operation is measured during the first pass with an off-load nip of s_{i11}. The corresponding yieldability C_{i11} can be calculated by means of formula (7):

$$C_{i11} = F_{i11}(\alpha_5 l^2 + \beta_4 l + \beta_4) + \delta_3 l + \Sigma_2$$

Product thickness e_{i11} is measured after this first pass in accordance with formula (1):

$$e_{i11} = s_{i11} + c_{i11}$$

The developed force F_{i12} is measured again in the second pass with an off-load nip s_{i12} and is used for deduction of the yieldability C_{i12} and then the end-of-pass thickness e_{i12} by means of formulae (7) and (1) as previously mentioned.

Once the entry and exit thicknesses and the rolling force for the second pass are known, the corresponding parameter r can be calculated by means of formula (2), which gives:

$$\mu_{i-2} = \frac{F_{i-2}}{1} \frac{e_{i-1}}{e_{i-1}-e_{i-2}}$$

defining the plasticity parameter for an exit thickness e_{i12} at a rolling force F_{i12}.

Since the sequence of operations is to be performed with a substantially identical rolling force F_1, the theoretical plasticity parameter value which would have been found if the second pass had been performed at the predetermined rolling force F_1 must be determined. This theoretical parameter r'_{i12} results from formula (5) which in this case is stated as follows:

$$\mu'_{i-2} = K_0 \frac{\delta_2 K_0 F_1 + \Sigma}{K_0 F_1 + \nu}$$

with, in accordance with formula (6):

$$K_0 = \frac{\alpha_3 F_{i-2} r_{i-2} [(\alpha_3 F_{i-2} r_{i-2})^2 + \delta_3 F_{i-2} r_{i-2}]}{\gamma_3 F_{i-2}}$$

Once the parameter r'_{i12} is known for a thickness e_{i12} and for the predetermined rolling force F_1, it is possible to determine that particular statistical curve of the family of closely related curves (FIG. 2) along which—except for unforeseen events which can be allowed for in a manner to be described hereinafter—the parameter representing plasticity in dependence upon thickness will vary, and therefore to calculate the affinity coefficient K corresponding to such curve.

If the thickness e_{i12} is above about 50 mm., from formula (4) we have:

$$K = \mu'_{i-2} \frac{1}{\alpha_2 e_{i-2}(e_{i-2}+\beta_2)+\gamma_2}$$

or, if e_{i12} is below 50 mm., from formula (3) we have:

$$K = \mu'_{i-2} \frac{\gamma_1 e_{i-2} + \delta_1}{\alpha_1 e_{i-2} + \beta_1}$$

A rolling Program can now be devised which defines the consecutive thicknesses to be given the product between the thickness e_{i12}, associated with the termination of the manual-control phase, and the end thickness i e_o.

FIG. 3 shows in graph form the procedure for calculating the program. The imposed rolling forces F_o and F_1 have been shown in FIG. 3 on the force-thickness coordinates system used in FIG. 1.

Knowledge of the trend of the parameter r is equivalent to knowledge of the plasticity curve 2 in FIG. 1, and so from the point e_o (FIG. 3) it becomes possible to determine seriatim the points A_0 (the point of intersection of abscissa value e_o and ordinate value F_o as shown in FIG. 3); and e_1, then A_1 (determined similarly to A_0 as shown in FIG. 3) and e_2, and so on up to a value close to e_12, which is the actual thickness of the product at the start of the truly automatic phase of rolling.

Actually, these values can be calculated directly from the equations hereinbefore defined. From equations (2) and (3), for thicknesses below 50 mm.:

$$\frac{F_n}{1} \frac{e_{n+1}}{e_{n+1}-e_n} = K \frac{\alpha_1 e_n + \beta_1}{\gamma_1 e_n + \delta_1}$$

which can also be stated:

$$(9)\qquad e_{n+1} = e_n \frac{1}{1 - \frac{F_n}{1K} \frac{\gamma_1 e_n + \delta_1}{\alpha_1 e_n + \beta_1}}$$

For thicknesses above 50 mm., from equations (2) and (4):

$$\frac{F_n}{1} \frac{e_{n+1}}{e_{n+1}-e_n} = K[\alpha_2 e_n(e_n+\beta_2)+\gamma_2]$$

which can also be stated:

$$(10)\qquad e_{n+1} = e_n \frac{1}{1 - \frac{F_n}{1K} \frac{1}{\alpha_2 e_n(e_n+\beta_2)+\gamma_2}}$$

Since the thickness e_o is almost always below 50 mm., formula (9) is used to determine the penultimate thickness e_1 by the introduction of the special value F_o of the rolling force of the final pass, so that:

$$e_1 = e_0 \frac{1}{1 - \frac{F_0}{1K} \frac{\gamma_1 e_0 + \delta_1}{\alpha_1 e_0 + \beta_1}}$$

The value F_1 of the current rolling force is introduced into the formula for calculation of the other intermediate thicknesses, so that:

$$e_2 = e_1 \frac{1}{1 - \frac{F_1}{1K} \frac{\gamma_1 e_1 + \delta_1}{\alpha_1 e_1 + \beta_1}}$$

until an intermediate thickness above 50 mm. is obtained. If, for instance, the thickness e_6 is the first result above 50 mm., the thickness e_7 and subsequent thicknesses are calculated from equation (10), so that:

$$e_7 = e_6 \frac{1}{1 - \frac{F_1}{1K} \frac{1}{\alpha_2 e_6(e_6+\beta_2)+\gamma_2}}$$

$$e_8=e_7\frac{1}{1-\frac{F_1}{1K}\frac{1}{\alpha_3 e_7(e_7+\beta_2)+\gamma_2}}$$

and so on until the thickness nearest the thickness e_{i12} obtained at the end of the second pass is reached.

Independently of the use of formula (10) for calculating thicknesses above 50 mm., a check of the motor torque required for reductions in this zone is made on the following basis, referring again to the case previously mentioned of the calculated thickness e_8. Starting from the thickness e_8, formula (8) is used, which defines the maximum possible reduction in actual or present rolling conditions. Therefore:

$$\Delta_e=\left[\frac{\alpha_4}{K1}\frac{e_8}{\alpha_3 e_8(e_8+\beta_2)+\gamma_2}\right]^{\frac{1}{2}}$$

If this result Δ_e is greater than the previously calculated reduction e_8-e_7, the maximum permissible torque is shown not to be reached and so the intermediate thickness is kept as permissible, but if Δ_e is less than e_8-e_7, the reduction is excessive and is limited to Δ_e, so that the intermediate thickness must be taken as $e'_8=e_7+\Delta_e$. This procedure is not accurate from a strictly theoretical point of view but is found in experience to give satisfactory results.

The rolling Program formed by the sequence of required intermediate thicknesses should following on accurately from the actual value e_{i12} obtained at the end of the second pass. Only in exceptional circumstances does the rough calculation result lead to this accuracy; as a rule, the calculations give two consecutive intermediate thicknesses e_j and e_{j+}on either side of the "meeting" thickness e_{i12} such that:

$$e_j<e_{i12}<e_{j+1}$$

The program already calculated then needs correcting, to which end the value of the correction relatively to the total thickness reduction is calculated:

$$\frac{e_j-e_{i-2}}{e_{i-2}-e_0}=\nu_1$$

If the value found of ν_1 is below the theoretical value or equal, for instance, to within 5 percent (0.05), a correction is made by expansion by making e_j coincide with e_{i12}—i.e., by replacing e_j by $e'_j=e_{i12}$—on the basis that this increase in the total variation of reduction will not cause any major changes in the rolling force.

The correction to bring e_j to e'_j is therefore:

$$e'_j=e_j\frac{1}{1+\nu_1}+e_0\frac{\nu_1}{1+\nu_1}=e_{i-2}$$

and similarly, for the other intermediate thicknesses:

$$e'_{j-1}=e_{j-1}\frac{1}{1+\nu_1}+e_0\frac{\nu_1}{1+\nu_1}$$

and so on, as shown in FIG. 3.

If, on the other hand, the value found for ν_1 is higher than the theoretical value, for instance, by up to 5 percent (0.05), a contraction operation is performed by making e_{j+1} coincide with e_{i12}—i.e., by replacing e_{j+1} by $e'_{j+1}=e_{i12}$—in fact equivalent to making an extra pass.

The correction factor:

$$\frac{e_{j+1}-e_{i-2}}{e_{i-2}-e_0}=\nu_2$$

is used and the correction to bring e_{j+1} to e'_{j+1} then becomes:

$$e'_{j+1}=e_{j+1}\frac{1}{1+\nu_2}+e_0\frac{\nu_2}{1+\nu_2}=e_{i-2}$$

and similarly for the other intermediate thicknesses:

$$e'_j=e_j\frac{1}{1+\nu_2}+e_0\frac{\nu_2}{1+\nu_2}$$

and so on.

Upon termination of this correction all the corrected intermediate thicknesses are stored and form the rolling program. The assumption will be made for the remainder of the description of the process that the value e_j has been corrected to $e'_j=e_{i12}$, all the other values $e_1, e_2 \ldots e_{j11}$ of the first rough calculation therefore being amended to $e'_1, e'_2 \ldots e'_{j11}$.

The program is then formed by the required consecutive thicknesses:

$(e_i\ e_{i11}\ e_{i12})\ e'_{j11}\ e'_{j12} \ldots e'_3\ e'_2\ e'_1\ e_0$, whereafter rolling proceeds under automatic control and the operator must follow the roll nip instructions, which are determined by the system as follows:

Before the first automatic pass—i.e., the pass of rank $i-3$ or $j-1$—the exit thickness of the second pass e_{i12} is known together with the required new thickness e'_{j11} and the theoretical plasticity parameter r'_{i12} calculated from the results of the first two passes. These data are used to calculate the theoretical force required in each pass to reach the thickness e_{j11}. This force is determined by means of formula (2) in the form:

(11)
$$F_n=\mu_n 1\frac{e_{n+1}-e_n}{e_{n+1}}$$

which in this case is stated as:

$$F_{j-1}=\mu'_{i-2}1\frac{e_{i-2}-e'_{j-1}}{e_{i-2}}$$

in which, as an approximation, the approximate plasticity parameter value r'_{i12} is introduced instead of the value r_{j11} which is still not known accurately. Once the required rolling force F_{j11} is known, the estimated yieldability is calculated:

$$c_{j11}=F_{j11}(\alpha_5 1^2+\beta_4 1+\gamma_4)+\delta_3 1+\Sigma_2$$

so that the required nip:

$$s_{j11}=e'_{j11}-c_{j11}$$

can be calculated, this latter instruction being given to the operator for this pass and being displayed by the computer on a display panel.

During performance of the pass of rank $j-1$, the system detects:

The actual off-load nip s'_{j11}, which may differ from the instructed value either because of human error on the operator's part or because of mechanical inaccuracy, and

the actual rolling force F'_{j11}, from which, after intermediate calculation of the yieldability c'_{j11} corresponding to the force F'_{j11}, the actual exit thickness:

$$e''_{j11}=s'_{j11}+c'_{j11}$$

is calculated. The system then performs all the requisite calculations for determining the off-load nip for the next pass of rank $j-2$ to bring the product from the thickness e''_{j11} to e'_{j12}.

To calculate the rolling force F_{j12} to be used, formula (11) is used as in the previous pass but with the introduction into it, as theoretical plasticity parameter r_{j12}, of a value linked to the previous actual values of such parameter, for instance, the mean value of the theoretical parameter r'_{i12} during the second pass and of the actual parameter r'_{j11} during the next pass, calculated by:

$$\mu'_{i-1}=\frac{F'_{j-1}}{1}\frac{e_{i-2}}{e_{i-2}-e''_{j-1}}$$

$$\therefore\ \mu_{i-2}=\frac{\mu'_{i-2}+\mu'_{i-1}}{2}$$

then

$$F_{j-2}=\mu_{j-2}1\frac{e''_{j-1}-e'_{j-2}}{e''_{j-1}}$$

and finally

$$c_{i-2}=F_{j-2}(\alpha_5 1^2+\beta_4 1+\gamma_4)+\delta_3 1+\Sigma_2$$

$$s_{j-2}=e'_{j-2}-c_{j-2}$$

which is the instruction displayed by the computer.

The system simultaneously compares the calculated rolling force F_{j12} with the predetermined force F_1.

If F_{j12} remains within predetermined limits of tolerance, for instance, ±10 percent of F_1, operations continue; otherwise the system completely recalculates the program in accordance with the principles hereinbefore described. The calculations are made in exactly the same way as described with reference to the end of the second pass. In general, if the calculated force is outside the indexed limits of tolerance, the program of intermediate thicknesses is recalculated.

It will be assumed hereinafter that F_{j12} is well within the permissible tolerance limits. During the pass j–2 the system detects, as during the previous pass, the actual off-load nip s'_{j12} and the actual force F'_{j12} to determine the actual exit thickness e''_{j12}.

FIG. 4 represents the calculated and actual values for thicknesses and rolling forces. The hatched zone corresponds to the permissible rolling-force tolerances on either side of F_1.

The system then makes seriatim the calculations, in a manner identical to what has been previously described, to determine the off-load nips for the next passes.

To determine the plasticity parameter to be introduced into formula (11) for each pass, one possibility is to use an extrapolation method using an equation of the kind:

$$(12)\ r_n = r'_{n+3} - 3r'_{n+2} + 3r'_{n+1}$$

r'_{n+1}, r'_{n+2}, r'_{n+3} denoting the actual parameters calculated during the three respective previous passes. Let it be assumed, for instance, in the case of the parameter r_3 applicable to the pass of rank 3:

$$r_3 = r'_6 - 3r'_5 + 3r'_4$$

To calculate the theoretical plasticity parameter r_o during the last pass made with a lower predetermined force F_o, the procedure is as follows:

Let F'_1 and e''_1 denote the actual force and the actual exit thickness of the penultimate pass. The actual value of the plasticity parameter r'_1 during this penultimate pass is calculated, whereafter a value r_o is calculated by application of the ordinary formula (12):

$$r_o = r'_3 - 3r'_2 + 3r'_1$$

this value would apply to an ordinary rolling force differing little from F_1.

From formulae (5) and (6) a new parameter value r'_o applicable to the rolling force F_o can be calculated:

$$\mu'_0 = K_0 \frac{\delta_2 K_0 F_0 + \Sigma}{K_0 F_0 + \nu}$$

with

$$K_0 = \frac{\alpha_3 - F_1\mu_0 + [(\alpha_3 - F_1\mu_0)^2 + \beta_3 F_1 \mu_0]^{1/2}}{\gamma_3 F_1}$$

For the sake of accuracy, the calculations then proceed from this value r'_o through a double iteration by the consecutive formulae (11) and (5) to approximate very close to the actual value of the force which will be applied in this final pass.

Consequently, from r'_o and according to formula (11):

$$F'_0 = \mu'_0 1 \frac{e'' - e_0}{e''_1}$$

and from F'_o, according to formula (5):

$$\mu''_0 = K_0 \frac{\delta_3 K_0 F'_0 + \Sigma}{K_0 F'_0 + \nu}$$

K_o having the same value as previously.

Then again from r''_o according to formula (11):

$$F''_0 = \mu''_0 1 \frac{e''_1 - e_0}{e''_1}.$$

The value F''_o is the one finally retained to calculate the corresponding yieldability c_o (formula 7) and the final off-load roll nip:

$$s_o = e''_1 - c_o.$$

During the final pass, as in the previous passes, the system samples the actual off-load nip and the actual force to deduce therefrom the actual end thickness e'_o and the difference $e'_o - e_o$. Statistical analysis of the results obtained shows that the end thickness of the roll products can be guaranteed to an accuracy of ±0.2 mm.

Of course, variations in the execution of the calculations fall under the invention. For instance, other formulae could be devised for the equations which give an approximate representation of the family of closely related curves, and the thickness at which the two kinds of equations used meet would also alter. Similarly, the formula representing mill yieldability in dependence upon the rolling force depends of course on constructional features of the mill and may vary according to the kind of mill.

Other extrapolation formulae could be used to determine a plasticity parameter from the values detected during the previous passes, or iteration could be effected further to determine the rolling force during the final pass.

This method can of course be used for widthwise sizing of the sheets, for in widthwise sizing a predetermined product width is required—i.e., actually a given width once the weight or volume of the initial product and the final dimension are known.

Use of the invention in hot strip mills also falls under the invention, for there is nothing preventing the general rolling principles hereinbefore described from being used for a number of roll housings, as in the case of a strip train, instead of for just a single mill. Of course, it is useful if the required thicknesses can be devised beforehand in the light of the optimum possibilities of available equipment.

We claim:

1. Process for rolling metal flats in a rolling mill having apparatus for measuring the rolling force and apparatus for measuring the nip of the rolls comprising the successive steps of performing two rolling passes and measuring the nip of the rolls and the rolling force on each pass, programming a computer to determine the number of further successive passes and the intermediate thicknesses of the flats to obtain a predetermined final thickness of metal flat utilizing a predetermined relation between the desired final thickness, a predetermined rolling force for the last pass, a predetermined constant rolling force for all the other passes and the measurements of the rolling forces and nips of the first two passes, determining the nip to be given to the rolls for the third pass, then carrying out the third pass, measuring the actual rolling force and the actual nip on the third pass and determining the nip to be given to the next pass utilizing a predetermined relation between the values already known and the actual rolling force and the actual nip of the cylinders measured during the third pass and then repeating these determinations for each following pass.

2. A process as described in claim 1 including measuring the rolling force of each pass and reprogramming the computer when the rolling force exceeds a predetermined value.