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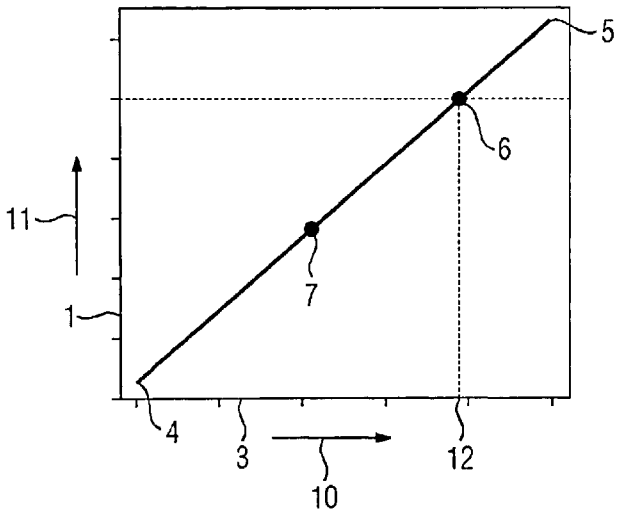
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(54) **Title**: METHOD FOR ADJUSTING FINAL STEEL PROPERTIES AT STEEL MILL FACILITY

(57) **Abstract**: The invention relates to a method for adjusting properties in the production of steel, in which by means of a computing unit values (7) for parameters (3) characterizing for desired properties (6) of the steel are determined with the aid of an experimental data set, whereat the values (7) are determined simultaneously. Furthermore the invention relates to a facility for producing steel.

FIG 2



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METHOD FOR ADJUSTING FINAL STEEL PROPERTIES AT STEEL MILL FACILITY

DESCRIPTION

The invention relates to a method for adjusting properties in the production of steel, in which by means of a computing unit values for parameters characterizing for desired properties of the steel are determined with the aid of an experimental data set.

Moreover, the invention relates to a facility for producing steel, comprising a facility control device, which comprises a computing unit, by means of which parameters characterizing values for desired properties of the steel are capable of being determined with the aid of an experimental data set.

Presently many efforts are given to improve the final production quality of steel. Steel rolling is a complicated technological process consisting of many stages, which are e.g. casting, hot rolling, edging, cold rolling, annealing or temper-rolling. On each stage the process is controlled by certain process parameters. The overall number of parameters may reach several hundreds. The examples of process parameters include chemical composition, geometrical parameters of the slab, the rolling speed, the strip coiling temperature (during hot rolling), the strip finishing temperature (during hot rolling), the reduction in thickness during cold rolling and the annealing temperatures. The before mentioned influence parameters reflect only a fraction of all the parameters influencing the properties of rolled steel, which is the final product of the steel production process. Among the properties that characterize the steel quality, the yield stress (Re), the ultimate stress (Rm) and the elongation (A80) belong to the most important properties. Depending on steel grade, costumer wishes and other conditions, it is often required to achieve certain values of output properties. Usually, such requirements are formulated as lower and upper limit values. For example, for a certain steel grade it may be desirable to get into an interval from 240 MPa to 280 MPa for the yield stress. The total variation of the yield stress for corresponding steel grade can reach from 190 to 310 MPa, since the process parameters that allow reaching desirable values for the yield stress are often unknown due to complexity of the steel rolling process. For the same

reason, the creation of a physical model, which considers the influence of process parameters on the yield stress is difficult. For this reason, several approaches have been published to calculate the processing parameters e.g. by neural networks. Thus, for example the usage of neural networks with mathematical approaches of higher order is known. The major disadvantage of using neural networks as a prediction model for searching for the process parameter values that lead to desired Re values is, that using neural networks results in complicated and computationally expensive search processes.

Therefore, it is the object of the present invention to provide a particularly effective and at the same time particularly fast method and a facility of the initially mentioned kind.

This task is solved by a method having the features of patent claim 1 and by a facility having the features of patent claim 8. Advantageous embodiments with expedient further developments of the invention are indicated in the dependent patent claims.

In the method according to the invention the values are determined simultaneously.

The determination of the values for parameters characterizing for desired properties of the steel corresponds to a simultaneous adjustment of the parameters which influence the steel grade. By means of the simultaneous adjustments of parameters the time consuming method of changing only one factor at a time to determine its single influence upon the steel quality can be avoided. In other words and especially in contrast to the determination of values by means of neural networks, the simultaneous adjustment of the parameters is a very quick method of setting parameter values in order to reach desired properties of the steel.

It has turned out to be advantageous, if by means of the computing unit a minimum value is determined for at least one of the desired properties, which is reached by means of the values of the parameters.

Determining a minimum value for a desired property of the steel can result in saving resources during the steel manufacturing. If e.g. a certain hardness of the steel is

required, the amount of alloying elements can be metered such that the minimum requirements to the steel are met precisely, or that the requirements to steel are met by means of the cheapest of the alloying continuances that can be used. Furthermore the thermal process that requires the least energy consumption can be chosen based on the values of the parameters.

It is further advantageous, if by means of the computing unit a maximum value for at least one of the desired properties is determined, which is reached by means of the values of the parameters.

By determining a maximum value for at least one of the desired properties of the steel by means of the computing unit it can be evaluated most effective for which operational demands the steel can be established. If the requirements for the steel outreach the achievable maximum value, one can abstain from e.g. extensive hardness tests or tensile tests. Instead by means of a computing unit can be determined in an early stage that to achieve even higher steel quality further procedures need to be performed not during the steel manufacturing, but rather subsequently. These procedures would include e.g. a nitriding process in conjunction with a subsequent tempering. In other words by means of the computing unit it can be determined in a particularly early stage of the steel production, whether further procedures need to be performed subsequent to the steel manufacturing, to meet the requirements, i.e. the desired properties of the steel.

It is further advantageous, if by the computing unit from the parameters relevant process parameters are determined, which are required for adjusting the desired properties of the steel.

The initial set of parameters that influence the desired properties of the steel comprises a quantity of several hundred. As an example some of these several hundred parameters are listed in table 1:

Table 1

Parameter	Parameter name
x_1	Strip finishing temperature at hot rolling
x_2	Strip coiling temperature at hot rolling
x_3	C
x_4	Mn
x_5	Si
x_6	P
x_7	S
x_8	Al
x_9	Strip thickness at hot rolling
x_{10}	Strip width at hot rolling
x_{11}	Strip length at hot rolling
x_{12}	Strip velocity at the least stand of hot rolling
x_{13}	Max number of enabled sprinkling water at hot rolling
x_{14}	Strip thickness after cold rolling
x_{15}	Strip velocity at annealing
x_{16}	Strip temperature after exposure section at annealing
x_{17}	Strip temperature after overaging section at annealing
x_{18}	Strip temperature after reheating section at annealing
x_{19}	Strip temperature after gas cooling section at annealing

In other words the parameters that are listed in table 1 represent a subset of the several hundreds of parameters that have influenced on the desired properties of the steel. As an

alternative to the listed parameters according to table 1 also other parameters from the several hundreds of parameters can be chosen whereat the other parameters can replace the parameters shown in table 1 as well as they can be added to the parameters shown in table 1. Furthermore the number of parameters shown in table 1 can also be reduced. The parameters illustrated in table 1 correspond to the most important parameters to influence the desired properties of the steel. From this most important parameters according to table 1, a subset of parameters, which correspond to process parameters, can be used to adjust the desired properties of the steel. Furthermore it has to be taken into account, that a certain subset of these process parameters is required for adjusting at least one desired property of the steel, whilst a different subset of process parameters is required for adjusting at least one different desired property of the steel. Since only a subset of certain parameters, which corresponds to the process parameters, is determined by the computing unit, whereat this certain process parameters are required for adjusting a certain desired properties of the steel, the time for adjusting the property can be significantly reduced.

It has turned out to be particularly advantageous if the computing unit determines the values of the parameters by means of linear regression.

The linear regression is a particularly simple method, and thus especially appropriate for a statistical model. In other words by means of the linear regression the minimum and maximum values for the desired properties of the steel can be determined extremely easy and fast. The linear regression is expressed by eq. 1:

$$Re = \alpha_0 + \sum_{i=1}^{19} \alpha_i \cdot x_i \qquad (1)$$

where α_i are tuneable parameters which are concerning the subset of parameters x_i characterizing for desired properties of the steel. Furthermore the linear regression provides a simple and very fast learning procedure as well as the absence of overfitting, since the latter is only a problem for mathematical equations of higher order. The advantage of linear regression models originates from the fact, that a linear function is

defined on a bounded area, whereat it has a minimum respectively maximum value on the respective boundary of this area. Therefore, it is quite straight forward to determine a minimum achievable Re value (Re_{min}) and a maximum achievable Re value (Re_{max}). This is done by parameterization of eq. 1, whereby eq. 2 arises:

$$Re=\frac{\alpha_0+\sum_{i=1}^{14}\alpha_i\cdot x_i+\sum_{i=15}^{19}\alpha_i\cdot x_i(y_i)}{} \quad (2)$$

whereat eq. 3 is defined as:

$$x_i(y_i)=x_i^{min}+y_i\cdot(x_i^{max}-x_i^{min}) \quad (3)$$
$$15\leq i\leq 19, 0\leq y_i\leq 1$$

As is shown in eq. 3, each of the parameters x_i is parameterized by real-valued parameters y_i ranging from 0 to 1.

Furthermore the parameters y_i have to satisfy eq. 4:

$$sign(\alpha_{15})\, y_{15}=sign(\alpha_{16})\, y_{16}=\ldots=sign(\alpha_{19})\, y_{19} \quad (4)$$

whereat the signum-conditions of eq. 5 have to be taken into account:

$$sign(x)=-1 \text{ for } x<0;\ sign(x)=0 \text{ for } x=0;\ \text{and}$$
$$sign(x)=0 \text{ for } x=0; \quad (5)$$

When, after defining the new adjustable parameter y, eq. 6 can be established:

$$y=sign(\alpha_{15})y_{15}=\ldots=sign(\alpha_{19})y_{19} \quad (6)$$

whereby the linear regression parameterization takes the form of eq. 7:

$$Re(y)=\alpha_0+\sum_{i=1}^{14}\alpha_i\cdot x_i+\sum_{i=15}^{19}\alpha_i\cdot x_i(y_i),\ \text{with } 0\le y\le 1 \qquad (7)$$

Now, by varying a single parameter y from 0 to 1, one can calculate Re_{min} and Re_{max} by taking into account the conditions of eq. 8:

$$Re^{min}=Re(0)$$
$$Re^{max}=Re(1) \qquad (8)$$

If the desired Re value, which corresponds to one of the desired properties of the steel is outside the interval [Re^{min}, Re^{max}] it cannot be reached. If the desired Re value is inside this interval, then it may be reached by adjusting the process parameters x_i. To calculate the required values x_i one has to first calculate values of y_i (see eq. 3), taking into account the restriction, which is expressed by eq. 4. This is done by substituting to the left part of eq. 7 the desired Re value and solving it with respect to y.

As an example, the following assumptions are made to explain the determination of predicted values, whereat table 2 shows a subset of parameters, which correspond to the process parameters, derived from the most important parameters that influence the properties of steel:

- there is a set of process parameters, which are listed in table 2, and the predicted value of Re for theses process parameters is 229 MPa
- the desired value of Re is 240 MPa
- the calculated values for Re_{min} and Re_{max} derived by means of eq. 8 are Re_{min} = 215 MPa and Re_{max} = 247 MPa

If a desired value of Re = 240 MPa has to be achieved, then one has to take a parameter value of y = 0,78. The values of the process parameters, which can e.g. be annealing parameters, are calculated using eq. 3 and eq. 6.

Table 2

Parameter	Predicted value	Desired value
x_{15}	130.3	120.0
x_{16}	655.0	681.1
x_{17}	292.5	302.0
x_{18}	384.5	397.2
x_{19}	336.3	351.4
Re	229	240

It is further advantageous, if by means of the experimental data set a data set concerning the linear regression is determined, which is utilized for adjusting the values of the parameters.

Due to the fact that experimental data are used for adjusting the values of the parameters by means of the linear regression, it can be ensured, that the results of the linear regression reflect the real connection between the parameters and the desired properties of the steel particularly accurate. The more experimental data are available to determine a data set concerning the linear regression, the more accurate the linear regression can adjust the values of the parameters.

Furthermore it is advantageous, if the parameters concerning the steel are independent of each other.

With independent variables it is particularly easy to determine each parameters influence on the steel properties. If the parameters are independent of each other, changing the value of one parameter will not affect the other parameters. Thus the influence of each single parameter to the steel quality can be evaluated particularly accurate.

The facility for producing steel according to the invention comprises a facility control device, which comprises a computing unit, by means of which parameters

characterizing values for desired properties of the steel are capable of being determined with the aid of an experimental data set. The values are capable of being simultaneously determined by means of the computing unit and are capable of being transmitted by means of the facility control device to associated sections of the facility.

By the deployment of the facility the mechanical properties of the steel, which correspond to the desired properties of the steel can be controlled particularly fast and efficient. By transmitting the values to associated sections, which are responsible of e.g. thermal processes or molding processes or alloying processes, the production of steel with desired properties can also be controlled particularly efficient.

The advantages and preferred embodiments described for the method according to the invention also apply to the facility according to the invention and vice versa.

The features and feature combinations mentioned above in the description as well as the features and feature combinations mentioned below in the description of figures and/or shown in the figures alone are usable not only in the respectively specified combination, but also in other combinations or alone without departing from the scope of the invention.

Further advantages, features and details of the invention are apparent from the claims, the following description of preferred embodiments as well as based on the drawings.

The drawings show in:

FIG 1 a histogram of different yield stresses, whereat each of the yield stresses occurs with a certain probability due to the usual scattering of steel production; and

FIG 2 a diagram, which illustrates the determination of a yield stress by means of a process parameter.

FIG 1 illustrates the frequency distribution of a yield stress 1 by means of a histogram.

The yield stress 1 is plotted on the abscissa and increases according to an arrow direction of an arrow 8. The frequency 2 is plotted on the ordinate of the histogram and increases according to an arrow direction of an arrow 9. The histogram illustrates, that different yield stresses 1 can be achieved during the manufacturing of steel according to a frequency distribution. In other words one has to take into account that the yield stress 1 which can be reached during the manufacturing lies within a scattering region.

FIG 2 illustrates the dependency of the yield stress 1 of a parameter 3, which is determined by a computing unit. The parameter 3 is plotted on the abscissa and increases to an arrow direction of an arrow 10. The yield stress 1 is plotted on the ordinate and increases according to an arrow direction of an arrow 11. As an example it is supposed, that a parameter 3, which is e.g. a strip velocity at annealing or e.g. a strip thickness after cold rolling, whereat a predicted value 7 of the yield stress 1 for this parameter 3 is determined. FIG 2 also illustrates the linear dependency of the yield stress 1 from the parameter 3 within a minimum boundary, which corresponds to a minimum value 4 and a maximum boundary, which corresponds to a maximum value 5. One can recognize, that if a desired value 6 which corresponds to the desired properties of the steel has to be reached, then the parameter 3 has to be set to a target value 12. In other words, by setting the parameter 3 to the target value 12, it can be achieved, that the desired value 6 and the predicted value 7 at least substantially agree with each other.

CLAIMS

1. A method for adjusting properties in the production of steel, in which by means of a computing unit values (7) for parameters (3) characterizing for desired properties (6) of the steel are determined with the aid of an experimental data set,
characterized in that,
the values (7) are determined simultaneously.

2. The method according to claim 1,
characterized in that,
by means of the computing unit a minimum value (4) is determined for at least one of the desired properties (6), which is reached by means of the values (7) of the parameters (3).

3. The method according to claims 1 or 2,
characterized in that,
by means of the computing unit a maximum value (5) for at least one of the desired properties (6) is determined, which is reached by means of the values (7) of the parameters (3).

4. The method according to any one of the preceding claims,
characterized in that,
by the computing unit from the parameters (3) relevant process parameters are determined, which are required for adjusting the desired properties (6) of the steel.

5. The method according to any one of the preceding claims,
characterized in that,
the computing unit determines the values (7) of the parameters (3) by means of linear regression.

6. The method according to claim 5,
characterized in that,

by means of the experimental data set a data set concerning the linear regression is determined, which is utilized for adjusting the values (7) of the parameters (3).

7. The method according to any one of the preceding claims,
characterized in that,
the parameters (3) concerning the steel are independent of each other.

8. A facility for producing steel, comprising a facility control device, which comprises a computing unit, by means of which parameters (3) characterizing values (7) for desired properties (6) of the steel are capable of being determined with the aid of an experimental data set,
characterized in that,
the values (7) are capable of being simultaneously determined by means of the computing unit and are capable of being transmitted by means of the facility control device to associated sections of the facility.

FIG 1

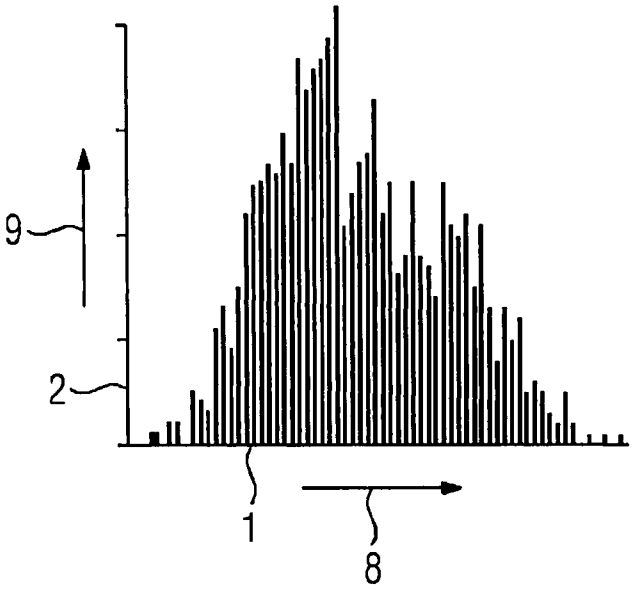
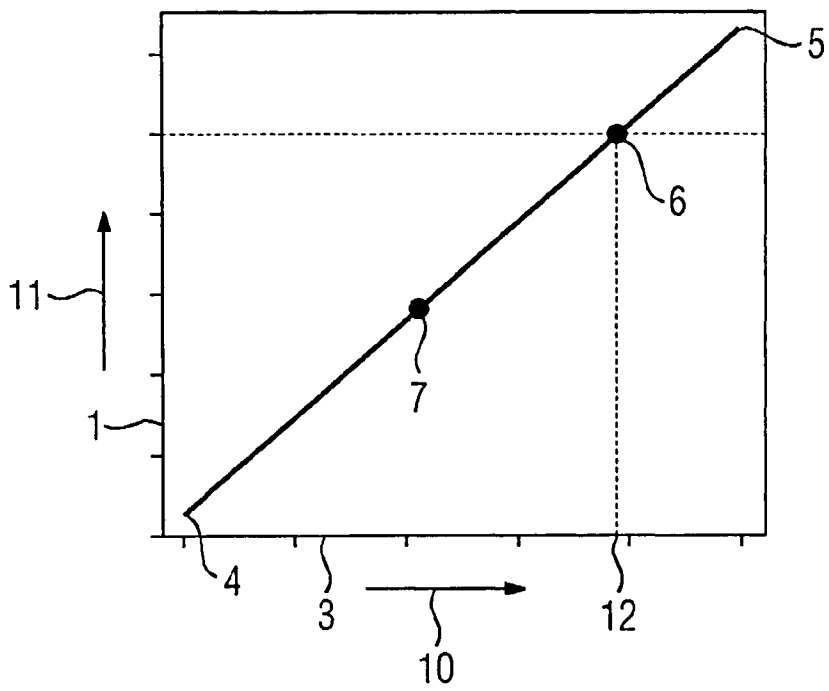


FIG 2



INTERNATIONAL SEARCH REPORT

International application No
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A. CLASSIFICATION OF SUBJECT MATTER
INV. B21B37/00 G05B19/418 G06Q50/04
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
G05B B21B G06Q

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 6 430 461 B1 (ANDORFER JOSEF [AT] ET AL) 6 August 2002 (2002-08-06) column 1, line 19 - line 23 column 3, line 25 - line 38 column 3, line 58 - column 5, line 2 column 6, line 66 - column 7, line 2 claims 1-8,13,20-25,32-36; figures -----	1-8
X	JP 2010 033536 A (NIPPON STEEL CORP) 12 February 2010 (2010-02-12) abstract paragraph [0010] - paragraph [0016] paragraph [0019] paragraph [0044] paragraph [0054] - paragraph [0072] figures ----- -/--	1-8

[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
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INTERNATIONAL SEARCH REPORT

International application No
PCT/RU2013/000396

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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X	US 2006/259176 A1 (FUJII TORU [JP]) 16 November 2006 (2006-11-16) paragraph [0002] paragraph [0006] - paragraph [0008] paragraph [0016] - paragraph [0017] claims; figures -----	8

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
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