

[54] **METHOD AND APPARATUS FOR OPERATING A PUSHER TYPE FURNACE**

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[58] Field of Search.....263/6 R, 52

[56] **References Cited**

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[57] **ABSTRACT**

A method and an apparatus for operating a pusher type furnace for reheating metal slabs for rolling sheet or strip therefrom, including an advance control of fuel quantity supplied to different zones of the furnace and an advance control of the pushing speed through the furnace on the basis of information about the slabs, the final product to be obtained and the rolling practice, such information being processed during the rolling.

For a mill with cogging and finishing train the control data for the pushing speed are calculated from an optimum rolling and coiling program in and behind the finishing train, and the temperatures are calculated backwards from the required coiling temperature to the average slab temperature to derive furnace conditions from the calculated pushing speed and this last temperature. This advance control of the furnace is, during heating and rolling, adjusted by real pushing speed and real temperature of the slabs in the furnace. Disturbances or delays in rolling entrain first a lower fuel supply, and after the delay is over, the heating, pushing and rolling are speeded up until the arrears are overcome.

10 Claims, 5 Drawing Figures

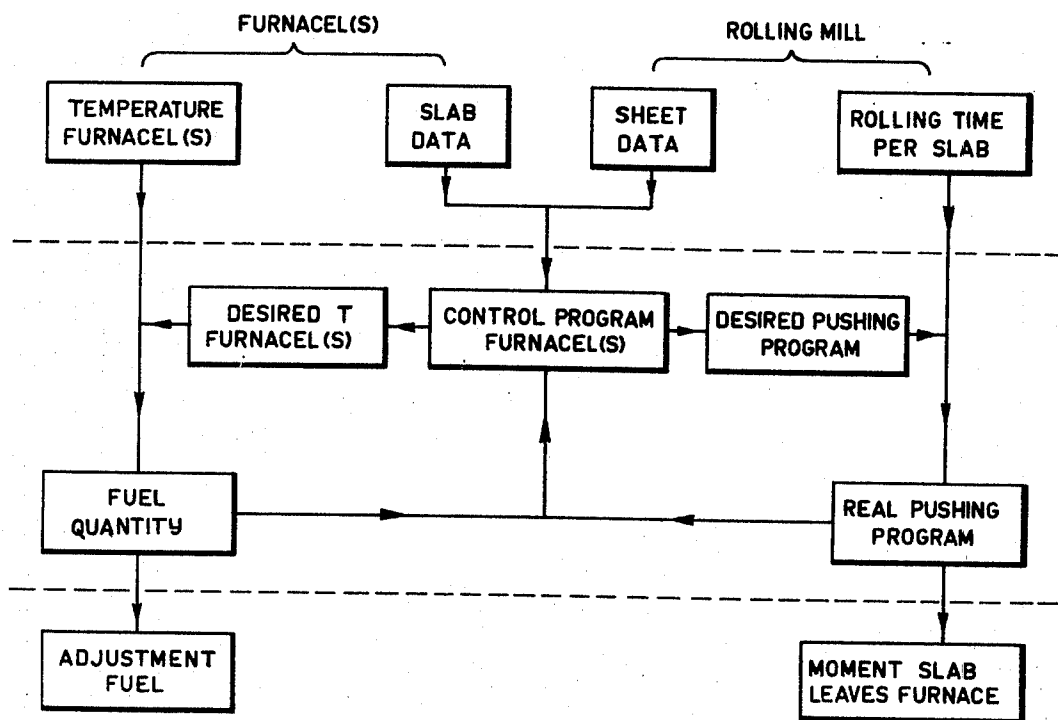


FIG. 1

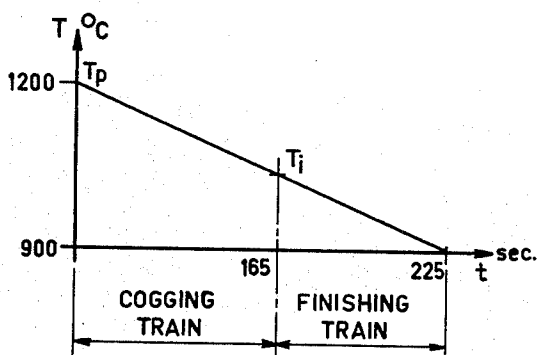


FIG. 2

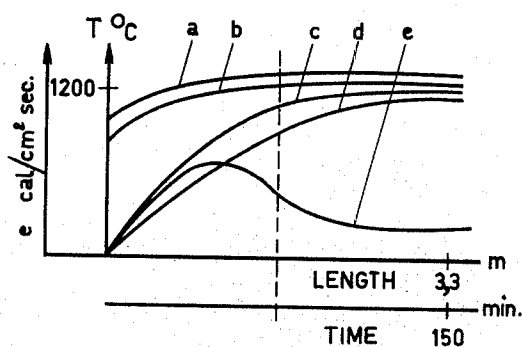
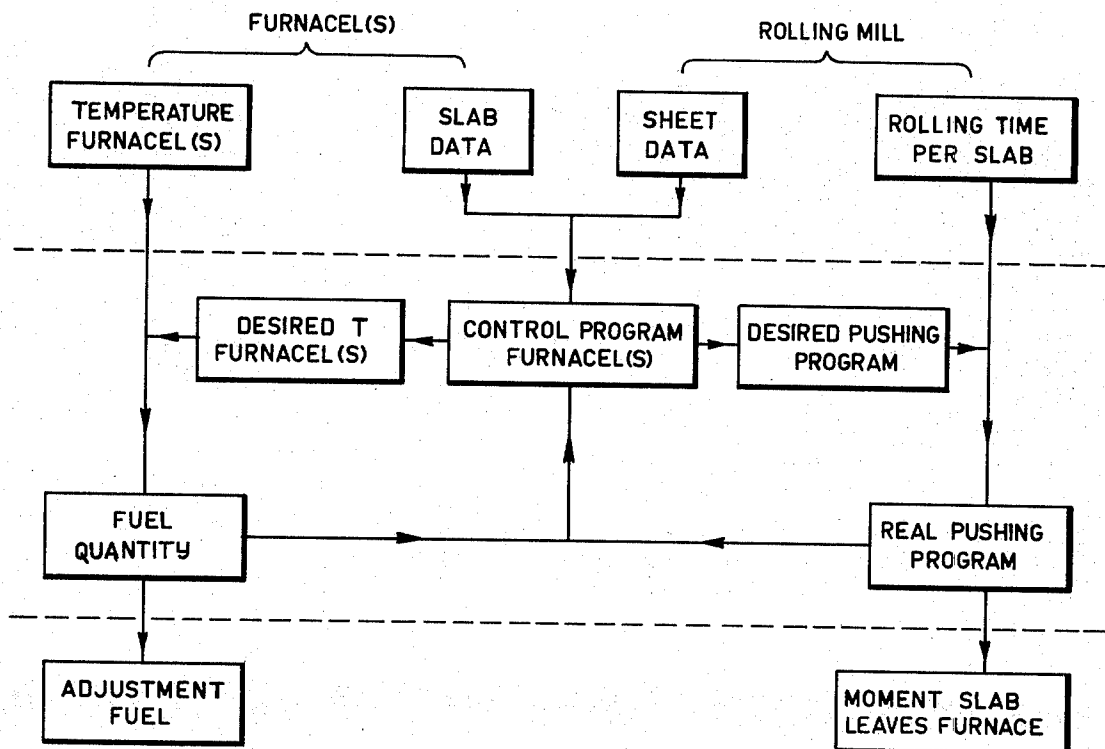


FIG. 5



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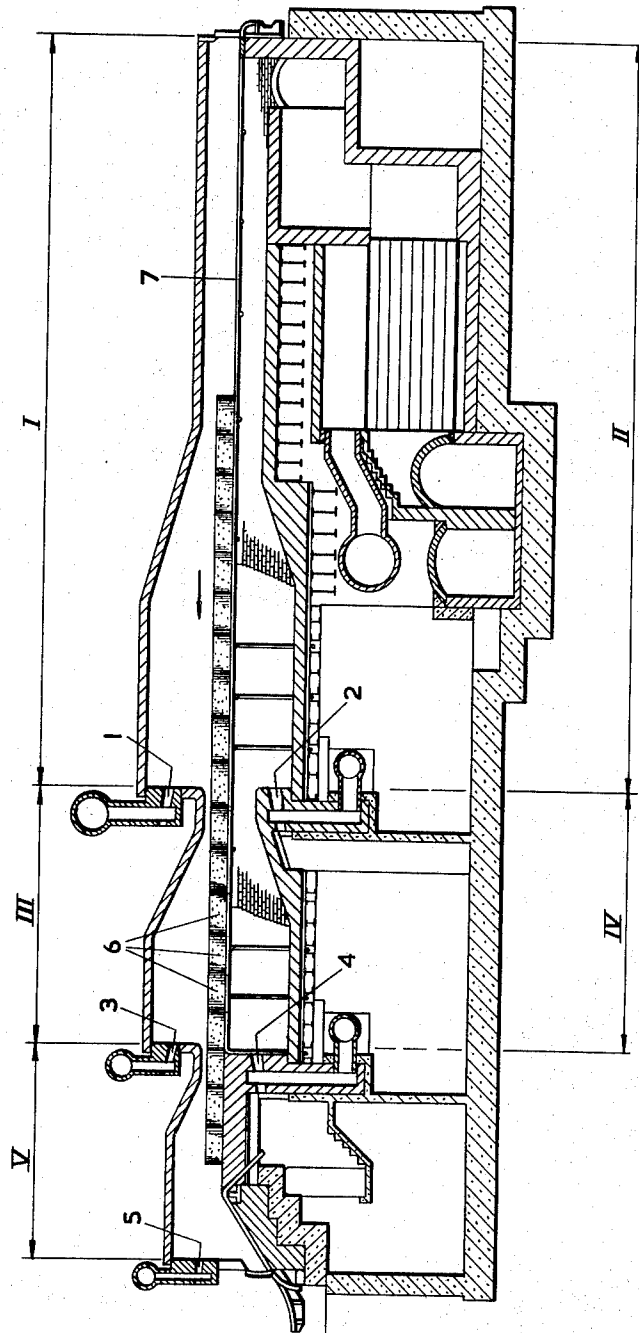
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FIG. 3



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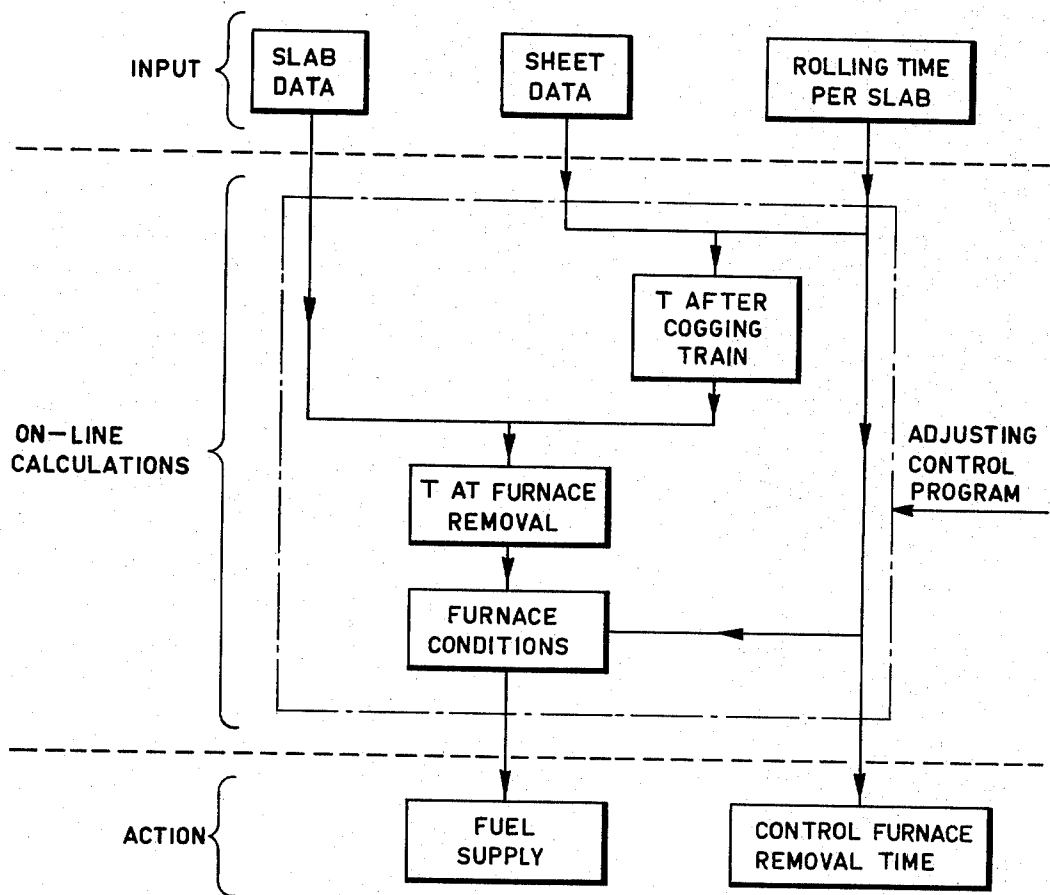
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FIG. 4



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METHOD AND APPARATUS FOR OPERATING A PUSHER TYPE FURNACE

This invention relates to a method and a device for operating one or more pusher type reheating furnaces for a rolling train, in particular for a wide strip mill for rolling steel slabs. When rolling wide steel strips of considerable lengths the rolling is started from steel slabs. Such slabs are pushed in contact with one another through a pusher type furnace and during their presence in said furnace they are heated to a temperature of about 1,200° C. After heating, the slabs are one after the other taken from the furnace and rolled out, as a rule each in two mutually separated series of rolling passages one after the other. Such series of passages are sometimes called the cogging or roughing mill passages and the finishing passages respectively.

Pusher type furnaces are generally known, e.g., from U.S. Pat. No. 3,022,056 to William H. Dailey, Jr, and from Iron and Steel Engineer, April, 1959, pp. 102-110.

In order to obtain a maximum efficiency from the whole plant it is necessary that the material of several slabs passes particularly as fast as possible and as closely joining as possible in the programmed sequence through the finishing mill. A modern development in this respect is to accelerate the mill during the finishing of each sheet therein in order to obtain at least approximately a temperature which is as constant as possible throughout the length of the sheet material. This has to do with the fact that an increase of the speed of the finishing rolls results in an increase in the rolling forces and thus an increase of the rolling energy dissipated into heat, by which the cooling during a longer time interval of the rearmost part of the sheet can be compensated.

It has appeared that for an optimum use of the finishing mill an accurate temperature control of the material before the finishing mill is necessary. This is so because, if the material is too cold, the finishing train should rotate at too high a speed, which requires a too heavy dimensioning of the rolling stands and moreover a final product of inferior quality will be obtained. Often the slab will in this case not be passed through the finishing mill, but will be made into scrap.

If on the contrary the slab is too hot for the finishing mill it is necessary to roll out the material with too low speed or to have it cool down first on a cooling bed. In both cases loss of production and a disturbance of the control of the pusher type furnace results. The temperature control of the material before the finishing train requires a control of temperature of the slabs before the roughing mill within about 10° accuracy. The temperature of the slab when leaving the pusher type furnace is a value, which is difficult to control and which among others depends on the dimensions of the slabs, the time of presence of the slabs in the furnace in different zones thereof and the rolling program. In practice the pusher type furnace is controlled in such a way that the slabs leave this furnace with a temperature which is about optimum for rolling out. In this respect it is tried to adapt the rolling program to the production of the furnace. Any disturbance which, as explained above, may occur when rolling out the slabs will in this case result in a serious disturbance of control of the furnace program. It is remarked that for delays in the

pushing through the furnace or in other disturbances of control thereof, an adjustment to correct this is very difficult. As the slabs are in contact with one another, their speeds are related. Moreover, the highest heating takes place in a restricted front part of the furnace, so that a correction for slabs which in that zone were not heated to the correct temperature will only be possible to a quite restricted extent in further parts of the furnace. A too high variation of the temperature in the front zones of the furnace is, however, neither possible, because thereby the material will be influenced in an adverse manner. Particularly for too high a temperature of the slab the oxide present thereon will begin to soften or even to melt. In both cases a subsequent cooling will entrain that the oxide will be bonded more intimately to the steel, so that a spraying away thereof before the several rolling passages will become impossible. This entrains the danger that rolled-in scale will occur. Moreover it is possible that molten oxide drips from the slabs and thereby contaminates the floor of the furnace to an undesired extent. Particularly the contamination of the burner nozzles should be feared in this respect. It has appeared that up to now it was not possible to obtain a successful automation of the control of the furnace.

Earlier attempts to obtain this were based upon the idea that a satisfactory control of the furnace would be possible by measuring the furnace conditions and/or the slab temperature when leaving the furnaces and by an additional control of the quantity of fuel supplied through a feed-back system. Several refinements of such a control were tried, but in this way a satisfactory furnace control always appeared impossible. This was shown not only by an inadmissibly wide field of variation of temperature of the slabs removed from the furnace, but also in the above-mentioned superheating phenomena of the oxide on the slabs. In particular an additional control in the manner described appears to be a failure in the case of an intentional transition to another finishing program and in case of a delay or interruption in the rolling process.

Such objections appear to be removable only by applying the idea, which is the basis of the present invention, that it is necessary to control (adjust) the furnace essentially beforehand, taking into account the entire desired program of the process for the product from the slab and up to and inclusive of the coiled sheet.

In this respect the invention consists in that the quantity of fuel supplied to different zones of the furnace(s) and the rate of speed of passage of the slabs or the like through the furnace(s) are controlled (adjusted) in advance on the basis of data, relating to the slabs or the like supplied to the furnace(s) and also to the desired information about the dimensions of the sheet to be rolled, the finishing temperature at the end of the hot rolling and the rolling practice (program and time) to be followed, which data in the course of the rolling process are used and treated in combination. All this can be obtained successfully in case of operating a rolling street which includes a cogging train and a finishing train if furthermore according to the invention the control data for the desired speed of passage of the slab or the like through the furnace are calculated on the basis of an optimum rolling and coiling program in and following the finishing train, that on the basis of

this rolling program are calculated first the temperature of the product when entering the finishing train, from this value the temperature thereof when leaving the cogging train, and from this value, in combination with the data about the slab, the required average slab temperature when it leaves the furnace, after which from the last-mentioned temperature and from the calculated speed of passage through the furnace the furnace conditions are derived.

In fact in this manner first of all for each sheet to be rolled from a slab the conditions in the finishing operations and the coiling are anticipated and therefrom for the finishing train and the apparatus following this train an optimum program is composed.

On the basis of correlations known as such the desired average temperature of the slabs when drawing them from the furnace(s) and the optimum program of pushing them through the furnace are determined from this program by calculation from this information backwards.

Again on the basis among others of these data and of knowledge about the heating mechanism in the furnace(s) it is possible to determine in this way a heating program for the furnace.

It is remarked that such a control program for the furnace(s) is difficult to determine without the use of computers, particularly if mutually deviating slabs with different destinations follow one another frequently.

As a result of the said control program not only the furnace practice is optimized, but also the optimizing of the finishing train practice is facilitated.

However, it is of particular importance that in normal operation the percentage of rejected sheets between cogging train and finishing train may be reduced to almost zero in that no slabs which are too cold have to be taken away in this zone in order to be scrapped. In fact in this way the operation is at all moments so to say compared with an ideal operation which was calculated beforehand with the aid of models.

In practice it is possible that deviations occur with respect to such an ideal operation. In part this may be the result of deviations between reality and the models used. However, it is also possible that somewhere in the entire process delays or disturbances of longer or shorter duration occur.

Moreover, as a rule the rolling plant will in practice have "hidden" reserves with respect to the models which may be used to advantage by further optimizing. This last case is in particular of importance after a disturbance has occurred.

In this respect it is according to the invention furthermore particularly preferable that in the new method, during the rolling process, on the basis of the continuously determined real speed of passage through the furnace, the furnace program which is primarily controlled in advance, is secondarily adjusted or additionally controlled for correction.

This may in many cases be perfected by having such an additional control or adjustment also take place on the basis of determinations of the course of the surface temperature of the slabs or the like in the furnace(s), and on the basis of calculations of the course of the temperature through said slab or the like.

The course of the surface temperature of the slabs in the furnace(s) may be determined in part by direct measurement and in part by calculations. Such calculations, which are performed by electric means in such a case mainly relate to eliminating of measuring inaccuracies as a result of the reflection of the walls and the radiation of combustion gases.

It has appeared that such an additional control with respect to a program, which is controlled (adjusted) in advance and is of the type as given above, is possible in a simple way and without the complications mentioned above. In case of a rather long time disturbance of the operation it is also possible according to the invention to apply a somewhat more simple type of additional control which gives good results. This is embodied in such a way that, when a delay occurs in the rolling program, the fuel supply to the furnace(s) is adjusted at a lower level, and that after this delay the rolling program, the speed of passage through the furnace(s) and the heat generation of the furnace(s) are temporarily brought to a higher level, dependent upon the arrears which were caused and until such arrears are overcome.

The amount in which the furnaces are temporarily brought to a lower level and wherein thereafter the pushing through program and the furnace heat generation are brought to a higher level may be determined both along empirical and along mathematical ways.

By increasing the number of flame zones in the furnace without restriction it is more easily possible to keep the finally desired slab temperature under control. However, for a too long furnace and so a long period of stay of the slabs therein the feed-back time of the data of the rolled product to the front zones of the furnace will become inconveniently long. A more important disadvantage of particularly long furnaces is, however, formed by the high costs thereof. Also the loss of steel by oxidation in the furnace makes it necessary to restrict the length thereof. An optimum operation when applying the new method has in this respect been obtained according to the invention by the use of a pusher-type furnace with two sets of upper and lower flame zones arranged in pairs, followed by a single upper flame zone, and in which the temperature control mainly takes place in the first set of upper and lower flame zones.

If an additional control of the process controlled or adjusted in advance is desired, it is recommendable to make use of a preferred circuit according to the invention. This consists in that the circuit includes a computer for determining the furnace control program during the process connected and adjusted so as to be fed with data about dimensions and composition of the slabs or the like to be supplied to the furnace, and with the data of the desired dimensions, finishing temperature and rolling time of the product to be made therefrom, so that this computer makes a control program for adjusting in advance the quantity of fuel to be supplied per zone of the furnace and a program for the moments of removing the heated slabs from the furnace, through the determinations of the desired temperature conditions in the furnace and the desired program of pushing the slabs through the furnace, and that this computer moreover is taken up in a control circuit which also includes means for adjusting the passage

program for the slabs or the like through the furnace, determined by the said control program for advance adjusting, and includes means for controlling the required definite pushing through program, also in dependence upon the real rolling practice determined during the process.

If, as given above the method is perfected by having the additional control (adjustment) also take place on the basis of determinations of the course of the surface temperature of the slabs in the furnace(s), and on the basis of calculations of the course of the temperature through said slabs, it is recommendable to embody this circuit moreover in such a way that said computer is also taken up in a second control circuit, which comprises means for adjusting a desired temperature distribution in the furnace(s) and means for controlling the quantity of fuel required thereto, also in dependency upon the temperature conditions in the furnace(s) determined during the process.

This invention will now be explained further with reference to the enclosed drawings, which, by way of example only, show details important for applying the invention.

FIG. 1 gives in general the course of the temperature of the material to be rolled through the rolling mill.

FIG. 2 shows diagrammatically the course of the heating up.

FIG. 3 is a somewhat diagrammatic drawing of a pusher furnace.

FIG. 4 gives diagrammatically only the main parts of the circuit for control (adjustment) in advance of the furnace(s).

FIG. 5 is a diagram of circuit for a complete control program of the furnace(s).

In FIG. 1 the temperature T of the material to be rolled is plotted against the time of stay t of the product in a rolling mill. A vertical dot and dash line gives the transition from the upstream cogging train to the downstream finishing train, at which point the temperature is T_f . For a particular case by way of example several numerical values are given, which, however, only serve the purpose to give some idea of what happens. The temperature T_f is, as remarked before, critical for the course of the rolling process in the finishing train. If T_f is too low, the quality of the material will be inferior, the rolling forces will be too high or even the sheet will be too cold and will have to be taken from the table at a point before the finishing train. If T_f is too high, the sheet should first be allowed to cool down or should be rolled out too slowly. In both cases production loss and disturbance of control of the furnace are the result. Determinative for T_f is the slab temperature T_p when leaving the pusher furnace.

In FIG. 2 the following curves are plotted against furnace length for constant speed of pushing:

a = temperature of the furnace gas

b = temperature of the furnace wall

c = temperature of the slab surface

d = temperature in the core of the slab

e = heat flow density through the slab surface.

A dotted line shows the point in the furnace where the first or upstream upper and lower flame zones terminate.

It appears clearly from this Figure that downstream these zones mainly only an equalization of temperature

and a heating through of the slabs take place. Considerable corrections in the slab temperature can no more be made.

In FIG. 3 a pusher furnace has been given diagrammatically, having five flame zones. The five flame zones, three upper zones and two lower zones, are indicated by I; II, III; IV and V. Reference numerals 1 to 5 incl. each indicate a row of burners, said row extending transversely to the plane of the drawing. The slabs 6 are pushed through in the direction of the arrows, therewith sliding over cooled rails 7.

FIG. 4 in principle indicates how the control program of the furnace(s) is built up. The diagram is divided by dotted lines, into three horizontal zones, comprising from top to bottom the input data of the furnace control, the computer operations and the actions which result therefrom on the process respectively.

The data of the slabs to be treated, the desired data of the rolled sheet and the desired data of the desired final rolling practice can be put in with the aid of punched cards, punched tapes or magnetic tapes in a manner known as such.

In fact this control program includes an optimum programming of the course of the process during and after the finishing rolling. From this programming the control program determines step by step the conditions necessary therefore, each time in an earlier phase of the process, from finishing rolling to conditions at the furnace. Finally the required furnace conditions result therefrom, which allow the surface temperature and the average temperature of the slabs, at and dependent on the moment at which the slabs leave the furnace to take a course, so as to attain the desired values.

The control program on the basis thereof calculates the starting values for the actions to be taken.

If these starting values would be used directly for the automatic adjustment of the fuel distribution and the control of the moments of withdrawal of the slabs from the furnace, no good heating and rolling process would be possible as a result of the deviations occurring in practice with respect to the models on which the calculations are based, or as a result of delays or disturbances in the process. On the other hand it is possible to use such a control program as an auxiliary means for a manual control of the furnaces. If, however, it is desired to obtain an automatic control of an optimized course of the process, some further refinements have to be made.

In this respect references is made to FIG. 5, which again has been divided by horizontal dotted lines into three horizontal zones, from top to bottom for input data, for operations and for actions respectively. In FIG. 5 it has been indicated that as additional input data the measured furnace temperature and the really observed pushing program are introduced. If and insofar as these deviate from the desired conditions it is possible to have the control program make corrections to the actions to be exerted. By introducing feed backs in the program as given in this Figure, this results in a combination of an "on-line" process, controlled in advance, and an "in-line" additional control thereof. In the control program the measured course of the furnace temperature is operated upon by calculation to give a surface temperature and an average temperature for each slab. With the aid thereof the fuel supply and

the pushing program can at any moment be adapted to small deviations.

For larger deviations as a result of a temporary disturbance a possibility of acceleration is provided in the control program. During the disturbance the slabs are heated through at a lower furnace heat development. After the disturbance, the average temperature of most slabs will, by said disturbance, have become higher than corresponds to normal operation, by which a certain reserve heat quantity will have been accumulated in the slabs. This may be used to advantage by temporarily accelerating the rolling program by multiplying the original speed by a factor which is a hyperbolic function of the arrears which occurred, and during a time interval in which the arrears will be caught up with.

As discussed above it is not necessary always to measure the course of the surface temperature of the slabs and to calculate the course of the temperature through the slabs therefrom. In this respect it is remarked that the input block at the left upper part of FIG. 5 for this temperature could be omitted together with the related feed back of the comparison of the desired and the real temperature.

It will be superfluous to give an elaboration of the diagrams discussed as to the structural details, as this will all be obvious for the expert.

It has appeared that by applying this invention a gain in productivity of at least 10 percent is possible, which moreover is combined with a more uniform quality of the rolled product.

I claim:

1. In a method for reheating work in the form of metal slabs for rolling sheet or strip therefrom with the aid of apparatus of the type that includes:

- i. a pusher type furnace having an upstream end into which the metal slabs are fed and having a downstream end to which they are pushed during the reheating, said furnace having fuel fed heating devices therein,
- ii. a rolling mill having an upstream end to which reheated slabs are delivered from the downstream end of said furnace, and
- iii. a computer,

the improvement which comprises:

- a. supplying to the computer advance data as to
 1. the dimensions of the slabs to be heated,
 2. the desired dimensions of the sheets to be rolled therefrom, respectively,
 3. the finishing temperature of such sheets desired to be attained at the end of the hot rolling, and
 4. the rolling mill practice desired to be followed in such rolling,
- b. programming the computer to calculate from such advance data
 5. the calculated temperature of the work required at the beginning of the finish rolling thereof,
 6. the delivery temperature of the slabs from the downstream end of the furnace needed to impart said calculated temperature to the work at the beginning of the finish rolling,
 7. the rate of delivery of the slabs from the downstream end of the furnace calculated to conform to said rolling mill practice, and

8. the calculated rate of flow of fuel to the furnace needed to impart said delivery temperature to the slabs at said calculated rate of delivery, and

c. adjusting the rate of pushing of said slabs in the furnace and the flow of fuel to said heating devices primarily to accord with the rates calculated in steps (b) (7) and (b) (8).

2. An improved method as claimed in claim 1 in which the improvement further comprises

d. supplying to the computer during the reheating operation data as to the temperatures actually existing in the furnace and the pushing rates actually being effected in the furnace, and

e. secondarily adjusting at least one of the rates of flow of fuel and of pushing of the slab in the furnace to reduce deviations between the data supplied in step (d) and the corresponding item of data calculated in step (b).

3. An improved method as claimed in claim 2, in which the actual temperature data supplied in step (d) is based on the course of the surface temperatures of the slabs in the furnace, in which the computer is programmed to calculate the average temperatures of the slabs on the basis of said surface temperatures and the course of the temperature equalization through the work, and in which the secondary adjustments of step (e) are effected to reduce deviations between said average temperatures and the temperatures calculated in step (b) (6).

4. An improved method as claimed in claim 1, in which the improvement further comprises

d. in the event of a delay in the rolling program, adjusting the rate of flow of fuel to the furnace to a lower level for the duration of said event, and

e. after termination of such event, temporarily increasing the rate of pushing of the slabs through the furnace and the rate of flow of fuel to the furnace until the arrears resulting from such event are overcome.

5. An improved method as claimed in claim 1, particularly applicable when fuel fed heating devices in the furnace are arranged in an upstream set near the upstream end of said furnace and in a downstream set near the downstream end of the furnace, and in which the adjustment of the rate of flow of fuel to said heating devices is effected mainly in said upstream set of heating devices.

6. An improved method as claimed in claim 1, particularly applicable when fuel fed heating devices in the furnace are arranged in an upstream set above and below the path of pushing of the slabs in the furnace, and in a downstream set above the path of pushing of the slabs in the furnace, and in a third set intermediate said upstream and downstream sets, and in which the adjustment of the rate of flow of fuel to said heating devices is effected mainly in said upstream set of heating devices.

7. An improved method as claimed in claim 1, applicable when the rolling mill comprises a finishing mill with a cogging mill upstream thereof, in which, in step (b) data item (5) is calculated on the basis of a desired optimum rolling and coiling program in and following such finishing mill, by calculating therefrom the speed of passage of the slabs through the furnace and the value of temperature of the work desired at the up-

stream end of the finishing mill, calculating from said value of temperature the temperature level for the work leaving the cogging mill, and calculating from said temperature level in combination with data item (1) supplied to the computer in step (a), the required average temperatures for the slabs when they leave the downstream end of the furnace; and in which the data of item (8) of step (b) are calculated from said average temperature and the calculated rate of pushing of the slab through the furnace.

8. In an apparatus for reheating work in the form of metal slabs for rolling sheet or strip therefrom, said apparatus being of the type which comprises

- i. a pusher type furnace having an upstream end into which the metal slabs are fed and having a downstream end to which they are pushed during the reheating, said furnace having fuel fed heating devices therein,
- ii. a rolling mill having an upstream end to which reheated slabs are delivered from the downstream end of said furnace, and
- iii. a computer,

the improvement which comprises

- a. means for supplying advance data as to
 1. the dimensions of the slabs to be heated,
 2. the desired dimensions of the sheets to be rolled therefrom, respectively,
 3. the finishing temperature of such sheets desired to be attained at the end of the hot rolling, and
 4. the rolling mill practice desired to be followed in such rolling, and
- b. adjusting and control means having advance data inputs connected to receive the advance data from said means (a) and having outputs connected to control the flow of fuel to said heating devices and the rate of pushing of the slabs in the furnace, said adjusting and control means being programmed to calculate from said advance data
5. the calculated temperature of the work required at the beginning of the finish rolling thereof,

6. the delivery temperature of the slabs from the downstream end of the furnace needed to impart said calculated temperature to the work at the beginning of the finish rolling,

7. the rate of delivery of the slabs from the downstream end of the furnace calculated to conform to said rolling mill practice, and

8. the calculated rate of flow of fuel to the furnace needed to impart said delivery temperature to the slabs at said calculated rate of delivery,

and to adjust the rate of pushing of said slabs in said furnace and the flow of fuel to said heating devices primarily to accord with the so calculated rates (7) and (8).

9. Improved apparatus as claimed in claim 8, wherein said adjusting and control means (b) has further input means connected to receive from said rolling mill during its operation data as to the actual rolling practice being realized therein, and wherein said adjusting and control means further comprises means responsive to the data received by said further input means for secondarily adjusting at least one of the rates of flow of fuel and of pushing of the slabs in the furnace to reduce deviations between the data recorded by said further input means and the corresponding advance data received by said advance data inputs.

10. Improved apparatus as claimed in claim 8, wherein said adjusting and control means (b) has further input means connected to receive from said furnace during the reheating operation data as to the temperatures actually existing in the furnace and the pushing rates actually being effected therein, and wherein said adjusting and control means further comprises means responsive to the data received by said further input means for secondarily adjusting at least one of the rates of flow of fuel and of pushing of the slabs in the furnace to reduce deviations between the data received by said further input means and the corresponding advance data received by said advance data inputs.

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