United States Patent

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[54] **TEMPERATURE CONTROL SYSTEM FOR MILL RUNOUT TABLE**
11 Claims, 9 Drawing Figs.

[52] U.S. Cl. 72/13, 72/201, 266/6
[51] Int. Cl. B21b 37/10
[50] Field of Search 72/9, 13, 201, 200, 202; 134/15, 64, 122, 57; 266/3, 6, 2.5

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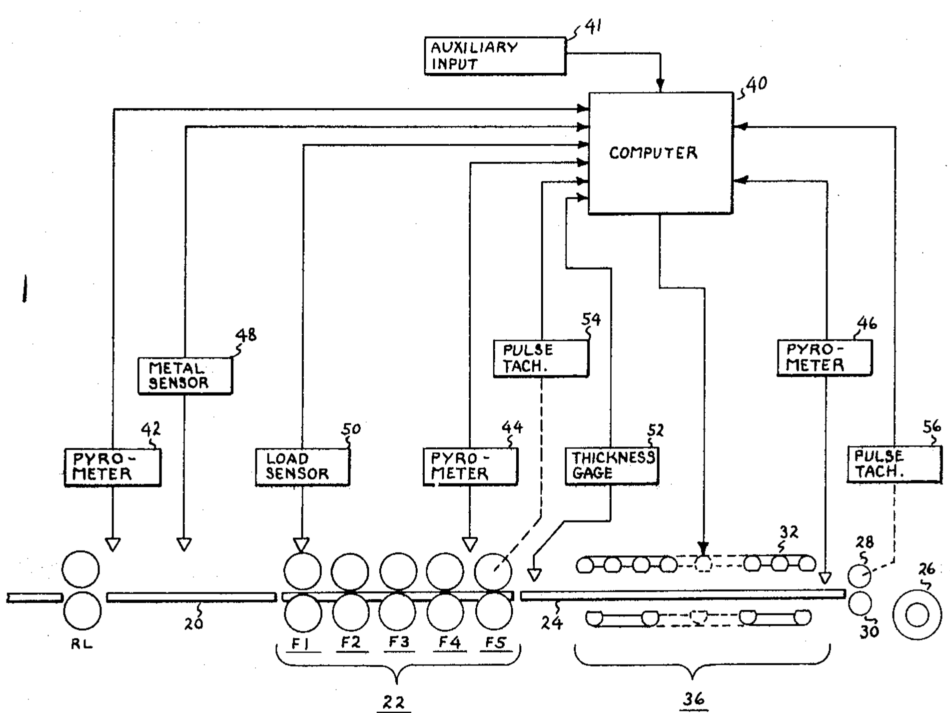
ABSTRACT: Individually controllable water sprays form a strip cooling zone at a runout table between the last stand of a hot strip finishing train and a coiler. The times required for successive sections of the strip to traverse the runout table (designated residence times) are calculated from a predetermined strip velocity-time profile. Using the residence times, the finishing train temperature, and the desired coiling temperature, spray patterns of varying lengths are calculated for successive sections. The spray patterns are changed to coincide with the movement of the sections across the runout table.



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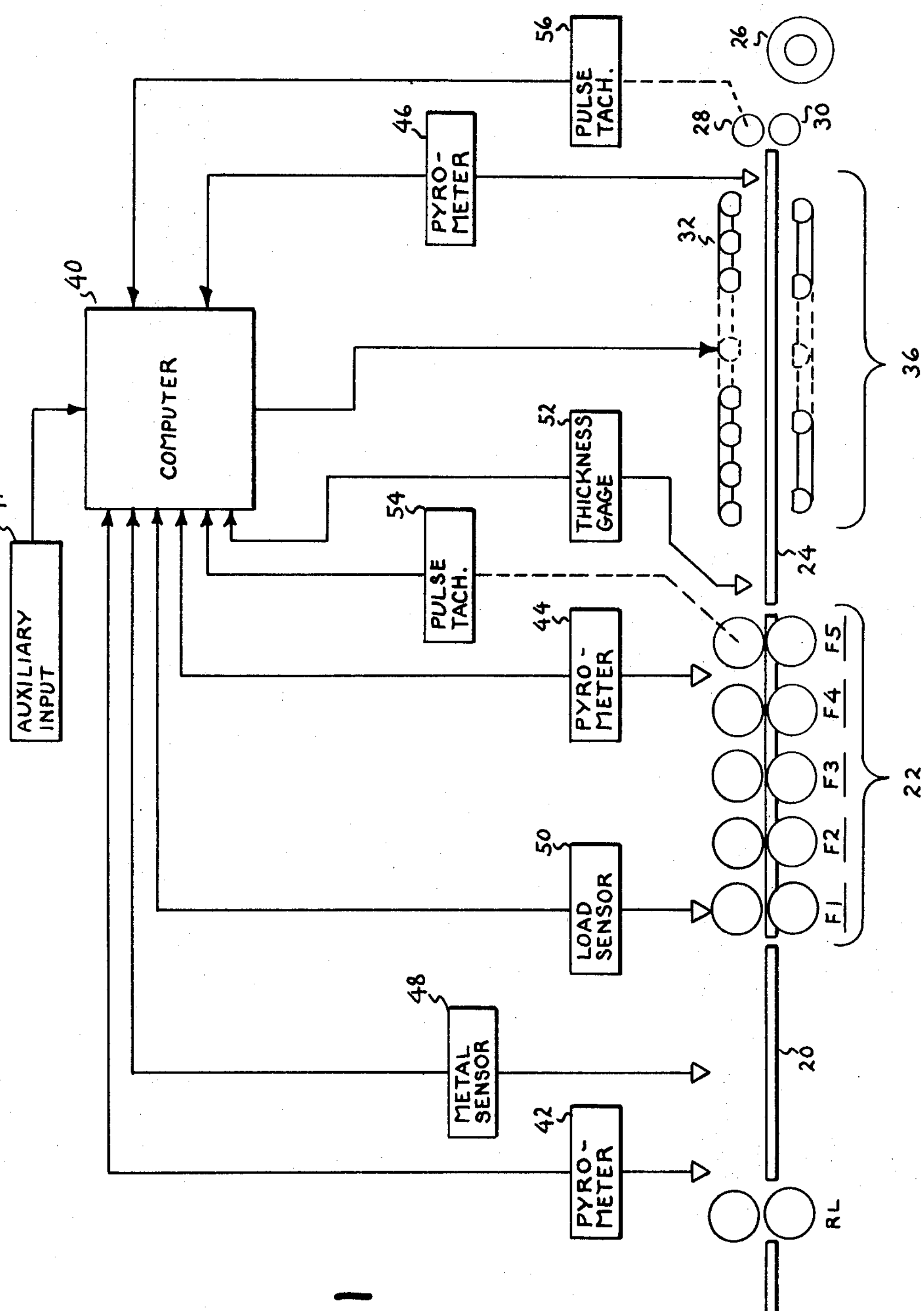

FIG. 1

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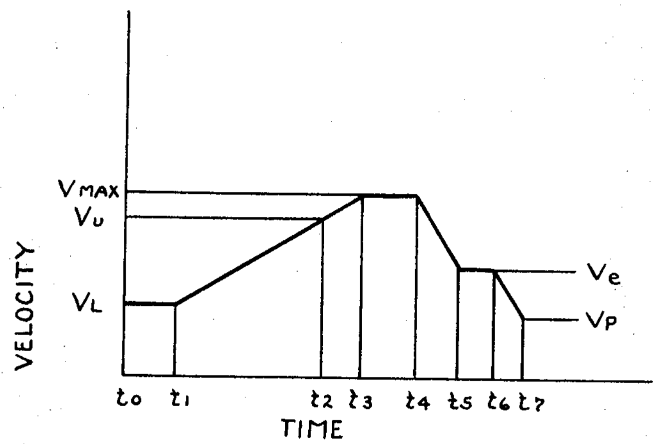
VMAX
VU
VL
Ve
VP
VELOCITY
t0 t1 t2 t3 t4 t5 t6 t7
TIME

FIG. 2

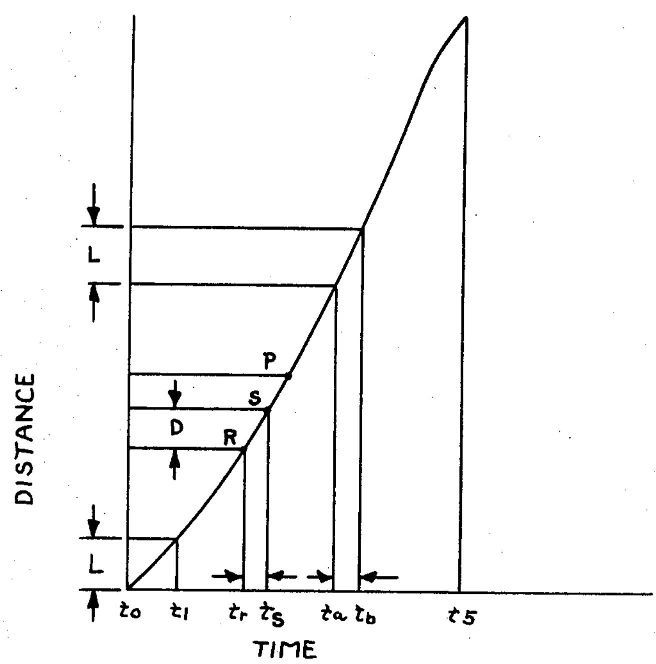
DISTANCE
L
D
L
P
S
R
t0 t1 tr ts ta tb t5
TIME

FIG. 3

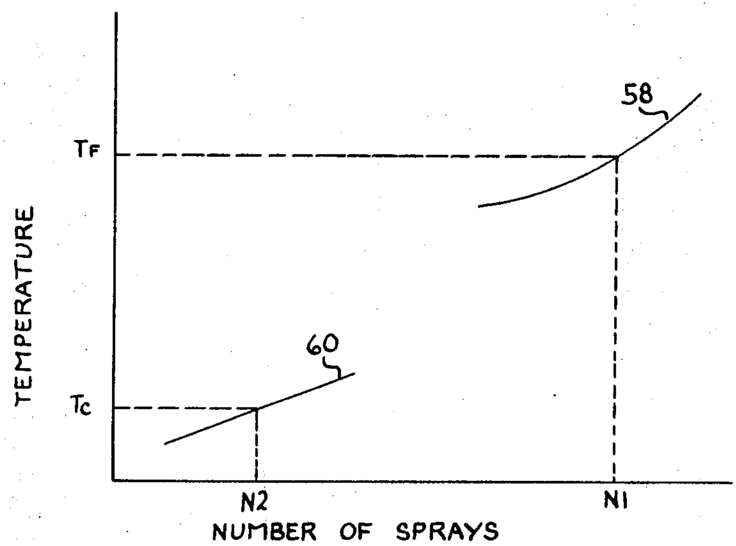
58
TF
TEMPERATURE
60
Tc
N2
N1
NUMBER OF SPRAYS

FIG. 4

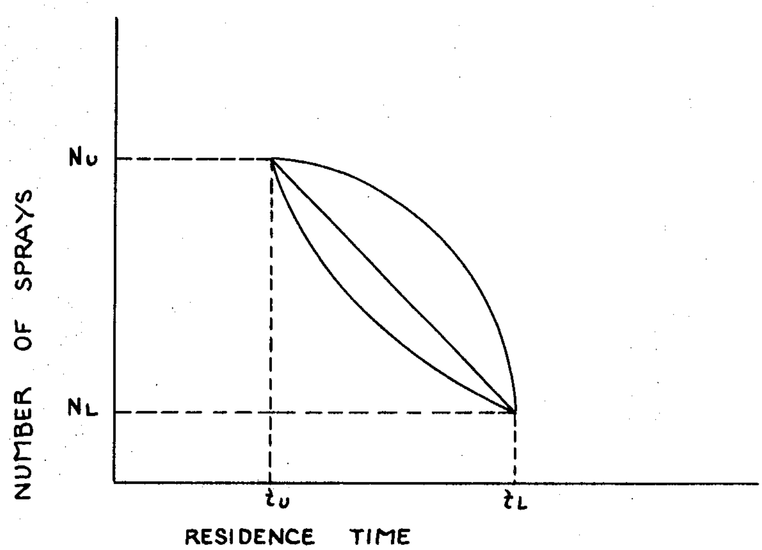
NU
NUMBER OF SPRAYS
NL
tU
tL
RESIDENCE TIME

FIG. 5

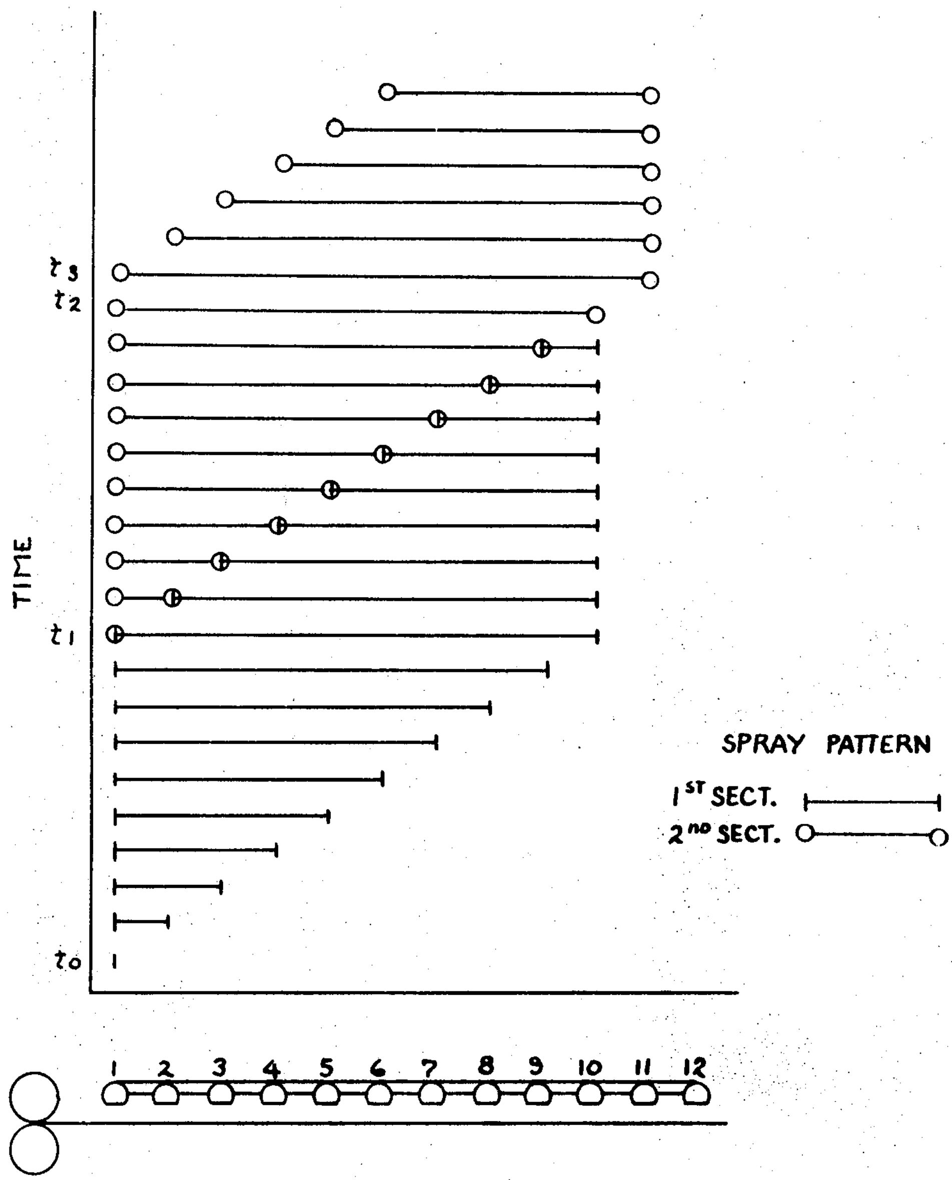
TIME
t_3
t_2
t_1
t_0
SPRAY PATTERN
1ST SECT.
2ND SECT.
1 2 3 4 5 6 7 8 9 10 11 12

FIG. 6

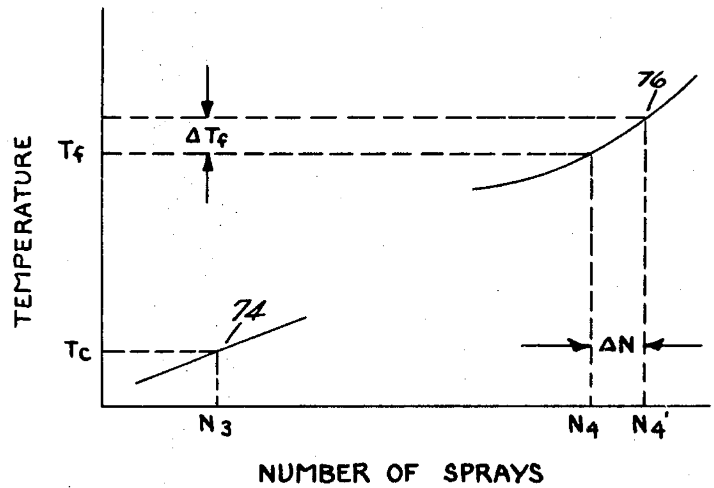

FIG. 7

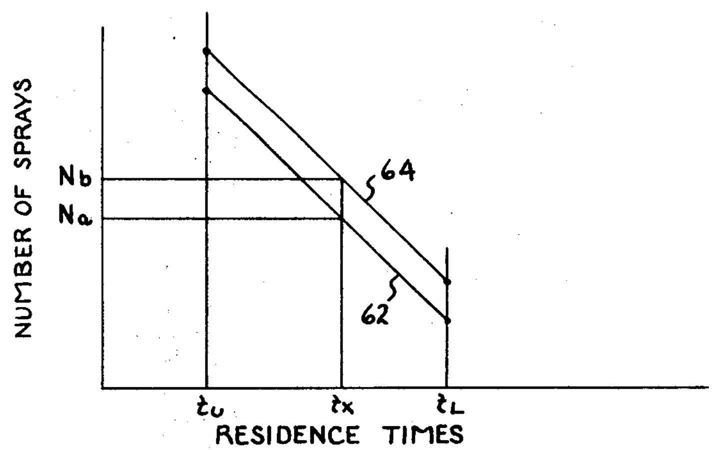

FIG. 8

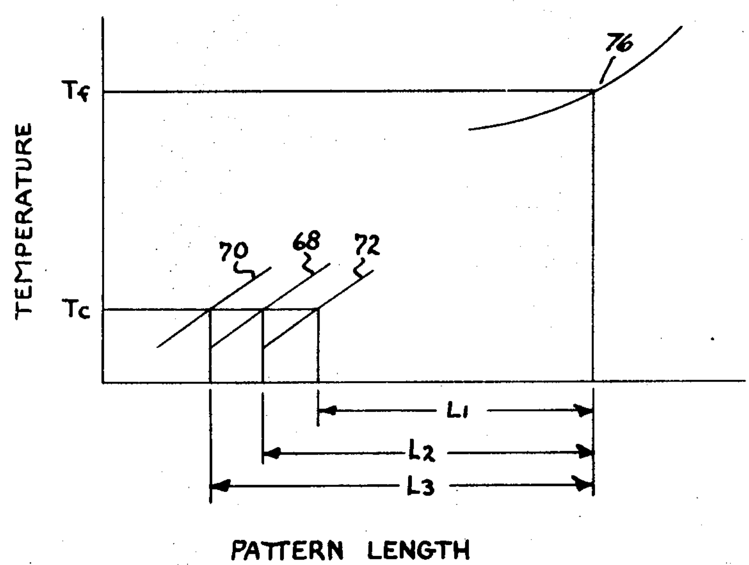

FIG. 9

TEMPERATURE CONTROL SYSTEM FOR MILL RUNOUT TABLE

BACKGROUND OF THE INVENTION

The present invention relates generally to metal deforming and more particularly to the controlled cooling of a workpiece following a metal-deforming operation.

In a tandem hot strip rolling mill, a relatively thick metal workpiece or slab having an initial temperature of approximately 2,200° F. is reduced to a relative thin, elongated metal strip as it passes through a number of mill stands arranged in tandem along a mill table. By the time the strip leaves the last stand in the mill, heat losses caused by radiation, interstand cooling sprays and/or strip-to-roll conduction reduce the strip temperature to 1,400° F. -1,750° F. depending upon the gage of the strip. Upon leaving the last stand, the strip traverses a runout table on its way to a coiler where it is coiled and banded. The runout table serves as a cooling zone in which the temperature of the strip is reduced to a level suitable for the coiling operation. Depending upon the gage of the strip, the desired coiling temperature may range from 850° F. to 1,500° F. Because the runout table is normally about 500 feet long and because the speed at which the strip exits the last stand of the finishing train may be as high as 3,500 feet per minute, water sprays positioned above and below the runout table are usually needed to provide sufficient cooling. The amount and distribution of cooling water delivered by these sprays is controlled to regulate the rate of cooling.

In some rolling mills, the water sprays are controlled manually. An operator observes the temperature of the strip by means of pyrometers located at the last stand in the finishing train and at the coiler. If predetermined temperature variations are observed, the operator tries to manipulate the distribution of cooling sprays to correct the temperature error. Instrument lag and operator response time coupled with the high speeds at which the strip traverses the runout table often keep the operator from altering the spray distribution at the time and place needed to properly correct the temperature deviation.

Automated control systems have been developed which respond to sensed temperature deviations to control the water sprays. However, even with these systems no attempt has been made to alter the spray distribution to affect only the area of temperature deviation. For example, if higher than normal temperatures are sensed at the entry to the runout table, an increased number of sprays are immediately applied to the strip already on the runout table regardless of the actual temperature of the strip in the area of the added sprays.

SUMMARY OF THE INVENTION

The present invention relates to the controlled cooling of a strip as it traverses a runout table. The residence time or time on the runout table is calculated for contiguous sections of the strip according to the extant velocity-time profile for the strip. Based on the residence time for each section and the initial and desired final temperatures of the strip, a spray pattern or number of sprays is calculated for each section. The sprays are then controlled to effect successive pattern adjustments as the appropriate sections traverse the runout table.

DESCRIPTION OF THE DRAWINGS

While the specification concludes with claims particularly pointing out and distinctly claiming that which is regarded as the present invention, details of a preferred embodiment of the invention may be more readily ascertained from the following detailed description when read in conjunction with the accompanying drawings in which:

FIG. 1 is a simplified view of a hot strip mill in which the invention finds use;

FIG. 2 is a representative velocity-time profile for a strip traversing a runout table;

FIG. 3 is a graph of the integral of part of the velocity-time profile of FIG. 2 with respect to time;

FIG. 4 is a graph of temperature curves used to calculate spray patterns at given workpiece speeds as a function of a desired temperature drop;

FIG. 5 is a graph showing a family of pattern v. residence time curves;

FIG. 6 is a representation of successive spray patterns for two contiguous sections of a strip;

FIG. 7 is a graph of temperatures v. numbers of sprays illustrating an adaptive process based on finishing train temperature feedback;

FIG. 8 is a graph of numbers of sprays v. residence times illustrating the effects of the adaptive process based on finishing mill temperature feedback; and

FIG. 9 is a graph of temperatures v. pattern lengths illustrating the effects of an adaptive process based on coiling temperature feedback.

DETAILED DESCRIPTION

In a hot strip mill, the initial reductions in the thickness of a metal slab are taken in a set of tandem mill stands known collectively as a roughing train. FIG. 1 shows, in greatly simplified form, the last stand R_L of a roughing train along with other components in a hot strip mill. As the slab emerges from the stand R_L, it moves across a mill table **20** toward a finishing train **22** consisting of mill stands **F1**, **F2**, **F3**, **F4**, and **F5** arranged in tandem. The final reductions in thickness are taken in the finishing train **22** to produce a metal strip 1,000 or more feet in length. As the strip emerges from the last stand **F5** in the finishing train **22**, it traverses a cooling or runout table **24** before being wound by a coiler **26**. Strip tension during the coiling operation is maintained by a pair of pinch rolls **28** and **30** located at the coiler end of the runout table **24**.

The strip temperatures at which the coiling operation may be carried out are considerably lower than the strip temperatures at the last stand in the finishing train **22**. A number of individually controllable cooling sprays, one of which is designated by the numeral **32**, are located above and below the runout table **24** to form a cooling zone **36** in which the strip is water-cooled to the proper temperature for coiling. The cooling zone **36** is typically on the order of 300 feet long and is made up of 20 to 100 sprays located above the runout table **24** and approximately the same number located below the runout table **24**.

The speed of a strip emerging from the finishing train **22** is not constant but may vary as the finishing train **22** is accelerated and decelerated to increase productivity or to maintain a constant finishing train temperature whenever possible while remaining within safe operating limits. To cool each section of the strip to a relatively constant temperature by the time that section reaches the coiler **26**, the amount of cooling water that is applied to the strip in the cooling zone **36** is adjusted by regulating the number of sprays that are turned on at a particular time. According to a preferred embodiment, the length of the spray pattern is varied while the volume of water delivered by each spray remains constant whenever that spray is on.

The temperature of the strip is monitored by three different pyrometers. The first pyrometer **42** is located at the exit side of the last stand R_L in the roughing train. The second pyrometer **44** is located between the penultimate stand **F4** and the last stand **F5** in the finishing train **22** whereas the third pyrometer **46** is located at the entry to the coiler **26**. The temperature sensed by the pyrometer **42** is one factor in determining the initial spray pattern. The temperature feedbacks from the pyrometers **44** and **46** may be used to modify spray patterns for a strip currently being cooled and to adapt stored data to improve the control of cooling of subsequent strips.

The ends of a strip are detected by a metal sensor **48** located above the mill table **20**, a load sensor **50** located in stand **F1** and a thickness gage **52** located between the stand **F5** and the cooling zone **36**. Detecting the ends of the strip are secondary functions for the load sensor **50** and the thickness gage **52**, their respective primary functions being measurement of roll separating forces at stand F1 and measurement of the final gage of a strip. A first pulse tachometer **54** mechanically coupled to one of the rolls in stand F5 monitors the velocity of and elapsed distance traveled by the strip as it emerges from the finishing train **22**. A second pulse tachometer **56** mechanically coupled to pinch roll **28** may be used to monitor the travel and velocity of the strip after the tail end of the strip leaves the stand F5 so that the pulse tachometer **54** is no longer effective. Outputs from the described sensors are applied to a computer **40** which has an auxiliary input **41** and an output to the sprays in cooling zone **36**.

The speeds at which the finishing train **22** operates determine the strip velocities until the tail end of the strip leaves stand F5. At that time, strip velocity control passes to the coiler **26**. In either situation, the speeds are determined by the properties of the strip according to predetermined relationships which, taken in chronological sequence, establish a velocity-time profile of the type illustrated in FIG. 2.

The relationships between the strip properties and the mill speeds are stored in computer **40**. Based upon information supplied through the described sensors and through auxiliary input **41**, computer **40** establishes the breakpoints and acceleration rates for the profile. Referring now to FIG. 2, when the head end of a strip emerges from finishing train **22** and reaches the runout table **24** at a time t_o, it moves at a lower base speed V_L equal to the thread speed of the finishing train **22**. The thread speed is established as a function of the strip temperature and gage at the entry to the finishing train **22**. The strip traverses the runout table **24** at the velocity V_L until the head end reaches the coiler **26** at time t_1. When the head end is picked up by the coiler **26**, the finishing train **22** and the coiler **26** are accelerated at a rate established by computer **40** as a function of the finished gage of the strip. The velocity of a sufficiently long strip may exceed an upper base speed V_u at time t_2 and reach a maximum speed V_{max} which is set by computer **40** as a function of the entry gage, width, and temperature of the strip to assure that the mill operates within power and torque limits. The speed V_u may be set as a fixed percentage of V_{max} which will permit temperature readings to be completed at V_u before the strip reaches V_{max}.

Assuming that V_{max} is reached at a time t_3, the finishing train **22** operates at that velocity until the tail end of the strip leaves the stand F1 in the finishing train **22** at a time t_4. After a delay proportional to strip dimensions and velocity, the finishing train **22** is decelerated at a fixed rate to a velocity V_e at which it is safe for the tail end of the strip to leave the stand F5. Like the acceleration rate for the strip, the value of velocity V_e is a function of the final gage of the strip. The tail end of the strip must be moving at the velocity V_e or less as it leaves stand F5 since the sudden release of strip tension at tail end exit velocities greater than V_e may cause the strip to whip along the runout table **24**. After the finishing train **22** has decelerated to the velocity V_e at a time t_5, the strip velocity is held constant until the tail end actually leaves stand F5. As the tail end crosses the runout table **24**, the speed of the strip is reduced further starting at a time t_6 to reduce the strip velocity to a safe pickup velocity V_p (preferably established by a mill operator) by a time t_7 when the tail end reaches the coiler **26**.

According to the present invention, the length of spray patterns are controlled as functions of (1) the time required for strip sections to traverse the runout table (residence times) and (2) the instantaneous location of those sections in the cooling zone **36**. Both residence times and locations for the sections may be derived through integration of the strip velocity-time profile with respect to time. FIG. 3 illustrates the integral of the velocity-time profile of FIG. 2 between the times t_0 and t_5. The vertical axis of the integral curve represents the elapsed distance traveled by the strip after the head end reaches the runout table at 0 elapsed distance and a base time t_o. The horizontal axis represents the time in seconds for a point on the strip to travel any set distance from the beginning of the runout table. For calculating residence times, the length of the runout table is represented by a fixed distance L along the elapsed distance axis. As would be expected from the velocity-time profile, the distance L is traveled by the head end of the strip in a residence time $t_1 - t_o$. The residence time for any other point on the strip is established as the time required (measured horizontally) for the point to move a distance L (measured vertically) along the integral curve. Assuming that a particular point reaches the beginning of the runout table at a time t_a, it may be seen from FIG. 3 that it will travel the distance L and thus remain on the runout table until a time t_b. The residence time for that point is equal to the difference between these two times or $t_b - t_a$.

In order for the residence time calculations to be useful, the sections for which calculations are made must be located relative to a base point. In a preferred embodiment, each section is located relative to the head end of the strip by pulse tachometer **54** and a suitable digital counter (not shown) once the head end is sensed by thickness gage **52**. The number of pulses produced by the pulse tachometer **54** is directly proportional to the elapsed distance traveled by the head end of the strip. Knowing the number of pulses produced by pulse tachometer **54** per foot of strip movement and the distance in feet between a particular section and the head end, the section can be identified as being at the beginning of the runout table when the accumulated count equals the product of the two. For example, if the pulse tachometer **54** produces 2 pulses per foot of strip movement and a section is known to be 300 feet behind the head end of the strip, that section is identified as being at stand F5 when the accumulated count equals 2 pulses/foot × 300 feet or 600 pulses.

The time in seconds required for a section to reach any point on the runout table after leaving the stand F5 may also be established using the integral curve of FIG. 3. At any particular time the elapsed distance traveled by the strip head end is known from the accumulated count, thus fixing the head end location on the integral curve. Assuming the head end has traveled an elapsed distance which places it at point P on the curve and that the spacing between the head end and the point under consideration is such that the point is at stand F5 at point R, the time required for the element to move a known elapsed distance D to a particular point or spray S on the runout table is seen to be equal to $t_s - t_r$.

In a preferred embodiment of the invention, residence times are calculated for contiguous, equally long sections of a strip. When the head end of the strip reaches the stand F5, the pulses which tachometer **54** begins to generate are applied to a preset countdown counter (not shown) having an initial count equivalent to the section length. Movement of the strip across the runout table causes the counter to count down to zero repeatedly. Conventional circuits are used to generate a sampling pulse whenever a zero count is detected and to reset the counter to its preset condition. Each sampling pulse initiates a residence time calculation.

For the calculated residence times to be of value, they must be translated into terms of spray patterns. Stored graphs of the type shown in FIG. 4 are first used to establish spray patterns needed for sections traversing the runout table at the lower and upper base speeds. These graphs, which may be derived empirically or from theoretical heat transfer equations, depict finishing mill temperatures and coiling temperatures versus the number of sprays at a specific constant speed which is either the lower or the upper base speed for the strip. The thermal behavior of metal strips naturally vary with the gage and type of steel being cooled, making it necessary to store families of curves for different gage ranges and major types of steel. Thus, FIG. 4 wherein curve **58** represents a range of finishing mill temperatures and curve **60** represents a range of coiling temperatures would be valid only for a particular type of steel having a gage within a particular gage range and moving at a particular speed, either the lower or the upper base speed.

To calculate the number of sprays needed to reduce the temperature of a strip from a predicted finishing mill temperature T_f to a desired coiling temperature T_c at a particular speed, the intercepts of the temperature levels T_f and T_e with the curves **58** and **60** respectively from one of a family of curves are established. The T_f-curve **58** intercept fixes a first number of sprays **N1**. Similarly, the T_c-curve **60** intercept fixes a second number of sprays **N2**. The total number of sprays or spray pattern needed to reduce the temperature from T_f to T_c is established as the difference between N1 and N1. The number of sprays N_L needed to bring about the specified temperature drop at the lower base speed V_L establishes a minimum of sprays. The number of sprays N_u needed to bring about the same temperature drop at the upper base speed V_u is calculated in the same manner. However, since the upper base speed V_u is made less than the maximum speed V_{max} to permit feedback of temperature data before mill slowdown is initiated, additional calculations are needed to determine the maximum number of sprays which might be needed. Since V_u is a fixed percentage of V_{max}, the fixed ratio V_{max}/V_u serves as a multiplier which, when taken times N_u, yields the maximum number of sprays N_{max} needed at velocity V_{max}.

The number of sprays N_u and N_L expressed as functions of residence times form the end points for a curve which expresses the number of sprays required for sections having intermediate residence times. Referring now to FIG. **5**, the curve may be linear, concave, or convex depending upon the characteristics and dimensions of the strip being cooled. Regardless of the shape of the curve, the number of sprays N_x needed for a strip having a residence time t_x may be determined as the mathematical solution to the equation

$$N_x = N_L + \left(\frac{t_L - t_x}{t_L - t_u}\right)^k * (N_u - N_L)$$

where

N_x = number of sprays for an element traversing the runout table in a residence time t_x;

N_L = number of sprays for an element traversing the runout table at the lower base speed;

N_u = number of sprays for an element traversing the runout table at the upper base speed;

t_L = residence time of an element traversing the runout table at the lower base speed;

t_u = residence time of an element traversing the runout table at the upper base;

t_x = residence time of the element under consideration; and

k = shape-determining constant.

By establishing the residence time for the head end of every strip section and repeatedly solving the given equation using the established residence times, the spray patterns required for properly cooling all of the sections are established. To assure that each section of the strip is subjected to the required number of sprays, the sprays are controlled in sequence to track the section across the runout table. This is illustrated in FIG. **6** for two successive sections of the same strip. For purposes of this illustration, it is assumed that the strip velocities and temperatures are at levels which require a pattern length of 10 sprays for the first section and 11 sprays for the second section. For purposes of illustration, each section is considered to be 60 feet long, spanning (for typical spray spacing) 10 sprays.

The end sprays in the spray pattern which exists at a particular time are represented by a short vertical bar for the spray patterns for the first section and by a small circle for the spray patterns for the second section. Sprays located directly beneath these end point symbols or beneath the horizontal lines joining the symbols are to be considered "on" or delivering cooling water.

The head end of the first section reaches the area beneath spray **S1** at a time t_0. Responding to an action signal, spray **S1** turns on and remains on as the head end passes beyond the area. As the first section moves along the runout table, sprays **S2** through **S10** are added to the pattern in sequence as the head end of first section reaches and passes beyond each of them. At a time t_1, the head end reaches the spray **S10**. The required 10 sprays are then operating and no additional sprays need be added for the first section. If there were no second section, the sprays **S1** through **S10** would be removed from the pattern in sequence as the tail end of the first section reached and passed beyond each of them until finally, at a time t_2, spray **S10** would be the only remaining operating spray.

There is, however, the second section, the head end of which corresponds to the tail end of the first section. The spray patterns for this second section are established in the same manner as the spray patterns for the first section. That is, sprays are added to a pattern in sequence to track the head end of the section and are removed in sequence to track the tail end of the section. However, because sprays **S1** through **S10** are already on when the head end of the second section reaches them, these sprays merely remain on continuously. The required eleventh spray **S11** is added just before the head end of the second section reaches it at a time t_3. At that time, the required eleven sprays are on but remain on only until the tail end of the second section passes beyond spray **S1**. The sprays **S1** through **S11** are then removed in sequence to track the tail end of the second section across the runout table until all eleven sprays are off again. Although only part of the spray removal sequence for the second section has been shown, it should be understood that the removal sequence does continue until every spray in the pattern at time t_3 is off again.

The illustration is based on a strip consisting of only two sections, which would be on the order of 120 feet long. In practice, strips are much longer than this. Consequently, the only times the tracking action is apparent are (1) when the sprays are added to track the strip head end across the runout table, (2) when the sprays are removed to track the strip tail end across the runout table, and (3) when sprays are added or removed to account for changes in the residence times and/or temperatures of intermediate sections entering the cooling zone.

The times required for the head and tail ends of a section to reach particular sprays after leaving the last stand are determined from the integral of the velocity-time profile as was described in connection with FIG. **3**. The control signals which are used to control values in the spray system are generated in accordance with these required times and in accordance with the known response times of the spray valves. For example, it may be known from the velocity-time integral that the head end of a section takes X seconds to travel from the last stand to a spray to be added to the pattern and that the spray itself requires Y seconds to go from its off to its on state. Consequently, the control signal for that spray would be generated (X–Y) seconds after the head end leaves the last stand. The same type of calculation would be made where the spray is to be turned off. However, the valve turnoff time may not be the same as its turn on time thus making it necessary to use a different quantity for the Y-term when removing sprays than when adding them.

To clarify the relationships between residence times, spray pattern lengths, and spray pattern timing in a preferred embodiment of the invention, the cooling of a strip is described with reference to FIG. **1**. The composition, entry gage, width, predicted final gage and temperature of the strip are supplied to computer **40** through auxiliary input **41** and pyrometer **42** before the strip enters the finishing train **22**. Using this information and stored relationships, computer **40** can determine the lower base speed V_L, the acceleration rate, the maximum speed V_{max}, and the last stand exit speed V_e.

When the strip is detected by metal sensor **48**, the spray L N_L and N_u required at the lower and upper base speeds are determined from stored data of the type depicted in FIG. **4** using the finishing train temperature and the desired coiling temperature. Since the initial spray pattern is partially a function of finishing train temperature, but must be calculated before the strip reaches the finishing train pyrometer **44**, the strip temperature is measured by pyrometer **42** and, based on known thermal conditions, is projected through the finishing train **22** to establish a predicted finishing mill temperature. The desired coiling temperature can be established by means of an operator input through auxiliary input **41**. In the alternative, coiling temperatures may be stored in the memory of computer **40** as a function of final gage. The timing of action signals needed to establish the initial spray pattern is not established until the head end is sensed by the load sensor **50** at stand F1 in the finishing train **22**. By delaying the calculation of action signals in this manner, timing errors due to unexpected delays between stands R_L and F1 are avoided.

When the strip head end reaches stand F5, the pulse tachometer **54** begins to monitor both strip velocity and the elapsed distance traveled by the strip head end. Spray pattern and timing calculations are initiated for the remainder of the strip when the head end is sensed by thickness gage **52**. As the head end of each succeeding section of the strip is identified at stand F5 by the pulse tachometer **54** acting on the preloaded counter, the residence time of that section is predicted from the extant velocity-time profile. The length of the spray pattern and the timing of the action signals are calculated for the section at stand F5, based on the velocity profile of the strip as it then exists.

The tail end of the strip is detected at the first stand F1 of the finishing train **22** by the loss in rolling load monitored by the load sensor **50**. The detection of the tail end initiates a mill slowdown procedure which causes the strip to slow to a safe exit velocity by the time the tail end reaches the last stand F5 of the finishing train **22**. Final turnoff times for the sprays which have been on for the last strip section are calculated at this same time. When the tail end of the strip passes thickness gage **52**, the optional pulse tachometer **56** may begin to monitor the strip velocity as the tail end traverses the runout table **24**.

The present invention, as described above, is predictive in nature. That is, spray pattern lengths and the timing of action signals are initially predicted as functions of predicted velocities, predicted temperatures, and predicted relationships between spray patterns and their effects on strip temperature. To provide a check on system performance while a strip is being cooled and to refine the predictive approach, adaptive feedbacks are provided by pyrometers **44** and **46**.

When the temperature at stand F5 as measured by pyrometer **44** deviates from the predicted constant finishing train temperature, the spray pattern lengths N_u and N_L required at the upper and lower base speeds are recalculated on a section-to-section basis to provide more or fewer sprays for each section depending on the magnitude and type of deviation between the predicted temperature and the measured temperature of the section. The adaptive process is illustrated with reference to FIGS. **7** and **8**. FIG. **7** is similar to FIG. **4** in depicting finishing train temperatures and coiling temperatures versus the number of sprays at a specific constant speed. As was discussed earlier, the number of sprays needed at the constant speed is determined before the strip reaches the runout table by establishing (1) a first number of sprays N3 defined by the intercept of the desired coiling temperature T_c and a coiling temperature curve **74** and (2) a second number of sprays N_4 defined by the intercept of the predicted finishing train temperature T_f and a finishing train temperature curve **76**. The number of sprays is equal to the difference between N_4 and N_3. If, however, the measured finishing train temperature of a strip section deviates from the predicted finishing train temperature T_f by an amount ΔT_f, the incremental number of sprays ΔN to be added or subtracted is determined from the intercept of the measured finishing train temperature $(T_f+\Delta T_f)$ and the finishing train temperature curve **76**. Since the shape of the finishing train temperature curve valid at one base speed probably will not be the same as the shape for the other base speed, the term ΔN may be different for the lower and upper base speeds.

The effect of the section-to-section adaptive process on pattern length calculations is shown in FIG. **8** wherein line **62** represents the originally calculated relationship between the numbers of sprays and the residence times. Assuming that the finishing mill temperature which is measured at any particular section exceeds the predicted temperature, new values for N_u and N_L for that section are calculated by the above-described procedure. The coordinates of the curve are changed at residence times t_u and t_L to establish a new curve **64**. Assuming that the particular section for which the recalculations are made has a residence time t_x, the number of sprays which will be applied to the section are increased from the number N_a based on the predicted finishing train temperature (curve **62**) to a number N_b based on the measured finishing train temperature (curve **64**).

In a preferred form of the invention, the adaptive process is simplified by noting the slope of the finishing train temperature curve **76** at predicted temperature T_f when original calculations are made. After that, incremental changes in the number of sprays to account for temperature deviations may be calculated as the product of the temperature deviation and the inverse of the slope. Such a simplification assumes that the finishing train temperature curve **76** is linear, which it isn't. However, for temperature deviations on the order of 100° F. or less, curve **76** is sufficiently linear to permit the simplification without introducing significant error. In the unlikely event the actual temperature deviation exceeds 100° F., the noted deviation may be limited to 100° F. during the adaptive calculations.

To refine the predictive approach on a strip-to-strip basis, the coiling temperatures at the lower and upper base speeds are monitored by pyrometer **46**. When a predetermined discrepancy between the desired coiling temperature and the monitored coiling temperature is noted, the stored coordinates of the appropriate FIG. **4** curve are altered. Referring to FIG. **9**, the alteration is effected by shifting the original coiling temperature curve **68** horizontally. If the monitored coiling temperatures exceed the desired coiling temperature, the curve could be shifted to the left to a new position **70**, thereby increasing the pattern length from L_2 to L_3 at the particular base speed for which FIG. **9** is valid. Conversely, if the monitored temperature falls below the desired coiling temperature, the curve could be shifted to the right to a new position **72** reducing the pattern length from L_2 to L_1.

Another type of adaptation involves the measured finishing mill temperature and the rate at which the strip is accelerated once it is threaded. It is a known practice to control mill acceleration in accordance with measured finishing mill temperatures. If the strip temperature varies, the mill is accelerated to reduce heat losses or decelerated to increase heat losses to attempt to maintain a constant finishing mill temperature. The acceleration rate needed to maintain a constant temperature for a strip of a particular gage is recorded. The next time a strip of that gage is rolled, the new acceleration rate is used in place of the old.

The same result may be obtained in mills where acceleration is not varied during the cooling of a particular strip. By noting the extent of deviation, an estimate of the needed new acceleration rate may be made. This estimate may be refined when the new acceleration rate is used during the cooling of subsequently processed strips.

What is claimed is:

1. For use in a rolling mill including a finishing train, a runout table with controllable cooling sprays, and a coiler, the method of cooling a strip as the strip traverses the runout table at varying velocities comprising the steps of:

a. calculating the time at which each of contiguous fixed length sections of the strip are situated at predetermined locations along the runout table; said calculation being accomplished by:

I. predictively establishing a velocity profile for the strip traversal along the runout table;

II. integrating the velocity profile with respect to time to ascertain the elapsed distance traveled by each fixed length section of the strip as a function of time; and

III) determining from the integral the time required for each section of strip to travel the elapsed distance between entry to the runout table and predetermined locations along the runout table,

b. determining the number of sprays required to cool each of the contiguous sections from a finishing train temperature to a desired coiling temperature as a function of the residence times of said sections on said runout table; and

c. altering the initiation and number of sprays applied to the strip in a sequence coinciding with the movement of the sections across the runout table whereby each of the contiguous sections is subjected to the number of sprays determined to be required for each section, each of said sprays being initiated at a time when said sections are determined to have traveled the required distance from entry to said table to be in registration with each of said number of sprays.

2. For use in a rolling mill including a finishing train, a runout table with controllable cooling sprays, and a coiler, the method of cooling a strip as the strip traverses the runout table at varying velocities comprising the steps of:

a. determining the amount of time during which each of contiguous sections of the strip will reside on the runout table;

b. determining the number of sprays required to cool each of the contiguous sections from a finishing train temperature to a desired coiling temperature as a function of the residence times, said required number of sprays being determined by:

I. calculating the number of sprays required to cool a strip section traversing the runout table at a lower base speed requiring a predetermined lower residence time from one of a family of stored curves wherein each curve in the family expresses the number of required sprays at the lower base speed for ranges of finishing train temperatures and coiling temperatures for a strip section having a gage falling within a particular gage range;

II. calculating the number of sprays required to cool the same strip section when that section traverses the runout table at an upper base speed requiring a predetermined upper residence time from one of a second family of stored curves where each curve in the second family expresses the number of required sprays at the upper base speed for ranges of finishing train temperatures and coiling temperatures for a strip section having a gage falling within a particular gage range; and

III. calculating the number of sprays required for each section having another residence time as a function of the relative magnitude of the other residence time and the upper and lower residence times, and

c. altering the number of sprays applied to the strip in a sequence coinciding with the movement of the sections across the runout table, whereby each of the contiguous sections is subjected to the number of sprays determined to be required for that particular section.

3. The method recited in claim **2** including the further steps of:

a. measuring the temperature of each section of the strip near the exit from the finishing train;

b. comparing the measured finishing train temperature with an expected finishing train temperature to determine the magnitude and type of temperature deviation exhibited by each section;

c. determining the number of sprays required to cool each section at the measured finishing train temperature utilizing said ones of said families of stored curves expressing the number of required sprays at the lower and upper base speeds; and

d. modifying the number of sprays applied to each section as the section traverses the runout table as a function of the difference between the number of sprays required for the expected finishing train temperature and the number of sprays required for the measured finishing training temperature.

4. The method recited in claim **2** including the additional steps of:

a. measuring the coiling temperatures obtained by use of the cooling sprays at strip sections requiring predetermined residence times to traverse the runout table;

b. comparing the measured coiling temperatures with the desired coiling temperatures to establish a temperature error;

c. displacing said ones of said families of stored curves by an amount proportional to the established temperature error; and

d. calculating the number of sprays required to cool a subsequently processed strip utilizing said displaced ones of said families of curves.

5. The method recited in claim **1** wherein the time at which a particular spray is to be added or removed to control the cooling of a particular section is established by establishing the time at which a spray-controlling signal should be generated both as a function of the determined travel time and the known response time of the spray.

6. A method as recited in claim **5** wherein the required number of sprays for each section is determined by:

a. calculating the number of sprays required to cool a strip section traversing the runout table at a lower base speed requiring a predetermined lower residence time from one of a family of stored curves where each curve in the family expresses the number of required sprays at the lower base speed for ranges of finishing mill temperatures and coiling temperatures for a strip section having a gage falling within a particular gage range;

b. calculating the number of sprays required to cool the same strip section when that section traverses the runout table at an upper base speed requiring a predetermined upper residence time from one of a second family of stored curves where each curve in the second family expresses the number of required sprays at the upper base speed for ranges of finishing mill temperatures and coiling temperatures for a strip section having a gage falling within a particular gage range; and

c. calculating the number of sprays required for each section having another residence time as a function of the relative magnitude of the other residence time and the upper and lower residence times.

7. The method recited in claim **2** including the further steps of:

a. measuring the temperature of each section of the strip near the exit from the finishing train;

b. comparing the measured finishing train temperature with an expected finishing train temperature to determine the magnitude and type of temperature deviation exhibited by each section;

c. modifying the number of sprays applied to the particular section as it traverses the runout table as a function of the temperature deviation exhibited by that section.

8. The method recited in claim **2** including the additional steps of:

a. measuring the coiling temperatures obtained by use of the cooling sprays on strip sections requiring predetermined residence times to traverse the runout table;

b. comparing the measured coiling temperatures with the desired coiling temperatures to establish a temperature error; and

c. modifying the relationship between the number of sprays and the finishing train and coiling temperatures as a function of the magnitude and type of temperature error to reduce the error during the cooling of subsequently processed strips.

9. The method recited in claim 6 including the additional steps of:
   a. measuring the temperature of each section of the strip near the exit from the finishing train;
   b. comparing the measured finishing train temperature with an expected finishing train temperature to determine the magnitude and type of temperature deviation exhibited by each section;
   c. modifying the number of sprays applied to each particular section as it traverses the runout table as a function of the temperature deviation exhibited by that section.

10. The method recited in claim 6 including the additional steps of:
   a. measuring the coiling temperatures obtained by the use of cooling sprays on strip sections traversing the runout table at the upper and lower base speeds;
   b. comparing the measured coiling temperatures with the desired coiling temperatures to establish temperature errors at the upper and lower base speeds; and
   c. modifying the number of sprays to be applied to sections of subsequently processed strips traversing the runout table at the upper and lower base speeds as a function of the magnitude and types of temperature errors measured at those speeds.

11. The method recited in claim 7 including the additional steps of:
   a. measuring the coiling temperatures obtained by the use of cooling sprays on strip sections requiring predetermined residence times to traverse the runout table;
   b. comparing the measured coiling temperatures with the desired coiling temperatures with the desired coiling temperatures to establish a temperature error; and
   c. modifying the number of sprays required to cool contiguous sections of the strip from the finishing train temperature to the desired coiling temperature as a function of the magnitude and type of temperature error.