

July 26, 1966

D. BEGGS

3,262,688

JET CONVECTION HEAT TRANSFER

Original Filed Oct. 30, 1961

4 Sheets-Sheet 1

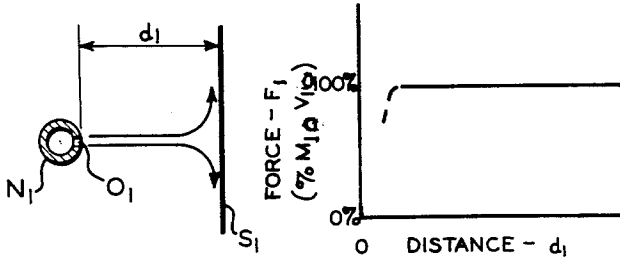


FIG. 1.

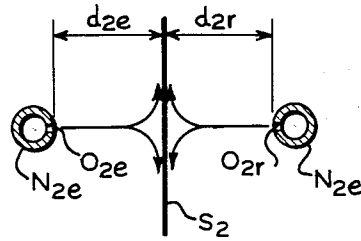


FIG. 2.

FIG. 3.

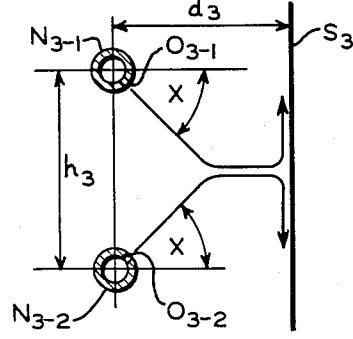
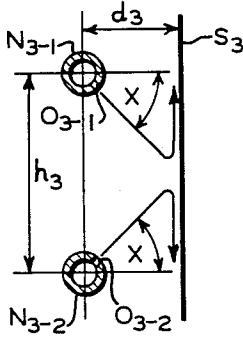
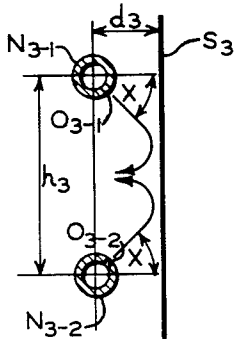


FIG. 4.

FIG. 5.

FIG. 6.

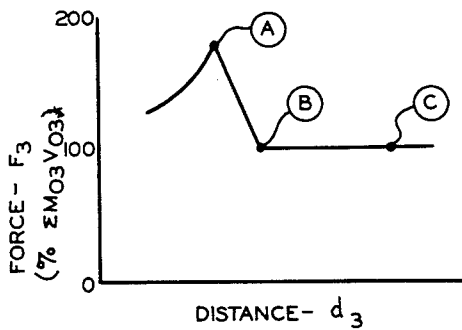


FIG. 7.

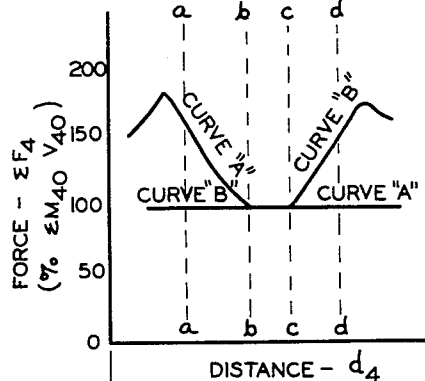


FIG. 8.

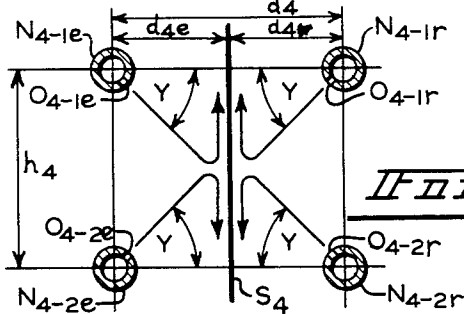


FIG. 9.

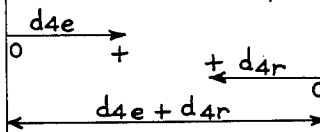


FIG. 10.

INVENTOR.
DONALD BEGGS

BY
Alfred L. Patmore, Jr.

ATTORNEY

July 26, 1966

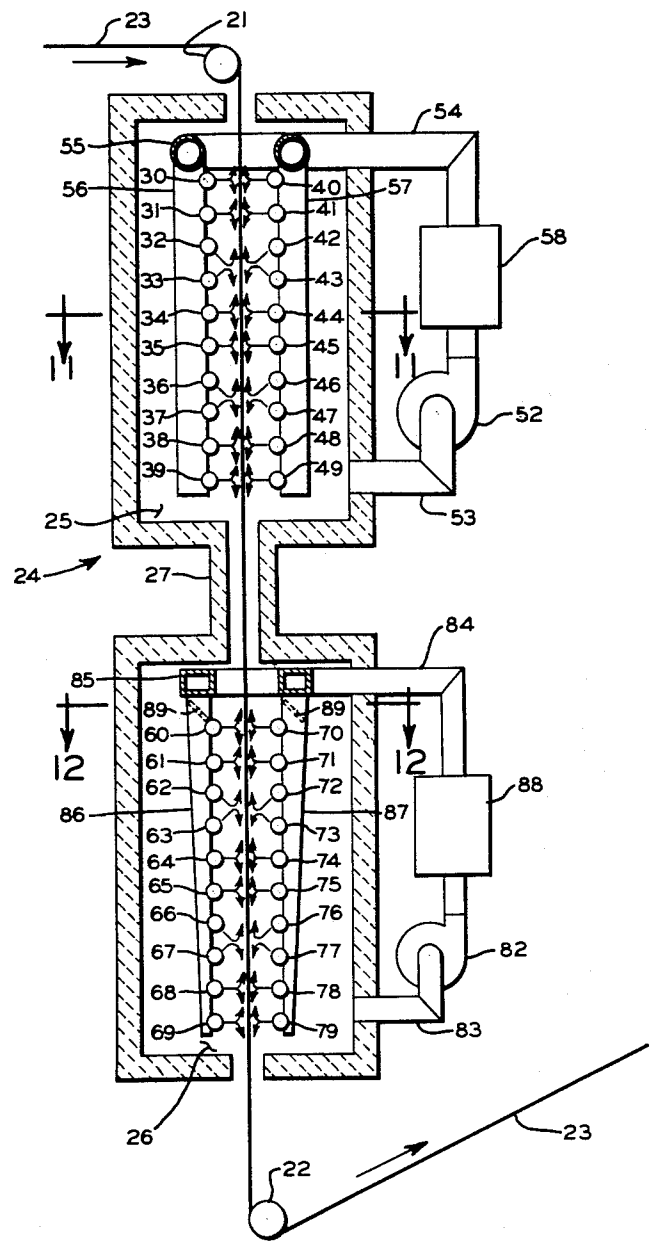
D. BEGGS

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INVENTOR.

DONALD BEGGS

BY

Alfred L. Patmore, Jr.

ATTORNEY

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D. BEGGS

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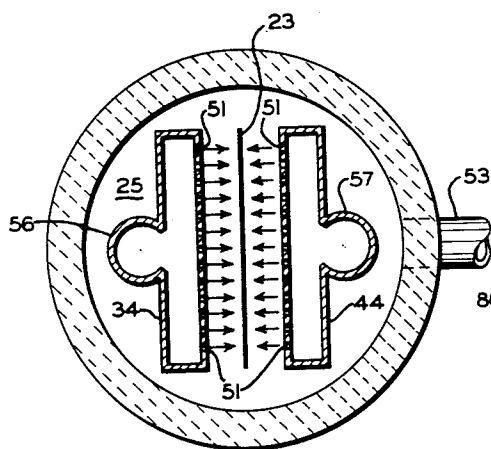


FIG. 11

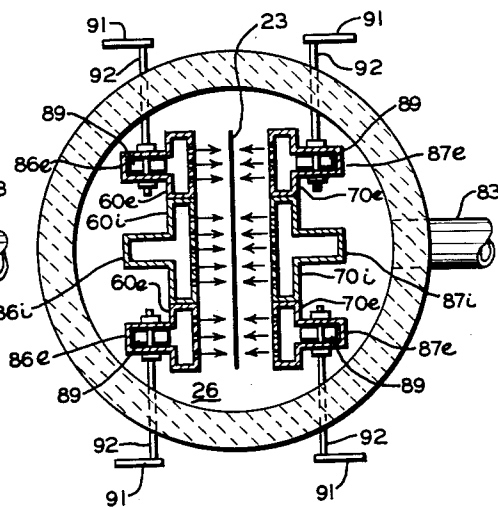


FIG. 12

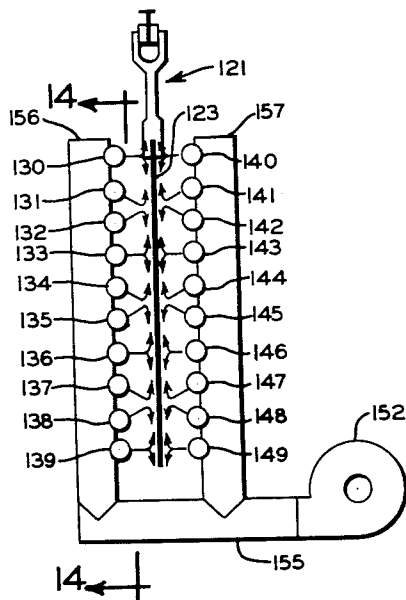


FIG. 13

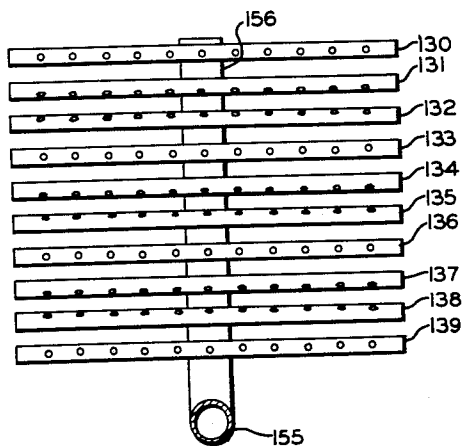


FIG. 14

INVENTOR.

DONALD BEGGS

BY

Alfred L. Patmore, Jr.

ATTORNEY

July 26, 1966

D. BEGGS

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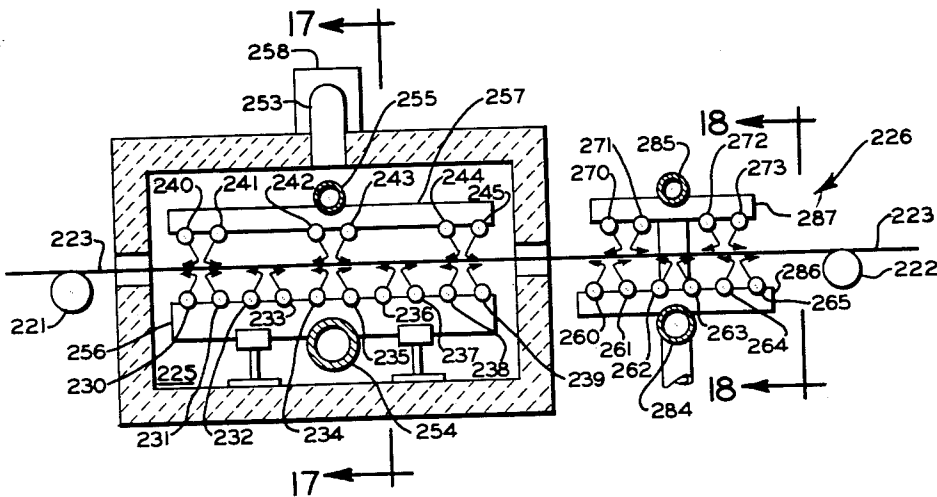


Fig. 16

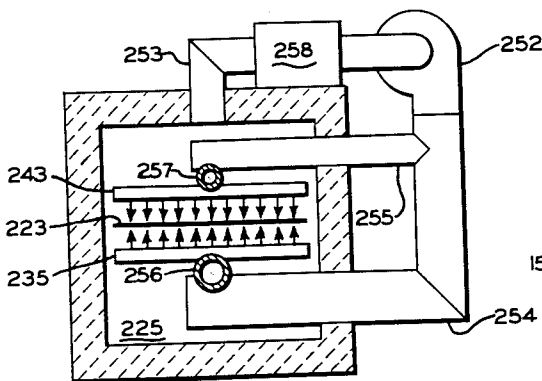


Fig. 17

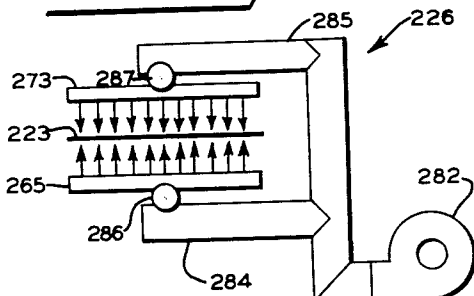


Fig. 18

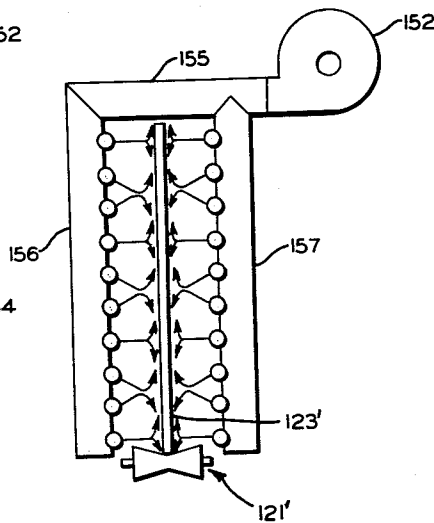


Fig. 19

INVENTOR.
DONALD BEGGS
BY
Alfred L. Patmore Jr.
ATTORNEY

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3,262,688

JET CONVECTION HEAT TRANSFER

Donald Beggs, Toledo, Ohio, assignor to Midland-Ross Corporation, Toledo, Ohio, a corporation of Ohio
Continuation of application Ser. No. 148,522, Oct. 30, 1961. This application June 3, 1965, Ser. No. 466,504
2 Claims. (Cl. 266—2)

This application is a continuation of application Ser. No. 148,522, filed October 30, 1961, now abandoned.

This invention relates to apparatus and method for directing compressible fluid in jets against a large generally flat surface, such as a sheet or strip of metal, in such a manner that the force exerted on the surface by the jets will increase as the distance between the surface and the source of jets decreases. The invention has particular applicability in processes where the compressible fluid is used to heat or cool the surface. Examples of such a process include the heat treating of a vertically disposed vertically moving strip of metal of indefinite length in an annealing furnace and the heat treating of a vertically disposed stationary metal sheet, plate or strip. The idea further relates to a process in which a sheet or strip is disposed horizontally over a source of heat transfer jets with the energy of the jets being used to support the sheet during the heat transfer process. The idea also relates to a process for heat treating metal plates or slabs of considerable rigidity in which the plates or slabs are supported in the vertical position on the bottom edge.

In recent years there has been a change in emphasis from radiation heat transfer to forced convection heat transfer in metallurgical furnaces. As is pointed out in Canadian Patent 613,946, this change in emphasis is due largely to the fact that forced convection heat transfer is independent of the surface emissivity of the material being processed, a factor which may vary widely between different portions of the same material. In addition, forced convection heat transfer may also be accomplished more rapidly than radiation heat transfer if proper aerodynamic considerations are taken into account in the design of the furnace.

The original furnaces designed to utilize rapid forced convection heat transfer, such as the furnace described in the aforesaid Canadian patent, accomplished the forced convection heat transfer step primarily by passing the compressible heat transfer fluid in a direction parallel to the surface of the material being processed. It has since been found, however, that a significant increase in the forced convection heat transfer coefficient between the heat transfer fluid and the material being processed (of the order of magnitude of 35% for the same expenditure of horsepower) can be obtained by directing the heat transfer fluid against the material in jets having a substantial component of motion directed normally to the surface of the material. This latter forced convection system is generally denoted "jet convection" to distinguish it from the former parallel-flow forced convection system.

The design of a jet convection system, however, is somewhat more complicated than a parallel-flow convection system. The impingement of a jet of compressible fluid against the surface of a sheet exerts a force on the sheet which, according to the law of conservation of momentum, is equal to the loss of momentum sustained by the jet, as measured before and after impingement. In mathematical terms this may be expressed by the equation:

$$F=M_1(V_1-V_f)$$

Wherein F is force in the direction normal to the strip; M_1 is the mass of the fluid in the heat transfer jet at the time of impingement; V_1 is the velocity of the jet in the

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direction normal to the strip immediately before impingement; and V_f is the velocity of the jet in the direction normal to the strip immediately after impingement. The magnitude of the force F, which must generally be quite substantial to obtain satisfactory heat transfer rates, tends to displace the sheet or strip away from the source of heat transfer jets unless a counter-balancing force is exerted on the opposite side of the sheet or strip. Where the sheet or strip and the source of compressible fluid jets are disposed vertically, the counter-balancing force may be obtained by means of a like source of jets disposed on the opposite side of the sheet or strip and adapted to direct jets of compressible fluid of equal magnitude against the opposite side of the sheet or strip. Where the sheet or strip and the source of compressible fluid jets are disposed horizontally at least some of the counter-balancing force is obtained by virtue of the weight of the sheet or strip which is supported on the jets.

The use of such counter-balancing techniques, in themselves, is not generally adequate to obtain the precise degree of strip alignment or stabilization generally required in practice. For example, in a vertical continuous strip annealing furnace it is necessary to locate the position of the strand of strip between opposite like sources of compressible heat transfer fluid jets with a precision of the order of magnitude of ± 1 inch in an unsupported span of approximately 70–80 feet. To achieve this degree of strip stabilization, it is necessary not only to counter-balance the jet forces on either side, as described, but to provide means to impose a substantial unbalanced restoring force whenever the strip has become excessively displaced from the desired strip position.

It is, therefore, an object of this invention to provide apparatus and method for directing compressible fluid in jets against a large generally flat surface in such a manner that the force exerted on the surface by the jets will increase as the distance between the surface and the source of jets decreases.

It is a further object of this invention to provide improved furnace equipment for heat treating a vertically moving strip of metal by means of jet convection heat transfer.

It is a further object of this invention to provide improved equipment for quenching a vertically disposed heated metal plate.

It is a further object of this invention to provide improved furnace equipment for heat treating a horizontally disposed horizontally moving strip of metal.

For a further consideration of what is considered to be novel and inventive attention is directed to the following portion of the specification, the drawing, and the appended claims.

In the drawing:

FIGURE 1 is a fragmentary view of apparatus adapted to direct a jet of compressible fluid normally against one side of a vertically disposed surface;

FIGURE 2 is a graph showing the magnitude of the force exerted on the surface by the jet of FIGURE 1, in terms of the percent of momentum possessed by the jet at its source, as a function of the distance between the source and the surface against which the jet is directed;

FIGURE 3 is a fragmentary view of apparatus adapted to direct opposed jets of compressible fluid normally opposite sides of a vertically disposed surface;

FIGURES 4–6 are fragmentary views illustrating apparatus adapted to direct a pair of converging jets of compressible fluid against a vertically disposed surface, the views differing from each other in the distance separating the sources of the converging jets and the vertically disposed surface;

FIGURE 7 is a graph showing the magnitude of the

force exerted on the surface by the converging jets of FIGURES 4-6, in terms of the percent of the total momentum possessed by both jets at their respective sources, as a function of the distance between the sources and the surface against which the converging jets are directed;

FIGURE 8 is a fragmentary view of apparatus adapted to direct opposed pairs of converging jets of compressible fluid against opposite sides of a vertically disposed surface.

FIGURE 9 is a graph showing the magnitude of the force exerted on each side of the surface of FIGURE 8 as a function of the position of the surface with respect to the opposite pairs of jets, the force on the left-hand side of the sheet being denoted by curve "A" and the force on the right-hand side of the sheet being denoted by curve "B";

FIGURE 10 is an elevational sectional view of a furnace constructed in accordance with the present invention and being adapted for annealing a continuous vertically moving strip of metal, the annealing process including the steps of sequentially heating and cooling the strip;

FIGURE 11 is a section view taken on line 11-11 of FIGURE 10;

FIGURE 12 is a sectional view taken on line 12-12 of FIGURE 10;

FIGURE 13 is a side elevational sectional view of apparatus embodying the present invention adapted to quench a vertically suspended sheet or plate by directing opposed jets of air against the opposite sides thereof;

FIGURE 14 is a sectional view taken on line 14-14 of FIGURE 13;

FIGURE 15 is an alternative embodiment of the apparatus of FIGURES 13 and 14 for quenching vertically disposed plates and slabs of sufficient rigidity to be supported on the bottom edge thereof;

FIGURE 16 is a side elevational sectional view of apparatus constructed in accordance with the present invention and being adapted for annealing a continuous horizontally moving strip of metal including the steps of sequentially heating and cooling the strip;

FIGURE 17 is a sectional view taken on line 17-17 of FIGURE 16; and

FIGURE 18 is a sectional view taken on line 18-18 of FIGURE 16.

Referring more particularly to FIGURE 1, a nozzle N_1 is provided having an outlet O_1 adapted to pass a jet of compressible fluid normally against the left-hand side of a vertically disposed surface S_1 which, in practice, may comprise a stationary sheet or a continuous vertically traveling strip. The outlet O_1 of nozzle N_1 is separated from the surface S_1 by a distance d_1 . The jet of fluid leaving nozzle N_1 has a mass M_{10} and a normal velocity V_{10} . As this jet traverses the distance d_1 in traveling towards sheet S_1 it entrains additional fluid from the surroundings and also sustains a decrease in velocity. Immediately before impinging on surface S_1 the jet fluid has an increased mass M_{11} , and a decreased normal velocity V_{11} . Immediately after impinging on surface S_1 the jet has a mass M_{1f} , which is equal to M_{11} , and a normal velocity V_{1f} . The normal force F_1 exerted on surface S_1 by the impingement is equal to the decrease in the normal momentum of the jet according to the law of Conservation of Momentum. This may be calculated according to the formula:

$$F_1 = (M_{11}V_{11}) - (M_{1f}V_{1f})$$

Since $M_{11} = M_{1f}$, the formula may be simplified to:

$$F_1 = M_{11}(V_{11} - V_{1f})$$

In the ordinary situation the impingement of the jet on surface S_1 will deflect the jet to a direction substantially parallel to the surface S_1 . Hence, V_{1f} will be zero and the normal force on the strip F_1 will be equal to $M_{11}V_{11}$. To simplify the calculation even further, however, it may be pointed out that the momentum of the jet remains substantially constant as it traverses the distance d_1 from out-

let O_1 to sheet S_1 according to the same law of conservation of momentum. Hence, the product $M_{10}V_{10}$ will be equal to the product $M_{11}V_{11}$ without regard to the distance d_1 between the outlet O_1 and surface S_1 . This relationship is graphically illustrated in FIGURE 2 which shows, for the nozzle arrangement of FIGURE 1, that the normal force F_1 of the jet exerted on surface S_1 remains approximately at 100% of the original momentum ($M_{10}V_{10}$) for all values of d_1 except very small values. Hence, force calculations may be made in terms of M_{10} and V_{10} which are more readily ascertainable quantities than M_{11} and V_{11} .

In order to maintain the relative position between surface S_1 and nozzle N_1 it is necessary to impose an additional force on surface S_1 equal to force F_1 and directed oppositely thereto. Where surface S_1 is disposed in a vertical plane this may be accomplished, as is shown in FIGURE 3, by using oppositely directed nozzles N_{2e} and N_{2r} adapted to deliver jets of compressible fluid of equal momentum ($M_{10}V_{20}$) against opposite sides of sheet S_2 . Nozzles N_{2e} and N_{2r} are disposed on opposite sides of surface S_2 and are adapted to deliver jets of equivalent momentum thereagainst through outlets O_{2e} and O_{2r} . Distances d_{2e} and d_{2r} respectively separate nozzles N_{2e} and N_{2r} from surface S_2 . In most installations it is desirable to maintain surface S_2 in a stabilized position substantially equidistant from nozzles N_{2e} and N_{2r} , i.e. d_{2e} and d_{2r} should be approximately equal. To achieve this desired condition it is beneficial to be able to exert a restoring or stabilizing force on surface S_2 whenever it deviates excessively from a condition where $d_{2e} = d_{2r}$. Such stabilizing or restoring force is most desirably in the form of jet force wherein the force on the left side of surface S_2 is increased when $d_{2e} < d_{2r}$ and the force on the right side of surface S_2 is increased when $d_{2r} < d_{2e}$. In the arrangement of FIGURE 3, however, the forces on either side of surface S_2 remain relatively constant with respect to distance, as is shown in FIGURE 2. Hence, the position of surface S_2 with respect to nozzles N_{2e} and N_{2r} is, undesirably, not stable.

An arrangement of jet nozzles has been discovered, however, which desirably tends to impose a restoring or stabilizing jet force on a surface as the surface is displaced from its desired position. Such arrangement, as is illustrated in FIGURES 4-6, comprises a pair of jet nozzles N_{3-1} and N_{3-2} disposed in a plane parallel to the surface S_3 being treated. Nozzles N_{3-1} and N_{3-2} , which are separated by a distance h_3 , are adapted to deliver converging streams of compressible fluid (preferably of equal momentum) against surface S_3 through outlets O_{3-1} and O_{3-2} . Outlet O_{3-1} is disposed in a direction which deviates from the normal to surface S_3 toward nozzle N_{3-2} by an angle X . Likewise, outlet O_{3-2} is disposed in a direction which deviates from the normal to surface S_3 toward nozzle N_{3-1} by an angle X .

Unlike the arrangement of FIGURE 1 wherein the force of the jet issuing from nozzle N_1 on surface S_1 remains relatively constant as d_1 is decreased, the summation of the forces of the jets of compressible fluid issuing from nozzles N_{3-1} and N_{3-2} in the arrangement of FIGURES 4-6 increases by almost 100% as distance d_3 is decreased, as is illustrated in FIGURE 7. Point (C) on the curve of FIGURE 7 represents the condition illustrated in FIGURE 6 wherein $d_3 > (h_3 + 2 \tan X)$ (i.e. the point of intersection of the converging streams is to the left of surface S_3). Point (B) on the curve of FIGURE 7 represents the condition illustrated in FIGURE 5 wherein

$$d_3 = h_3 + 2 \tan X$$

(i.e. the point of intersection of the converging streams is at surface S_3). Point (A) on the curve of FIGURE 7, in turn, represents the condition illustrated in FIGURE 4 wherein $d_3 < h_3 + 2 \tan X$ (i.e. the point where the converging streams would intersect, if it were not for surface S_3 , is to the right thereof). The reason for the rapid in-

crease in force on surface S_3 as d_3 is decreased below the value $h_3 \div 2 \tan X$ may be understood from an application of the momentum theory to the arrangements of FIGURES 4-6. In the situations of FIGURES 5 and 6, i.e. where $d_3 \geq h_3 \div 2 \tan X$ the individual jets from nozzles N_{3-1} and N_{3-2} impinge upon surface S_3 as though they were a single jet issuing from a single nozzle in a direction normal to S_3 . After impingement these jets deflect in a direction parallel to S_3 with a combined final normal velocity (V_{3f}) equal to zero. Hence, their combined normal force on S_3 , F_3 , is equal to their combined original momentum in a direction normal to S_3 , $M_{30}V_{30}$. In the situation of FIGURE 4, however, where $d_3 < h_3 \div 2 \tan X$, the individual jets impinge upon S_3 and are deflected therefrom generally normally thereto. Hence, normal velocity V_{3f} is not zero as in the case of FIGURES 5 and 6 but is some negative value with respect to V_{31} which numerically approaches V_{31} . In the simple case where V_{3f} is numerically equal to V_{31} the force exerted on S_3 will be:

$$\Sigma F_3 = \Sigma M_{31}[V_{31} - (V_{3f})] = 2\Sigma M_{31}V_{31} = 2\Sigma M_{30}V_{30}$$

Thus, if S_3 is caused to move in a direction toward nozzles N_{3-1} and N_{3-2} thereby causing d_3 to decrease below the value of $h_3 \div 2 \tan X$, a stabilizing force is imposed on S_3 tending to restore it to a position where $d_3 = h_3 \div 2 \tan X$. As seen from the above equation, this restoring force can be made to approach 100% of the value of $\Sigma M_{30}V_{30}$. In practice, restoring forces of the order of magnitude of 80% of the value of $\Sigma M_{30}V_{30}$ can be readily obtained.

The efficacy of the use of converging jets to stabilize the location of a sheet or strip surface in the manner described depends on the presence of the substantially unobstructed escape area between the nozzles which deliver the converging streams. Without a substantially unobstructed escape area between the converging nozzles (preferably of the order of magnitude of at least 50% of the projected area of surface S on the nozzles) it will be difficult to obtain the reversal of fluid flow at values of

$$d_3 < h_3 \div 2 \tan X$$

needed for the increased momentum change which creates the desired restoring force

FIGURE 8 illustrates a pair of nozzles N_{4-1e} and N_{4-2e} and a like pair of nozzles N_{4-1r} and N_{4-2r} adapted to deliver converging streams of fluid against each opposite side of surface S_4 , disposed vertically through outlets O_{4-1e} , O_{4-2e} , O_{4-1r} , and O_{4-2r} . The nozzles in each pair are vertically separated by a distance h_4 . Each nozzle emits a stream of fluid of equal momentum toward S_4 in a direction which deviates from the normal to S_4 toward the other nozzle of the same pair by an angle Y . The pairs of nozzles are separated from each other by a distance d_4 which is equal to or slightly greater than $h_4 \div \tan Y$. Strip S_4 is preferably disposed intermediate the pairs of nozzles (i.e. $d_{4e} = d_{4r} = h_4 \div 2 \tan Y$).

In practice, it is preferred that the angle by which each nozzle deviates from the normal to S_4 be in the range of from 30° to 60° , i.e. with an included angle between the converging streams from 120° to 60° . It is also preferable, but not necessary, that each nozzle in a set of two pairs of stabilizing nozzles deviate from the normal to the strip toward the other nozzle of the same pair by the same angle, as is indicated by angle Y of FIGURE 8.

FIGURE 9 is a graph of the normal forces acting on S_4 as a function of its location between the pairs of nozzles for a given angle. Curve "A" represents the combined force imposed on the left-hand side of S_4 by the jets from nozzles N_{4-1e} and N_{4-2e} . Curve "B" represents the combined force imposed on the right-hand side of S_4 by the jets from nozzles N_{4-1r} and N_{4-2r} . Vertical lines $a-a$, $b-b$, $c-c$, and $d-d$ represent hypothetical positions of S_4 between the pairs of nozzles. Thus, for any strip position between lines $b-b$ and $c-c$ the forces on each side of S_4 , from curves "A" and "B," are balanced at 100% of $\Sigma M_{40}V_{40}$ and there is no tendency to restore the strip to its

original position as it is displaced within this region. In practice the horizontal distance between $b-b$ and $c-c$, which represents the excess of d_4 over $h_4 \div \tan Y$, may be maintained at any value from zero to 2 or 3 inches depending on the accuracy of strip or sheet stabilization required. In some instances d_4 may even be slightly less than the value $h_4 \div \tan Y$.

If, for some reason, S_4 is displaced to the left to a position represented by line $a-a$ (i.e. where d_{4e} is considerably less than d_{4r}) it will be subjected to a force unbalance which tends to restore it to a position at the right. This force will arise by virtue of the fact that the normal force on the left side of S_4 , from curve "A," is equal to approximately 150% $\Sigma M_{40}V_{40}$ whereas the resisting force on the right side of S_4 , from curve "B" is equal to only 100% $\Sigma M_{40}V_{40}$. Similarly, if S_4 is displaced to the right to a position represented by $d-d$, a restoring force equal to the difference of $\Sigma M_{40}V_{40}$ of curves "B" and "A" will tend to restore S_4 to the left. In addition to correction of lateral deviation of sheet S_4 the nozzle arrangement of FIGURE 8 has also been found capable of correcting other kinds of sheet or strip displacement such as twisting, bowing and the like.

FIGURE 10 depicts roller means 21 and 22 adapted to pass a continuously moving sheet of metal 23 vertically downwardly through an annealing furnace, indicated generally at 24, comprising wall means forming a cylindrical heating chamber 25 and a subjacent cylindrical cooling chamber 26 with an intermediate restricted throat 27 therebetween. It is to be understood that the direction of travel of strip 23 through furnace 24 could be vertically upwardly in which case the elevation of heating chamber 25 with respect to cooling chamber 26 would be the opposite of that shown. It is also to be understood that chambers 25 and 26 can be constructed in other than a cylindrical configuration.

Disposed on vertical planes within heating chamber are two opposed sets of fluid nozzles adapted to deliver jets of compressible heat transfer fluid (heating fluid) towards opposite side of strip 23. The first group of fluid nozzles comprises nozzles 30-39 and the second group comprises nozzles 40-49.

To stabilize the position of strip 23 intermediate the groups of nozzles it is necessary to provide one or more sets of opposed pairs of stabilizing nozzles arranged in the manner of the opposed pairs of nozzles of FIGURE 8. In the apparatus illustrated two sets of opposed pairs of stabilizing nozzles have been provided, although it is to be understood that this number is merely illustrative. The first set of stabilizing nozzles comprises a first pair of converging nozzles 32 and 33 and a second opposed pair of converging nozzles 42 and 43. Nozzles 32 and 33 deliver converging jets of compressible fluid against one side of strip 23 and nozzles 42 and 43 deliver converging jets of fluid against the other side thereof. Hence, nozzles 32, 33, 42 and 43 correspond, respectively, to nozzles N_{4-1e} , N_{4-2e} , N_{4-1r} , and N_{4-2r} of the schematic nozzle arrangement of FIG. 8. Likewise, the second set of opposed pairs of converging nozzles comprises nozzles 36, 37 and 46, 47.

Individual nozzles 40-49 may be of any desired construction so long as there is substantial unobstructed fluid escape area between adjacent nozzles in the same group of nozzles. Each nozzle may be formed very simply, however, as is shown in FIGURE 11, by drilling a plurality of outlet ports 51 along a horizontal line through one side of the wall of a metallic cylinder with closed ends, the cylinder extending laterally with respect to the strip and being at least as long as the width of the widest strip to be processed. An alternative nozzle port construction, not shown, comprises a single elongate milled slot in each metallic cylinder.

Compressible heating fluid, which will generally be gaseous products of combustion or a gaseous protective atmosphere, is circulated into heating contact with strip

23 through nozzles 30-49 by means of blower 52 which evacuates spent heating fluid from heating chamber 25 through outlet pipe 53. Heating fluid from blower 52 is returned to heating chamber 25 through inlet pipe 54 which connects with toroidal manifold 55 which, in turn, connects with vertically extending headers 56 and 57. The heating fluid which flows from manifold 55 into header 56 passes therefrom into the first group of nozzles 30-39 which are attached to header 56 in fluid flow relationship. Likewise, the heating fluid which flows from manifold 55 into header 57 passes therefrom into the second group of nozzles 40-49, attached to header 57 in fluid flow relationship. Disposed in the heating fluid circulating path between outlet pipe 53 and inlet pipe 54 is a heater unit, indicated schematically at 58, which may be controllably operated in the manner taught in United States Patent 2,991,989 to D. K. Martin.

Cooling zone 26 is constructed in much the same manner as heating zone 25 except that means are provided to vary the distribution of compressible heat transfer (cooling) fluid across the width of strip 23. As is pointed out in United States Patent 2,983,497 to W. H. Dailey, Jr., there is a natural tendency in strip cooling apparatus to cool the edges of a moving strip more rapidly than the center thereof. This causes the edges of the strip to become wrinkled, a condition which cannot be easily rectified by subsequent processing. Accordingly, compressible cooling fluid, which may be air or a gaseous protective atmosphere, is circulated into cooling contact with strip 23 through opposed groups of nozzle means 60-69 and 70-79. Each of nozzle means 60-79 comprises three (3) individual laterally aligned nozzles which constitute an intermediate nozzle and end nozzles disposed on opposite sides of the intermediate nozzle. Each intermediate nozzle is indicated by a suffix "i" after the numeral of the respective nozzle means (e.g. intermediate nozzles 60i and 70i of FIGURE 12). Likewise, each end nozzle is indicated by a suffix "e" after the numeral of the respective nozzle (e.g. end nozzles 60e and 70e of FIGURE 12).

To stabilize the position of strip 23 intermediate opposed groups of nozzle means 60-69 and 70-79 it is necessary to arrange the nozzle means into one or more pairs of opposed nozzle means to deliver opposed pairs of converging streams against opposite sides of the strip in the manner of the opposed pairs of nozzles of FIGURE 8. Thus, nozzle means 60-79 are arranged to provide two sets of stabilizing nozzle means adapted to circulate two (2) sets of opposed pairs of converging jets against opposite sides of strip 23. The first set of opposed pairs of converging jets are circulated from nozzle means 62, 63, and 72, 73 which are arranged respectively, in the manner of nozzles N_{4-1e}, N_{1-2e}, and N_{4-1i}, N_{4-2i} of FIGURE 8. Likewise, a second set of opposed pairs of converging streams are circulated against strip 23 from nozzle means 66, 67, and 76, 77.

The circulation of compressible cooling fluid through nozzle means 60-79 is accomplished by means of blower 82 which evacuates a stream of spent cooling fluid from cooling chamber 26 by means of outlet pipe 83 and returns it to chamber 26 past cooler 88, indicated schematically, by means of inlet pipe 84. Inlet pipe 84 connects with annular manifold 85 which, in turn, connects with vertically extending header means 86 and 87.

Header means 86 and 87 each comprise three (3) headers which constitute one intermediate header and two end headers disposed on either side of the intermediate header. Each intermediate header is indicated by a suffix "i" after the numeral of the respective header means (i.e. intermediate headers 86i and 87i). Likewise, each end header is indicated by a suffix "e" after the numeral of the respective header means (i.e. end headers 86e and 87e). Each of the individual headers is disposed in fluid flow relationship with a vertically extending row of individual nozzles and is adapted to cir-

culate cooling fluid from manifold 85 thereinto. Thus, intermediate header 86i circulates cooling fluid from manifold 85 into nozzles 60i-69i, intermediate header 87i circulates cooling fluid into nozzles 70i-79i, etc., each of end headers 86e circulates cooling fluid into a vertically extending row of nozzles 60e-69e, and each of end headers 87e circulates cooling fluid into a vertically extending row of nozzles 70-79e.

The control of the cooling effect of the compressible cooling fluid with respect to the width of the strip which, as has been pointed out previously, is important for the reasons described in the aforesaid United States Patent 2,983,497, is obtained by providing control means to control the relative quantities of cooling fluid which flows from manifold 85 into the individual headers of a given header means. Since the problem is, inherently, always one of a tendency to overcool the edges of the strip, suitable control means need comprise only restricting means to restrict the flow of cooling fluid from manifold 85 into the end headers of each header means allowing a continuous full flow into the intermediate header.

In the simplest case (not shown) the restricting means will be non-regulable such as a fixed restricting orifice associated with each end header. It is generally preferable, however, to make the restricting means regulable such as a butterfly damper 89 inserted in each of end headers 86e and 87e immediately subjacent the connection of the respective header to manifold 85. Each of dampers 89 may be manually regulated from outside the cooling zone by means of a handle 91 attached to rod 92 which, in turn, is attached to damper 89.

FIGURES 13 and 14 illustrate the application of the jet convection heat transfer process of the instant invention including the stabilizing jet nozzle arrangement of FIGURE 8 to apparatus for quenching metallic sheets or plates following the heating step of a heat treating process. The apparatus comprises two groups of opposed nozzles including a first group of 130-139 and a second group of 140-149. Means comprising an overhead conveyor system, indicated generally at 121, are provided to dispose metallic sheet 132 intermediate the opposed groups of nozzles 130-139 and 140-149. Compressible cooling fluid (generally air from the atmosphere) is circulated into cooling contact with sheet 123 in jets having at least a substantial component of motion directed normally thereto through nozzles 130-149 by means of blower 152. The stream of air from blower 152 passes into a manifold 155 from whence it passes into vertically extending headers 156 and 157. Header 156 is disposed in fluid flow relationship with the first group of nozzles 130-139 and header 157 is disposed in fluid flow relationship with the second group of nozzles 140-149.

The quantity and distribution of compressible cooling fluid that is delivered against opposite sides of sheet 123 respectively from first group of nozzles 130-139 and second group 140-149 is equivalent so as to counterbalance the forces on opposite sides thereof. However, merely counterbalancing the forces on opposite sides is not generally sufficient since sheet 123 can easily be displaced from the preferred position to the left or right by external vibration and other reasons. Accordingly, it is desirable to provide means for stabilizing the position of sheet 123 in a preferred location by imposing a restoring force thereagainst as it deviates from the preferred position.

Stabilization of the position of sheet 123 intermediate the two groups of nozzles is obtained by arranging at least some of the nozzles of each group into one or more sets of stabilizing nozzles comprising opposed pairs of converging nozzles adapted to deliver opposed pairs of converging jets of compressible cooling fluid against opposite sides of the suspended sheet in accordance with the arrangement of FIGURE 8. The illustrated arrangement comprises three (3) such sets of stabilizing nozzles, although this number is merely illustrative. The first set of stabilizing nozzles comprises a first pair of nozzles 131

and 132 and a second opposed pair of nozzles 141 and 142. Nozzles 131 and 132 deliver converging streams of air against one side of sheet 123 and nozzles 141 and 142 against the other side thereof. The second set of stabilizing nozzles comprises a first pair of converging nozzles 134 and 135 and a second opposed pair of converging nozzles 144 and 145. Likewise, the third set of stabilizing nozzles comprises a first pair of converging nozzles 137 and 138 and a second opposed pair of converging nozzles 147 and 148. In instances where a vertically disposed workpiece 123' is of adequate thickness to be self-rigid, as in the case of a thick plate or a slab, it may be readily vertically disposed intermediate opposed groups of nozzles by supporting it at the bottom edge thereof, as by means of an hourglass conveyor roller system 121' as shown in FIG. 15. The apparatus of FIGURE 15 otherwise corresponds to the apparatus of FIGURES 13 and 14. It is also to be noted that the arrangements of FIGURES 13-15 may also be adapted for heating processes by modifications obvious to a skilled artisan.

FIGURES 16-18 illustrate apparatus for sequentially heating and cooling a horizontally moving continuous strip of metal. The apparatus comprises rollers 221 and 222 for conveying strip 223 in a horizontal plane sequentially through furnace chamber 225 and cooling means, indicated generally at 226, which is not enclosed within a chamber but may be, if desired. Disposed within heating chamber on a plane parallel to strip 223 and subjacent thereto is a set of nozzles 230-239 which are adapted to deliver compressible heating fluid against the underside of strip 223 in jets having a component of motion directed perpendicularly thereto. In the arrangement illustrated, the weight of the portion of the strip within furnace chamber 225 will be at least partially supported by the force of impingement thereagainst of the jets from nozzles 230-239.

To stabilize the elevation of strip 223 so as to prevent it from sagging dangerously close to nozzles 230-239 the nozzles are arranged in pairs of stabilizing nozzles in the manner of the nozzles of FIGURES 4-6 so as to increase the force of jet impingement on the underside of strip 223 as the distance between the strip and the nozzles is reduced. Hence, nozzles 230-239 are arranged in five pairs of stabilizing nozzles, although it is to be understood that this figure is illustrative. The five pairs of stabilizing nozzles are 230 and 231; 232 and 233; 234 and 235; 236 and 237; and 238 and 239. The outlet of each nozzle is adapted to deliver heat transfer fluid therefrom at an angle which deviates from the normal to strip 223 toward the other nozzle of the pair. With this arrangement of nozzles the force against the underside of strip 223 will increase as strip 223 sags closer to nozzles 230-239 in the manner as explained in connection with FIGURES 4-6 and the accompanying graph of FIGURE 7.

In some instances the total magnitude of the force on the underside of strip 223 from the jets of fluid issuing from nozzles 230-239 may exceed the weight of that portion of the strip suspended thereover. In such event a force balance may be achieved by providing a second set of nozzles 240-245 disposed in a plane parallel to, and superjacent, strip 223 and arranged in three pairs of stabilizing nozzles to increase the force on the upper side of strip 223 as the distance therebetween is decreased thereby safeguarding against contact against strip 223 and nozzles 240-245. The three pairs of stabilizing nozzles are 240 and 241; 242 and 243; and 244 and 245. The outlet of each nozzle is adapted to deliver heat transfer fluid therefrom at an angle which deviates from the normal to strip 223 toward the other nozzle of the pair.

The compressible heating fluid (products of combustion or gaseous protective atmosphere) which is circulated into heating contact with strip 223 in jets from nozzles 230-245 is delivered thereto by means of a blower 252. Blower 252 evacuates spent heating fluid from chamber 225 by means of outlet pipe 253 and returns heating fluid thereto by means of inlet pipes 254 and 255

which deliver heating fluid, respectively, to longitudinal headers 256 and 257. Header 256 delivers heating fluid to nozzles 230-239, and header 257 delivers heating fluid to nozzles 240-245. A heater, indicated schematically at 258, is interposed in the flow circuit intermediate outlet pipe 253 and blower 252 although, if preferred, heater 258 can be located downstream of blower 252.

Cooling means 226 comprises a set of nozzles 260-265 disposed on a plane parallel to strip 223 and subjacent thereto. Nozzles 260-265 are adapted to deliver compressible cooling fluid (air from the atmosphere) against the underside of strip 223 in jets having a substantial component of motion directed perpendicularly thereto, the force of the impingement of the jets against the underside of strip being used to support the strip.

To prevent strip 223 from sagging too low nozzles 260-265 are arranged in pairs of stabilizing nozzles in the manner of the nozzles of FIGURES 4-6 so as to increase the force of jet impingement on the underside of strip 223 as the strip sags closer to the nozzles. Hence, three pairs of stabilizing nozzles are provided comprising nozzles 260 and 261; 262 and 263; and 264 and 265. The outlet of each nozzle is adapted to deliver cooling fluid toward sheet 223 at an angle which deviates from the normal toward the other nozzle of the same pair.

Where the total force of the jets from nozzles 269-265 impinging on the underside of strip 223 exceeds the weight of strip 223 suspended thereover a second set of nozzles 270-273, disposed in a plane superjacent strip 223 and parallel thereto, is provided. Nozzles 270-273, like nozzles 260-265, are arranged in pairs of converging nozzles to stabilize the position of strip 223 with respect thereto. The first pair of converging nozzles comprises nozzles 270 and 271, and the second pair of converging nozzles comprises nozzles 272 and 273.

Cooling fluid is delivered to nozzles 260-265 and 270-273 from blower 282 by way of delivery pipes 284 and 285 which connect, respectively, with longitudinal headers 286 and 287. Header 286 is connected to nozzles 260-265 and header 287 is connected to nozzles 270-273.

The foregoing invention has been described in connection with the heat treatment of generally flat metal bodies such as sheets, strips, and plates, including metal bodies of such classification having localized buckles and other defects, for the reason that it is believed that the invention will find greatest utility in this field. However, it is contemplated that the invention will find utility in the heat treatment of other generally flat materials such as paper, textiles, glass, and the like. It is also contemplated that the invention can be used to direct converging jets of compressible cooling medium against the generally flat surface of a body for other than heat transfer purposes such as in an air conveyor system or in the holding zone of a heat treating furnace. It should, therefore, be understood that the use of the term "strip" in the appended claims denotes work not only in strip form, but in any generally flat body form such as sheets, strip and plates.

The best mode known to me to carry out this invention has been described in terms sufficiently full, clear, concise, and exact as to enable any person skilled in the art to practice the invention. However, it is understood that various modifications will be readily apparent to a skilled artisan without departing from the scope of the invention which is defined only by the appended claims.

I claim:

1. Apparatus for treating work in strip form comprising in combination: means for passing said strip along a predetermined path; a pair of nozzle means spaced apart a distance h and disposed adjacent but spaced from said predetermined path a distance d each of said nozzle means being arranged to direct flow of compressible fluid against one of the generally flat surfaces of said strip substantially transversely over the entire width of said strip; circulating means for circulating compressible fluid to the nozzle means; port means associated with each nozzle means positioned for directing substantially all of the

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compressible fluid circulated thereto toward the flat surface in a direction which deviates from the normal thereto by an angle X inclined toward the other nozzle means of the pair; and wherein the spacing between said pair of nozzle means and said predetermined path, d , and the distance between each of said nozzle means of said pair, h , are related as follows:

$$d = h + 2 \tan X$$

2. Apparatus according to claim 1 further comprising: a pair of second nozzle means spaced apart a distance h and disposed adjacent but spaced from said predetermined path and a distance d on the side of said predetermined path opposite from said pair of nozzle means, second nozzle means being arranged to direct flow of compressible fluid against the other of the generally flat surfaces

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of said strip substantially transversely over the entire width of said strip; wherein said circulating means also circulates compressible fluid to the second nozzle means; second port means associated with each second nozzle means positioned directly opposed said port means for directing substantially all of the compressible fluid circulated thereto toward the flat surface in a direction which deviates from the normal thereto by an angle X inclined toward the other nozzle means of the pair.

No references cited.

JOHN F. CAMPBELL, *Primary Examiner.*

CHARLES W. LANHAM, *Examiner.*

ART GRIEF, *Assistant Examiner.*