Aug. 27, 1963 W. A. BLONN 3,102,009

APPARATUS FOR THERMAL TREATMENT OF METAL

Filed March 28, 1960 4 Sheets-Sheet 1

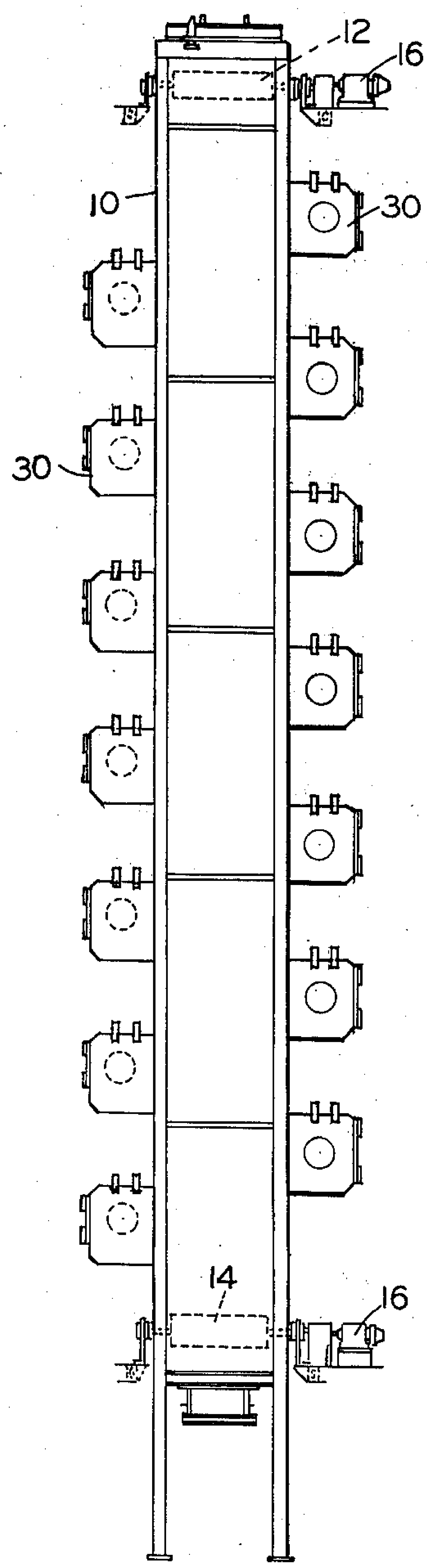

FIG. 1

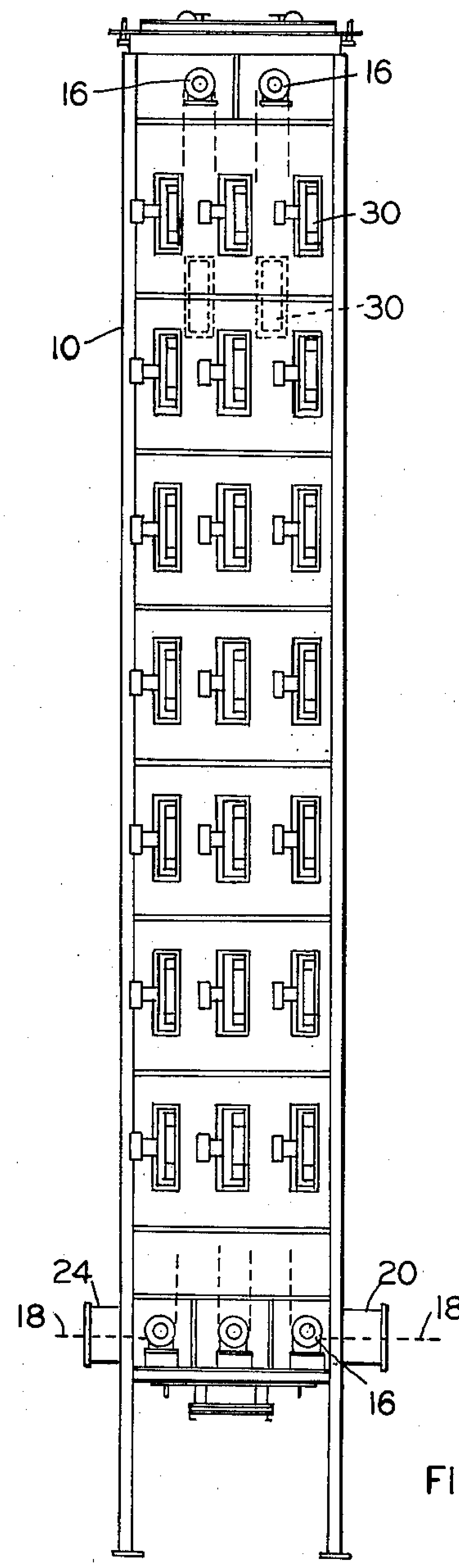

FIG. 2

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APPARATUS FOR THERMAL TREATMENT OF METAL

Filed March 28, 1960 4 Sheets-Sheet 2

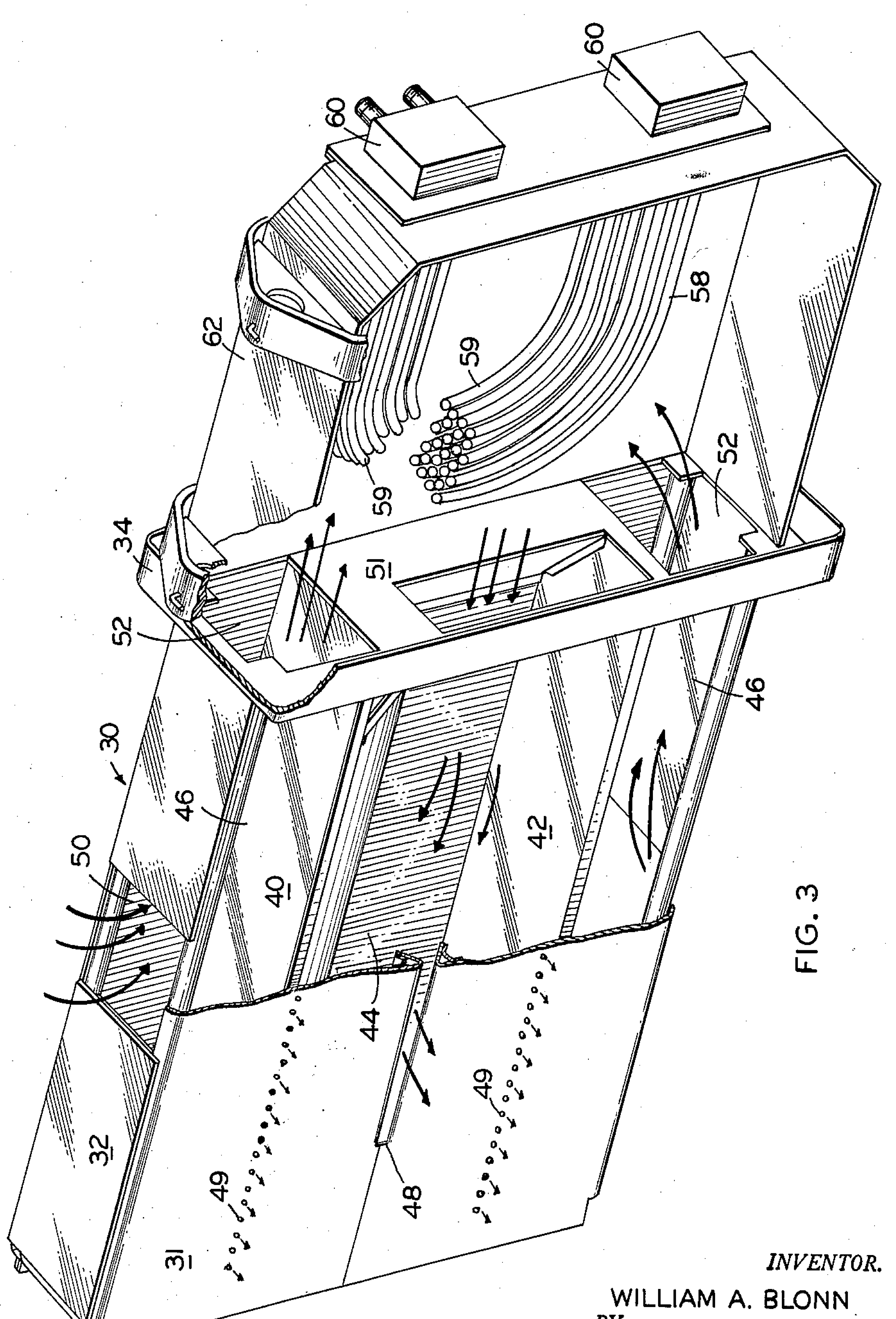

FIG. 3

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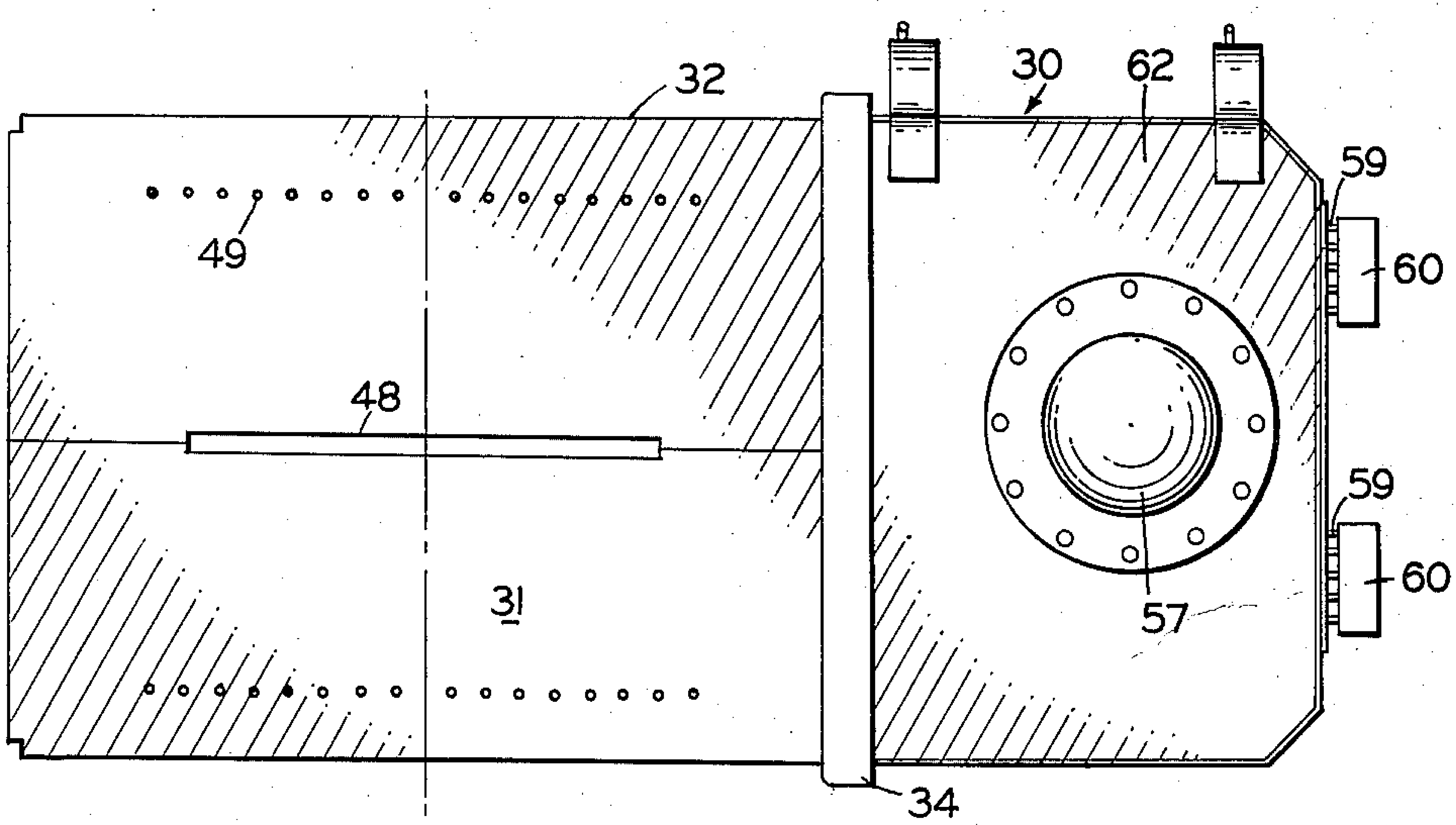

FIG. 5

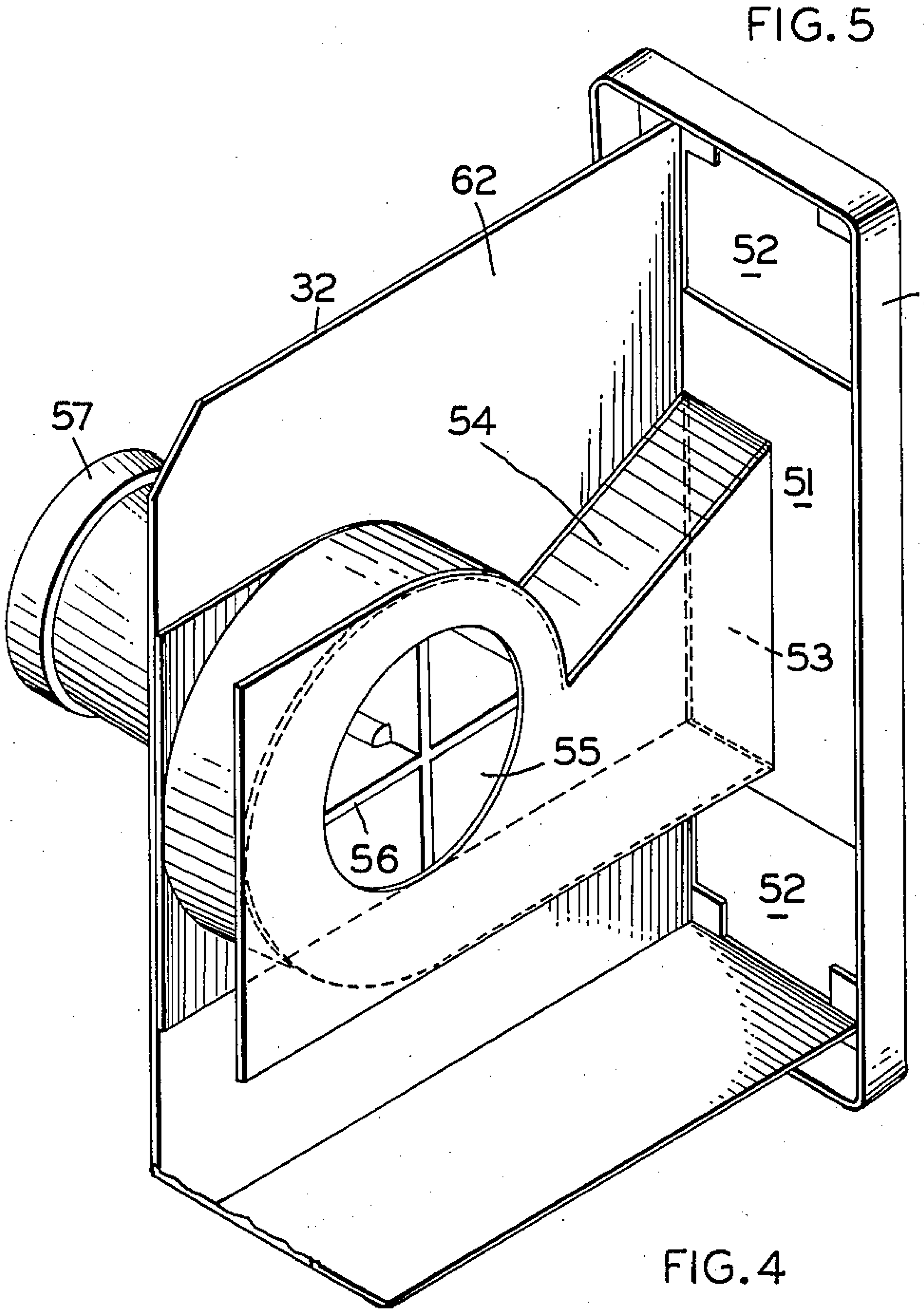

FIG. 4

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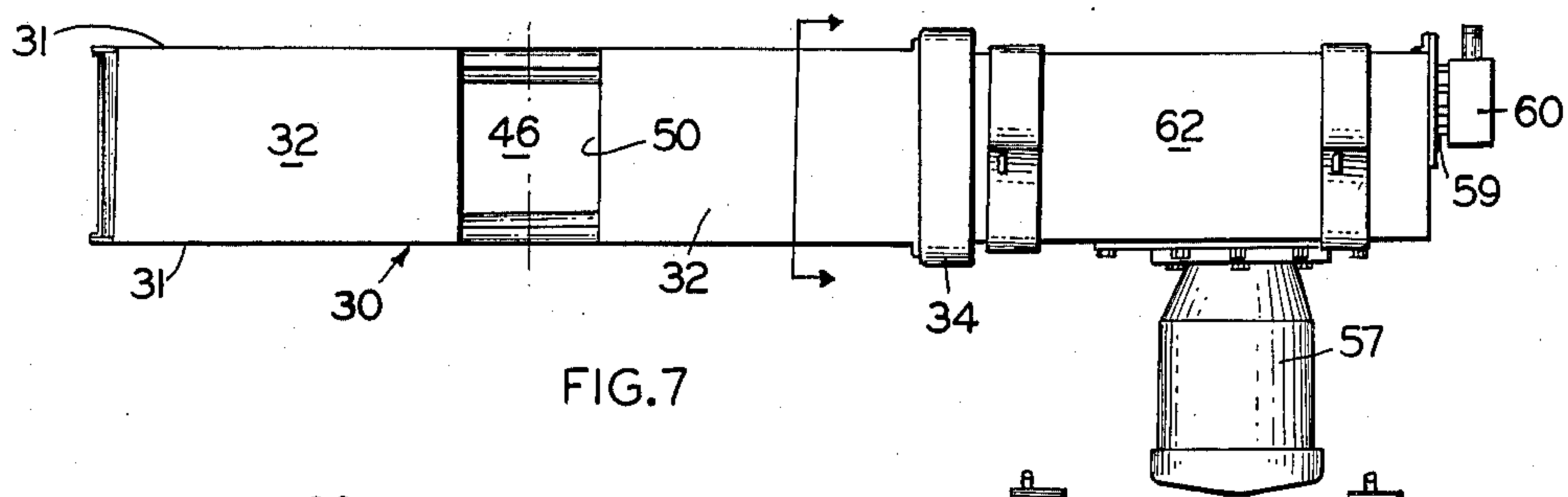

FIG. 7

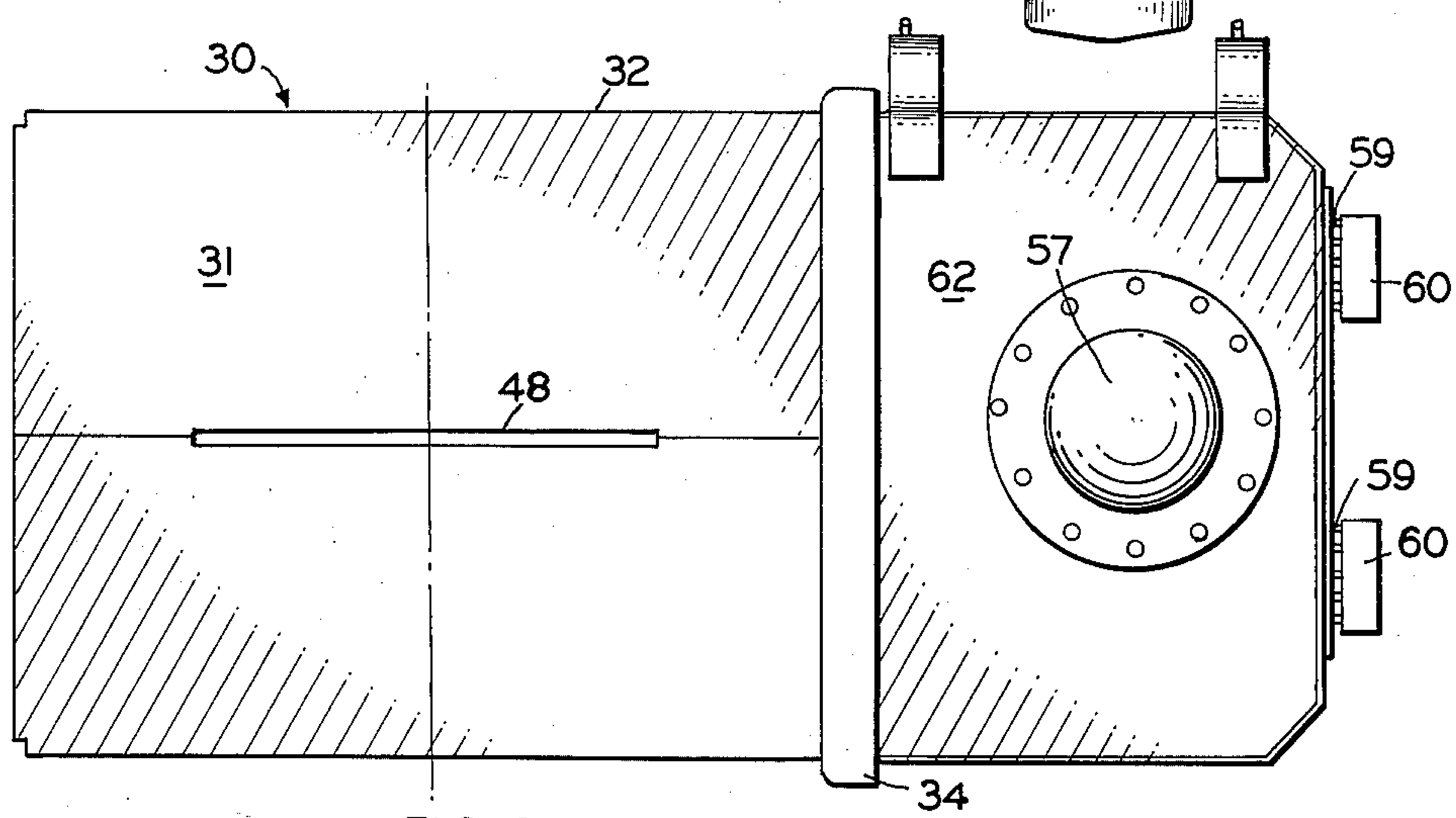

FIG. 6

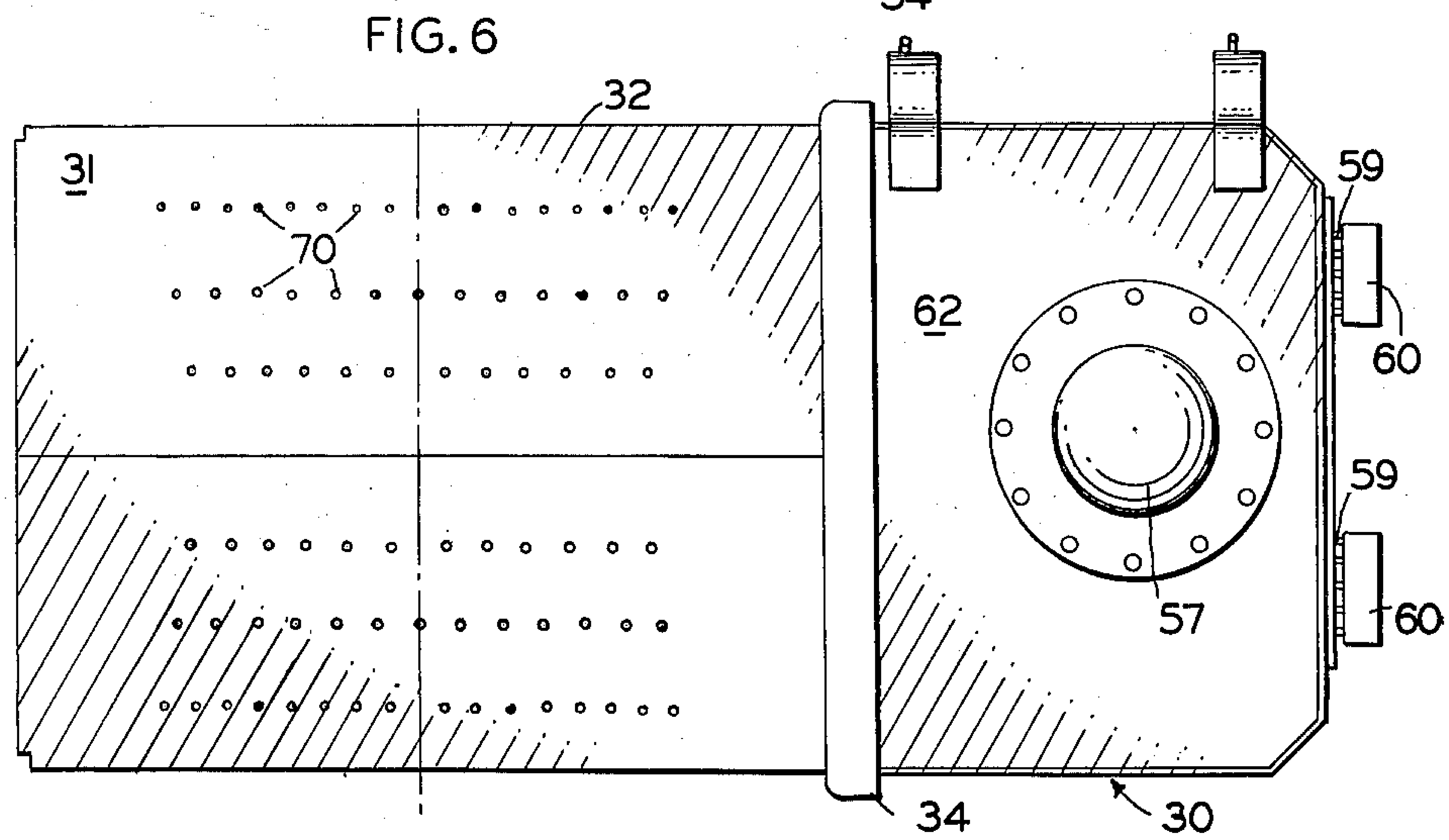

FIG. 8

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3,102,009
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3,102,009

APPARATUS FOR THERMAL TREATMENT OF METAL

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Filed Mar. 28, 1960, Ser. No. 17,960
10 Claims. (Cl. 34—159)

This invention relates to a novel and improved apparatus for the thermal treatment of metal and is particularly adapted for use in combination with an annealing furnace for continuously annealing strip steel whereby the apparatus of this invention would be utilized to cool the continuously moving strip after it leaves the annealing furnace. While the invention offers particular advantages as means for cooling metal in combination with a tower annealing furnace, the apparatus of this invention may also be utilized in conjunction with other processes for the treatment of metal and particularly may be utilized for heating instead of cooling. Accordingly, it should be understood from the outset that in the following description and appended claims, wherever the invention is described in connection with a cooling process for continuously moving strip metal, it is to be fully understood that there is intended to be included the use of the invention with other forms of metal and/or in a heating process as well.

A well known construction for a tower annealing furnace for continuously annealing strip steel comprises a furnace housing through which an elongated sheet of metal or "strip" is passed. The furnace is provided with a plurality of respectively associated pairs of upper and lower rolls to support and drive the strip through the furnace in a plurality of parallel, vertically extending loops. This vertical multi-pass arrangement of the furnace permits the length of strip within the furnace to be many times greater than the length of the furnace, thus providing a substantial reduction in the length of the equipment over that required for a single horizontal pass arrangement. After the strip leaves the furnace, it is necessary to cool the strip in a controlled manner. In some cases it is desirable to cool the strip as quickly as possible from a relatively high to a moderately low temperature. At other times, it may be desirable to cool the strip from a relatively high temperature of around 1000° F. to a moderate temperature of approximately 500° F. and then cool the strip quickly to a relatively low temperature of about 150° F. It is, of course, always desirable to maintain the size and particularly the length of the cooling apparatus as small as possible in order to maintain the plant facility requirement for the over-all installation at a minimum.

One heretofore known arrangement for cooling strip comprises a plurality of vertically arranged parallel cooling structures in which is circulated cooling water to provide heat transfer from the strip by means of radiation. The strip is passed between the coolers in a vertical multi-pass fashion by means of strip supporting and driving structure similar to that of a tower furnace. The water cooled radiation type coolers are relatively satisfactory for reducing strip temperature from a high to a moderate temperature in a fairly short length of time but are not as satisfactory for quickly reducing the temperature of the strip from a moderate to a relatively low temperature. It is not unusual for a strip cooler of this type to have as many as thirty to thirty-five passes, thus providing a structure having an undesirably large space requirement.

Another type of strip cooler is shown in United States Patent No. 2,521,044, issued September 5, 1950, in the names of W. B. Cooper and E. J. Seabold. In the apparatus of this patent the strip is passed through the cooling section in a vertical multi-pass arrangement at a lineal

speed on the order of 200 to 250 feet per minute. A portion of the strip cooling section comprises a plurality of sets of cooling units spaced longitudinally of the cooling section with each set of units comprising a plurality of units arranged vertically in spaced relation alongside the path of the strip. Each of these cooling units comprises a plurality of cooling water conducting coils arranged to provide a large area of cooling surface having a general plane lying parallel to and closely adjacent to a next adjacent strip. A low pressure rise axial flow fan is located adjacent the side of the coils opposite the strip for blowing atmosphere through the coils and toward the strip. With the apparatus of the Cooper et al. patent, the strip is cooled by reason of radiation between the strip and the large cooling area presented by the next adjacent cooling coils. Also, the low velocity cooled atmosphere circulated by the fan effects convection cooling of the strip. While a combination radiation and convection cooler of the type shown in the aforementioned patent may provide a higher heat transfer coefficient than a pure radiation type cooler, it still does not provide a sufficiently increased heat transfer coefficient to permit marked increases in strip speed without undesirably increasing the over-all size of the apparatus by the addition of more passes of cooling. Also, if the movement of the hot strip is stopped, the strip will be cooled quickly by radiation heat transfer between the strip and the next area of cooling coils. The resultant reduction in temperature and thus the pressure of the atmosphere within the cooling section may be at a rate greater than can be compensated for by make-up atmosphere. There will thus tend to be created a partial vacuum within the cooling section which may cause structural collapse of the walls of the cooling section. Also, this rapid cooling of the strip may tend to cause bluing of the strip, resulting in the necessity of later scrapping of the portion of the strip disposed within the furnace.

A novel and improved concept of cooling or heating continuously moving strip material is described and claimed in copending United States Patent Application Serial No. 850,438, filed November 2, 1959, in the name of William L. Zabriskie, the employer-assignee of the invention of said application also being the employer-assignee of the invention of this application. The aforementioned copending application describes and claims a jet cooling system for discharging a high velocity jet of cooled atmosphere against a next adjacent moving strip of metal. In one aspect of that invention, it is contemplated that a plurality of jet cooling units will be arranged in a plurality of vertical spaced apart rows in combination with a housing similar to a housing for a tower furnace. The jet cooling units are self-contained units, in that each mounts its own motor driven high pressure rise fan and each contains heat exchanger means for cooling the atmosphere recirculated by the cooling unit for jet discharge against a next adjacent pass of moving strip. Each unit further comprises a plenum chamber which is connected to the outlet of the high pressure rise atmosphere recirculating fan. The plenum chamber is provided with orifice means opening outwardly thereof for the discharge of cooled atmosphere against the strip. The combination of orifice discharge means with a high pressure rise fan provides a high velocity jet discharge from each unit rather than the low velocity flow achieved in a construction such as in the aforementioned Cooper et al. patent, wherein one side of the plenum chamber is substantially entirely open and a low pressure rise axial fan discharges into the plenum chamber. Strip cooling apparatus incorporating jet cooling units of the type described provide a marked improvement in heat transfer and other performance, and at the same time the use of the jet cooling units results in a marked decrease in the size of the apparatus. However, it is desired to make certain improvements in the performance of apparatus incorporating jet cooling units of the type described, particularly in the areas of strip flutter and twist.

Accordingly, it is the primary object of the present invention to provide novel improvements in a jet cooling system of the type described which will provide, in connection with fast moving strip, improved stabilization against flutter and which will reduce if not eliminate any tendency of the strip to twist.

It is another object of the present invention to provide novel improvements in a jet cooling unit of the type described which will result in a reduction in size of the unit without any reduction in performance thereof and which will result in improved protection against atmospheric collapse.

Other objects and advantages of this invention will be in part obvious and in part pointed out in detail hereinafter.

In one aspect thereof, my invention comprises a jet cooling unit of the type described in which the orifice means for the discharge of cooled atmosphere from the plenum chamber of the unit comprises a plurality of small diameter orifices arranged in a plurality of rows with the rows being spaced apart in a direction corresponding to the direction of movement of strip passed through the unit. The plurality of small diameter orifices correspond in total hydraulic area to the hydraulic area of a narrow elongated slot or nozzle extending laterally of the strip path past the unit and fully across the strip. By the term hydraulic area is meant the total measured area of the discharge openings of the unit reduced by an amount corresponding to the contraction of the jets as they pass through the discharge orifices and by an amount corresponding to a reduction of the atmosphere flow as it is discharged from the plenum chamber. Thus, it can be seen that the term "orifice means" as used herein is intended to define jet discharge means such as might commonly be referred to as an orifice and as opposed to large area low velocity discharge means such as represented by the large discharge opening in the Cooper et al. patent. The provision of a plurality of spaced apart rows of orifices rather than a slot as a means for discharging atmosphere from the jet cooler tends to reduce any Bernoulli effect caused by the passage of high velocity atmosphere between and parallel to the jet cooling unit and a next adjacent strip. Where a plurality of jet cooling units of the type described are arranged in a pair of vertically extending horizontally spaced apart rows so as to discharge atmosphere against a pass of strip moving parallel to and between the rows, it is another aspect of my invention to vertically offset the units in one row relative to the units in the next adjacent row in order to stagger the jet discharge streams on one side of the strip relative to the jet streams on the other side of the strip. Another aspect of my invention is the location of the heat exchanger means for the jet cooling unit in a position entirely externally of the housing or tower and in a position remote from the strip passing through the housing. As will be hereinafter apparent, this aspect of the invention is a result of the desire for and results in a reduction in size of the jet cooling units and contributes to improved performance of the apparatus as a whole from the standpoint of stabilization of strip movement and also provides improved ease of manufacture and maintenance of the jet cooling units. A more detailed understanding of the foregoing as well as other aspects of the invention may be had by reference to the following description when taken in connection with the accompanying drawings, in which:

FIG. 1 is an end elevational view of an exemplary strip cooling tower incorporating improved jet cooling units constructed in accordance with this invention;

FIG. 2 is a side elevational view of the cooling tower of FIG. 1;

FIG. 3 is an enlarged, perspective view, partly cut away, of one of the jet cooling units of FIG. 1, with the fan and motor assembly removed;

FIG. 4 is a perspective view of the fan and motor assembly of the jet cooler of FIG. 3;

FIG. 5 is a reduced scale, side elevational view of the jet cooling unit of FIG. 3;

FIG. 6 is a side elevational view of an alternate embodiment of a jet cooling unit constructed in accordance with this invention;

FIG. 7 is a top view of the unit of FIG. 6; and

FIG. 8 is a side elevational view of another alternative embodiment of a jet cooling unit constructed in accordance with this invention.

With reference to the drawings and particularly FIGS. 1 and 2, there is illustrated examplary strip cooling apparatus of a type for which the present invention is adapted for use. The apparatus comprises a tower-like housing **10** constructed to contain a controlled atmosphere and to exclude air from entering the housing. The housing includes a plurality of pairs of upper and lower driving rolls **12** and **14**, with the upper rolls **12** being spaced a substantial distance above the lower rolls **14**. As shown in FIG. 1, suitable drive means such as electric motors **16** are supported on the housing **10** and are drivingly connected to the rolls **12** and **14**. The strip **18** enters the housing **10** through a suitable atmosphere seal **20** and is passed alternately around the upper and lower rolls **12** and **14** which support the strip **18** in a plurality of vertically extending loops to provide the strip with a vertical multi-pass path through the housing **10**. The strip leaves the housing **10** through a suitable seal **24** which precludes exhausting of atmosphere through the exit opening for the strip. Suitable means are provided, but not shown, for introducing and maintaining a proper amount of controlled atmosphere in the housing **10**. In the interest of brevity, further details regarding the specific construction of the housing **10** with respect to such things as the supporting and driving of the strip through the housing as well as the control of strip speed, maintenance of atmosphere conditions, etc., will not be described, inasmuch as such details are not necessary for a full understanding of the present invention and are well known to those skilled in the art.

A plurality of atmosphere recirculating jet cooling units **30** are supported on each of the opposite sides of the housing **10** in a plurality of horizontally spaced vertically extending rows. The jet cooling units **30** supported on the side of the housing opposite the side illustrated in FIG. 2 are, as shown in dotted lines, arranged in vertical rows, with the vertical rows of units being horizontally spaced apart so as to be disposed between alternate pairs of next adjacent strip passes. On the side of the tower illustrated in FIG. 2, it can be seen that a vertical row of jet units **30** is disposed outwardly of each end pass of the strip **18** as well as between the next adjacent pairs of jet units supported on the other side of the tower housing. In this manner a row of jet cooling units **30** is disposed next adjacent each face or side of the strip **18** in each pass of the strip.

With reference to FIGS. 3 to 5, each jet cooling unit comprises a casing **32** provided with a mounting flange **34** which telescopically fits within a complementally shaped collar or flange on the wall of the housing **10**. The flange **34** may be bolted, spot welded or otherwise suitably secured to the mounting collar or flange on the housing in order to retain the unit on the housing while at the same time permit removal of the unit when desired or necessary.

With the jet unit **30** mounted on the housing as shown in FIG. 1, the portion of the casing disposed to the left of the flange **34**, as viewed in FIGS. 3 and 5, will be disposed within the housing. With reference to FIG. 3, a pair of walls or partitions **40**, **42** extend longitudinally of the casing and divide the casing into a central plenum chamber **44** extending longitudinally of the casing **32** and a pair of inlet or suction chambers **46** extending parallel to and disposed on opposite sides of the plenum chamber. As will be apparent from FIG. 2, when the jet unit is mounted on the housing **10**, the plenum and inlet chambers of the unit will be aligned in a direction extending parallel to the path of strip movement in a next adjacent pass of strip.

To provide for the jet discharge of atmosphere from within the plenum chamber **44** toward a next adjacent strip, a plurality of orifices are provided in each casing **30** in the form of a narrow elongated slot or nozzle **48** and a plurality of small diameter holes **49** arranged in a pair of rows extending parallel to and disposed on opposite sides of the elongated orifice **48** in spaced relation thereto. The slot **48** extends longitudinally of the jet cooler so as to extend laterally of a next adjacent strip and parallel to the general plane of the strip. The length of the slot **48** is preferably at least equal to the width of the strip intended to be cooled so as to assure uniform cooling across the full width of the strip. As best shown in FIG. 3, in order to enhance the nozzle characteristics of the orifices **48**, the casing **32** is provided with diverging lips **61** extending from the longitudinal bordering edge portions of each orifice **48** and inwardly of the plenum chamber **44**. In the case of jet cooling units located between next adjacent passes of strip, the casing **32** is provided with a slot **48** and a pair of rows of holes **49** on each of the faces **31** of the casing so as to provide for the simultaneous discharge of atmosphere in opposite directions toward the next adjacent strip. In the interest of brevity and clarity, only one slot **48** and pair of rows of holes **49** is shown in the jet cooler of FIG. 3. As will, of course, be understood, in the case of each of the end units associated with the end passes in the housing, only one slot **48** and holes **49** will be provided, inasmuch as these units are operative on only one side of the strip in the next adjacent pass. For a reason to be described hereinafter, the opposite ends of each row of holes **49** are preferably spaced outwardly of the ends of the slot **48**.

With reference to FIG. 3, each of the inlet chambers **46** is provided with an inlet opening **50**, which as shown is facing at right angles to the faces **31** of the casing **32** and away from the plenum chamber **44**. For a reason to be hereinafter described, the inlet openings **50** are preferably of a length substantially less than that of the orifice discharge means and are generally centered relative to the orifice means so as to be generally centered laterally of and relative to a next adjacent strip.

As can be seen from FIGS. 3 and 4, the casing **32** is provided with a partition or wall **51** which extends laterally of the casing to provide an end wall for the inlet and plenum chambers. The wall **51** is provided with a pair of openings **52** opening into the inlet chambers **46** and a central opening **53** opening into the plenum chamber **44**. As will be apparent from FIGS. 3 to 5, a fan housing **54** is mounted on the end portion of the casing **32** located on the side of the wall **51** opposite the plenum chamber. The fan housing has an outlet connected to the opening **53** in the wall **51**. The exterior surfaces of the fan housing in cooperation with the wall **51** and other surrounding portions of the casing **62** form a heat exchange chamber with which the inlet chambers **46** are connected by the openings **52**. The fan housing is provided with an inlet **55** leading to the fan blades **56** of a high pressure rise radial flow fan which is driven by an electric motor **57** located externally of and mounted on the casing **62**. In order to provide cooling of the atmosphere drawn into the chamber surrounding the fan housing, there is provided a water cooled heat exchanger **58** which, as shown in FIG. 3, comprises a plurality of U-shaped tubes **59** connected at their ends to headers **60** located externally of and closely adjacent the end wall of the casing **32**. The tubes are preferably jointless and are preferably brazed to the casing and/or headers externally of the casing **62** so that no joints will be located within the casing **62**.

As should be apparent from a consideration of FIGS. 3 and 4, the fan housing **54** is mounted alongside one face of the casing **62**, and the opening **53** in the partition **51** is offset laterally of the partition toward the face of the casing **62** next adjacent the fan housing. In this manner, the fan housing is spaced from the other face of the casing **62** so that the heat exchanger tubes **59** may be disposed alongside the fan housing and between the fan housing and the other face of the casing **62**. As should also be apparent from a consideration of FIGS. 3 and 4, with the fan housing and heat exchanger in assembled condition within the casing **62**, the bight portion of the tubes **59** will extend about the inlet **55** of the fan housing so that atmosphere passing into the fan will first be required to come into heat exchange relationship with the cooling tubes **59**. As will be realized by those skilled in the art, other suitable heat exchanger means could be employed for cooling purposes. Further, where the jet unit is to be used for heating rather than cooling, heated water or steam could be passed through the tubes **59**, or other suitable heating means could be employed.

In the operation of a tower cooling apparatus incorporating an improved jet cooling unit of the present invention, energizing of the drive motor **57** will cause atmosphere to be drawn in through the inlet openings **50**, through the inlet chamber **46** and the heat exchanger **58**, and then through the fan and into the plenum chamber **44** for high velocity jet discharge through the nozzle or slot **48**. As this discharge jet of atmosphere engages a next adjacent strip, it will split into two paths and flow in opposite directions longitudinally of the strip for recirculation into the inlet openings **50** of the cooling unit. The atmosphere, as it is recirculated through the jet cooler by the fan, will, of course, be cooled by the heat exchangers **58**. The spacing of the inlet openings **50** a substantial distance from the slot **48** and in a direction parallel to the direction of strip movement provides a high velocity flow of atmosphere in opposite directions longitudinally of the strip for a substantial distance. Inasmuch as the next adjacent coolers in each vertical row provide a similar flow of atmosphere, there will be provided a high velocity flow of atmosphere longitudinally over the strip in each pass but, of course, with the flow being divided into a plurality of zones spaced vertically along each pass. Moreover, in view of the fact that a pair of inlet or suction chambers are provided in conjunction with each jet discharge orifice means to draw off the spent atmosphere at a plurality of places along each vertical pass, and a suction and pressurizing fan motor **16** is provided for each of the plenum chambers, the quantity of air recirculated through each of the jet discharge orifices is automatically regulated. Thus, the cooling atmosphere is not pumped from one end of the cooling tower to the other.

One of the primary resistances to heat transfer from the strip to the cooled atmosphere circulated by the cooling units is provided by a boundary layer of hot atmosphere which is carried along by the fast moving strip. One of the advantages of a jet cooler of the type described is that the high velocity discharge of cooled atmosphere from the orifices **48** penetrates this boundary layer of hot atmosphere and wipes it from the strip, thus bringing the cooled atmosphere into improved heat transfer relation with the strip. In order to achieve this boundary layer removal it is preferred that, at or closely adjacent the point where the jet splits into two paths longitudinally of the strip, the cooled atmosphere have a velocity in the path of strip movement at least equal to the lineal speed of the strip. In this manner, the momentum of the circulating atmosphere will, at the desired point, be at least equal to the momentum of the boundary layer.

As a specific example of the improvement in heat transfer obtainable through the use of jet cooling units of the type described, a typical pure radiation cooling installation for cooling strip from 900° F. to 225° F. might require an installation approximately 1500 feet long and involving thirty passes of strip. In such an installation, the first eighteen passes might be used to reduce the strip temperature from 900° F. to 460° F., the remaining twelve passes reducing the strip temperature from 460° F. to 225° F. Also, the final twelve passes of radiation cooling might be replaced with four passes of a jet cooling arrangement of the type described. It might be noted that two additional passes of jet cooling would suffice to reduce the strip temperature from 225° F. to 150° F. It will, of course, be recognized that it is much more difficult to extract heat from the strip in the lower temperature ranges than in the higher ranges. For example, if it were desired to replace the initial eighteen passes of radiation cooling with the faster jet cooling apparatus, only two passes of jet cooling would be required in order to achieve the same reduction in strip temperature. A specific arrangement of jet cooling units for the four passes mentioned above comprised five vertical rows of jet units with each row consisting of seven jet units. The slots 48 in each row of units were spaced apart approximately 7 feet, with each slot being approximately 36 inches long and 0.8 inch wide. The jet discharge velocity at the orifice was selected to be on the order of approximately 10,000 feet per minute for a lineal strip speed of approximately 1500 feet per minute. Heat transfer coefficients on the order of 17 to 19 were obtained, as compared with heat transfer coefficients on the order of 3 to 5 obtainable from a conventional pure radiation type cooling arrangement.

From the above it can be seen that jet cooling units provide a marked reduction in the number of passes required to reduce the strip temperature over a given range, thus obviously resulting in a marked improvement in the space requirement for the apparatus. In this connection, a reduction in the length of the cooling apparatus on the order 75 percent would not be unusual. The reduction in length of the apparatus, of course, results in a corresponding reduction in the number of rows and associated structure. However, the high speed jet discharge of atmosphere against a fast moving strip supported at widely spaced points passing closely adjacent the relatively large surface area of the jet cooling units results in a tendency for the strip to flutter or, in other words, move rapidly back and forth between next adjacent cooling units of next adjacent passes. This flutter may cause engagement of the strip with the cooling units so as to cause surface damage to the strip, and, of course, violent strip movement of this type may tend to result in structural damage to the strip. Therefore, in accordance with this invention the jet cooling units in each vertical row thereof are staggered vertically relative to the units in the next adjacent vertical row so as to vertically offset the geometric center of the hydraulic area of the jet discharge orifices acting on opposite sides of the strip. While this staggering of the cooling units results in a substantial reduction in, if not elimination of, strip flutter, it has been found that if the oppositely facing inlet openings of the next adjacent cooling units in each row are too closely spaced, there may be provided an area of relatively low static pressure between the next adjacent cooling units in each row. The staggering of the cooling units will thus result in a high pressure discharge jet being located opposite the relatively low pressure zone on the other side of the strip. This pressure unbalance may tend to cause the strip to be drawn toward the inlet zone between the cooling units. Accordingly, it is desirable to space the jet discharge units 32 a substantial distance vertically of each other. Referring to FIGS. 1 and 2, each jet discharge unit in each vertical row of units is shown as being positioned so as to be located vertically between the next adjacent pair of jet discharge units 32 acting on the opposite side of the strip as it passes along the strip path therebetween. As shown, the inlets 50 of each jet discharge unit is substantially aligned in the direction of strip movement with the inlet 50 of the jet discharge units on the opposite side of the strip path. Thus, as shown, jet discharge orifice means acting on opposite sides of the strip are staggered and are centered opposite the space between the inlets 50 of the next adjacent pair of jet discharge units on the opposite side of the same strip path.

The location of the heat exchange means in the manner and position shown in FIG. 3 permits the cooling units to be reduced in height or in other words in the dimension corresponding to the direction of strip movement past the unit. In this manner a greater spacing of the inlet openings 50 may be obtained without requiring any increase in the spacing of the jet discharge slots 48. Another advantage of the location and configuration of the heat exchanger shown in FIG. 3 is that it is located entirely outside the tower housing and remote from the strip being treated by the jet unit. In this manner, if for any reason the movement of hot strip is halted there will be no direct radiation heat transfer between the strip and the heat exchanger such as occurs in pure radiation type coolers or in coolers of the type shown in the aforementioned Cooper et al. patent. Additionally, the remote location of the heat exchanger relative to the strip reduces any convection heat transfer to a minimum. Accordingly, in the event strip movement is halted there will be no rapid cooling of the strip and atmosphere, which rapid cooling may cause a sharp and rapid reduction in pressure within the tower housing. Such a rapid reduction in the pressure of the atmosphere or, as it is commonly referred to, atmosphere collapse, can cause severe buckling and damage to the housing of the cooling apparatus. Further, the provision of the single horseshoe shaped heat exchanger fitting around the inlet opening of the blower fan rather than the provision of separate heat exchangers in the inlet chamber 46 provides an obvious reduction in parts and thus contributes to ease and economy of manufacture. The fact that there are no joints in the portion of the heat exchanger located inside the jet cooler housing precludes the possibility of any water leakage occurring within the jet cooling unit, which leakage might affect the dew point within the cooling tower.

The reduction in height of the cooling unit, attendant to the location of the heat exchanger outside of the inlet chambers 46, also reduces the tendency for a Bernoulli effect to be created between the strip and the closely adjacent faces of the cooling units. As will be observed, with a strip moving at approximately 1500 feet per minute and spaced only approximately 4 inches from the faces of the cooling units, and with a high velocity flow of atmosphere being passed between and parallel to the strip and next adjacent face of the casing, there is an ideal situation for a Bernoulli effect to result. The reduction in height of the cooling unit will reduce the tendency for the creation of the Bernoulli effect by reducing the span of the casing over which the strip travels. Also, in accordance with one aspect of the invention, the inlet openings 50 are dimensioned to have a length of no greater than approximately 65 percent of the length of the jet orifice means, and the openings are generally centered relative to the plenum chamber portion of the unit and thus the strip path so that the mass of atmosphere flow entering the cooling unit will be generally centered relative to the lateral centerline of the orifice means and thus the midsection of the strip. This materially reduces, if not substantially eliminates, any tendency of the strip to twist about its longitudinal axis, such as might occur were the openings relatively long, for example, of a length corresponding to the width of the strip. This tendency of the strip to twist is caused by the tendency of the atmosphere entering the inlet openings of the unit to crowd toward the fan end of the plenum chamber or in other words toward the end of each inlet opening next adjacent the fan. This results in a low pressure area along the corresponding edge of the strip which tends to cause this edge of the strip to move toward the face of the cooling unit housing. The same situation exists with respect to the next adjacent cooling unit in the same vertical row of units. In the case of the next adjacent unit, however, the fan is next adjacent the other edge of the strip with the result that this edge of the strip tends to be moved in the opposite direction, with a resulting twisting of the strip about its longitudinal axis. The reduction in length of the inlet openings to substantially less than strip width and the general centering of the openings relative to the strip path materially reduces the distortion of atmosphere flow at the inlet openings and materially reduces tendency of the strip to be twisted. While it will be apparent that reduction of strip twisting might further be improved by offsetting the inlet openings toward the end of the cooling unit remote from the fan, it has been found that generally satisfactory results are obtained by centering the inlet openings relative to the lateral centerline of the orifice means which extends laterally of the plenum chamber and is adapted to extend parallel to the centerlin of a next adjacent strip path.

As noted above, the passage of high velocity atmosphere between the fast moving strip and next adjacent faces of the jet cooling unit housings tends to create a Bernoulli effect which may cause the strip to ride against the faces of the jet units. While the reduction in height of the units, due to the remote location of the heat exchanger, reduces the Bernoulli effect, it is desired to further reduce and, ideally, to eliminate this problem. Thus, in accordance with this invention, I provide the small diameter holes 49 which are arranged in a pair of rows extending parallel to and spaced on opopsite sides from the jet discharge slot 48. These anti-Bernoulli holes provide an atmosphere discharge flow toward the adjacent face of the strip which tends to reduce the velocity, in the direction of the path of the strip, of the atmosphere discharged from the nozzle 48 and further provides a substantial amount of turbulence in the area where the discharge from the holes 49 meets the discharge from the nozzle 48. In this manner, the Bernoulli effect tends to be cancelled out, and the increase in turbulence provides improved heat transfer between the total discharge of the jet cooling unit and the atmosphere within the tower.

While it is preferred that the anti-Bernoulli orifices 49 be provided, it will be apparent that the remaining aforedescribed novel construction and advantages of the present invention may be provided in a jet cooling unit without the provision of the orifices 49. Such a modified cooling unit is shown in FIGS. 6 and 7, wherein like reference numerals refer to like parts described above in connection with the embodiment of FIGS. 3 and 5.

Another alternative and the preferred embodiment of this invention is shown in FIG. 8. The jet cooling unit of FIG. 8 comprises a structure which is identical with that of the embodiment of FIGS. 3 to 5, with the exception of the orifice discharge means. In the embodiment of FIG. 8, the orifice discharge means provided consists of a plurality of small diameter openings or orifices 70 arranged in a plurality of rows each extending longitudinally of the plenum chamber or, in other words, at right angles to the direction of movement of the strip, and with the rows being spaced apart in the direction of strip movement. The orifices are preferably arranged in a generally rectangular pattern having a centerline extending generally laterally of the face of the plenum chamber and adapted to extend longitudinally of a next adjacent strip path. The orifice pattern has a length preferably at least equal to the width of strip which will most commonly be processed with the apparatus so as to assure uniform cooling across the width of the strip. However, as will be apparent from FIG. 8, it is preferred that the inner horizontal rows of orifices be of progressively lesser length so that there will be fewer jets impinging on the edge of the strip than upon the center thereof. This pattern of the orifices is desired inasmuch as the edge of the strip tends to cool faster than the center and thus the reduction in number of coling jets at the edge of the strip results in a more uniform cooling across the strip.

It should be noted that the orifices 70 in the face of the plenum chamber are truly orifices, and the provision of these openings in the plenum chamber does not merely result in a screen or mesh-like configuration. In this connection, it is preferred that the total area of the orifices 70 be no greater than 10 percent the immediate area of the face of the cooling unit through which the orifices extend. By the immediate area is meant that area of the face of the cooling unit which is defined by the overall geometric pattern of the orifices. It should further be noted that the smallest percentage of openings in any screen or similar item commonly available is about 15 percent of of the immediate area covered by the openings in the screen.

In a jet cooling unit of the type shown in FIG. 8 the velocity of atmosphere through the plenum chamber of the unit will be substantially less than the velocity of the jets of atmosphere issuing from the orifices 70. In this connection, it is preferred that the jet velocity be approximately ten times the velocity of the atmosphere in the plenum chamber. Correspondingly, it is preferred that the total area of the orifices 70 on each side of the cooling unit be approximately one-tenth the cross sectional area of the plenum chamber. The cross sectional area of the plenum chamber is that indicated by the cross sectional arrows of FIG. 7 or, in other words, the area of the plenum chamber lying in a plane extending longitudinally of the direction of strip movement and also at right angles to the path of strip movement past the cooling unit.

It has been found that the provision in a jet cooling unit of the type described of orifice discharge means of the type shown in FIG. 8 provides improved strip behavior in that the Bernoulli effect is minimized and further the strip, even at high lineal speeds, will not experience any violent whipping or adverse flutter. In utilizing jet cooling units having the construction of the embodiment of FIG. 8, heat transfer coefficients on the order of 18 B.t.u. per hour per square foot per degree Fahrenheit have been obtained utilizing a flow of 1750 s.c.f.m. of atmosphere having the density and thermal properties of air and at a velocity of approximately 8,000 feet per minute. It is believed that the improved performance obtained from this preferred embodiment of the invention results from the provision of a multiplicity of jets which maintain a high coefficient of heat transfer over a wider area of the strip than is possible with a single slot-type jet discharge. Further, it is believed that the multiplicity of small jets distributed laterally and longitudinally of the strip enhances stabilization of the strip as it passes by the cooler. In this connection, it is believed that the multiplicity of jets arranged in the relatively large pattern as shown in FIG. 8 provide a more uniform and larger area of support for the strip than in the case of a single flat orifice discharge cooling unit. Further, it is believed that the multiplicity of jets arranged in the relatively large pattern of FIG. 8 tend to provide a self-correcting feature for stabilizing strip movement and reducing flutter and/or twisting of the strip. The multiplicity of jets each being of comparatively small size results in the velocity and volume of air passing through each individual jet being relatively constant regardless of the distance of the strip from the jet cooler, within a reasonable range. Inasmuch as the force of each jet on the strip acting to move the strip away from the jet cooler will diminish substantially as the distance between the strip and jet cooler increases, it can be seen that with a constant velocity and volume of atmosphere passing through each orifice opening any movement of any portion of the strip away from the jet cooling unit will result in a lesser force being exerted on the strip by the jets impinging on that portion of the strip, and the strip will tend to be moved back to its original position by the jets impinging on opposite portions of the strip. Thus, the multiplicity of small diameter jets provides an automatic self-correction of strip position with respect to any variation in distance of the strip from the cooler such as might occur during twisting of the strip or during a transient flutter condition.

Inasmuch as the velocity of the atmosphere issuing from each orifice 70 diminishes as the distance increases from the orifice to the next adjacent strip, it is preferred that the ratio of the distance between the orifice and next adjacent strip to the diameter of each orifice not exceed ten to one. At this ratio of strip spacing to orifice diameter, the velocity of the jet as it impinges on the strip will be approximately 65 percent of the maximum velocity of the jet. Any further increase in this ratio without a substantial increase in fan horsepower results in a material decrease in performance of the cooling units, inasmuch as the velocity of the jets as they impinge on the strip will not be sufficiently effective in tending to remove the barrier layer of hot gases carried along with the strip. Therefore, the scrubbing or removing of this barrier layer will be greatly minimized. Where a plurality of jet cooling units as shown in FIG. 8 are arranged in the manner shown in FIGS. 1 and 2, the ratio of strip spacing to orifice diameter is related to the ratio between the spacing of next adjacent vertical rows of jet cooling units to the diameter of each of the orifices in the cooling units. As expressed in this manner, the ratio should not exceed approximately twenty to one.

A specific example of a preferred embodiment of a cooling unit of the type shown in FIG. 1 comprised a 5 horsepower electric motor driving a radial fan providing a jet discharge velocity of approximately 8,000 feet per minute. The plenum chamber of the unit was approximately 64 inches long by 50½ inches wide and 14 inches thick. Thus, each face of the plenum chamber was approximately 64 inches by 50½ inches. Eighty-two orifices of ⅝-inch diameter each were provided on the face of the plenum chamber. These orifices were arranged in six rows in a pattern as shown in FIG. 8, with sixteen orifices in the outer two rows, thirteen orifices in the next adjacent two inner rows, and twelve orifices in the two innermost horizontal rows. The orifices in each row were spaced apart 2½ inches on center. The rows of orifices were spaced apart a distance of 4 inches on center with the exception of the two innermost rows which were spaced apart a distance of 6 inches on center. The immediate area of the orifices 70 was an area approximately 37½ inches long by 24 inches wide, and the total area of the orifices 70 was approximately 3 percent of this immediate area. The cooling unit was primarily intended for use with strip approximately 30 inches wide. In this connection, the inlet openings of the cooling unit were centered relative to the orifice pattern and were approximately 18 inches long. A plurality of such units were mounted in the manner shown in FIGS. 1 and 2 utilizing a horizontal spacing between next adjacent vertical rows of units of approximately thirteen times the diameter of the orifices. In other words, the ratio of the spacing of the strip and cooling units to the diameter of the orifices was approximately 6.5. With such a ratio, the velocity of the jets impinging on the strip was approximately 90 to 95 percent of the maximum velocity of the jet, thus maintaining optimum tendency for the penetration of the boundary layer of hot air carried by the strip.

While the invention has been described in terms of the specific embodiments shown, it will, of course, be understood that various modifications and alterations might be made in the structures shown without departing from the scope of the invention. Particularly, it is again emphasized that the units may be utilized for heating as well as cooling and that in all cases in the foregoing description and appended claims where the apparatus is described in terms of cooling it is to be understood that it is intended also to include heating. Accordingly, the foregoing description and accompanying drawings are to be taken only in an illustrative sense and not as limiting the invention.

It is also to be understood that the language in the following claims is intended to cover all of the generic and specific features of the invention herein described and all statements of the scope of the invention which, as a matter of language, might be said to fall therebetween.

What I claim as new and desire to secure by Letters Patent of the United States is:

1. A jet cooling unit of the type described comprising a housing adapted to be removably supported alongside a path of movement of strip material, a motor driven high pressure rise fan supported on said housing and having an inlet and an outlet, the housing being provided with a plenum chamber connected in flow communication with the fan outlet, said plenum chamber having a generally flat face adapted to be disposed substantially parallel to the path of strip movement, orifice means for the high velocity discharge of atmosphere from the plenum chamber substantially at right angles toward a next adjacent strip path, said orifice means including an elongated narrow slot extending laterally of the strip path and a plurality of orifices disposed on opposite sides of the slot with the orifices on each side of the slot being arranged substantially in a row extending parallel to the slot, the housing further being provided with enclosed suction chambers spaced apart on opposite sides of the orifice means and longitudinally thereof in the direction of strip movement past the unit, said suction chambers being connected in flow communication with the fan inlet to pull spent atmosphere from the surface of the strip for recirculation, and heat exchanger means disposed within the housing and in the path of movement of atmosphere through the housing.

2. A jet cooling unit of the type described comprising an elongated housing adapted to be supported alongside a path of movement of strip material, a motor driven high pressure rise fan supported on one end of the housing and having an inlet and an outlet, a plenum chamber at the other end of said housing in flow communication with the fan outlet, said plenum chamber having a generally flat face adapted to be disposed substantially parallel to the path of strip movement, said flat face providing orifice means for the discharge of high velocity atmosphere therefrom substantially at right angles toward a next adjacent strip, said orifice means extending longitudinally of the housing, a pair of inlet chambers spaced apart laterally of the housing and longitudinally with respect to the path of strip movement and on opposite sides of the plenum chamber in flow communication with the fan inlet, each inlet chamber being provided with an inlet opening generally centered relative to said orifice means and having a dimension longitudinally of said housing substantially less than that of said orifice means, and heat exchanger means disposed within the housing remote from said inlet openings and in the path of atmosphere circulated through the housing by the fan.

3. A jet cooling unit of the type described comprising a housing adapted to be supported alongside a path of movement of strip material, a motor driven high pressure rise fan supported on said housing and having an inlet and an outlet, the housing being provided with a plenum chamber connected in flow communication with the fan outlet, the plenum chamber having a face adapted to be

disposed parallel to a next adjacent strip path, the face of the plenum chamber being provided with orifice means for the discharge of atmosphere therefrom, said orifice means consisting of a plurality of small diameter orifices spaced apart laterally and longitudinally of a centerline lying in the general plane of said face and adapted to extend parallel to the centerline of a next adjacent strip path, said housing further having a pair of inlet chambers spaced apart on opposite sides of said plenum chamber in the direction of said centerline of the orifice means, each inlet chamber having an inlet opening facing in the direction of said centerline of said orifice means and having a length no greater than approximately 65% of the length of said orifice means as measured at right angles to the centerline of the orifice means, each inlet opening being generally centered relative to said centerline of said orifice means, and heat exchanger means disposed within the housing remote from said inlet openings and in the path of atmosphere circulated through the housing.

4. In apparatus of the type described, a housing having means for passing strip therethrough in a predetermined path, and means for cooling the strip comprising a plurality of jet cooling units supported on the housing and arranged in at least a pair of rows extending parallel to and on opposite sides of at least a portion of said strip path, each cooling unit in each row of said pair of rows thereof including a plenum chamber provided with orifice means for the discharge of atmosphere therefrom and toward the other row of cooling units of said pair thereof, the orifice means in one row of said pair of rows being offset relative to the orifice means in the other row of said pair in the direction of the strip path between said pair of rows, said orifice means consisting of a plurality of small orifices spaced apart laterally of and longitudinally of the strip path between said pair of rows of units, said orifices being arranged in a pattern extending laterally of the strip path between said pair of rows, each cooling unit being provided with atmosphere inlet openings spaced apart on opposite sides of said orifice means and longitudinally of said strip path, each of said inlet openings being generally centered relative to the centerline of said pattern which extends parallel to the strip path between said pair of rows and being of a length substantially less than that of said pattern, each cooling unit including a motor driven high pressure rise fan for circulating atmosphere from said inlet means to said plenum chamber, each cooling unit further including heat exchanger means in the unit and disposed in the path of atmosphere from said inlet means to said plenum chamber.

5. In apparatus of the type described, a housing having means for passing strip therethrough in a predetermined path, and means for cooling the strip comprising a plurality of jet cooling units supported on the housing and arranged in at least a pair of rows extending parallel to and on opposite sides of at least a portion of said strip path, each cooling unit in each row of said pair of rows thereof including a plenum chamber provided with a face extending parallel to the strip path between said pair of rows, said face being provided with orifice means for the discharge of atmosphere from the plenum chamber, the orifice means in one row of said pair of rows being offset relative to the orifice means in the other row of said pair in the direction of the strip path between said pair of rows, said orifice means consisting of a plurality of small orifices spaced apart laterally of and longitudinally of the strip path between said pair of rows of units, said orifices being arranged in a pattern extending laterally of the strip path between said pair of rows, the faces of the plenum chambers in each row of units in said pair of rows being spaced from the faces of the plenum chambers of the other row in said pair as measured at right angles to said strip path a distance no greater than twenty times the diameter of one of said orifices,

each cooling unit being provided with atmosphere inlet openings spaced apart on opposite sides of said orifice means and longitudinally of said strip path, each of said inlet openings being generally centered relative to the centerline of said pattern which extends parallel to the strip path between said pair of rows and being of a length substantially less than that of said pattern, each cooling unit including a motor driven high pressure rise fan for circulating atmosphere from said inlet means to said plenum chamber, each cooling unit further including heat exchanger means in the unit and disposed in the path of atmosphere from said inlet means to said plenum chamber.

6. In apparatus for heating or cooling strip metal, a substantially airtight housing having means at widely spaced points for supporting strip metal passing therethrough, a plurality of jet discharge units positioned on said housing and arranged between the strip supporting means in at least a pair of vertical rows extending parallel to and spaced apart on opposite sides of the strip path, each of said jet discharge units being provided with a plenum chamber having orifice means for discharging high velocity jets of conditioned atmosphere substantially at right angles toward the general plane of the strip path, each of said jet discharge units further having a pair of suction chambers disposed on both sides of the orifice means in a direction longitudinally thereof with respect to the strip path, the orifice means of the jet discharge units positioned on opposite sides of the strip path being relatively offset so that the strip is alternately subjected to high velocity jets of conditioned atmosphere on one side and then the other as it passes along the strip path, each orifice means on one side of the strip path being displaced longitudinally along the strip path at least as far from the next adjacent orifice means discharging atmosphere on the opposite side of the strip as is the inlet opening for the suction chamber of said next adjacent orifice means.

7. In apparatus for heating or cooling strip metal, a substantially airtight housing having means for passing strip metal therethrough in a plurality of vertically extending loops to provide a multi-pass path for the strip through the housing, supporting rolls adapted to be positioned in the loops to support the strip and to guide it along the strip path, a plurality of jet discharge units mounted on said housing and arranged between the strip supporting rolls in at least a pair of rows extending parallel to and spaced apart on opposite sides of the strip path, each of said jet discharge units being provided with a plenum chamber having orifice means for discharging high velocity jets of conditioned atmosphere substantially at right angles toward the general plane of the strip path, each of said jet discharge units further having a pair of suction chambers disposed on both sides of the orifice means in a direction longitudinally thereof with respect to the strip path, the orifice means of the jet discharge units positioned on opposite sides of the strip path being relatively offset so that the strip is alternately subjected to high velocity jets of conditioned atmosphere on one side and then the other as it passes along the strip path, each orifice means on one side of the strip path being displaced longitudinally along the strip path at least as far from the next adjacent orifice means discharging atmosphere on the opposite side of the strip as is the inlet opening for the suction chamber of said next adjacent orifice means.

8. In apparatus for heating or cooling strip metal, a substantially airtight housing having means for passing strip metal therethrough in a plurality of vertically extending loops to provide a multi-pass path for the strip through the housing, supporting rolls adapted to be positioned in the loops to support the strip and to guide it along the strip path, a plurality of jet discharge units mounted on said housing and arranged between the strip supporting rolls in at least a pair of rows extending paral-

lel to and spaced apart on opposite sides of the strip path, each of said jet discharge units being provided with a plenum chamber having orifice means formed by a plurality of small diameter openings for discharging high velocity jets of conditioned atmosphere substantially at right angles toward the general plane of the strip path, each of said jet discharge units further having a pair of suction chambers disposed on both sides of the orifice means in a direction longitudinally thereof with respect to the strip path, the orifice means of the jet discharge units positioned on opposite sides of the strip path being relatively offset so that the strip is alternately subjected to high velocity jets of conditioned atmosphere on one side and then the other as it passes along the strip path, the geometric center of the hydraulic area of the orifice means on one side of the strip path being displaced longitudinally along the strip path at least as far from the geometric center of the hydraulic area of the next adjacent orifice means discharging atmosphere on the opposite side of the strip as is the inlet opening for the suction chamber of said next adjacent orifice means.

9. In apparatus for heating or cooling strip metal, a substantially airtight housing having means for passing strip metal therethrough in a plurality of vertically extending loops to provide a multi-pass path for the strip through the housing, supporting rolls adapted to be positioned in the loops to support the strip and to guide it along the strip path, a plurality of jet discharge units mounted on said housing and arranged between the strip supporting rolls in at least a pair of rows extending parallel to and spaced apart on opposite sides of the strip path, each of said jet discharge units being provided with a plenum chamber having orifice means formed by a plurality of small diameter openings for discharging high velocity jets of conditioned atmosphere substantially at right angles toward the general plane of the strip path, each of said jet discharge units further having a pair of suction chambers disposed on both sides of the orifice means in a direction longitudinally thereof with respect to the strip path, each of said jet discharge units further being provided with a fan having its outlet connected with the plenum chamber thereof and its inlet connected with the suction chambers thereof to pull the spent atmosphere from the surface of the strip material, the orifice means of the jet discharge units positioned on opposite sides of the strip path being relatively offset so that the strip is alternately subjected to high velocity jets of conditioned atmosphere on one side and then the other as it passes along the strip path, the geometric center of the hydraulic area of the orifice means on one side of the strip path being displaced longitudinally along the strip path at least as far from the geometric center of the hydraulic area of the next adjacent orifice means discharging atmosphere on the opposite side of the strip as is the inlet opening for the suction chamber of said next adjacent orifice means.

10. A continuous process strip annealing furnace having means for heating or cooling strip metal passing therethrough comprising a furnace housing having means for supporting moving strip metal therein, a plurality of plenum chambers in said furnace housing positioned adjacent and on opposite sides of the plane of said strip, said plenum chambers being spaced apart from each other along the path of strip movement, orifice means in said plenum chambers for discharging a gaseous medium against the surfaces of said strip at high velocity, inlet means positioned between said plenum chambers along the path of strip movement and aligned to establish gaseous medium flow paths from said orifice means to said inlet means in directions substantially parallel to the path of strip movement, said inlet means forming low pressure suction zones in between and alternately spaced with said orifice means along the path of strip movement, said orifice means on one side of the strip being displaced along the path of strip movement from the orifice means on the opposite side of the strip such that the orifice means on one side are substantially aligned with the low pressure suction zones on the opposite sides, fan means connected to said plenum chambers for pressurizing the gaseous medium within said plenum chambers, means connecting said inlet means back to said fan means to establish recirculating flow paths for said gaseous medium impinging against the strip, and heat exchanger means connected in series flow relationship with said fan means and said recirculating flow paths to provide for recirculation of said gaseous medium through said heat exchanger means.

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