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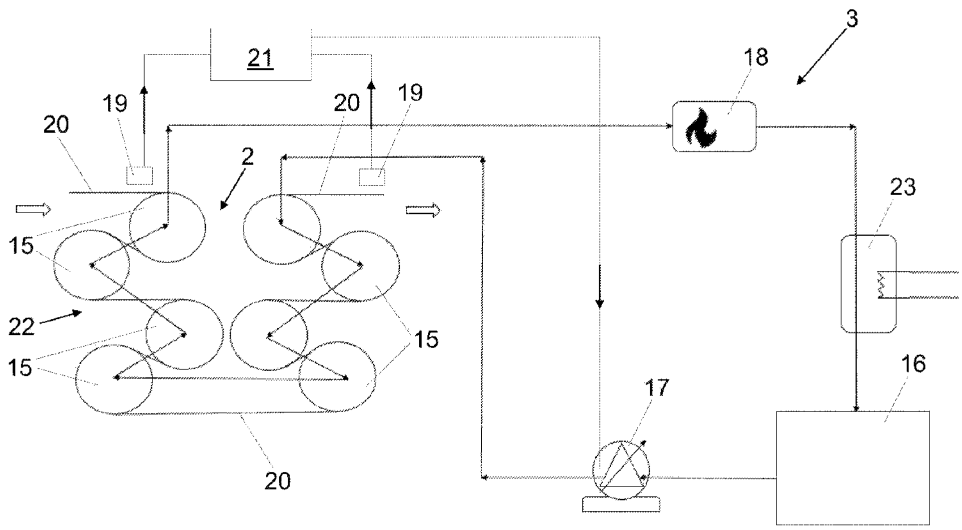

Fig. 5

(57) Abstract: A metal strip production plant comprising • - a hot-rolling mill for producing a strip from a cast product; • - a cooling station (2) for cooling the strip, arranged downstream of said hot-rolling mill and provided with a first heat exchanger (22); • - a closed circuit (3) feedable with a first heat-transfer fluid, part of said closed circuit (3) passing through said first heat exchanger (22) for subtracting thermal energy from the strip by heating the first heat-transfer fluid; • - a second heat exchanger (23), cooperating with said closed circuit (3) for transferring thermal energy from said first heat-transfer fluid to a second heat-transfer fluid; • - a further circuit feedable with the second heat-transfer fluid, cooperating with said second heat exchanger (23) and configured to convert at least part of the thermal energy transferred to said second heat-transfer fluid into electric energy and/or to convey at least part of the thermal energy transferred to said second heat- transfer fluid towards at least one user.

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A METAL STRIP PRODUCTION PLANT AND A RELATED PROCESS

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Field of the invention

The present invention relates to a metal strip production plant and related production process.

Background art

The winding temperature of the strip in the winder at the outlet of a hot-rolling mill for strips (HSM, hot strip mill) varies from 750°C to 250°C, depending on the type of steel and desired mechanical features of the final rolled product.

The current production cycle provides that at the outlet of the hot-rolling mill the hot-rolled strip is wound into coils, which are stored for 2 or 3 days in a special cooling area, so that they can reach the right temperature for shipping or subsequent cold treatments, generally around 80°C.

This method of operating has a number of disadvantages, and in particular:

- a considerable amount of thermal energy dispersed into the environment;
- high investment in coil storage structures at the outlet of the hot-rolling mill;
- lengthy production times of the final product, as it is necessary to wait for the coils to reach an average temperature of around 80°C before shipping or before transferring the coils for subsequent processing.

A metal strip production plant with these disadvantages is disclosed in document WO2015/018673A1.

Considering, for example a rolling mill capacity for hot strips of 4,000 kt/year with an average temperature of 580°C of the strips stored in the storage area and an end cooling temperature equal to 80°C, $1.476*10^9$ MJ/year, i.e. 46.80 MW are wasted in the environment in one year.

In general, the production of steel involves a series of processes: the fusion of the raw materials, the purification and addition of possible chemical elements, casting, rolling and finishing of the product.

To ensure punctual deliveries, the steel producer must take into account the processing times and potential delays, from the moment an order reaches the plant until the finished product is loaded for transport.

The delivery dates promised to the final customer must be achievable by the producer, and acceptable by the customer, and the lead-time between the order and the delivery must take into account the processing times and the intermediate waiting times as with the current air-cooling step of the coils.

The cooling of the coils of hot-rolled strip in the storage area disadvantageously influences the delivery times, as it lengthens the lead-time; furthermore, the climatic conditions, such as humidity, room temperature and ventilation influence the cooling time in a way difficult to control.

In some plants, in order to reduce the storage and cooling times, the coils are cooled by spraying water onto the outer surface thereof, disadvantageously producing vapor, therefore energy dispersed into the environment, and wastewater to be treated in a special plant, in addition to potential defects in the material related to oxidation phenomena.

Furthermore, when the cooling is accelerated during storage, an increase is expected in the yield point with a corresponding decrease in ductility (elongation at break). This aspect is insignificant for ferrite-perlite-type microstructures already completely developed at the time of cooling at the run-out table of the hot-rolling mill, but it could be more relevant for bainitic-type microstructures and if the microstructure were not completely developed at the time of winding at the downcoiler. It is also important to consider the precipitation state that can influence not only the hot mechanical features, but also the subsequent cold-rolling process and the recrystallization annealing.

Therefore, the need is felt to make a metal strip production plant and related process capable of overcoming the aforesaid drawbacks.

Summary of the invention

It is an object of the present invention to develop a metal strip production plant, which allows recovering thermal energy of the strip downstream of the hot rolling, avoiding the dispersion thereof into the environment.

It is another object of the present invention to develop a production plant that allows obtaining a controlled time for the cooling of the hot-rolled strip, with the further advantage of reducing the lead time by 1 or 2 days.

It is another object of the present invention to develop a metal strip production process, which is more sustainable and has a reduced environmental impact with respect to the processes of the background art.

The present invention achieves at least one of said objects, and other objects, which will be apparent in light of the present description, by means of a metal strip production plant comprising:

- a hot-rolling mill for producing a strip from a cast product;
- a cooling station for cooling the strip, arranged downstream of said hot-rolling mill and provided with a first heat exchanger;
- a closed circuit feedable with a first heat-transfer fluid, part of said closed circuit passing through said first heat exchanger for subtracting thermal energy from the strip by heating the first heat-transfer fluid;
- a second heat exchanger, cooperating with said closed circuit for transferring thermal energy from said first heat-transfer fluid to a second heat-transfer fluid;
- a further circuit feedable with the second heat-transfer fluid, cooperating with said second heat exchanger and configured to convert at least part of the thermal energy transferred to said second heat-transfer fluid into electric energy and/or to convey at least part of the thermal energy transferred to said second heat-transfer fluid towards at least one user;

wherein said first heat exchanger comprises, or consists of, a plurality of cooling rollers crossed, preferably in sequence, by said part of the closed circuit;

and wherein the cooling rollers are provided with at least one inner channel, formed so that said cooling rollers can be crossed by the first heat-transfer fluid to cool the metal strip by conduction, said cooling rollers being adapted to be in direct contact with the strip.

A further aspect of the invention relates to a related metal strip production process, carried out by means of the aforesaid plant, the process comprising the following steps:

a) hot-rolling a cast product for producing a strip by means of the hot-rolling mill;

b) cooling the strip in the cooling station while running through the first heat exchanger, which is crossed by the first heat-transfer fluid flowing in the closed circuit by recovering thermal energy from the strip;

c) transferring thermal energy recovered from said first heat-transfer fluid to the second heat-transfer fluid by means of the second heat exchanger;

d) converting at least part of the thermal energy transferred to said second heat-transfer fluid into electricity and/or conveying at least part of the thermal energy transferred to said second heat-transfer fluid towards at least one user, by means of the further circuit cooperating with said second heat exchanger;

wherein in step b) the strip runs winding itself in sequence around cooling rollers of a plurality of cooling rollers defining the first heat exchanger, said cooling rollers being provided with at least one inner channel crossed by the first heat-transfer fluid flowing into the circuit for cooling the metal strip by conduction, said cooling rollers being in direct contact with the strip.

Advantageously, the solution of the invention allows recovering about 75% of the thermal energy of the hot-rolled strip, which is currently dispersed into the environment. Said energy can be reused, for example, as electrical and/or thermal energy in the same production plant or supplied to any further user.

The solution of the present invention can allow obtaining a saving in emissions of about 60,000-70,000 t/year of carbon dioxide, for example, thanks to electricity and/or hot water that can be produced by means of recovering the heat of the hot-rolled strips, with considerable savings in carbon tax that is now provided in numerous countries around the world, and a reduced ecological impact in general.

A further advantage of the present invention is represented by a reduction in the lead-time, which directly influences the profit of the steel producer and produces internal (producer side) and external (customer side) consequences, which are listed in the following table.

Consequence	Type	Effect
Quicker delivery	External	On the sale price with respect to competitors
Quicker adaption of products	Internal	On the sale price with respect to competitors
Less inventory	Internal	Positive economic effect
Reduction of waste	Internal	Quicker feedback on technical process
Increased safety in production plants	Internal	The reduced storage capacity is safer

Further features and advantages of the invention will become more apparent in light of the detailed description of exemplary but not exclusive embodiments.

The dependent claims describe particular embodiments of the invention.

Brief description of the figures

The description of the invention refers to the accompanying drawings, which are provided by way of non-limiting example, in which:

Figure 1 shows a block diagram of part of a first layout of a plant according to the invention;

Figure 2 shows a block diagram of part of a second layout of a plant according to the invention;

Figure 3 shows a block diagram of part of a third layout of a plant according to the invention;

Figure 4 shows a block diagram of part of a fourth layout of a plant according to the invention;

Figure 5 shows a first part of an embodiment of a plant according to the invention;

Figure 6 shows a second part of said embodiment;

Figure 7 shows alternative solutions of the configuration of the cooling rollers;

Figure 8 shows a top view of an example of the configuration of the cooling rollers;

Figure 9 shows an example of a hot-rolled strip coil storage area;

Figure 10 shows different layouts of a further part of a plant according to the invention;

Figure 11 shows examples of inner channels in a roller of a heat exchanger of the plant according to the invention.

The same reference numerals and letters in the drawings identify the same elements or components.

Description of illustrative embodiments of the invention

Examples of a metal strip production plant according to the invention are illustrated with reference to the Figures.

In all the embodiments of the invention, the plant comprises (Figures 1-6):

- a hot-rolling mill 1 for producing a strip from a cast product, such as a slab;
- a cooling station 2 for cooling the strip, in a controlled manner, arranged downstream of the hot-rolling mill 1 and provided with a first heat exchanger 22;

- a closed circuit 3 (Figure 5) feedable with a first heat-transfer fluid, part of said closed circuit 3 passing through the first heat exchanger 22 for subtracting thermal energy from the strip by said first heat-transfer fluid;
- a second heat exchanger 23, cooperating with the closed circuit 3 for transferring thermal energy from the first heat-transfer fluid to a second heat-transfer fluid;
- a further closed circuit 5 (Figure 6) feedable with the second heat-transfer fluid, cooperating with the second heat exchanger 23 and configured to convert at least part of the thermal energy transferred to said second heat-transfer fluid into electric energy and/or to convey at least part of the thermal energy transferred to said second heat-transfer fluid towards at least one user.

In a first embodiment of the invention, illustrated in Figures 5 and 6, the closed circuit 3 further comprises, considering the flow direction of the first heat-transfer fluid:

- a tank 16 of the first heat-transfer fluid, arranged downstream of the second heat exchanger 23,
- a pump 17 arranged between the tank 16 and the first heat exchanger 22,
- preferably an auxiliary heating device 18 arranged between the first heat exchanger 22 and the second heat exchanger 23.

A thermally insulated pipe connects all the aforesaid components of the circuit 3 in sequence.

The pump 17 is preferably operated by an electric motor.

The auxiliary heating device 18 can be an external natural gas heater or an electric heater for allowing cold starting of the energy recovery system.

Preferably, temperature sensors 19 are provided, e.g., pyrometers or thermal cameras or thermocouples, upstream and downstream of the first heat exchanger 22 for detecting the surface temperature of the strip and, therefore, controlling the cooling station 2.

Advantageously a control device 21 can be provided, adapted to receive temperature data by the temperature sensors 19 and consequently adjust the flow rate of the first heat-transfer fluid passing through the first heat exchanger 22, e.g., by acting on the operating parameters of the pump 17.

Preferably, the further circuit 5 configured to convert part of the thermal energy transferred to the second heat-transfer fluid into electric energy is based on a closed-loop Brayton cycle.

In the non-limiting example in Figure 6, said further circuit 5 comprises, considering the flow direction of the second heat-transfer fluid:

- a compressor 12, arranged upstream of the second heat exchanger 23;
- a turbine 13, arranged downstream of said second heat exchanger 23, for the production of mechanical energy, which can be transformed, in turn, into electricity by an alternator 26, coupled to the rotating axis of the turbine;
- preferably, a third heat exchanger 24, arranged downstream of the turbine 13, for removing a portion of thermal energy from the second heat-transfer fluid, for example by producing hot water at a high temperature;
- preferably a fourth heat exchanger 25, arranged between the third heat exchanger 24 and the compressor 12, for removing a further portion of thermal energy from the second heat-transfer fluid, for example by producing hot water at a low temperature.

Advantageously, in the solution of the invention the first heat exchanger 22 comprises, or consists of, a plurality of cooling rollers 15 (Figure 5) crossed, preferably in sequence, by a part of the closed circuit 3, and thus crossed by the first heat-transfer fluid. The hot-rolled metal strip 20 runs winding itself in sequence about the cooling rollers 15, which allow the advancement of the metal strip 20, and the first heat-transfer fluid passing through said rollers subtracts thermal energy from the strip. Said first heat-transfer fluid preferably runs in the opposite direction to the advancement direction of the strip, gradually increasing its own temperature.

The cooling rollers 15 are preferably made of a material with a high heat-exchange coefficient.

Preferably, the cooling rollers 15 are bridle rollers adapted to modify the direction of the strip path, for example defining a serpentine path of the strip, and controlling the strip tension.

Said cooling rollers, operable by electric motors, are configured so that the first heat-transfer fluid circulates in cascade between the rollers. Preferably, there are provided respective rotating joints with hydraulic connections on the sides of the rollers, at the inlet and at the outlet, for the first heat-transfer fluid circulating in cascade between the rollers for gradually cooling the strip.

The cooling rollers 15 vary in number, e.g. from 3 to 8. However, it is also possible to make groups of rollers 15 that exceed 8 in number.

Figure 7 illustrates configuration examples of the rollers 15 of the heat exchanger 22. The heat exchange capacity is also a function of the contact surface between strip 20 and rollers 15: the best results are obtained in configurations in which the roller 15 is wound by the strip over at least 180°. However, if it is necessary to vary the heat exchange, it is possible to vary the angle at which the roller 15 is wound from the strip, increasing said angle to exchange more heat and reducing said angle to exchange less heat.

Advantageously, in the solution of the invention, the cooling rollers 15 are provided with at least one inner channel, formed so that the rollers 15 can be crossed by the first heat-transfer fluid to cool the metal strip by conduction, the rollers 15 being in direct contact with the strip.

For example, the rollers 15 can have a diameter between 1 and 2 meters and a length of at least 2 meters, with inlet and outlet of the first heat-transfer fluid, for the inner channels of the rollers, through the hubs of the respective roller.

The rollers 15 are preferably interposed between a first stretch and a second stretch of the closed circuit 3 and the respective at least one inner channel of the rollers is an integral part of the closed circuit 3 so as to be crossed by the first heat-transfer fluid and cool the metal strip by conduction.

As shown diagrammatically in the non-limiting examples in Figures 5 and 8, the inner channels of the rollers 15 are connected in series, by means of intermediate stretches of the circuit 3.

It is possible to arrange a series of valves 27, e.g., by-pass valves, to avoid supplying one or more inner channels if it is necessary to decrease the heat exchange.

It is not excluded that the inner channels of the rollers 15 are connected in parallel (solution not shown) and communicating at the ends with the first stretch and second stretch of the circuit 3.

The inner channels of the rollers 15, preferably through inner channels, can define a rectilinear axis, substantially parallel to the longitudinal axis of the respective roller 15, or a helical or spiral axis that is wound about the longitudinal axis of the respective roller 15.

Only one inner channel, or inner jacket, can be present inside each roller 15, which can be annular or non-annular in shape, for example; or several inner channels or inner cavities can be present, possibly communicating with one another. Some non-limiting examples of peripheral inner channels 15' can be seen in the cross-sections of a roller 15, shown in Figure 11. The inner channels 15' can have any cross-section shape, not only round. For example, the cross-section can be polygonal.

In a first variant of the layout of the metal strip production plant of the invention, directly downstream of the cooling station 2 there are provided in sequence a pickling line 6 and a cold-rolling mill 7, preferably arranged directly in line with the hot-rolling mill 1 and the cooling station 2 (Figure 1), so that the product exiting the hot-rolling mill 1 at a high temperature can directly enter the pickling line 6, after thermal energy recovery of the strip by means of the cooling station 2 positioned between said hot-rolling mill 1 and said pickling line 6. This allows an endless-type production, i.e. without cuttings of the strip, potentially until the galvanizing downstream of the cold-rolling and/or until the subsequent painting.

If desiring to operate in semi-endless or coil-to-coil mode, by cutting the strip at the end of the hot rolling, the continuity of the strip can be restored by means of a welding machine 8 positioned between the cooling station 2 and said pickling line 6 for welding the head of a newly cooled strip to the tail of a previously cooled strip to be pickled (Figure 2).

These production methods have the further advantage of not comprising the formation of the coils and the relative storage station.

In a second variant of the layout of the metal strip production plant of the invention, shown diagrammatically in Figure 3, there are further provided, with respect to the first variant, between the hot-rolling mill 1 and the cooling station 2:

- a winding station 9 arranged to wind the strip and form at least one coil at the end of the hot rolling;

- a coil storage station 10, arranged off-line downstream of the winding station;
- an unwinding station 11 for unwinding the at least one coil that has reached a predetermined temperature in the storage station.

Downstream of said unwinding station 11 there are provided the cooling station 2, where the recovery of thermal energy from the strip takes place, and subsequently a further winding station 9'. The coils wound in said further winding station 9' are then brought, when necessary, to a pickling line 6 and a cold-rolling mill 7 in the same production plant, or they are transported to be pickled in a different strip production plant. Before pickling, the strip coils are obviously unwound.

Preferably, a welding machine 8 is provided between the further winding station 9' and the pickling line 6 for welding the head of a newly unwound strip to the tail of a previously unwound strip to be pickled, so as to reset the endless mode for the pickling and subsequent treatments.

In a third variant of the layout of the metal strip production plant of the invention diagrammatically shown in Figure 4, there are further provided between the hot-rolling mill 1 and the cooling station 2, with respect to the aforesaid first variant, a winding station 9 configured to wind the strip and form at least one coil and an unwinding station 11 for subsequently unwinding the at least one coil and feeding the strip to the cooling station 2, where the recovery of thermal energy from the strip is carried out, and then to the pickling line 6 and to the cold-rolling mill 7 of the same production plant.

Preferably, a welding machine 8 is provided between the cooling station 2 and the pickling line 6 for welding the head of a newly cooled strip to the tail of a previously cooled strip to be pickled, so as to reset the endless mode for the pickling and subsequent treatments. Alternatively, the welding machine 8 is provided between the unwinding station 11 and the cooling station 2 for welding the head of a newly unwound strip to the tail of a previously unwound strip to be subjected to cooling with the recovery of thermal energy and then pickling.

In the second variant and in the third variant of the layout of the plant of the invention, where there is provided the formation of coils of hot-rolled strip, thermographic systems can be provided for selecting the coils to be unwound and fed to the cooling station 2 based on the external temperature thereof, both to avoid a possible increase in the yield point and a corresponding decrease in the ductility (elongation at break) caused by the acceleration of strip cooling in the cooling station 2, and to optimize and maximize the recovery of thermal energy from the strip.

For example, infrared devices 28 are provided, such as thermal cameras or pyrometers, for identifying the coils with an external temperature of less than, or equal to, a threshold limit of 500°C. In fact, advantageously, the effects of the possible increase in yield point and corresponding decrease in ductility, which would be obtained by accelerating the cooling of the strip by means of the first heat-transfer fluid, can be considered negligible below 500°C.

The thermal images are transmitted to an evaluation software, which, based on the temperature measured, defines the correct loading sequences for unwinding the coils and feeding the strip to the cooling station 2, and thus, to the first heat exchanger 22.

In the case of the second layout variant, at least one infrared thermal camera 28 is mounted to an overhead crane 29 of the coil storage station 10 for selecting the coils to be moved to the unwinding station 11 (Figure 9).

In the case of the third layout variant, at least one infrared thermal camera 28 is mounted to the structure of the winding station 9 for selecting the coils to be unwound and fed to the cooling station 2.

Preferably, in all layout variants of the plant, the hot-rolling mill 1 comprises (Figure 10):

- a first rolling mill 35 or roughing mill, preferably comprising from two to four rolling stands, for performing a hot roughing of the slab and obtaining a blank, i.e. a so-called transfer bar;

- and a second rolling mill 39 or finishing mill, preferably comprising from four to seven rolling stands, for performing a hot finishing of the transfer bar and obtaining a strip.

The plant of the present invention, in some embodiments thereof, can comprise, in sequence (Figures 10a and 10b):

- a continuous casting machine 30 for casting a slab, preferably a slab having a thickness from 30 to 170 mm;

- a possible shear 31, e.g. a pendular shear for cutting the slab in the event of an emergency;
- a tunnel heating furnace 32, for maintaining or equalizing or increasing the temperature of the slab;
- at least one possible vertical rolling stand 33 (edger), or at least one possible press for reducing the width of the slab and bringing it closer to that of the desired strip, so as to reduce the waste and improve the yield;
- a possible first descaler 34, immediately upstream of the roughing mill 35;
- the roughing mill 35;
- a possible shear 36 for cutting the transfer bar in the case of an emergency or for eliminating the ends that may have an irregular shape, avoiding damaging the working rollers of the finishing mill 39 and reducing the probability of coggling with the consequent generation of waste;
- a rapid induction heating device 37, the power of which can be modulated and opportunely activated to restore the temperature that the product loses with roughing and thus enter the finishing mill while remaining in the austenitic field;
- a possible second descaler 38, immediately upstream of the finishing mill 39;
- the finishing mill 39;
- a laminar cooling device 40, e.g., in the shape of a roller table, positioned downstream of the second rolling mill 39 and immediately upstream of cutting means 41, said roller table being provided with laminar cooling systems for the upper and lower surfaces of the rolled strip;
- at least two winding systems 42, arranged downstream of the cutting means 41, defining the aforesaid winding station 9 and comprising, for example, gripping rollers and deflectors, winding reel, winding rollers and coil unloading system.

In an alternative embodiment of the plant, shown in Figure 10c, the rapid induction heating device 37 is not provided, and there are provided in sequence:
- the continuous casting machine 30;
- the possible shear 31;
- at least one possible vertical rolling stand 33 (edger), or at least one possible press;
- the possible first descaler 34, immediately upstream of the roughing mill 35;

- the roughing mill 35;

- the possible shear 36 for cutting the transfer bar;

- the tunnel heating furnace 32, for maintaining or equalizing or increasing the temperature of the transfer bar;

- the possible second descaler 38, immediately upstream of the finishing mill 39;

- the finishing mill 39;

- the laminar cooling device 40;

- the cutting means 41;

- the at least two winding systems 42, defining the aforesaid winding station 9.

In all these embodiments in Figures 10a, 10b and 10c, downstream of the winding station 9 there are provided:

- the possible unwinding station 11;

- the possible coil storage station 10, arranged off-line between the winding station 9 and the unwinding station 11;

- the cooling station 2, which cools the strip in a controlled manner by means of the first heat-transfer fluid;

- the possible welding machine 8;

- the pickling line 6;

- the cold-rolling mill 7;

- a possible annealing oven;

- a possible galvanizing and/or painting line of the strip.

A metal strip production process, carried out by means of a plant according to the invention, is described below.

In all the embodiments thereof, the process comprises the following steps:

a) hot-rolling a cast product for producing a strip by means of the hot-rolling mill 1;

b) cooling the strip in the cooling station 2 while running through the first heat exchanger 22, which is crossed by the first heat-transfer fluid flowing in the circuit 3 recovering thermal energy from the strip;

c) transferring thermal energy recovered from the first heat-transfer fluid to the second heat-transfer fluid by means of the second heat exchanger 23;

d) converting at least part of the thermal energy transferred to said second heat-transfer fluid into electric energy and/or conveying at least part of the thermal energy transferred to said second heat-transfer fluid towards at least one user, by means of the further circuit 5 cooperating with the second heat exchanger 23.

Advantageously, in step b) the strip runs winding itself about the cooling rollers 15, which allow the advancement of the metal strip 20 and define the first heat exchanger 22. Said cooling rollers 15 are crossed, preferably in sequence, by the first heat-transfer fluid flowing in the circuit 3, preferably in the opposite direction to the strip advancement, gradually increasing the temperature thereof at the expense of the strip.

By way of example, the cooling station 2 is dimensioned for a maximum flow rate of 600-620 t/h of the strip, e.g. , 610 t/h (169.4 kg/s).

Preferably, the temperature of the hot-rolled strip at the outlet of the hot-rolling mill 1 varies from 750°C to 250°C, depending on the types of steel and the desired mechanical features of the final rolled material.

When the temperature of the hot-rolled strip, directly at the exit of the finishing mill 39 of the hot-rolling mill 1 or at the exit of the possible laminar cooling device 40, is less than, or equal to 500°C, the strip can be directly fed to the cooling station 2 for a controlled cooling of the strip with recovery of part of the thermal energy thereof. After this cooling, the strip has a temperature in a range from 75 to 85°C, preferably 80-85°C, and a pickling and a cold rolling of the strip are performed, preferably in line with the hot rolling.

In the case of pickling performed immediately downstream of the cooling station 2, this represents a further energy saving as it is then necessary to compensate only the thermal losses of the pickling tank, saving about 5 MW in thermal energy, which is usually supplied to the plant as steam.

Instead, when the temperature of the hot-rolled strip, directly at the exit of the finishing mill 39 of the hot-rolling mill 1 or at the exit of the possible laminar cooling device 40, is greater than 500°C, the following steps are provided

- winding the strip into coils by means of the winding station 9;
- moving the coils off-line to the storage station 10;
- moving the coils from the storage station 10 to the unwinding station 11 when the temperature of the coils is less than, or equal to 500°C;

- unwinding the strip by means of the unwinding station 11 for feeding the cooling station 2.

After cooling in the cooling station 2, the strip has a temperature in a range from 75°C to 85°C, preferably 80-85°C, and a pickling and a cold rolling of the strip are performed.

Alternatively, after this cooling, the strip has a temperature in a range from 75 to 85°C, preferably 80-85°C, and there are provided a further winding of the strip in coils in a further winding station 9' (Figure 3), and subsequently, in the same production plant or in a separate production plant where the coils are transported, an unwinding of the strip to perform a pickling and a cold rolling.

In the variant in Figure 4, instead, when the temperature of the hot-rolled strip, directly at the exit of the finishing mill 39 of the hot-rolling mill 1 or at the exit of the possible laminar cooling device 40, is greater than 500°C, the following steps are provided

- winding the strip into coils by means of the winding station 9;
- unwinding the strip by means of the unwinding station 11 for feeding the cooling station 2 only when the temperature of the coils is less than, or equal to 500°C.

After cooling in the cooling station 2 the strip has a temperature in a range from 75 to 85°C, preferably 80-85°C, the head of a newly cooled strip is welded to the tail of a previously cooled strip to obtain a continuous strip to be subjected to pickling and subsequent cold rolling. Alternatively, the head-tail welding can be performed between the unwinding station 11 and the cooling station 2 for welding the head of a newly unwound strip to the tail of a previously unwound strip to be subjected to cooling with the recovery of thermal energy and then pickling.

Where there is provided the formation of coils of hot-rolled strip, the selection of the coils to be unwound and fed to the cooling station 2 based on the external temperature thereof can be automated by means of thermographic systems, such as infrared cameras 28, cooperating with an evaluation software for evaluating the thermal images transmitted, which, based on the temperature measured, defines the correct loading sequences for unwinding the coils and feeding the strip to the cooling station 2, and therefore to the first heat exchanger 22.

By way of example, in the cooling station 2 the strip can enter at a temperature of 480-500°C and comes out at a temperature of 75-85°C, while the first heat-transfer fluid, for example a diathermic oil, can enter the heat exchanger 22 at a temperature of about 70-80°C and comes out at a temperature of about 230-245°C, for example after passing through the cooling rollers 15 in series.

As a further example, the cooling station 2 of the invention allows transferring about 30,000 kW from the strip to a diathermic oil with a strip inlet temperature of 500°C, and about 10,000 kW for a strip temperature of 250°C.

Advantageously, to better adjust the cooling of the strip in the cooling station 2, a detection of the strip surface temperature can be provided upstream and downstream of the cooling station 2 by means of the temperature sensors 19. The adjustment of the flow rate of the first heat-transfer fluid passing through the first heat exchanger 22, in particular passing through the cooling rollers 15 is carried out by means of the control device 21 receiving the temperature data detected by said temperature sensors 19 and can consequently act, for example, on the operating parameters of the pump 17.

Preferably, the first heat-transfer fluid consists of diathermic oils or molten salts or molten metals.

The maximum operating temperature of a diathermic oil is preferably of about 300-390°C. A diathermic oil particularly suited for use in the plant of the invention has a maximum operating temperature of 310-330°C.

Preferably, the maximum temperature of the diathermic oil in the plant of the invention must not exceed 250°C.

Among the advantages of using diathermic oil there are:

- outstanding performance at high temperature, including excellent thermal stability and low vapor pressure;
- constant and reliable performance in transferring heat for long periods of time;
- it provides an uniform, reliable, efficient process heat, without requiring high pressures;
- the high boiling point contributes to reducing volatility and problems of fluid loss associated with other fluids;

- it is not corrosive for the metals commonly used in the construction of heat-transfer systems.

As an alternative to the diathermic oil, the first heat-transfer fluid can consist of molten salts.

The maximum operating temperature of a molten salt is about 550-600°C (depending on the type of salt). A molten salt particularly suited for use in the plant of the invention has a maximum operating temperature of about 490-510°C, e.g., about 500°C.

Preferably, the minimum temperature of the molten salt in the plant of the invention must not be less than 250°C (to avoid solidification of the salts and negative consequences on the process).

Among the advantages of using molten salts there are:

- the low-pressure liquid state thereof at high temperatures, unlike water, for example, which reaches high pressures at high temperatures;
- a specific heat lower than water while allowing a greater storage of energy;
- the storage tank for the molten salts is very similar to that of water;
- in the case of losses, since there are no high pressures, the use thereof is not dangerous despite being a comburent.

For example, said molten salts can be a binary mixture consisting of potassium nitrate KNO_3 and sodium nitrate $NaNO_3$, which has a range of stable use between 280°C and 530-550°C, or a ternary mixture consisting of potassium nitrate KNO_3, sodium nitrate $NaNO_3$ and potassium nitrite KNO_2, or a ternary mixture consisting of potassium nitrate KNO_3, sodium nitrate $NaNO_3$ and calcium nitrate $CaNO_3$. Both ternary mixtures have a range of stable use between 180°C and 530°C. The use of the ternary mixture containing the calcium nitrate is preferable because the potassium nitrite is a potentially cancerogenic substance.

In both examples, the molten salt mixture must be kept within the respective range of stable use.

At the lower end of the range of stable use it is necessary for the possible second heat-transfer fluid, which will remove heat from the mixture of molten salts used as the first heat-transfer fluid, to come into contact with the salts at a relatively high temperature so as not to have areas in the heat exchanger 23 in which the salts tend to solidify.

Preferably, the second heat-transfer fluid is supercritical carbon dioxide (sCO_2) or a suitable inert gas.

A supercritical fluid describes any substance, which is in the temperature and pressure conditions above the critical point thereof, in which the liquid and gaseous phases are no longer distinguishable.

Preferably, the conversion of at least part of the thermal energy transferred to the second heat-transfer fluid into electric energy takes place by means of a closed-loop Brayton cycle.

In particular, the low compressibility of the carbon dioxide near the critical point offers the opportunity of developing a high efficiency closed Brayton cycle.

The closed-loop Brayton cycle comprises the following steps (Figure 6):

- compression of the second heat-transfer fluid in the compressor 12;
- heating of said second heat-transfer fluid in the second heat exchanger 23;
- expansion of said second heat-transfer fluid in the turbine 13, producing mechanical energy;
- cooling of the second heat-transfer fluid.

In particular, the second heat-transfer fluid is indirectly heated by the first heat-transfer fluid through the second heat exchanger 23.

The transfer of energy to the system occurs during the expansion of the second heat-transfer fluid in the turbine 13.

The second heat-transfer fluid exiting the turbine 13 is thus cooled at a predetermined temperature for entering the compressor 12.

Once the compression is complete, the second heat-transfer fluid is sent to the second heat exchanger 23 for closing the cycle.

The efficiency of the cycle is function of the ratio between pressures entering and exiting the turbine 13 and of the temperature entering the turbine. Furthermore, it is highly dependent on the minimum pressure of the cycle.

During the cooling step, the cycle can produce, by means of the third heat exchanger 24, hot water at a high temperature, e.g. greater than, or equal to 80°C, to be reused in the steelworks, and produce, by means of the fourth heat exchanger 25, hot water at a low temperature, which can represent the only waste of energy towards the environment at the cooling tower.

The closed-loop Brayton cycle with sCO_2 works in a single step without condensation. The carbon dioxide has relatively low critical pressure and critical temperature, equal to 7.4 MPa and 31°C, respectively. Consequently, the fluid can be compressed and heated to a supercritical state before expansion. The energy cycle using the supercritical carbon dioxide is relatively close to being an ideal energy cycle for the following reasons:

- very high thermal capacity close to the critical point, i.e. a good use of the heat available by virtue of an elevated expansion and low performance of compression with the possibility of direct coupling with the source of heat;
- working fluid, which is benign as it is not corrosive, non-toxic, thermally stable and subject to dry expansion to avoid erosion;
- low capital cost;
- almost zero emissions;
- high loading flexibility;
- low operating and maintenance costs;
- reduction in volume with respect to the production of obtainable energy (high power density).

In particular, the increase in temperature and pressure of the carbon dioxide close to the critical point results in a rapid change in the thermophysical properties thereof; the density of the carbon dioxide close to the critical point is similar to the density of the liquid thereof and considerably reduces the work of the compressor. The greater energy density of the supercritical carbon dioxide with respect to other working fluids, e.g., almost double with respect to the steam, leads to a significant reduction in size of most of the components of the system, such as the turbine 13 and the compressor 12, resulting in reduced volume of the plant and lower capital costs. However, the use of other suitable supercritical fluids as a second heat-transfer fluid is not excluded.

CLAIMS

1. A metal strip production plant comprising

- a hot-rolling mill (1) for producing a strip from a cast product;
- a cooling station (2) for cooling the strip, arranged downstream of said hot-rolling mill (1) and provided with a first heat exchanger (22);
- a closed circuit (3) feedable with a first heat-transfer fluid, part of said closed circuit (3) passing through said first heat exchanger (22) for subtracting thermal energy from the strip by heating the first heat-transfer fluid;
- a second heat exchanger (23), cooperating with said closed circuit (3) for transferring thermal energy from said first heat-transfer fluid to a second heat-transfer fluid;
- a further circuit (5) feedable with the second heat-transfer fluid, cooperating with said second heat exchanger (23) and configured to convert at least part of the thermal energy transferred to said second heat-transfer fluid into electric energy and/or to convey at least part of the thermal energy transferred to said second heat-transfer fluid towards at least one user;

wherein said first heat exchanger (22) comprises, or consists of, a plurality of cooling rollers (15) crossed, preferably in sequence, by said part of the closed circuit (3);

and wherein the cooling rollers (15) are provided with at least one inner channel, formed so that said cooling rollers (15) can be crossed by the first heat-transfer fluid to cool the metal strip by conduction, said cooling rollers (15) being adapted to be in direct contact with the strip.

2. A plant according to claim 1, wherein downstream of said cooling station (2) a pickling line (6) and a cold-rolling mill (7) are provided in sequence, preferably arranged directly in line with the hot-rolling mill (1) and the cooling station (2); preferably wherein a welding machine (8) is provided between said cooling station (2) and said pickling line (6) for welding the head of a newly cooled strip to the tail of a previously cooled strip to be pickled.

3. A plant according to claim 1 or 2, wherein, between the hot-rolling mill (1) and the cooling station (2), there are provided:

- a winding station (9) arranged to wind the strip and form at least one coil;

- an unwinding station (11) for unwinding said at least one coil;
- a coil storage station (10), arranged off-line between the winding station (9) and the unwinding station (11);

preferably, wherein a further winding station (9') is provided downstream of said cooling station (2).

4. A plant according to claim 1 or 2, wherein a winding station (9) and a subsequent unwinding station (11) are provided, arranged between said hot-rolling mill (1) and said cooling station (2); said winding station (9) being adapted to wind the strip and form at least one coil, and said unwinding station (11) being adapted to unwind the at least one coil for feeding the strip to the cooling station (2); preferably wherein a welding machine (8) is provided between said cooling station (2) and a pickling line (6) for welding the head of a newly cooled strip to the tail of a previously cooled strip to be pickled; or wherein a welding machine (8) is provided between said unwinding station (11) and the cooling station (2) for welding the head of a newly unwound strip to the tail of a previously unwound strip to be cooled by means of said cooling station (2).

5. A plant according to any one of the preceding claims, wherein said further circuit (5), configured to convert the thermal energy transferred to said second heat-transfer fluid into electric energy, is based on a closed-loop Brayton cycle; preferably wherein said further circuit (5) comprises, considering the flow direction of the second heat-transfer fluid:

- a compressor (12), arranged upstream of said second heat exchanger (23);
- a turbine (13), arranged downstream of said second heat exchanger (23);
- a third heat exchanger (24), arranged downstream of said turbine (13), for removing a portion of thermal energy from the second heat-transfer fluid and conveying said portion towards a user;
- preferably a fourth heat exchanger (25), arranged between said third heat exchanger (24) and said compressor (12), for removing a further portion of thermal energy from the second heat-transfer fluid and conveying said further portion towards a further user.

6. A plant according to any one of the preceding claims, wherein said circuit (3) further comprises, considering the flow direction of the first heat-transfer fluid:

- a tank (16) for the first heat-transfer fluid, arranged downstream of said second heat exchanger (23),
- a pump (17) arranged between said tank (16) and said cooling station (2),
- preferably an auxiliary heating device (18) arranged between said cooling station (2) and said second heat exchanger (23).

7. A plant according to any one of the preceding claims, wherein temperature sensors (19) are provided upstream and downstream of the cooling station (2) for detecting the surface temperature of the strip; and wherein a control device (21) is provided, adapted to receive temperature data by said temperature sensors (19) and consequently adjust the flow rate of the first heat-transfer fluid passing through said first heat exchanger (22).

8. A metal strip production process, carried out by means of a plant according to any one of the preceding claims, the process comprising the following steps:

a) hot-rolling a cast product for producing a strip by means of the hot-rolling mill (1);

b) cooling the strip in the cooling station (2) while running through the first heat exchanger (22), which is crossed by the first heat-transfer fluid flowing in the circuit (3), recovering thermal energy from the strip;

c) transferring thermal energy recovered from said first heat-transfer fluid to the second heat-transfer fluid by means of the second heat exchanger (23);

d) converting at least part of the thermal energy transferred to said second heat-transfer fluid into electric energy and/or conveying at least part of the thermal energy transferred to said second heat-transfer fluid towards at least one user, by means of the further circuit (5) cooperating with said second heat exchanger (23);

wherein in step b) the strip runs winding itself in sequence about cooling rollers of a plurality of cooling rollers (15) defining the first heat exchanger (22), said cooling rollers (15) being provided with at least one inner channel crossed by the first heat-transfer fluid flowing in the circuit (3) to cool the metal strip by conduction, said cooling rollers (15) being in direct contact with the strip.

9. A process according to claim 8, wherein after step b) the strip has a temperature in a range from 75 to 85°C and a pickling and a cold rolling of the strip are carried out, preferably in line with the hot rolling.

10. A process according to claim 8, wherein, between step a) and step b), the following steps are provided

- winding the strip into coils by means of a winding station (9);
- moving the coils off-line to a storage station (10);
- moving the coils from the storage station (10) to an unwinding station (11) when the temperature of the coils is less than, or equal to, 500°C;
- unwinding the strip by means of the unwinding station (11) for feeding the cooling station (2);

preferably, wherein after step b) the strip has a temperature in a range from 75 to 85°C and a pickling and a cold rolling of the strip are performed, or wherein after step b) a further winding of the strip into coils is provided in a further winding station (9'), and subsequently the strip is unwound for performing a pickling and a cold rolling.

11. A process according to claim 8, wherein, between step a) and step b), the following steps are provided

- winding the strip into coils by means of a winding station (9);
- when the temperature of the coils is less than, or equal to, 500°C, unwinding the strip by means of an unwinding station (11) for feeding the cooling station (2);

preferably wherein, after step b), the strip has a temperature in a range from 75 to 85°C and there is provided a welding of the head of a newly cooled strip to the tail of a previously cooled strip to obtain a continuous strip to be subjected to pickling and subsequent cold rolling; or wherein there is provided a welding of the head of a strip newly unwound from the unwinding station (11) to the tail of a previously unwound strip for obtaining a continuous strip to be subjected to step b).

12. A process according to any one of claims 8 to 11, wherein the first heat-transfer fluid consists of diathermic oils or molten salts or molten metals, while the second heat-transfer fluid is supercritical carbon dioxide (sCO_2) or an inert gas.

13. A process according to any one of claims 9 to 12, wherein a detection of the surface temperature of the strip is provided upstream and downstream of the cooling station (2) by means of temperature sensors (19); and wherein there is provided an adjustment of the flow rate of the first heat-transfer fluid passing through the first heat exchanger (22) and, therefore, an adjustment of the cooling

of the strip by means of a control device (21) receiving the temperature data detected by said temperature sensors (19).

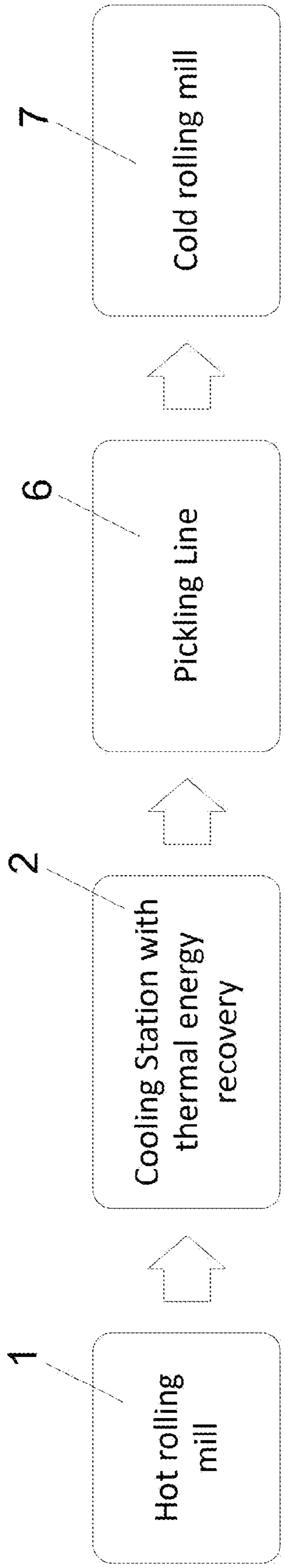
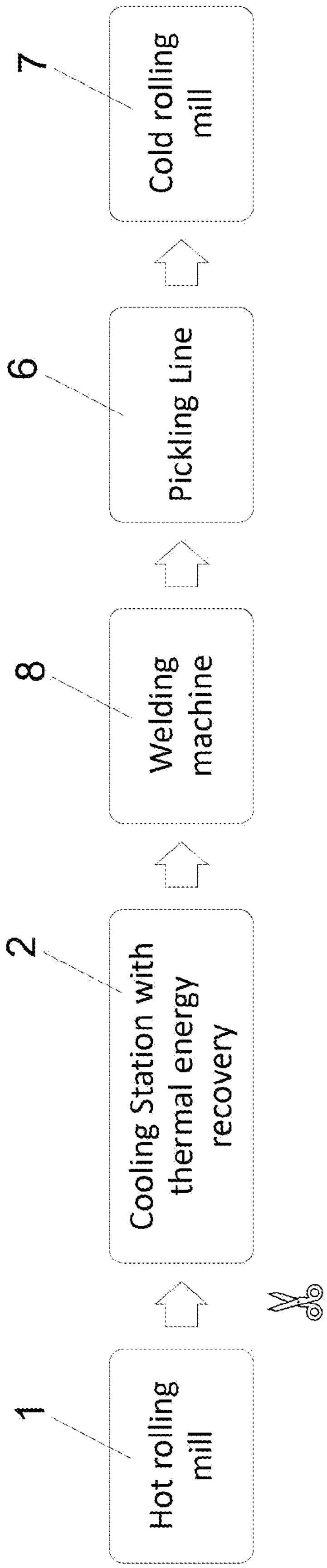

1
Hot rolling mill
2
Cooling Station with thermal energy recovery
6
Pickling Line
7
Cold rolling mill

Fig. 1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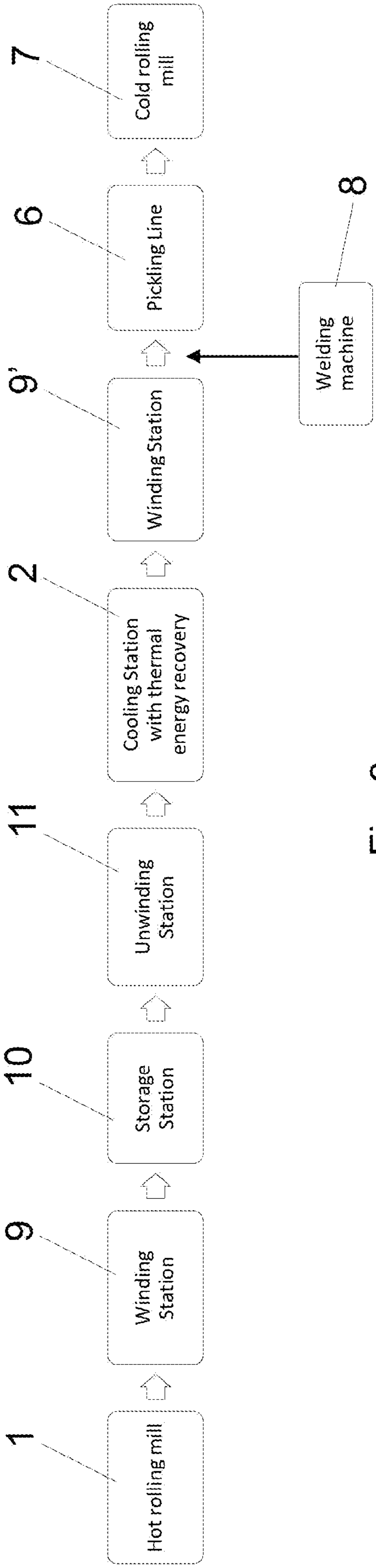
2
Cooling Station with thermal energy recovery
8
Welding machine
6
Pickling Line
7
Cold rolling mill

Fig. 2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9
Storage Station
10
Unwinding Station
11
Cooling Station with thermal energy recovery
2
Winding Station
9'
Welding machine
8
Pickling Line
6
Cold rolling mill
7

Fig. 3

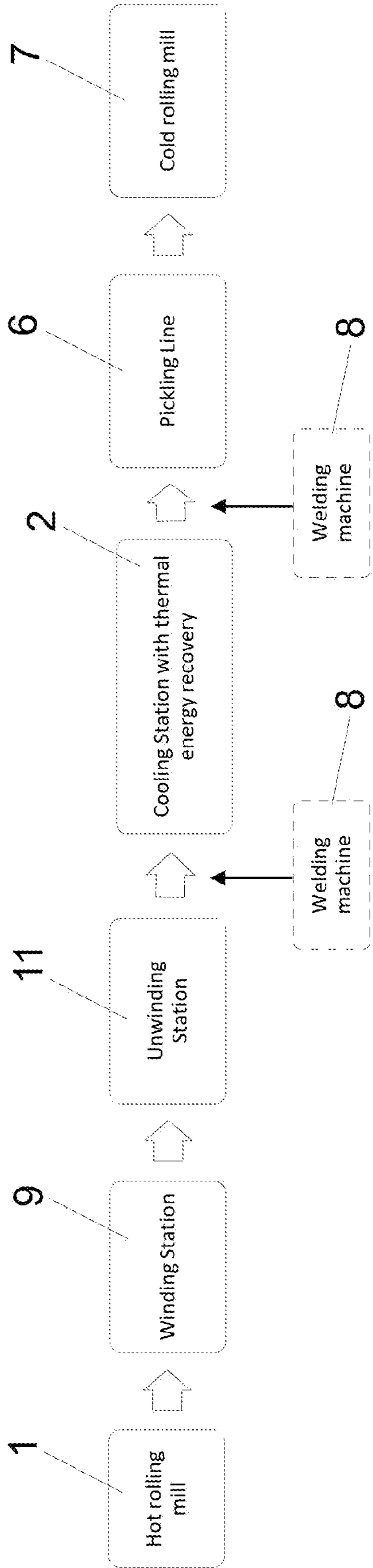
Hot rolling mill
1
Winding Station
9
Unwinding Station
11
Welding machine
8
Cooling Station with thermal energy recovery
2
Welding machine
8
Pickling Line
6
Cold rolling mill
7

Fig. 4

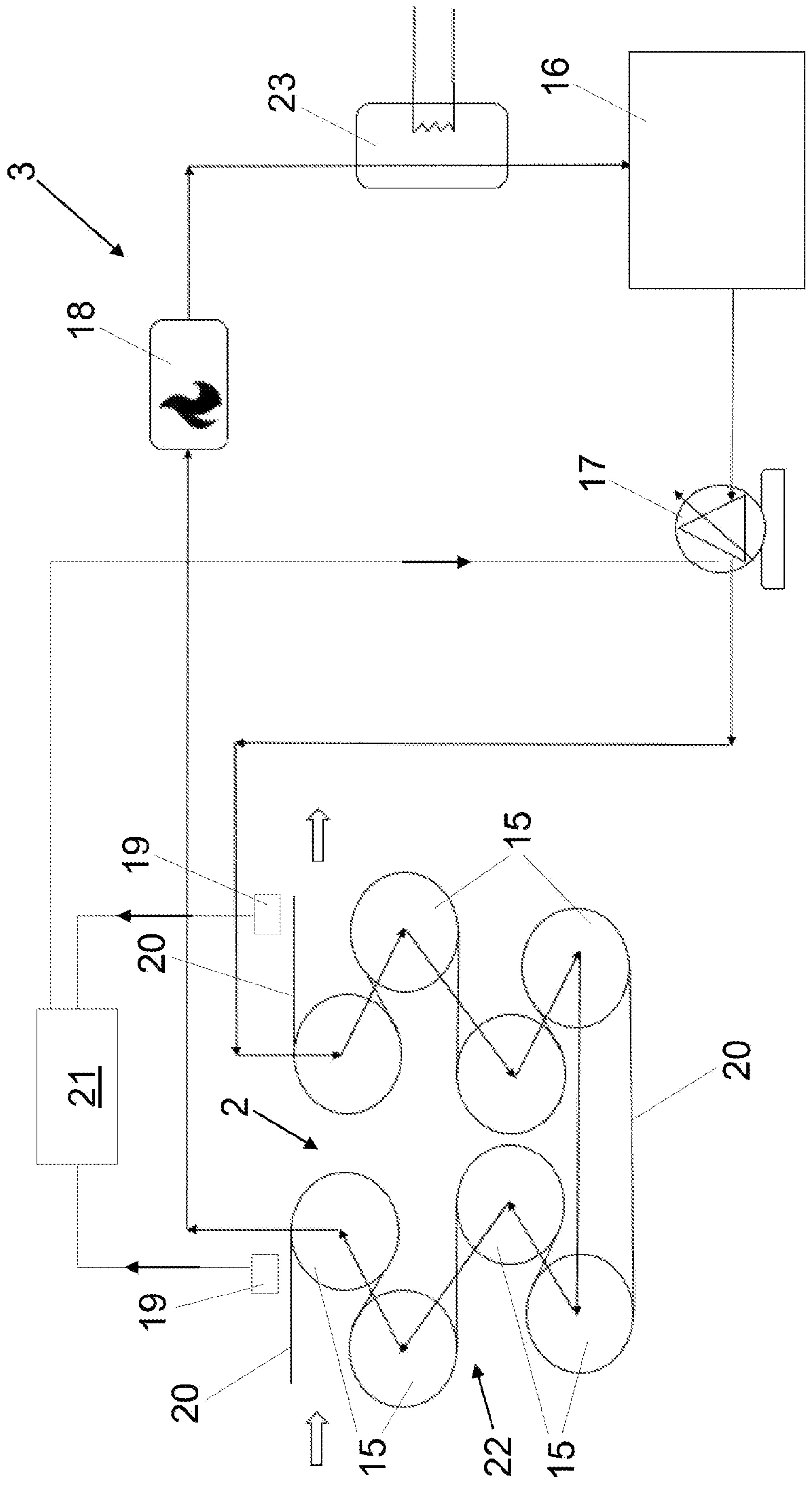

Fig. 5

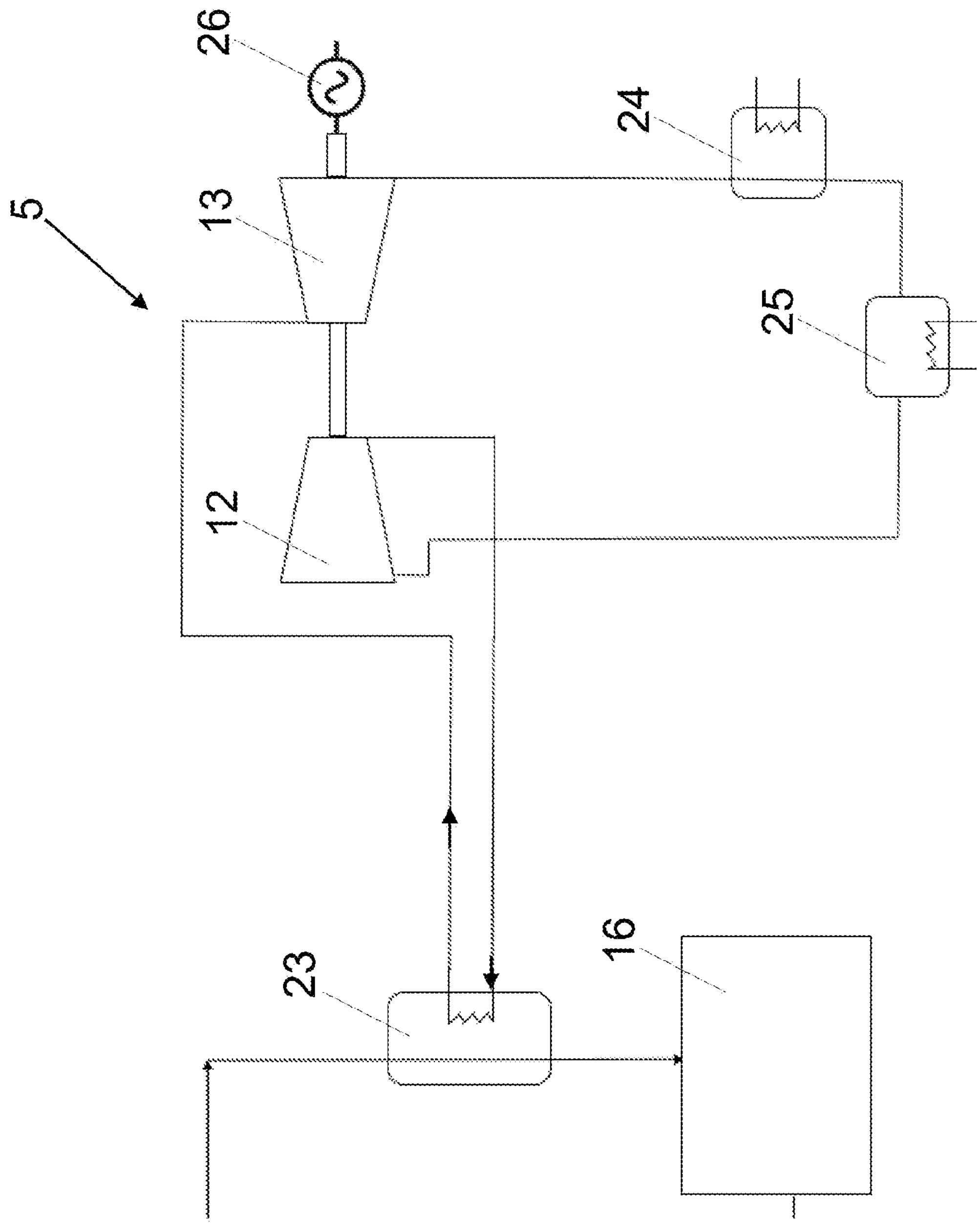

Fig. 6

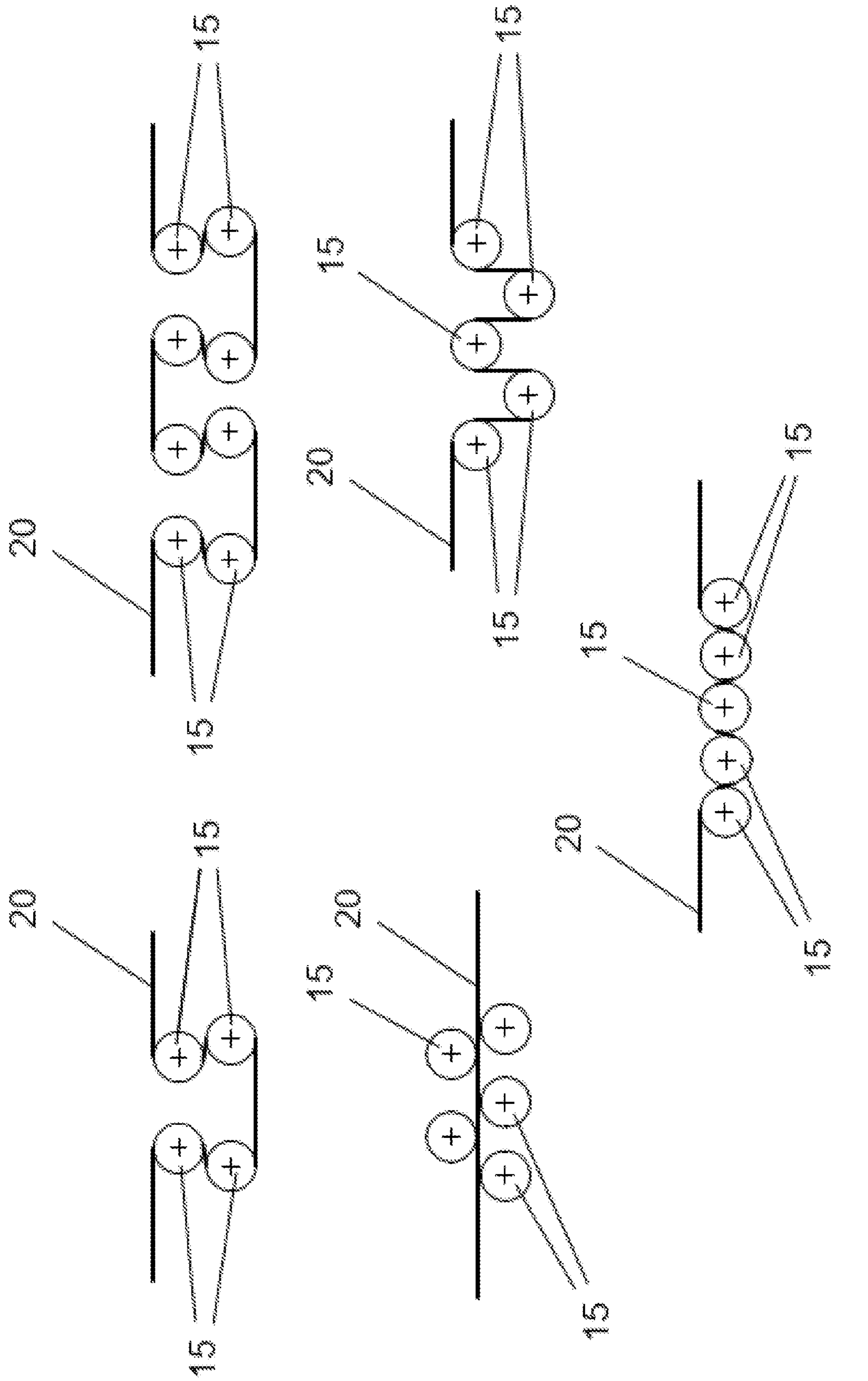

Fig. 7

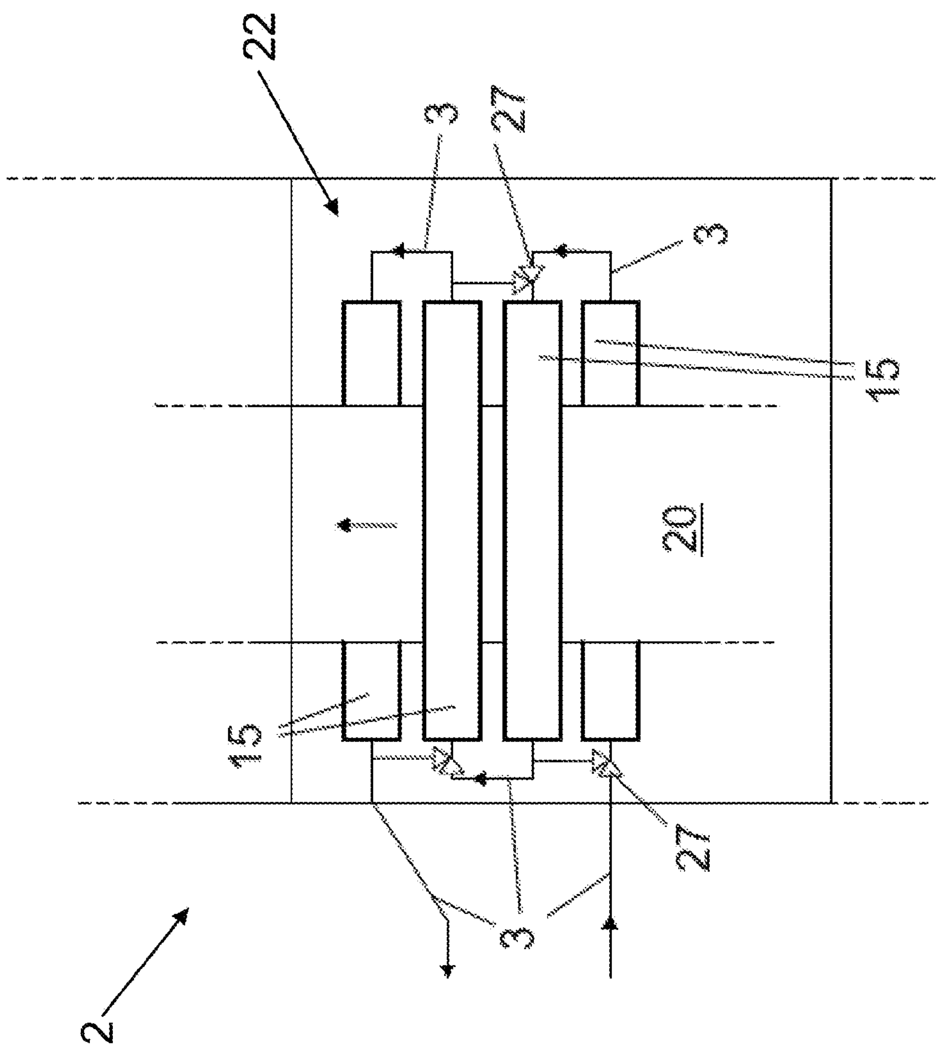

Fig. 8

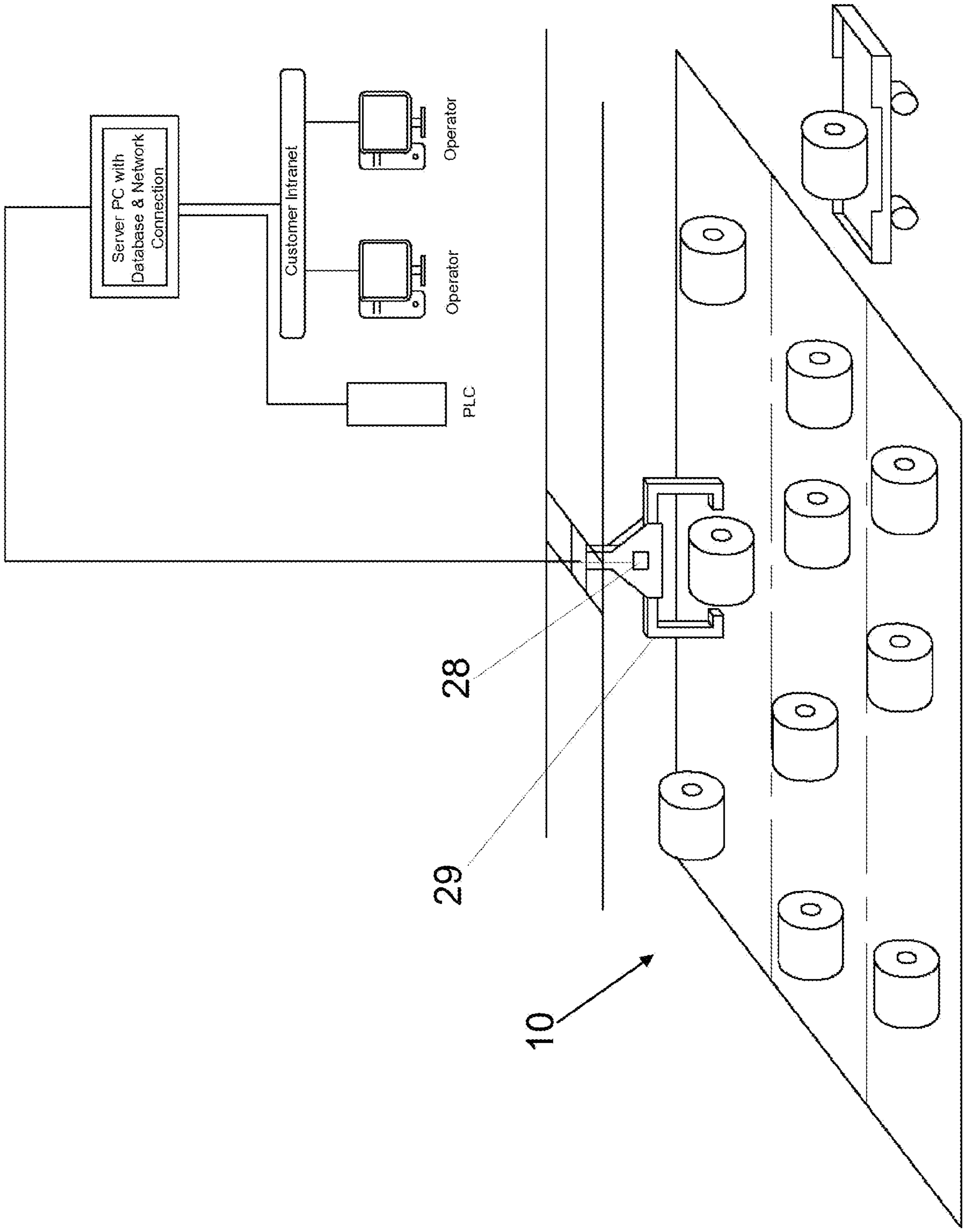
Server PC with Database & Network Connection
Customer Intranet
Operator
Operator
PLC
28
29
10

Fig. 9

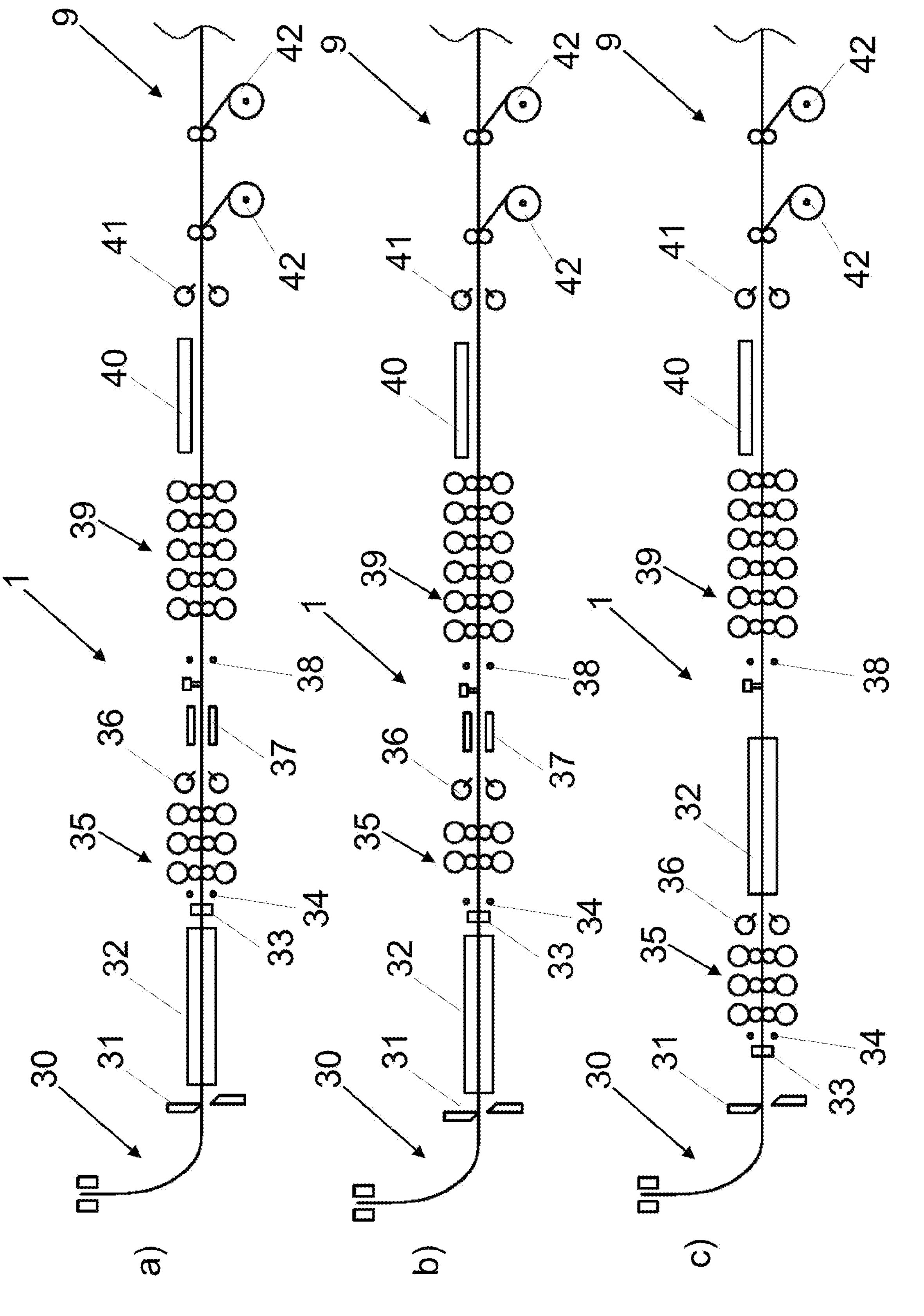

Fig. 10

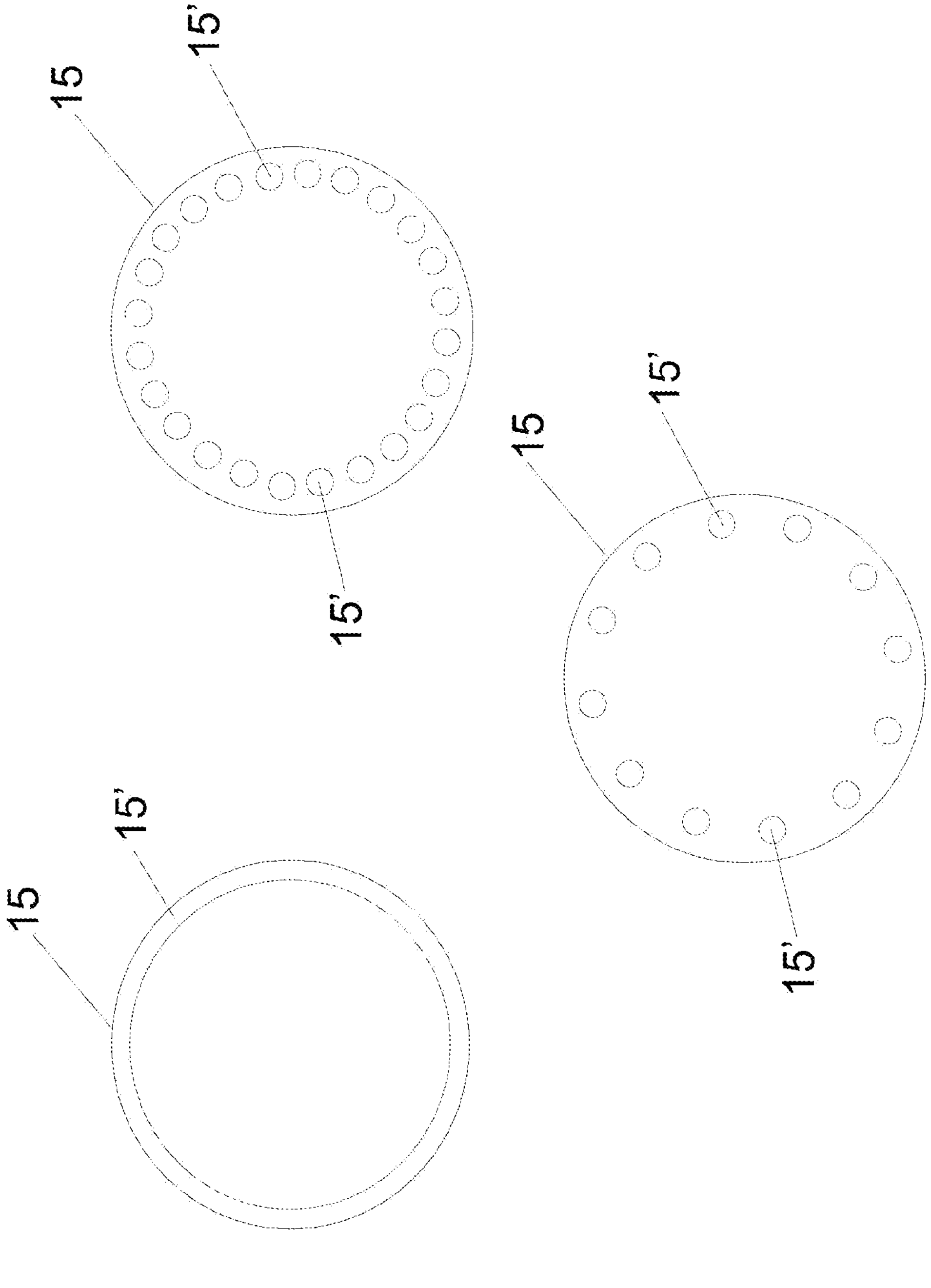

Fig. 11

INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2024/055197

A. CLASSIFICATION OF SUBJECT MATTER
INV. B21B45/00 B21B45/02
ADD.

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

B. FIELDS SEARCHED

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

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

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO 2015/018673 A1 (SIEMENS AG [DE]) 12 February 2015 (2015-02-12) cited in the application paragraph [0029] - paragraph [0030]; claims 1-8; figure 3	1-13
A	CN 209 631 819 U (UNIV TIANJIN) 15 November 2019 (2019-11-15) abstract; claims 1-4; figure 1	1-13
A	EP 2 506 992 B1 (SMS SIEMAG AG [DE]) 16 July 2014 (2014-07-16) paragraph [0045] - paragraph [0046]; claims 1,5; figure 1	1-13
A	KR 2010 0005803 U ((HYMR) HYUNDAI HYSCO) 7 June 2010 (2010-06-07) abstract; figure 1	1,3

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

[X] See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance;; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance;; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
29 August 2024	11/09/2024

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Forciniti, Marco

1

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP S62 134110 A (MITSUBISHI HEAVY IND LTD) 17 June 1987 (1987-06-17) abstract; figures 1,3 -----	1,4

1

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/IB2024/055197

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 2015018673 A1	12-02-2015	CN 105682824 A	15-06-2016
		EP 3030364 A1	15-06-2016
		WO 2015018673 A1	12-02-2015
CN 209631819 U	15-11-2019	NONE	
EP 2506992 B1	16-07-2014	DE 102009056264 A1	09-06-2011
		EP 2506992 A1	10-10-2012
		WO 2011067119 A1	09-06-2011
KR 20100005803 U	07-06-2010	NONE	
JP S62134110 A	17-06-1987	NONE	