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(54) **TREATMENT PROCESS FOR BARS**

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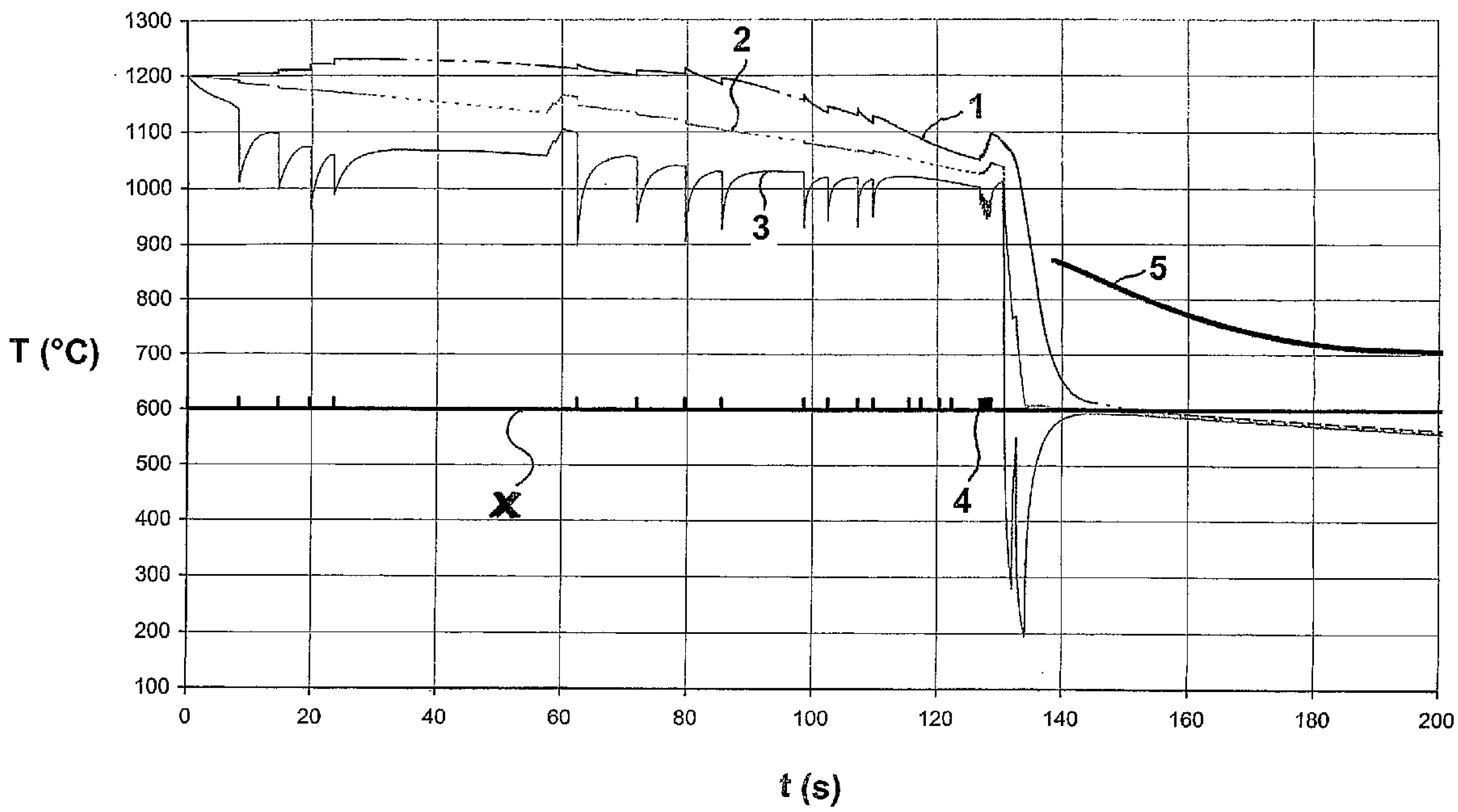
(57) **ABSTRACT**

Treatment process for stainless steel bars, in particular a solution quenching, to be performed directly in-line downstream of the rolling mill which makes it possible to obtain a material devoid of intergranular corrosion and with microstructural characteristics suitable for subsequent uses. Advantageously, said process also makes it possible to improve the productivity of the entire rolling plant. The treatment is suitable to be performed on austenitic, ferritic, or austeno-ferritic stainless steel bars, Al—Cu alloy bars, Nickel alloy bars, and all other alloys requiring rapid cooling in order to prevent undesired phase precipitations. Prevention of intergranular corrosion obtained with the treatment process of the invention makes it possible to prevent problems, and relative costs, during surface treatment of the bars and those that could occur in final use.



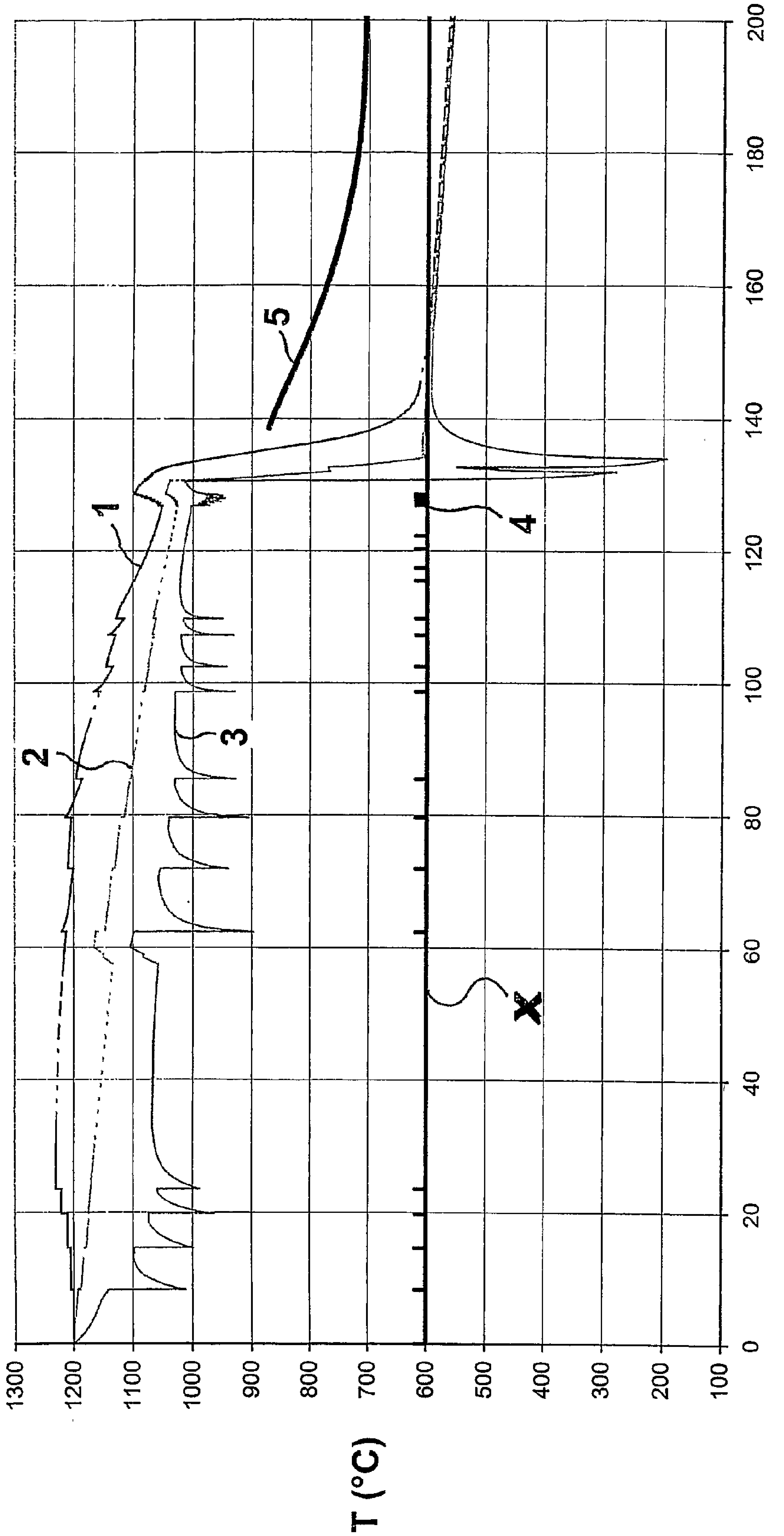

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Fig. 1

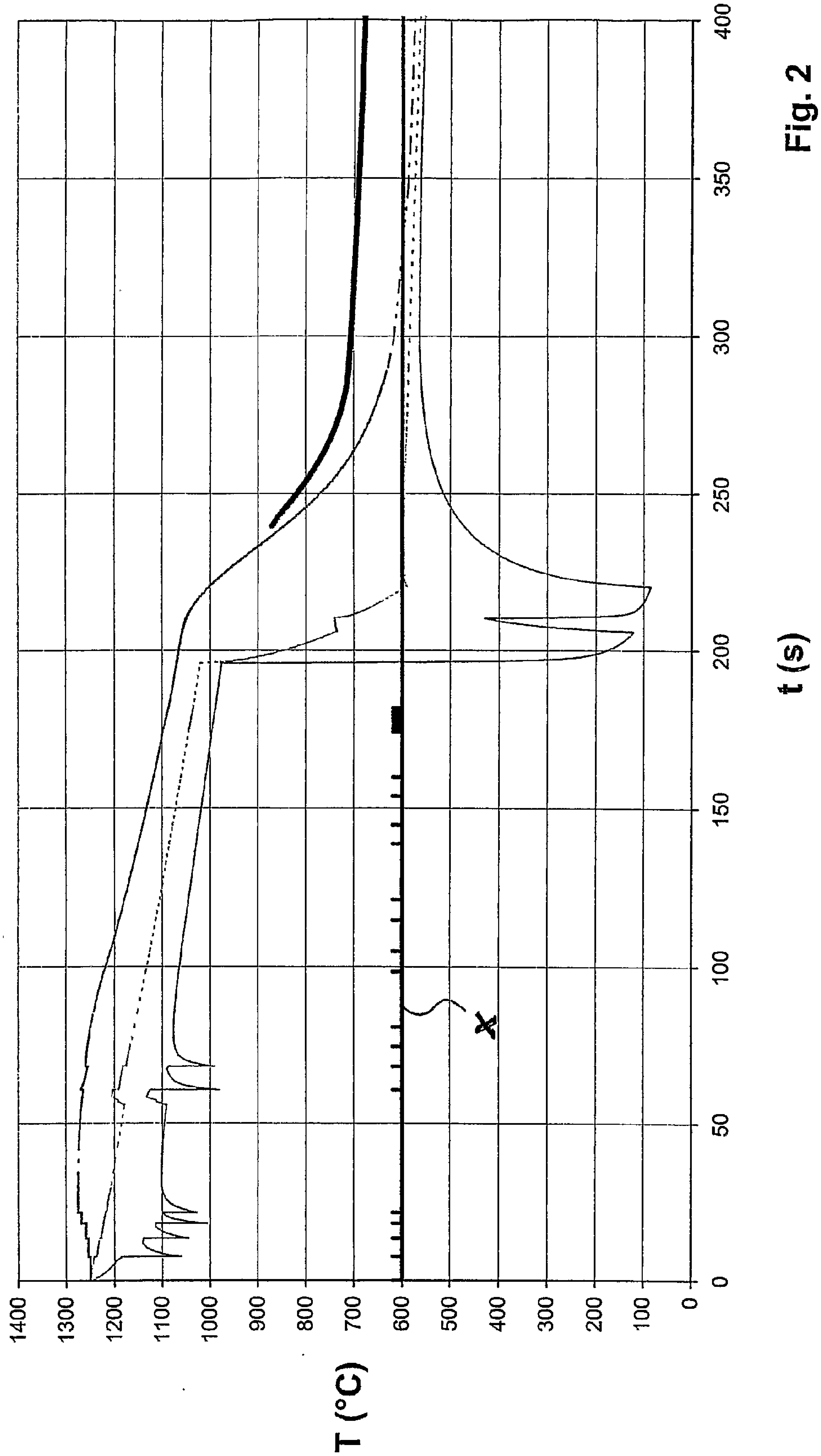

Fig. 2

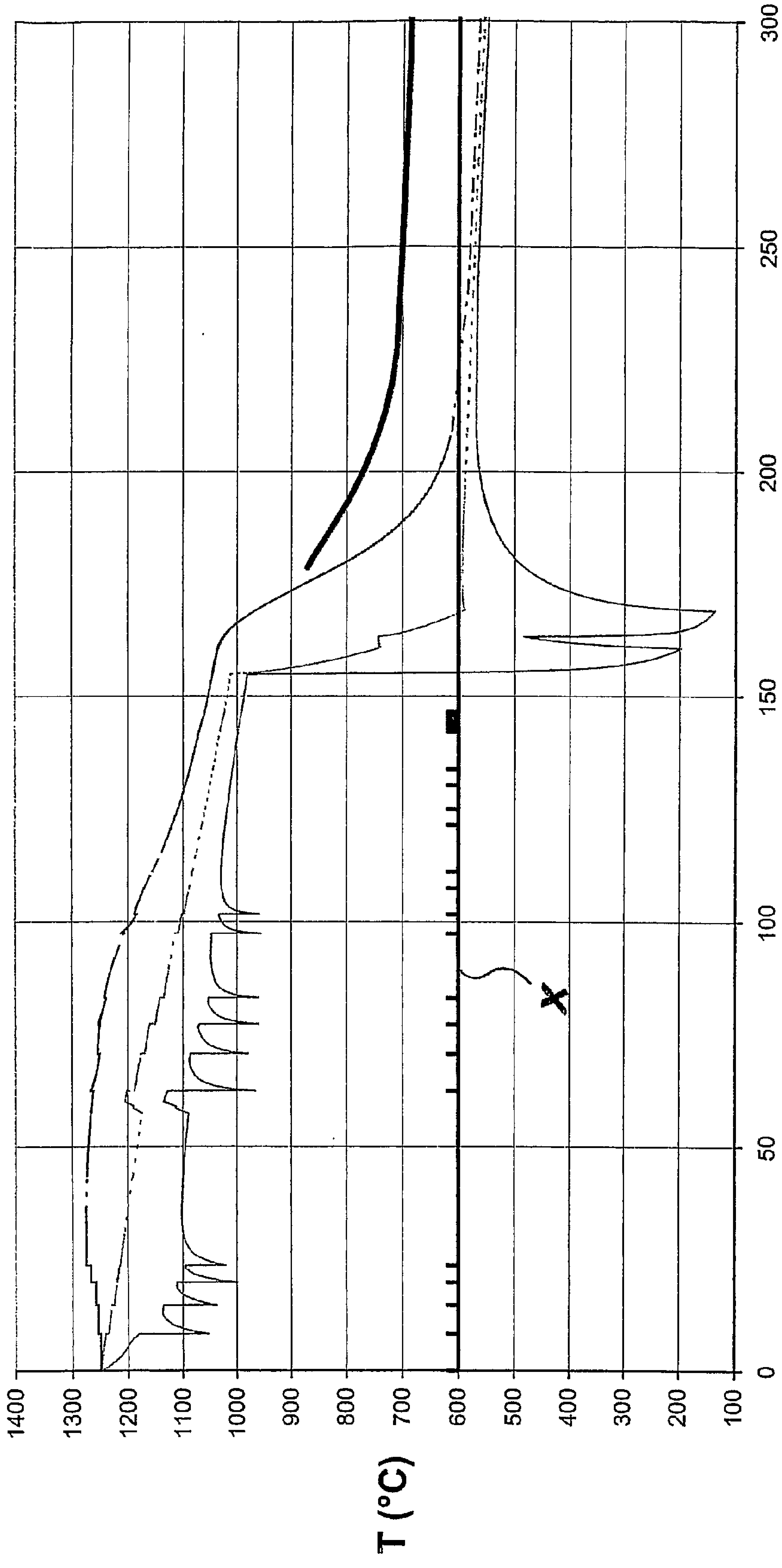
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Fig. 3

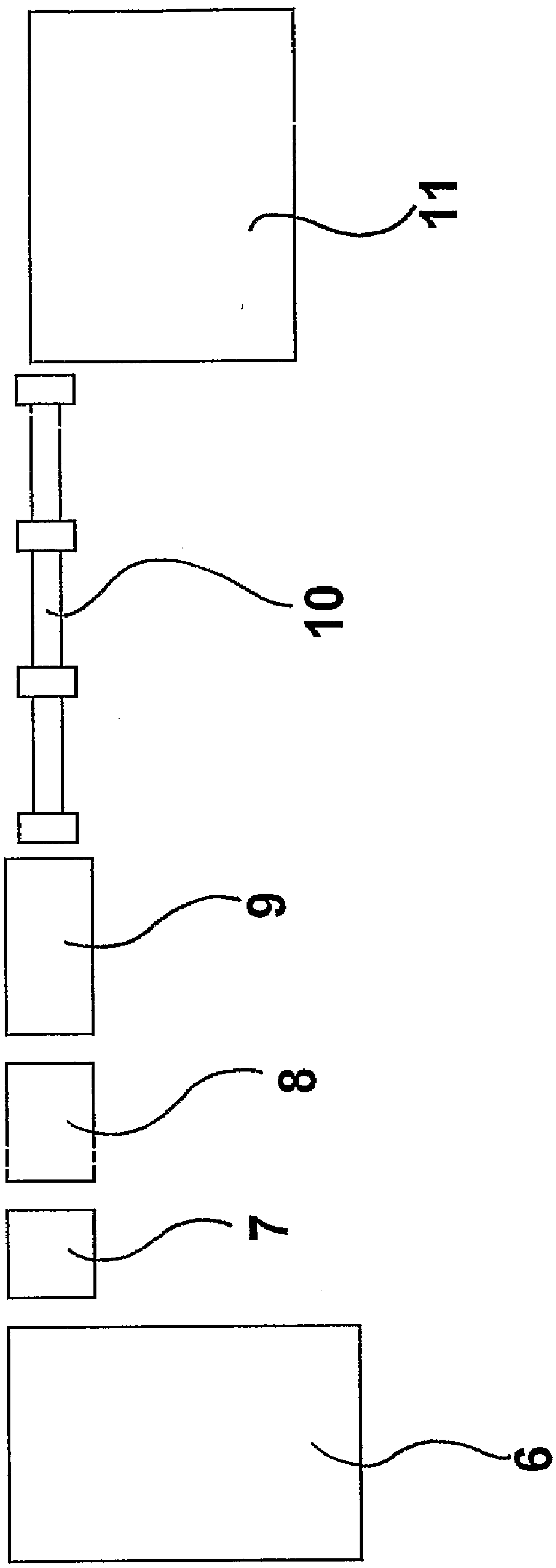

Fig. 4

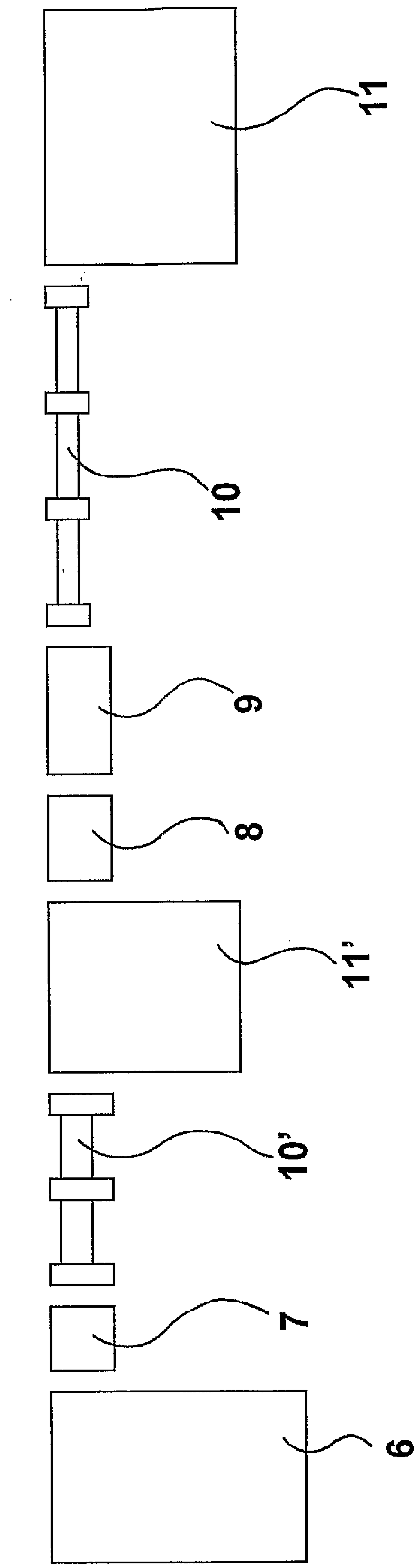

Fig. 5

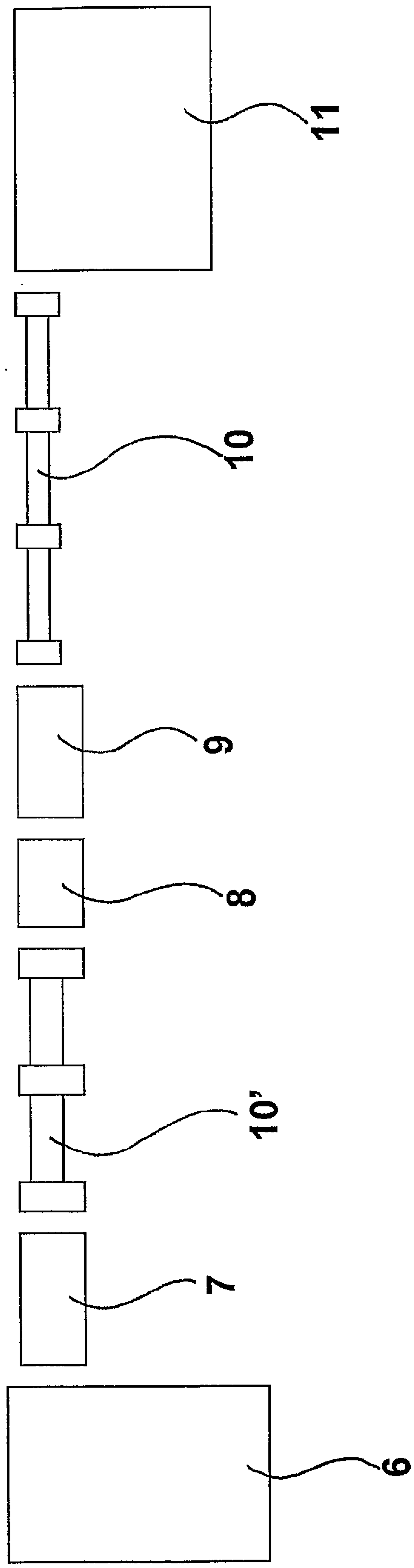

Fig. 6

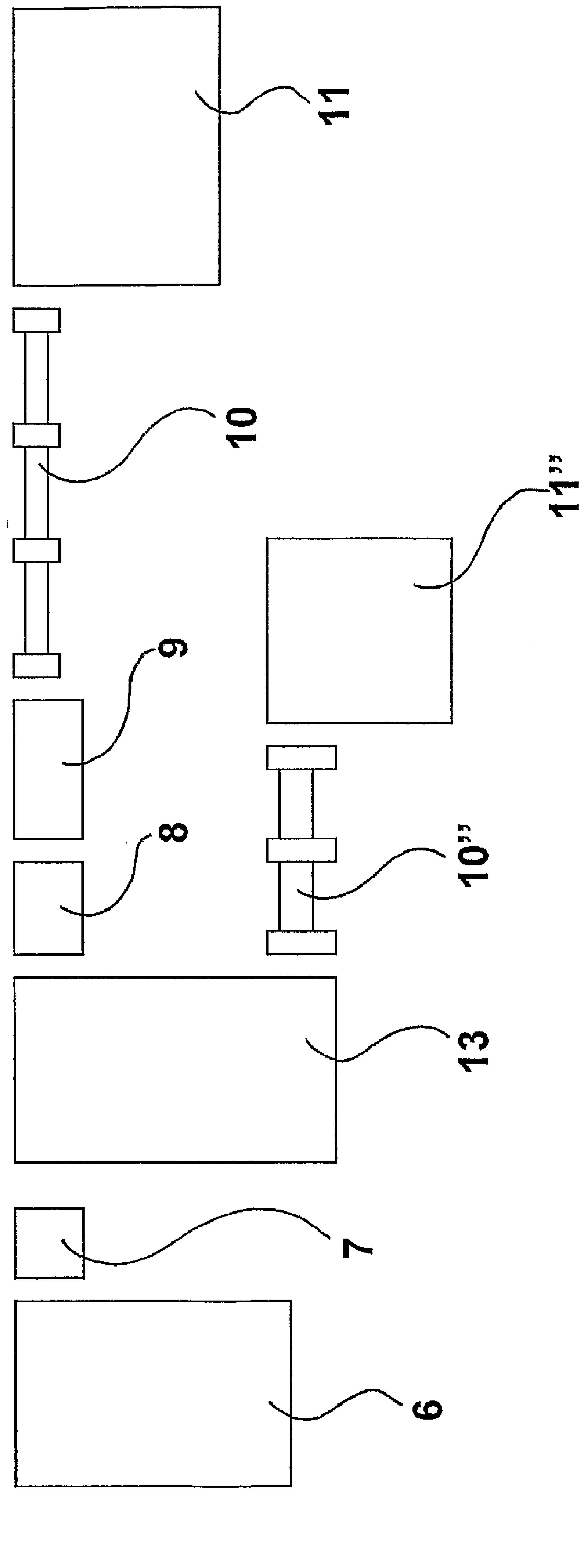

Fig. 7

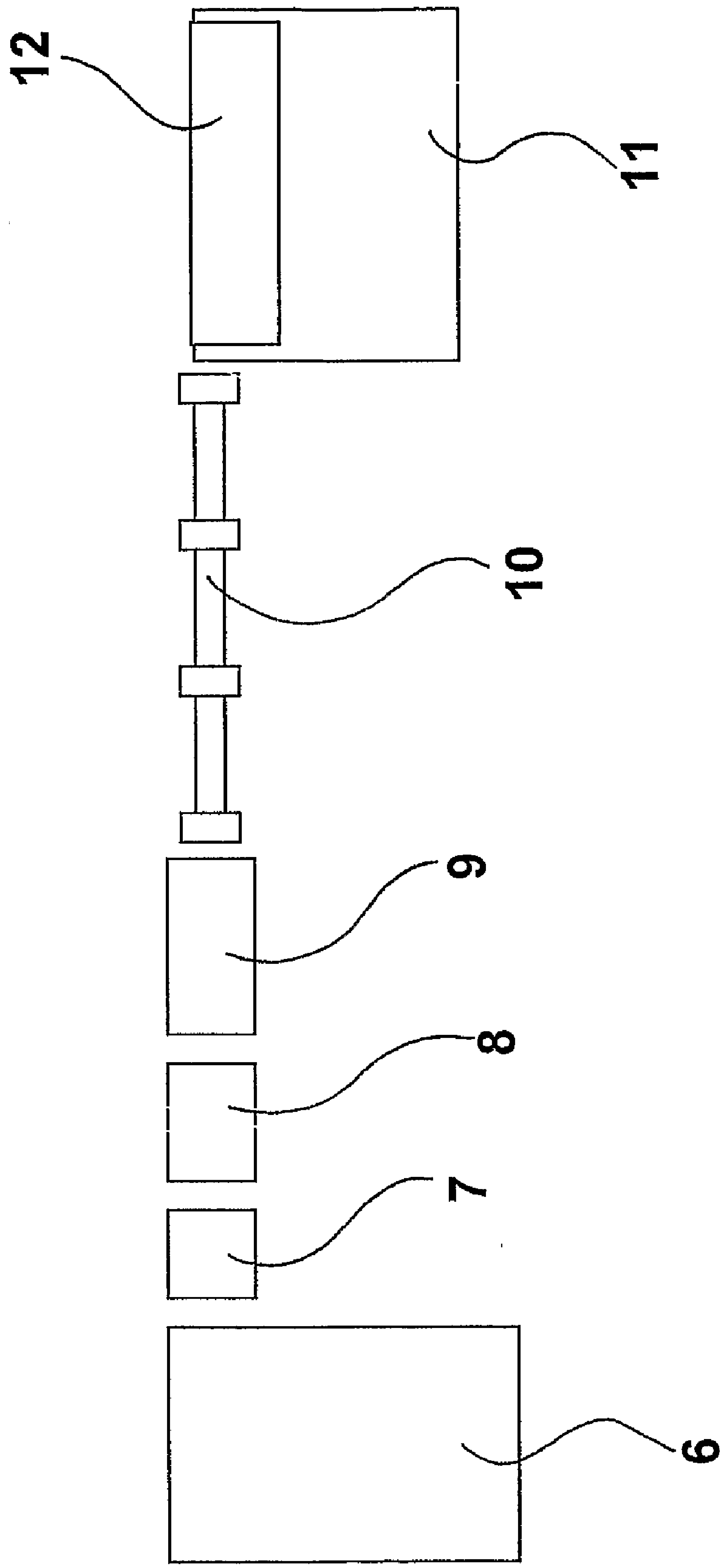

Fig. 8

TREATMENT PROCESS FOR BARS

FIELD OF THE INVENTION

[0001] The present invention relates to an in-line treatment process of rolled bars, in particular to a solution quenching treatment, at the outlet of the rolling train, of bars in stainless steel, nickel alloys or other alloys that require rapid cooling after rolling.

STATE OF THE ART

[0002] The structure of austenitic steels is practically composed only of austenite stable at ambient temperature; the chromium carbides, which may be held in supersaturated solid solution in the austenite, are capable of precipitating, at the austenite grain boundary, when the steel is heated in the interval ranging from 450 to 850° C. or cooled slowly through this interval. The considerable carbide-forming power of the Cr causes disproportionation of the alloy at the grain boundary, while in the centre of the grains the Cr content remains practically unchanged. In the case in which the content of free Cr, that is, not bonded to form carbides, drops locally below the limit of stainlessness (12%), the steel becomes susceptible to inter-granular attack. Attack by intergranular corrosion can cause disbonding of a grain with respect to the others, with a considerable decrease in mechanical resistance and to impacts, notwithstanding a negligible loss in mass.

[0003] As they are well known in literature, further details will not be given here on steels and on the problems related to the effects of an attack of intergranular corrosion.

[0004] To prevent problems of intergranular corrosion, action is taken on the metal either through heat treatment carried out later, off-line, or by modifying the chemical composition, so that the carbides of Cr or of other secondary phases do not precipitate. The methods used comprised the following:

[0005] a decrease in the content of C,

[0006] use of stabilizing elements, such as Ti, Nb, V and Ta, together with an off-line stabilization treatment.

[0007] Solution quenching, also referred to as "hyper-quenching" or "negative quenching", is intended as a rapid cooling treatment to prevent precipitation of chromium carbides of other secondary phases. The only thing this treatment has in common with conventional quenching is the cooling speed from the austenization temperature, and not the structural and hardening effects which normally occur for hardenable steels.

[0008] As known, during off-line solution quenching, by a re-heating at high temperature the chromium carbides precipitated at the grain boundary during heat treatment, or when the metal was held at a temperature in the critical interval of carbide precipitation, or cooled slowly through this interval, are dissolved. Therefore, solution heat treatment makes it possible to increase the resistance to intergranular corrosion by delivering a material without areas that are deficient in chromium content and therefore immune to intergranular corrosion.

[0009] Normally, the temperature interval in which the solution heat treatment is performed ranges from 950 to 1200° C., more frequently from 1000 to 1100° C., with holding times of around 1 minute per mm of thickness.

[0010] Therefore, the treatment is performed at the lowest temperature sufficient to solubilize the carbides and to eliminate the degree of stress caused by the various processing cycles, while the permanence at this temperature is strictly related to the thickness of the product treated and must be kept to the minimum times required.

[0011] Higher temperatures and longer holding times can, in fact, cause more pronounced softening and, depending on the parameters adopted, also promote undesirable enlargement of the grains, which is needed for certain specific applications.

[0012] To prevent precipitation of the chromium carbides, austenitic stainless steels must be cooled rapidly from the solution treatment temperatures.

[0013] In a bar rolling plant, the off-line process consists in quenching, that is, immersing the rolled bars in special tanks of water or suitable fluids. These tanks are usually small in size and allow the treatment of limited length bars, drastically reducing the yield of the plant and overall productivity. In this case, the bars are cooled to below 300° C.

[0014] If the treatment is performed outside the line, it has the disadvantage of requiring intermediate storage and reheating from ambient temperature to a temperature of around 1100 to 1200° C., with considerable energy consumption as well as consumption of material and maintenance. Moreover, the bars must be straightened after quenching in the tank, even simply to be transported and stored. All this requires considerable overall dimensions of the plant, high maintenance and leads to low productivity.

[0015] The in-line treatment provides quenching after hot rolling in a quench tank of water or suitable fluids that can be set up downstream of the rolling mill.

[0016] In this case, the bars must be straightened after quenching in the tank, even simply to be transported and stored. All this requires considerable overall dimensions of the plant, high maintenance and leads to low productivity. Furthermore, it is not always possible to guarantee that the temperatures at the beginning of the treatment are the optimal temperatures, both for obtaining a material without carbides, and for obtaining a homogeneous microstructure in terms of size of the austenitic grain.

SUMMARY OF THE INVENTION

[0017] The present invention makes it possible to perform the solution quenching on bars with round, square, hexagonal, rectangular section, directly at the outlet of the rolling mill, and to obtain a high quality product that does not require straightening and is free of scoring and surface defects. The process is performed in a compact plant, without specific maintenance requirements, which allows to eliminate all costs related to intermediate storage of the material, as well as those related to reheatings in furnace, which are necessary for normal off-line treatments. This highly flexible system makes it possible to pass from producing one shape to another one without having to perform mechanical intervention with the related loss of time.

[0018] The main advantages of this invention are due to:

[0019] 1) performing the solution quenching in-line with the rolling process;

[0020] 2) efficiency of the plant and reduction of the use of equipment and maintenance;

[0021] 3) increase of the global productivity of the plant;

[0022] 4) elimination of straightening after the treatment;

[0023] 5) drastic reduction in surface defects;

[0024] 6) elimination of costs linked to intermediate storage and reheating;

[0025] With regard to the above points, we stress that:

[0026] 1) A primary object of the present invention is to produce a treatment process for stainless steel bars, in particular a solution quenching treatment, directly in line downstream of the rolling mill, which makes it possible to obtain a material devoid of intergranular corrosion and with microstructural characteristics suitable for subsequent uses. In fact, the use of austenitic stainless steels is based on their structure, and even minimum microstructural variations may have a considerable influence on the corrosion behaviour of the final product in different environments. Moreover, these structural variations can have enormous importance, not only in relation to final application, but also in relation to the surface treatments to which the product must be subjected: in fact, corrosion phenomena could also occur during these surface treatments.

[0027] 2) The high efficiency of the heat exchange achieved in the cooling devices, or simply quenching tanks, with water or other suitable fluids allows a reduction of the dimensions and amount of equipments necessary, obtaining a particularly compact plant which is capable of providing completely solubilized material up to diameters of 130 mm and equivalent sections. The possibility of extending the treatment to larger diameters depends on the speeds adopted. The reduction of the devices used and their simplicity means that less maintenance is necessary.

[0028] 3) A further object of the invention is to perform the treatment so as to improve the productivity of the entire rolling plant. It is possible to process bars of any length, and this depends only on the size of the final cooling device.

[0029] 4) The design of the quenching tanks with water or other suitable fluids and the operating parameters adopted permit to achieve not only a high heat exchange but also an optimal uniformity of cooling which guarantees the straightness necessary to eliminate the straightening of the bars after treatment, contrarily at the bars treated in the traditional way which have to be straightened after quenching in tank, even simply to be transported and stored.

[0030] 5) The devices used for the treatment also allow a drastic reduction in surface defects, improving the overall quality of the finished product.

[0031] 6) The possibility of treating the bars directly in line, at the outlet of the rolling train, avoids intermediate storage and re-heating from ambient temperature to temperatures of around 1100 to 1200° C. with evident energy saving. This treatment is suitable to be performed on austenitic, ferritic or austeno-ferritic stainless steel bars, Al—Cu alloy bars, Nickel superalloy bars, and bars of any other alloy which requires rapid cooling.

[0032] Therefore, the present invention proposes to achieve the aforementioned objects by providing an in-line heat-treatment process of bars exiting from a rolling mill in which, according to claim **1**, there is provided immediately after at least a first rolling stage a solution quenching treatment in a solution quenching line, with a cooling speed such that a first curve, representing bar core temperature trend versus time, does not intersect and stays below a second precipitation curve of secondary phases, tipical for the bar material.

[0033] The dependent claims describe preferred embodiments of the invention.

BRIEF DESCRIPTION OF THE FIGURES

[0034] Further characteristics and advantages of the invention shall be more evident in the light of the detailed description of a treatment process for bars, of which some results are shown by way of a non-limiting embodiment, with the aid of the accompanying drawings, wherein:

[0035] FIG. **1** shows the temperature trend through the section of a first bar during rolling and the treatment of the invention;

[0036] FIG. **2** shows the temperature trend through the section of a second bar during rolling and the treatment of the invention;

[0037] FIG. **3** shows the temperature trend through the section of a third bar during rolling and the treatment of the invention.

[0038] FIGS. **4**, **5**, **6**, **7**, **8**, show some configurations of a rolling plant that is suitable to perform the treatment in-line of the invention.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS OF THE INVENTION

[0039] To determine the treatment process of the invention, which makes it possible to obtain, directly after rolling, a material devoid of intergranular corrosion and with microstructural characteristics suitable for subsequent uses, it was fundamental to identify the following parameters:

[0040] the position of the devices adapted to guarantee the correct treatment;

[0041] the initial treatment temperature interval to obtain a structure totally devoid of carbides and with a homogeneous microstructure;

[0042] the end of treatment temperatures, that is, those for which passing through the critical range of carbide precipitation can be considered to have terminated, and for which distortion due to residual heat is avoided.

[0043] The duration of the treatment according to this invention is a parameter which depends on the dimensions of the bar and on the rolling speed.

[0044] Other important parameters to perform the solution quenching treatment in line, directly downstream of the rolling mill, comprise:

[0045] rolling parameters, such as speed, reduction ratios and temperature, suitable to guarantee an initial austenitic structure and, therefore, an optimal grain dimension for subsequent uses;

[0046] the speed at which the rolled bar is fed through a cooling device to guarantee the minimum times required to perform the desired thermal gradient;

[0047] the necessary flow rates and pressures of the cooling fluid, generally water, inside the device in order to guarantee a heat exchange coefficient that is sufficient to obtain the minimum thermal gradient required.

[0048] FIGS. **1** to **3** show the experimental results related to the trend of the parameter temperature for the treatment according to the invention.

[0049] The diagram in FIG. **1** represents the temperature trend of a first AISI 304 austenitic steel bar, along a cross-section thereof, while it is being fed through the entire rolling plant. In particular, the curve **1** represents the temperature trend of the centre of the bar, also defined as core, along a cross section, orthogonal to the longitudinal axis of said bar; the curve **2** represents the temperature trend in an intermediate surface; the curve **3** the trend of the outer surface of the bar. The positions of the various rolling stands present in the production plant, used for these tests, are indicated on the horizontal axis X. It can be seen how, at the outlet of the last stand **4** of the rolling train, solution quenching treatment of the bar commences, by feeding it through a suitable cooling device, with a cooling speed that allows a temperature trend of the core of the bar that does intersect and that remains below the precipitation curve **5** of the carbides, or sensibilization curve. This curve **5** is a function of the chemical composition of the material of which the bars are composed and also depends on the dimension of the grain and, therefore, on the section of the bar being treated. Precipitation curves are easy to find in specialized literature. This first bar, relative to FIG. **1**, is fed to the rolling train with a dimension of 41 mm and is reduced to a dimension of 27 mm with a rolling speed of 4.9 m/s. The initial rolling temperature is between 1100° C. and 1150° C. The temperature of the bar at the start of solution quenching treatment ranges from 1050° C. to 1100° C., while at the end of treatment it ranges from 350 to 500° C. The treatment time ranges from 4 to 6 seconds, in order to prevent carbide precipitation and to obtain the required straightness, while the pressure of the cooling fluid is around 4-8 bar.

[0050] Analogously, the diagram in FIG. **2** represents the temperature trend, during the treatment of the invention, through the section of an AISI 304 steel bar with a diameter of 86 mm, obtained by rolling with a feed speed of 0.7 m/s starting from an initial rolling temperature of between 1130 and 1180° C. The initial treatment temperature of the invention ranges from 950 to 1000° C., while at the end of treatment it ranges from 500 to 600° C. The treatment time suitable to prevent carbide precipitation is in this example of about 35 to 40 seconds, while the pressure of the cooling fluid is around 4-6 bar.

[0051] The diagram in FIG. **3**, instead, refers to an AISI 304 stainless steel bar with a diameter of 60 mm, obtained by rolling with a feed speed of 1.2 m/s starting from an initial rolling temperature of between 1130 and 1180° C. In this case the initial treatment temperature ranges from 980 to 1020° C., while at the end of treatment it ranges from 450 to 600° C. In this case the treatment time ranges from 18 to 24 seconds in order to prevent carbide precipitation and to obtain the required straightness; the pressure of the cooling fluid is around 4-8 bar.

[0052] In all three examples in FIGS. **1** to **3** it was possible, therefore, to obtain by means of the solution quenching treatment of the invention, performed directly on the rolling line, a material with a high resistance to intergranular corrosion. This is due to the choice of treatment parameters within specific intervals which prevent undesired phase precipitations such as those of the chromium carbides. The solution quenching stage of the invention is suitable to be performed also on ferritic or austeno-ferritic stainless steel bars, Nickel superalloy bars, and all other alloys that require rapid cooling.

[0053] The treatment of bars of the invention is suitable to treat products in bars with a diameter ranging from 10 mm to approximately 130 mm, and the equivalent in square, hexagonal or rectangular sections, said treatment being characterised by the following parameters:

[0054] an initial treatment temperature ranging approximately from about 950 to 1200° C.;

[0055] an end of treatment temperature ranging from 350 to 650° C.

[0056] Advantageously, the cooling speed is between 10 and 150° C./sec.

[0057] The cooling device that allows implementation of the in-line solution process of the invention consists in a series of cooling boxes, housing pipes with pressurized water, or suitable fluids, and with a distribution of the jet of water, or suitable fluids, suitable to guarantee uniform cooling of the entire section of the bar, avoiding distortions of the bar typical of rapidly cooled austenitic steels.

[0058] A number of cooling boxes is necessary to guarantee the thermal gradient required by the treatment of the invention. The thermal gradient, which a cooling box must produce on the bar, varies as a function of the diameter of the bar, the grade of the steel and the end treatment temperature required. There is provided also a system to support the bar, suitable to ensure the absence of surface scoring and to correctly centre the bar to achieve uniform cooling.

[0059] With the treatment process of the invention, performed directly during rolling, it is therefore possible to avoid intermediate storage and re-heating from ambient temperature to a temperature of around 1100 to 1200° C. with evident energy saving; it is no longer necessary to straighten the bars after the cooling; productivity is the nominal plant productivity as the process is performed directly during rolling; the entire production plant is more compact and requires less maintenance.

[0060] FIGS. **4**, **5**, **6**, **7**, **8** show some of the possible solutions for the configuration of the plant that allow the in-line execution of the stages of rolling and solution quenching treatment in which the total or partial cooling is carried out in boxes of water or other suitable cooling fluids.

[0061] FIG. **4** gives a schematic illustration of an initial basic configuration of the plant, comprising:

[0062] a reheating furnace **6** for semi-finished products, such as billets,

[0063] a roughing train **7**, an intermediate train **8** and a finishing train **9** which define respectively the first, second and third stage of rolling the bars,

[0064] a first solution quenching line **10** comprising a series of cooling boxes with water or other suitable fluids,

[0065] a discharging device **11** for the bars.

[0066] Before the quenching treatment in the first solution quenching line **10**, the bars can also undergo just one stage of rolling in the roughing rain **7**, or just two stages of rolling in the roughing **7** and intermediate **8** trains.

[0067] The configuration in FIG. **5**, meanwhile, shows how the bar is cooled in a second solution quenching line **10'**, placed immediately downstream of the first stage of rolling, and therefore of the roughing train **7**; it also shows that the bar is discharged into an intermediate bar discharging device **11'**. The remainder of the plant is as that described for FIG. **4**, from the second stage of rolling in the intermediate train **8** and comprising said first solution quenching line **10**. This configuration is particularly advantageous because it makes it possible to better control the temperature at the beginning of the treatment for those bars that only require the first stage of rolling: indeed, it avoids these bars remaining for too long in the air throughout the other rolling stages, which would not be activated, before reaching the entrance of the solution quenching line. Furthermore, this configuration helps the operations on the section of the line downstream of the intermediate bar discharge device **11'**, in the sense that it is possible to simultaneously produce and carry out maintenance or changes on said section; this makes the plant more flexible. This configuration is suitable to be suggested to the user when installing a new plant.

[0068] In the configuration in FIG. **6**, unlike that in FIG. **5**, there is no intermediate discharge device **11'**, leading to greater compactness of the plant; thus it is possible to reduce it by around 30 m in length.

[0069] The configuration in FIG. **7**, like that in FIG. **5**, makes it possible to discharge separately those bars that undergo just one stage of rolling. In this case, there are advantageously two parallel lines, which comprise respectively the first line **10** and a second line **10"** of solution quenching, which are fed by a device **13** that transfers the bars, placed downstream of the first stage of rolling. Downstream of the second line **10"** there is provided a second discharge device **11"**. This configuration is suitable to be incorporated into a plant that already has a solution quenching line, such as that illustrated in FIG. **4**.

[0070] Lastly the configuration in FIG. **8** provides that the solution quenching treatment is carried out in two stages: the first stage is carried out in the first solution quenching line **10**, placed downstream of the finishing train **9**, and the second stage is carried out in a water tank **12** which is integrated into the bar discharge device **11**; the advantage of this configuration lies in the fact that the length of the solution quenching line **10**, in which the first stage is carried out, is shorter, for example, than the equivalent length in the configuration in FIG. **4**, further increasing the compactness of the plant.

[0071] The particular methods of embodiment described herein do not limit the content of this application, which covers all embodiments of the invention defined by the claims.

1-14. (canceled)

15. In-line heat treatment of bars exiting a rolling mill wherein, immediately after at least one stage of rolling, there is provided a solution heat-treatment in a solution heat-treatment line (**10**, **10'**, **10"**), with an initial temperature of the bars comprised between 900 and 1200° C., characterised in that there is provided a quenching speed comprised between 10 and 150° C./sec, and in that the final temperature of the solution heat-treatment of the bars is between 350 and 650° C., such that a first curve (**1**), which represents the temperature pattern at the core of the treated bar over time, does not intersect and remains below a second curve (**5**) showing precipitation of carbides, specific to the material of the treated bar.

16. Process according to claim **15**, wherein said bars are of circular, square, hexagonal, rectangular section.

17. Process according to claim **16**, wherein said bars are in stainless steel.

18. Process according to claim **16**, wherein said bars are in nickel alloys.

19. Process according to claim **15**, wherein two stages of rolling take place before the solution heat-treatment in said first solution heat-treatment line (**10**), said stages including the passage of the bars to a roughing train (**7**) and an intermediate train (**8**) respectively.

20. Process according to claim **15**, wherein three stages of rolling take place before the solution heat-treatment in said first solution heat-treatment line (**10**), said stages including the passage of the bars to a roughing train (**7**), an intermediate train (**8**) and a finishing train (**9**) respectively.

21. Process according to claim **15**, wherein said at least one stage of rolling includes the passage of the bars into a roughing train (**7**) downstream of which the bars undergo said solution heat-treatment in a second line of solution heat-treatment (**10'**, **10"**).

22. Process according to claim **19**, wherein said solution heat-treatment includes two stages, the first of which on said solution heat-treatment line (**10**) and the second of which in a quenching medium (**12**) that is integrated into a first bar discharge device (**11**).

23. Process according to claim **20**, wherein said solution heat-treatment includes two stages, the first of which on said solution heat-treatment line (**10**) and the second of which in a quenching medium (**12**) that is integrated into a first bar discharge device (**11**).

24. Process according to claim **19**, wherein after said solution heat-treatment the bars are discharged into a first discharge device (**11**), called first device (**11**) as it is situated immediately downstream of said first solution heat-treatment line (**10**).

25. Process according to claim **20**, wherein after said solution heat-treatment the bars are discharged into a first discharge device (**11**), called first device (**11**) as it is situated immediately downstream of said first solution heat-treatment line (**10**).

26. Process according to claims **15** or **21**, wherein after said first stage of rolling there is a stage in which the bars are transferred to a second solution heat-treatment line (**10"**).

27. Plant for rolling and in-line heat treatment of bars including

means for heating (**6**) a semi-finished product,

means for rolling said semi-finished product, including a roughing train (**7**), an intermediate train (**8**) and a finishing train (**9**),

a first solution heat-treatment line (**10**) including a series of quenching tanks with water or other quenching fluids,

a first bar discharge device (**11**) equipped with a quenching tank (**12**).

28. Plant according to claim **27**, wherein between said roughing train (**7**) and said intermediate train (**8**) there is a second line of solution heat-treatment (**10'**).

29. Plant according to claim **28**, wherein immediately downstream of said second solution heat-treatment line (**10'**) there is a second bar discharge device (**11'**).

30. Plant according to claim **27**, wherein downstream of the roughing train (**7**) there is a device (**13**) to transfer the bars to a second solution heat-treatment line (**10"**) followed by a second discharge device (**11"**).

* * * * *