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**Takeuchi et al.**(10) **Pub. No.: US 2006/0124202 A1**(43) **Pub. Date: Jun. 15, 2006**(54) **NITRIDING METHOD AND DEVICE****Publication Classification**(76) Inventors: **Yutaka Takeuchi**, Saitama (JP);  
**Hitoshi Karasawa**, Saitama (JP);  
**Hideo Kojima**, Saitama (JP)(51) **Int. Cl.**  
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Correspondence Address:

**ARENT FOX PLLC****1050 CONNECTICUT AVENUE, N.W.****SUITE 400****WASHINGTON, DC 20036 (US)**(57) **ABSTRACT**(21) Appl. No.: **10/559,531**(22) PCT Filed: **Jun. 10, 2004**(86) PCT No.: **PCT/JP04/08133**(30) **Foreign Application Priority Data**

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A pulse voltage having a frequency of 15 kHz is applied from a discharging power supply unit (48) to between a crankshaft (12) and an electrode plate (45) at a current density of 2.5 mA/cm<sup>2</sup> to generate a glow discharge and an electric heater (34) is driven at a 40% output (64 kW/kg) to heat the crankshaft (12) to up to 400° C., and then heating is continued with the current density of a glow discharge set at 0.5 mA/cm<sup>2</sup> and the output of the electric heater (34) set at 90% (144 kW/kg), thereby effecting nitriding at a desired nitriding temperature.

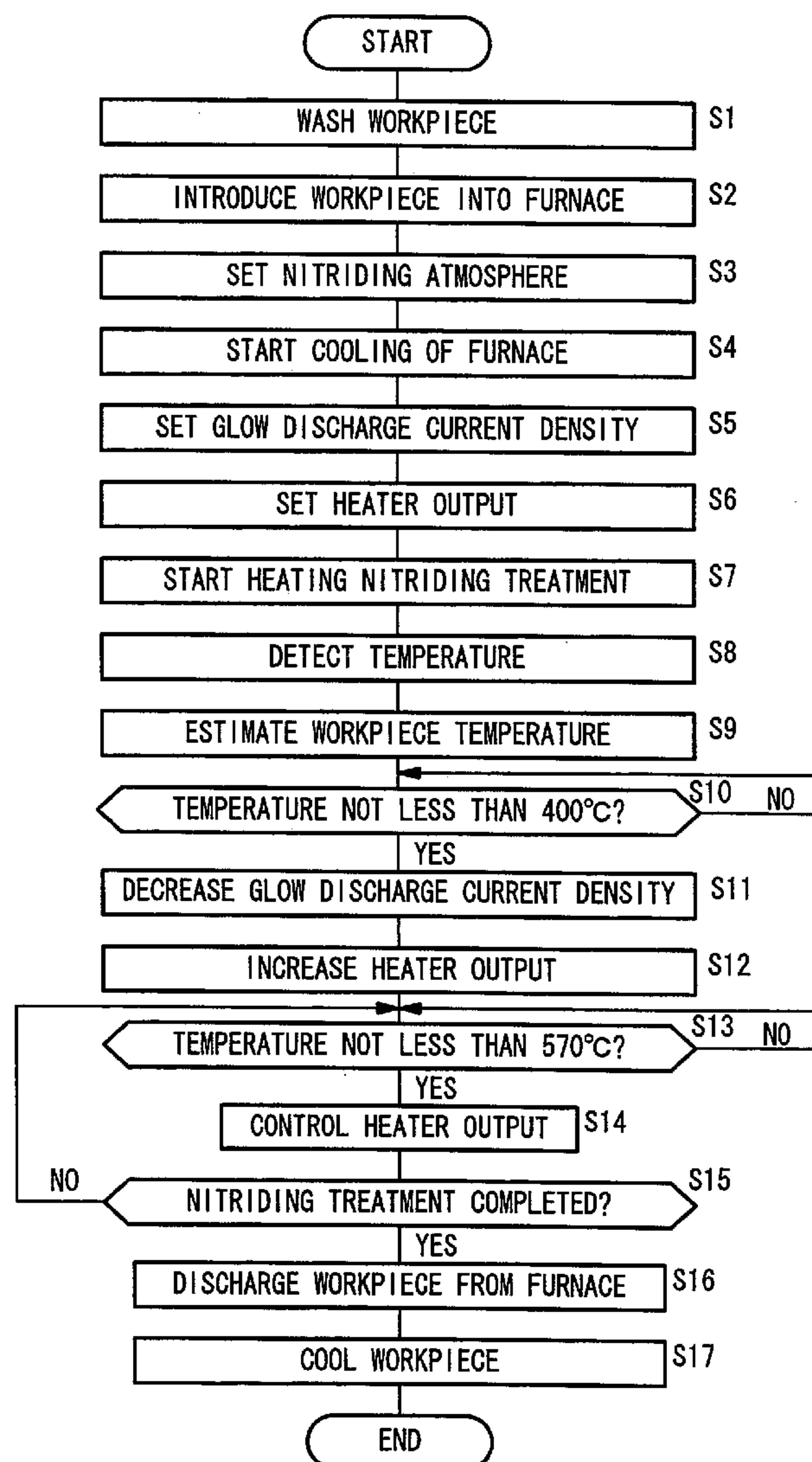
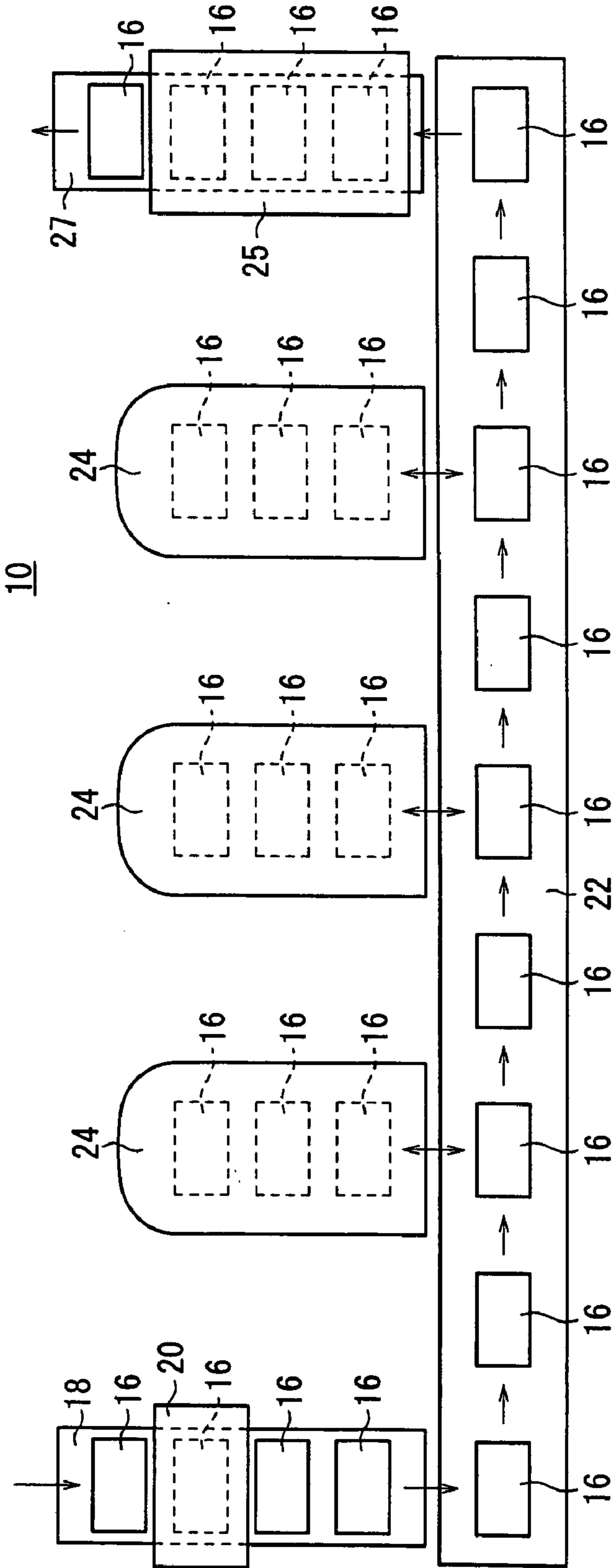
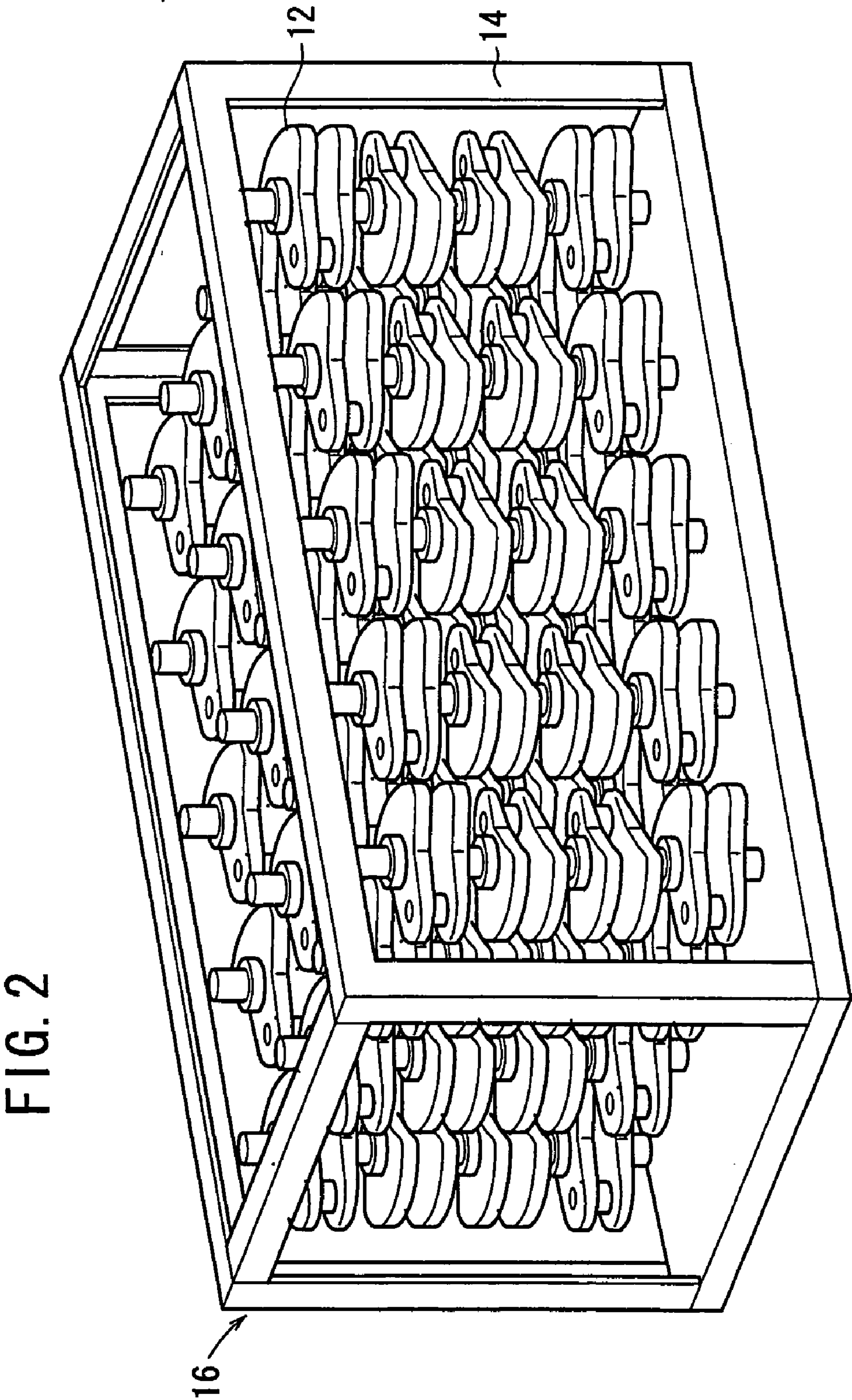


FIG. 1









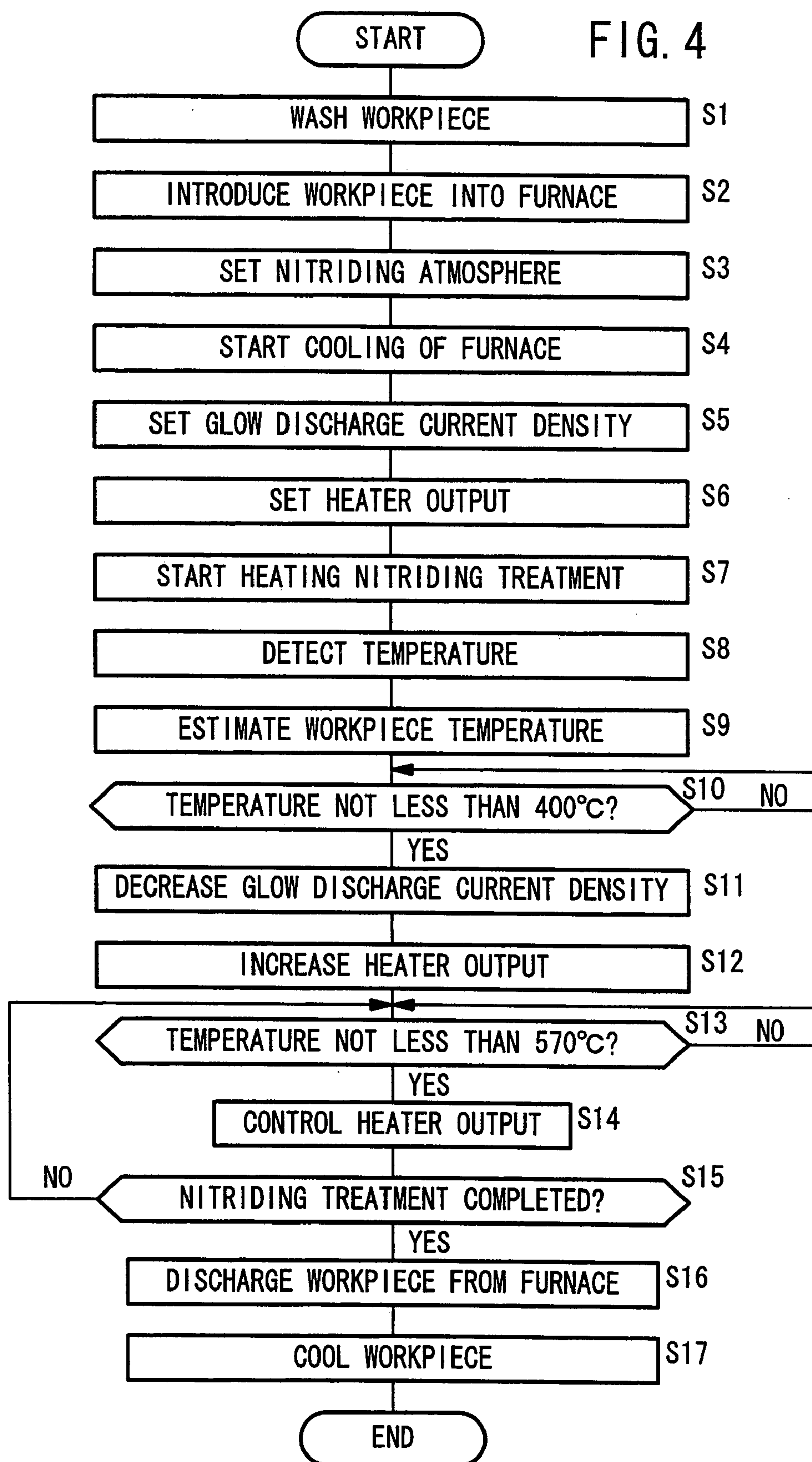
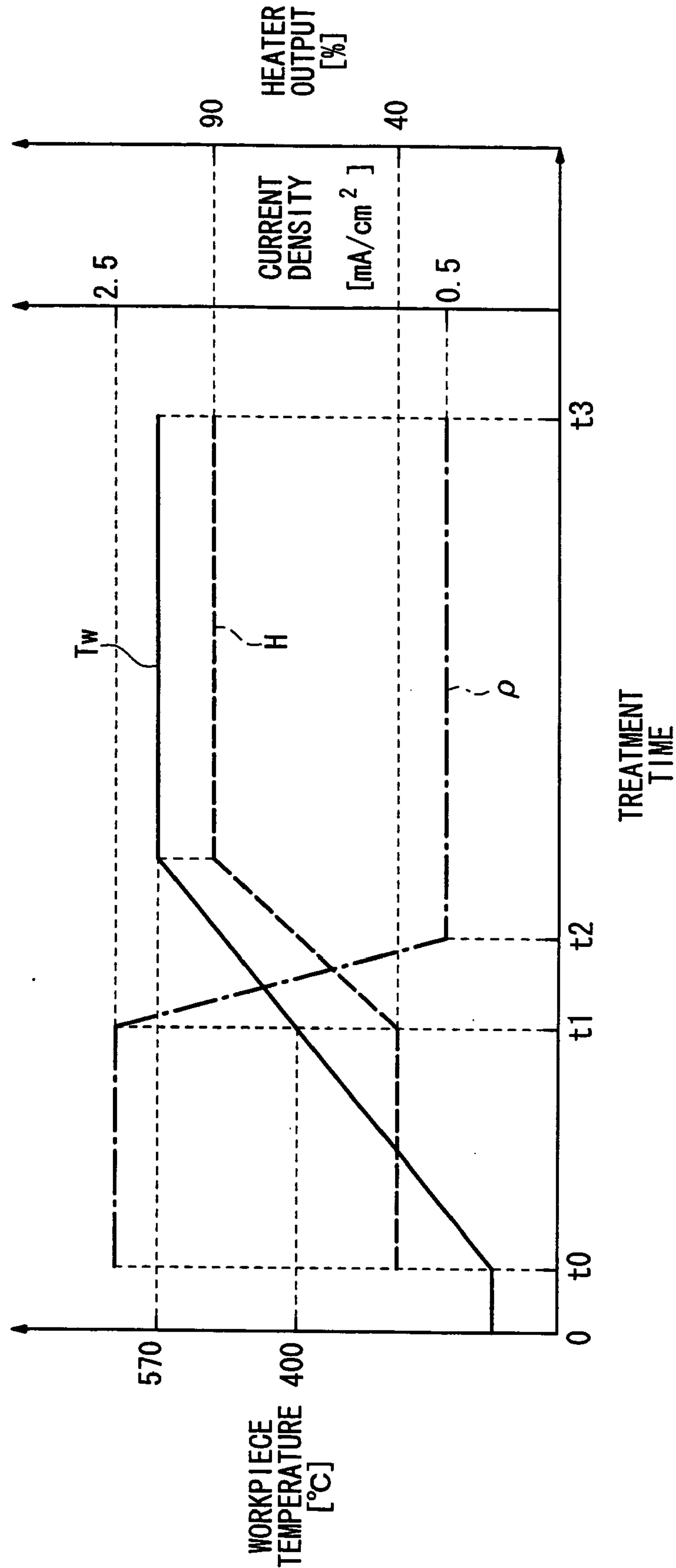


FIG. 5





**NITRIDING METHOD AND DEVICE****TECHNICAL FIELD**

[0001] The present invention relates to a nitriding treatment method and a nitriding treatment apparatus for performing a nitriding treatment for a workpiece in a heat treatment furnace.

**BACKGROUND ART**

[0002] The nitriding treatment resides in a process in which a surface of a workpiece composed of a steel material is nitrided to form an iron nitride layer, and thus the surface of the workpiece is hardened. The nitriding treatment is widely carried out. A method for the nitriding treatment includes a plasma nitriding treatment in which the plasma heating is performed by means of the glow discharge.

[0003] In the case of such a treatment, when the workpiece is cold, the glow discharge becomes unstable. Depending on certain situations, any inconvenience arises such that the arc discharge is caused, and a part of the workpiece surface is melted, and/or it is impossible to apply any uniform nitriding treatment. In particular, when the temperature distribution of the workpiece is nonuniform, it is impossible to obtain satisfactory products, because the degree of advance of nitriding differs depending on the positions of the product.

[0004] In view of the above, in order to heat the workpiece quickly and uniformly up to a desired temperature at which the nitriding treatment can be performed stably, a conventional technique is known, which is constructed such that a heating means such as an infrared heater or a graphite cloth heating element is arranged around the workpiece, and the workpiece is heated by using the heating means together with the glow discharge (see, for example, Japanese Laid-Open Patent Publication Nos. 52-82641 and 53-23836).

**DISCLOSURE OF THE INVENTION****PROBLEMS TO BE SOLVED BY THE INVENTION**

[0005] However, for example, when a plurality of workpieces having complicated shapes are simultaneously heated in a heat treatment furnace, it is impossible to obtain any uniform temperature distribution for the workpieces when the glow discharge and the heating means are simply used together as in the conventional technique as described above.

[0006] That is, the heat, which is brought about by the glow discharge, is basically generated such that the nitrogen ions, which are produced by the glow discharge, collide with the workpiece surface. However, when the workpiece is heated to be not less than a certain temperature, the surrounding workpieces are heated by the radiation heat of the workpiece itself. Therefore, the difference in temperature appears between the region which is disposed close to the heating means and the region which is disposed separately from the heating means. If a large number of heating means are arranged among the workpieces, this problem can be dissolved. However, it is almost impossible to construct the heating means arranged at appropriate positions among the workpieces in relation to a production line such as those used in the various kinds and small quantity production (job shop type production or flexible manufacturing) in which it

is required to perform the nitriding treatment for the workpieces having different shapes.

[0007] A general object of the present invention is to provide a nitriding treatment method and a nitriding treatment apparatus in which a workpiece is heated quickly and uniformly up to a temperature at which a stable nitriding treatment can be performed, making it possible to apply the nitriding treatment in a state in which the workpiece temperature dispersion is scarcely caused.

[0008] A principal object of the present invention is to provide a nitriding treatment method and a nitriding treatment apparatus in which an extremely satisfactory nitriding treatment can be applied to a large number of workpieces having complicated shapes.

[0009] Another object of the present invention is to provide a nitriding treatment method and a nitriding treatment apparatus which can be easily applied to different workpieces of many types.

[0010] Still another object of the present invention is to provide a nitriding treatment method and a nitriding treatment apparatus in which a satisfactory nitriding treatment can be applied when the present invention is applied to a lateral type heat treatment furnace.

[0011] Still another object of the present invention is to provide a nitriding treatment method and a nitriding treatment apparatus in which an extremely satisfactory nitriding treatment can be applied by managing the workpiece temperature highly accurately.

**MEANS FOR SOLVING THE PROBLEMS**

[0012] According to the present invention, the pulse voltage, which is used to generate the glow discharge, is allowed to have a frequency of not less than 1 kHz. Accordingly, the period of time, in which the current is continuously applied, is not more than 1 ms, and the continuation of the arc discharge is avoided with a short detecting time. Thus, the current is cut off before arrival at a voltage at which any arc mark appears. Therefore, the stable glow discharge state can be maintained by avoiding the appearance of any arc mark, and it is possible to effect the heating without damaging the workpiece surface. It is preferable that the detecting time is shorter. Therefore, it is preferable that the power source to be used for generating the pulse voltage is, for example, those which operate at about 15 kHz. The workpiece is directly heated by the glow discharge. Therefore, the present invention does not depend on, for example, the shape of the workpiece and the arrangement of the workpiece. In particular, it is possible to uniformly increase the workpiece temperature in the heat treatment furnace even in the case of a structure such as those of the lateral type heat treatment furnace in which any dispersion tends to appear depending on, for example, the convection current, the distance from the heating element, and the number of workpieces. The workpiece can be quickly heated in a state in which the uniform temperature distribution is maintained by using the glow discharge and the heating effected by the heating element together. As a result, the period of time, which is required for all workpieces to arrive at a certain temperature, is short. Further, it is possible to shorten the period of time which is required to retain the workpieces at the certain temperature as well.



[0013] The workpiece temperature is detected during the heating, and the current density of the glow discharge is decreased after the temperature arrives at 350° C. Accordingly, it is possible to avoid the generation of any excessive radiation heat from the workpiece itself heated by the glow discharge, it is possible to uniformly maintain the temperature distribution in the heat treatment furnace, and it is possible to avoid any sudden increase in temperature. Subsequently, when the workpiece is further heated from this temperature by using the heating element arranged around the workpiece, it is possible to set the workpiece at a desired nitriding treatment temperature highly accurately.

[0014] In this case, if the workpiece temperature exceeds the desired nitriding treatment temperature, it is feared that any abnormal microstructure is formed in the workpiece. However, in the present invention, the heat generation, which is brought about by the glow discharge, can be adjusted highly accurately. Therefore, the workpiece can be set at a high temperature at which no overshoot occurs, and it is possible to shorten the period of time required for the nitriding treatment.

[0015] It is preferable that the current density of the glow discharge is 0.05 to 7 mA/cm<sup>2</sup>. If the current density is less than 0.05 mA/cm<sup>2</sup>, then the glow discharge is unstable especially at low temperatures, and it is impossible to perform the uniform heating. On the other hand, if the current density is larger than 7 mA/cm<sup>2</sup>, then the transition to the arc discharge is caused, and any damage arises in the workpiece. If the current density is less than 0.1 mA/cm<sup>2</sup>, a long period of time is required to raise the temperature. Further, if the current density exceeds 4 mA/cm<sup>2</sup>, then ion collision tends to occur, for example, at projections when the workpiece has the projections or the like, and it is feared that the heating is advanced abnormally. Therefore, it is preferable that the current density is within a range of 0.1 to 4 mA/cm<sup>2</sup>.

[0016] Further, in the present invention, in order to detect the workpiece temperature highly accurately without using any contact type thermometer, a dummy workpiece is arranged in the heat treatment furnace. The contact temperature and the radiation temperature of the dummy workpiece are detected, and the radiation temperature of the workpiece is detected. The radiation temperature of the workpiece is corrected on the basis of the difference in temperature between the contact temperature and the radiation temperature of the dummy workpiece to estimate the temperature of the workpiece itself. When the heating, which is effected by the glow discharge and the heating element, is controlled on the basis of the workpiece temperature estimated as described above, then the workpiece temperature can be managed highly accurately, and it is possible to perform the extremely satisfactory nitriding treatment.

#### BRIEF DESCRIPTION OF THE DRAWINGS

[0017] FIG. 1 shows a schematic arrangement of a nitriding treatment system including a nitriding treatment apparatus according to an embodiment of the present invention;

[0018] FIG. 2 illustrates workpieces as objectives of the nitriding treatment and a magazine for accommodating the workpieces;

[0019] FIG. 3 illustrates an arrangement of a lateral type heat treatment furnace and a control circuit thereof according to the embodiment of the present invention;

[0020] FIG. 4 shows a flow chart illustrating a nitriding treatment method according to the embodiment of the present invention; and

[0021] FIG. 5 illustrates the relationship among the workpiece temperature, the current density, and the heater output in the nitriding treatment method according to the embodiment of the present invention.

#### BEST MODE FOR CARRYING OUT THE INVENTION

[0022] FIG. 1 shows a schematic arrangement of a nitriding treatment system 10 including a nitriding treatment apparatus according to an embodiment of the present invention. As shown in FIG. 2, a plurality of crank shafts 12 as workpieces are supplied to the nitriding treatment system 10 in a form of a magazine 16 in which the plurality of crank shafts 12 are positioned with a jig 14.

[0023] The nitriding treatment system 10 comprises a washing machine 20 which removes, for example, dust and oil adhered to the crank shafts 12 transported by a conveyer 18, a conveyer 22 which receives the washed crank shafts 12 from the conveyer 18 to transport them to respective work stations, lateral type heat treatment furnaces 24 which are arranged at the plurality of work stations along the conveyer 22, and a cooling tank 25 which cools the crank shafts 12 transported by a conveyer 27 connected to the terminal end of the conveyer 22.

[0024] FIG. 3 illustrates an arrangement of the lateral type heat treatment furnace 24 and its control circuit arranged for each of the work stations.

[0025] The lateral type heat treatment furnace 24 is a heat treatment furnace for applying the plasma nitriding treatment to the crank shafts 12. The lateral type heat treatment furnace 24 is constructed as the lateral type. The magazine 16 with the positioned crank shafts 12 is placed into/out of the lateral type heat treatment furnace 24 in the horizontal direction. The lateral type heat treatment furnace 24 has an inner partition wall 28 and an outer partition wall 30 which are arranged on a base pedestal 26.

[0026] The inner partition wall 28 forms a nitriding treatment chamber 32 which involves a nitriding atmosphere for accommodating the crank shafts 12 together with the jig 14. The space, which is disposed between the inner partition wall 28 and the outer partition wall 30, forms a cooling liquid passage 33 for cooling the inner partition wall 28 to eliminate any influence of the heat radiation and facilitate the control when the temperature of the nitriding treatment chamber 32 is raised.

[0027] A plurality of electric heaters 34 (heating elements) are arranged along the inner partition wall 28 and the base pedestal 26 in the nitriding treatment chamber 32. A dummy workpiece 36, which has physical properties equivalent to those of the crank shaft 12, is arranged in the nitriding treatment chamber 32. The dummy workpiece 36 may be the crank shaft 12 itself.

[0028] A negative electrode 38, which is electrically connected to the magazine 16, is arranged for the base pedestal 26 by the aid of an insulator 40. Further, a negative electrode 42, which is electrically connected to the dummy workpiece 36, is arranged for the base pedestal 26 by the aid of an



insulator 44. An electrode plate 45 is arranged at the inside of the electric heaters 34 of the nitriding treatment chamber 32. A positive electrode 46 is connected to the electrode plate 45. An electric discharge power source unit 48 (glow discharge-generating means), which applies a pulse voltage having a frequency of not less than 1 kHz, is connected between the negative electrodes 38, 42 and the positive electrode 46. A heater power source unit 50 (heating means) is connected to the electric heaters 34.

[0029] The nitriding treatment chamber 32 is arranged with a workpiece radiation thermometer 52 for detecting the radiation temperature of the crank shaft 12, a dummy workpiece radiation thermometer 54 for detecting the radiation temperature of the dummy workpiece 36, and a dummy workpiece contact thermometer 56 composed of a thermocouple fixed to the dummy workpiece 36 for detecting the contact temperature of the dummy workpiece 36. The workpiece radiation thermometer 52, the dummy workpiece radiation thermometer 54, and the dummy workpiece contact thermometer 56 are connected to a temperature-detecting unit 58 (temperature-detecting means, temperature-calculating means). The temperature-detecting unit 58 postulates or estimates the temperature of the crank shaft 12 from the respective detected temperature data.

[0030] A vacuum suction pump 60, which sucks the gas contained in the nitriding treatment chamber 32 to obtain a desired degree of vacuum, is connected to the nitriding treatment chamber 32 via a valve 62. A nitriding treatment gas supply unit 64, which supplies a gas for performing the plasma nitriding treatment, for example, a nitriding treatment gas as a mixed gas of nitrogen gas, hydrogen gas, ammonia gas, and argon gas into the nitriding treatment chamber 32, is connected to the nitriding treatment chamber 32 via a valve 66. A cooling liquid supply unit 68 for supplying the cooling liquid is connected to the cooling liquid passage 33 via a valve 70. The system is constructed such that the cooling liquid, which is supplied to the cooling liquid passage 33, is dischargeable to the outside via a valve 72.

[0031] The electric discharge power source unit 48, the heater power source unit 50, the temperature-detecting unit 58, the vacuum suction pump 60, the nitriding treatment gas supply unit 64, and the cooling liquid supply unit 68 are controlled by a control unit 74 (control means).

[0032] The nitriding treatment system 10 according to the embodiment of the present invention is basically constructed as described above. Next, its operation, function, and effect will be explained in accordance with a flow chart shown in FIG. 4.

[0033] At first, as shown in FIG. 2, the magazine 16, in which the plurality of crank shafts 12 are positioned in the jig 14, is prepared. The magazine 16 is placed into the washing machine 20 by using the conveyer 18 to remove dust and oil adhered to the respective crank shafts (Step S1).

[0034] Subsequently, the magazine 16, in which the crank shafts 12 have been washed, is transported by using the conveyer 22 to introduce the magazine 16 into the nitriding treatment chamber 32 of each of the lateral type heat treatment furnaces 24 (Step S2). In this arrangement, the lateral type heat treatment furnace 24 is of the horizontal type. Therefore, the following advantages are obtained as

compared with the vertical type. That is, the plurality of magazines 16 retained with the crank shafts 12 can be easily placed into/out of the nitriding treatment chambers 32. Further, the layout of the nitriding treatment system 10 can be simplified. Furthermore, the number of the crank shafts 12 to be treated at once can be increased with ease. In contrast, in the case of the vertical type, it is necessary that the heat treatment chamber has a large size in the upward direction.

[0035] When the magazine 16 is introduced into the nitriding treatment chamber 32, the bottom of the jig 14 is connected to the negative electrode 38 arranged for the base pedestal 26. The dummy workpiece 36, which has the physical properties equivalent to those of the crank shaft 12, is previously arranged in the nitriding treatment chamber 32.

[0036] The nitriding treatment chamber 32 is set to have a nitriding atmosphere after introducing the magazine 16 into the nitriding treatment chamber 32 and tightly closing the lateral type heat treatment furnace 24 (Step S3). In this procedure, the control unit 74 is operated so that the vacuum suction pump 60 is driven to suck the air contained in the nitriding treatment chamber 32 until arrival at a predetermined degree of vacuum, and then the nitriding treatment gas supply unit 64 is driven to introduce, into the nitriding treatment chamber 32, the nitriding treatment gas composed of the mixed gas of, for example, nitrogen gas, hydrogen gas, ammonia gas, and argon gas.

[0037] Subsequently, the cooling liquid supply unit 68 is driven to introduce the cooling liquid into the cooling liquid passage 33 disposed between the inner partition wall 28 and the outer partition wall 30 and start the cooling of the wall surface of the inner partition wall 28 (Step S4). The control unit 74 sets the pulse voltage having a frequency of 15 kHz and a current density  $\rho$  of 2.5 mA/cm<sup>2</sup> for the electric discharge power source unit 48 (Step S5). Further, the control unit 74 sets the output H of the heater power source unit 50 to 40% (Step S6). The heater power source unit 50 is operated at the maximum output (100%) when the amount of electrical energy (thermal energy) of the crank shaft 12 introduced into the nitriding treatment chamber 32 is 160W per 1 kg. Thus, 40% of the output H is 64W/kg.

[0038] After setting the treatment conditions as described above, the heating of the nitriding atmosphere in the nitriding treatment chamber 32 and the nitriding treatment are started (Step S7). In this procedure, as shown in FIG. 5, when the crank shafts 12 are introduced, and the setting of the respective treatment conditions is completed to drive the electric discharge power source unit 48 and the heater power source unit 50 (treatment time tO), then the glow discharge is generated by the pulse voltage applied between the negative electrode 38 and the positive electrode 46. The nitriding treatment gas in the nitriding treatment chamber 32 is ionized by the glow discharge to make the collision against the surfaces of the crank shafts 12. Accordingly, the crank shafts 12 are heated. Further, the electric heaters 34, which are arranged around the outer circumference of the magazine 16 for retaining the crank shafts 12, generate the heat, and the nitriding atmosphere of the nitriding treatment chamber 32 is heated by the radiation heat brought about by the heat generation. The glow discharge is also caused on the surface of the dummy workpiece 36. Therefore, the dummy workpiece 36 is also heated in the same manner as described above.



[0039] In this situation, the voltage having the pulse frequency of 15 kHz is applied between the negative electrodes 38, 42 and the positive electrode 46. Therefore, a stable glow discharge state, in which no arc discharge is caused, is maintained even in a state in which the nitriding atmosphere is not sufficiently subjected to the increase in temperature up to a temperature at which the stable nitriding treatment can be started. That is, the period of time, in which the current is continuously applied, is extremely short, and the continuation of the arc discharge is stopped with a short detecting time. Accordingly, the current is cut off before arrival at a voltage at which any arc mark appears. It is possible to avoid the appearance of any arc mark and maintain the stable glow discharge state. Therefore, any situation, in which the surface of the crank shaft 12 is damaged by the arc discharge, does not occur. The heating brought about by the glow discharge is not caused by the radiation heat but caused by the collision of nitrogen ions or nitrogen radicals produced by the glow discharge against the crank shafts 12. Therefore, when the temperature is less than 350° C., then any influence is scarcely exerted by the radiation heat of the crank shafts 12, and no influence is exerted by the shapes of the crank shafts 12 and the positional relationship of the crank shafts 12 arranged adjacently to one another. Therefore, the crank shafts 12 are uniformly heated by the glow discharge. Further, the nitriding atmosphere of the nitriding treatment chamber 32 is heated by the radiation heat from the electric heaters 34 which are arranged along the inner partition wall 28 and which are set to provide the low output. Therefore, the crank shafts 12 are quickly heated up to the desired stable nitriding treatment temperature in the state in which the temperature distribution is uniformly maintained.

[0040] During the temperature-raising process, the cooling liquid is supplied to the cooling liquid passage 33. For example, when the inner partition wall 28 is cooled and maintained at a temperature of not more than 100° C. with the cooling liquid, it is possible to avoid such a situation that the radiation heat from the electric heaters 34 is reflected by the inner partition wall 28 to excessively heat the crank shafts 12 arranged inside. Therefore, it is possible to raise the temperature of the crank shaft 12 more uniformly.

[0041] On the other hand, the temperature of the crank shaft 12 is estimated highly accurately by using the temperature of the dummy workpiece 36 arranged in the nitriding treatment chamber 32 and the radiation temperature of the crank shaft 12 (Steps S8, S9).

[0042] That is, the workpiece radiation thermometer 52, which is arranged close to the crank shaft 12, detects the radiation temperature  $Trw$  as the temperature of the radiation heat radiated from the crank shaft 12. The dummy workpiece radiation thermometer 54, which is arranged close to the dummy workpiece 36, detects the radiation temperature  $Trd$  as the temperature of the radiation heat radiated from the dummy workpiece 36. Further, the dummy workpiece contact thermometer 56, which is fixed to the dummy workpiece 36, detects the correct contact temperature  $Tcd$  of the dummy workpiece 36.

[0043] Accordingly, the temperature-detecting unit 58 determines, as the temperature correction value  $\Delta T$ , the difference between the radiation temperature  $Trd$  of the dummy workpiece 36 detected by the dummy workpiece

radiation thermometer 54 and the contact temperature  $Tcd$  of the dummy workpiece 36 detected by the dummy workpiece contact thermometer 56 to calculate the temperature  $Tw$  of the crank shaft 12 by using the temperature correction value  $\Delta T$  as follows:

$$Tw = Trw + \Delta T$$

When the temperature of the crank shaft 12 is calculated as described above, it is possible to highly accurately estimate the temperature  $Tw$  of the crank shaft 12 in a non-contact manner without fixing any thermometer such as a thermocouple to the crank shaft 12.

[0044] Subsequently, the control unit 74 executes the process for judging whether or not the temperature  $Tw$  of the crank shaft 12 estimated by the temperature-detecting unit 58 is not less than 400° C. during the heating of the nitriding atmosphere of the nitriding treatment chamber 32 (Step S10). In this procedure, if the temperature  $Tw$  of the crank shaft 12 is not less than 400° C., then it is impossible to ignore the influence of the heat radiation of the crank shaft 12 itself, and it is feared that any temperature unevenness appears on the crank shaft 12 if the heating by the glow discharge is continued as it is.

[0045] Accordingly, if it is judged that the temperature  $Tw$  of the crank shaft 12 arrives at 400° C. (treatment time  $t1$ ), then the control unit 74 controls the electric discharge power source unit 48 to lower the current density  $p$  of the glow discharge to be applied between the negative electrode 38 and the positive electrode 46 down to 0.5 mA/cm<sup>2</sup> (Step S11), and the output of the heater power source unit 50 is raised up to 90%, i.e., 144 kW/kg (Step S12).

[0046] In this procedure, when the current density  $p$  is lowered down to 0.5 mA/cm<sup>2</sup>, then it is possible to suppress such a situation that the radiation heat is radiated from the crank shaft 12 heated by the glow discharge, and it is possible to suppress any sudden heating which would be otherwise caused by the glow discharge of the crank shaft 12. When the output of the heater power source unit 50 is raised up to 90%, it is possible to heat the crank shaft 12 up to the desired nitriding treatment temperature at which no overshoot is caused by the radiation heat from the electric heaters 34, in a state in which the temperature distribution of the crank shaft 12 is uniformly maintained. When the temperature of the crank shaft 12 is controlled by using the electric discharge power source unit 48 and the heater power source unit 50, for example, it is preferable to perform the following control. That is, the current density  $p$  is gradually lowered from the treatment time  $t1$  to the treatment time  $t2$  in accordance with the temperature  $Tw$  of the crank shaft 12 estimated by the temperature-detecting unit 58, while the output of the heater power source unit 50 is gradually increased from the treatment time  $t1$  until arrival at the desired nitriding treatment temperature of the crank shaft 12.

[0047] After the temperature  $Tw$  of the crank shaft 12 arrives at the desired nitriding treatment temperature of 570° C. (Step S13), the control unit 74 controls the heater power source unit 50 to maintain the temperature  $Tw$  of the crank shaft 12 at the nitriding treatment temperature of 570° C. (Step S14). During this process, the nitriding treatment is advanced on the surface of the crank shaft 12 in accordance with the reaction of nitrogen ion and iron ion.

[0048] When the predetermined period of time elapses, and the nitriding treatment is completed (Step S15, treat-



ment time t3), then the crank shafts 12 are discharged from the lateral type heat treatment furnace 24 together with the magazine 16 (Step S16). The magazine 16, which has been discharged from the lateral type heat treatment furnace 24, is transported by the conveyer 22, and the magazine 16 is placed into the cooling tank 25 to perform the cooling treatment (Step S17). After that, the magazine 16 is discharged to the outside by the aid of the conveyer 27.

1-12. (canceled)

13. A nitriding treatment method for performing a nitriding treatment for a workpiece in a heat treatment furnace, said nitriding treatment method comprising:

a first step of applying a pulse voltage having a predetermined current density at a frequency of not less than 1 kHz between said heat treatment furnace and said workpiece to heat said workpiece by means of generated glow discharge; and

a second step of decreasing said current density of said pulse voltage after a temperature of said workpiece arrives at 350° C., and then heating said workpiece up to a desired nitriding treatment temperature by using a heating element arranged around said workpiece, wherein

said nitriding treatment is performed by means of nitrogen ion or nitrogen radical generated by said glow discharge.

14. The nitriding treatment method according to claim 13, wherein

said workpiece is heated by heat generated by said glow discharge and said heating element in said first step; and

heating is effected in said second step such that an amount of heat generated by said heating element is higher than that in said first step.

15. The nitriding treatment method according to claim 13, wherein said current density of said pulse voltage is gradually decreased in said second step, while said workpiece is gradually heated up to said nitriding treatment temperature by using said heating element arranged around said workpiece.

16. The nitriding treatment method according to claim 13, wherein said nitriding treatment temperature is maintained to execute said nitriding treatment after said workpiece arrives at said desired nitriding treatment temperature in said second step.

17. The nitriding treatment method according to claim 13, wherein said current density of said pulse voltage is 0.05 to 7 mA/cm<sup>2</sup>.

18. The nitriding treatment method according to claim 13, wherein said current density of said pulse voltage is 0.1 to 4 mA/cm<sup>2</sup>.

19. The nitriding treatment method according to claim 13, wherein said temperature of said workpiece is determined by detecting a temperature difference between a radiation temperature and a contact temperature of a dummy workpiece arranged in said heat treatment furnace, detecting a radiation temperature of said workpiece, and correcting said radiation temperature of said workpiece with said temperature difference.

20. A nitriding treatment apparatus for performing a nitriding treatment for a workpiece in a heat treatment furnace, said nitriding treatment apparatus comprising:

a glow discharge-generating means which generates glow discharge by applying a pulse voltage having a predetermined current density at a frequency of not less than 1 kHz between said heat treatment furnace and said workpiece;

a heating means which heats said workpiece by using a heating element arranged in said heat treatment furnace;

a temperature-detecting means which detects a temperature of said workpiece; and

a control means which controls said current density of said glow discharge effected by said glow discharge-generating means on the basis of said temperature of said workpiece detected by said temperature-detecting means and which controls said heating means,

wherein said temperature-detecting means includes:

a dummy workpiece radiation thermometer which detects a radiation temperature of a dummy workpiece arranged in said heat treatment furnace;

a dummy workpiece contact thermometer which detects a contact temperature of said dummy workpiece;

a workpiece radiation thermometer which detects a radiation temperature of said workpiece; and

a workpiece temperature-calculating means which calculates said temperature of said workpiece by calculating a temperature difference between said radiation temperature and said contact temperature of said dummy workpiece and correcting said radiation temperature of said workpiece with said temperature difference.

21. The nitriding treatment apparatus according to claim 20, wherein said heat treatment furnace includes:

a nitriding treatment chamber which accommodates said workpiece and which is surrounded by an electrode plate for generating said glow discharge in cooperation with said workpiece;

a heating chamber which involves said heating element arranged around an outer circumference of said electrode plate and which is surrounded by a partition wall; and

a cooling means which is arranged around an outer circumference of said partition wall and to which a cooling liquid for cooling said partition wall is supplied.

22. The nitriding treatment apparatus according to claim 20, wherein said heat treatment furnace is a lateral type heat treatment furnace.

23. The nitriding treatment apparatus according to claim 20, wherein said workpiece is a crank shaft.