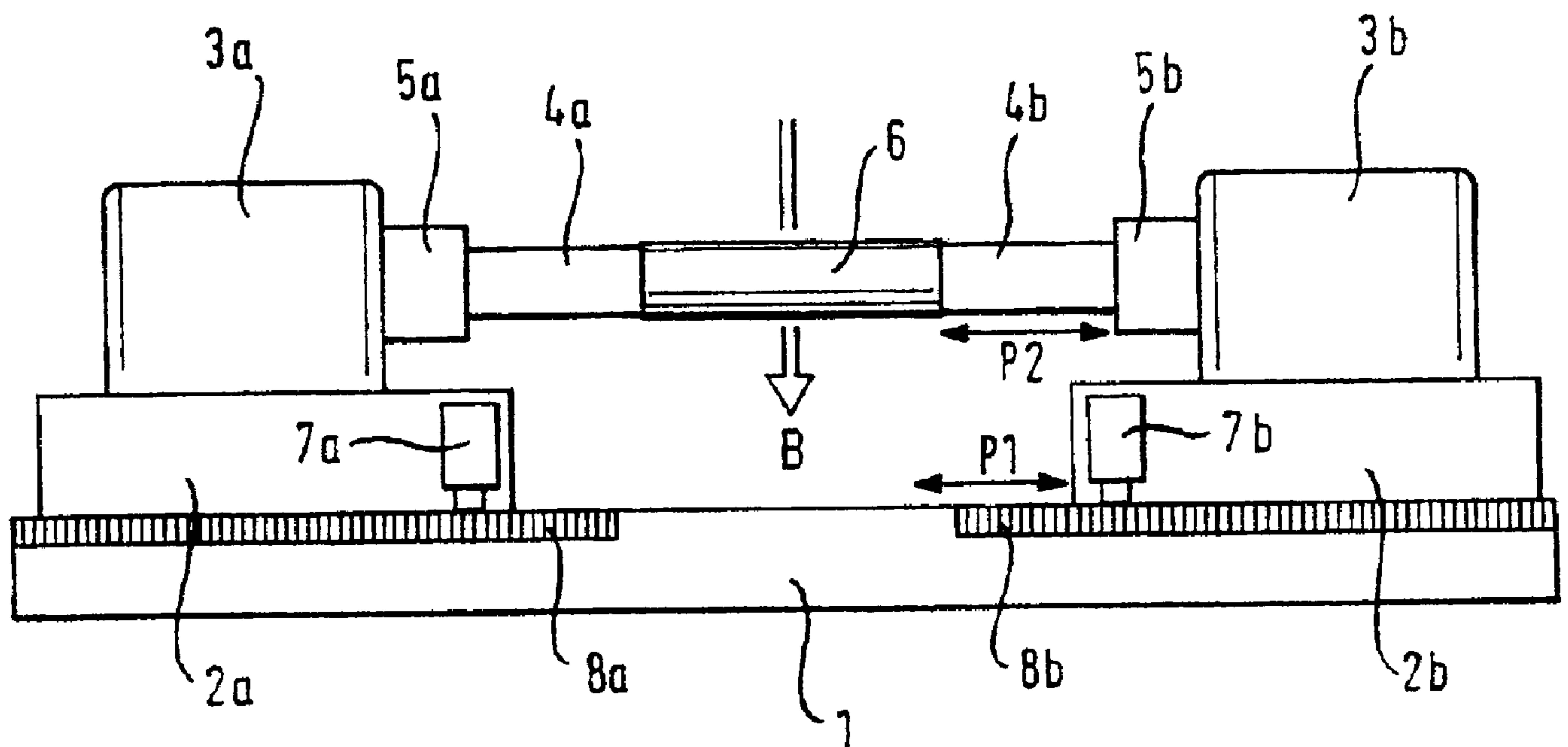




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(54) Titre : PROCEDE D'ECHAUFFEMENT PAR INDUCTION D'UNE PIECE METALLIQUE
(54) Title: METHOD FOR INDUCTION HEATING OF A METALLIC WORKPIECE



(57) Abrégé/Abstract:

A method for induction heating of a metallic workpiece to a desired temperature by rotating the workpiece relative to a direct-current magnetic field permeating the workpiece is rendered distinct by the features that the workpiece is clamped between two clamping jaws adapted to be rotated about a common axis, that at least one of the clamping jaws is driven to rotate, that at least one of the clamping jaws is adapted to be actively displaced along or parallel to the rotation axis, that the contact force of at least one of the clamping jaws is regulated, and that at least one mechanical parameter representative of the workpiece temperature is measured as an actual value and is compared with a desired value of this mechanical parameter as being representative of the desired temperature.



Abstract

A method for induction heating of a metallic workpiece to a desired temperature by rotating the workpiece relative to a direct-current magnetic field permeating the workpiece is rendered distinct by the features that the workpiece is clamped between two clamping jaws adapted to be rotated about a common axis, that at least one of the clamping jaws is driven to rotate, that at least one of the clamping jaws is adapted to be actively displaced along or parallel to the rotation axis, that the contact force of at least one of the clamping jaws is regulated, and that at least one mechanical parameter representative of the workpiece temperature is measured as an actual value and is compared with a desired value of this mechanical parameter as being representative of the desired temperature.

Method for Induction Heating of a Metallic Workpiece

Field of the Invention

The invention relates to a method for induction heating of a metallic workpiece to a
5 desired temperature by by moving, in particular rotating, the workpiece relative to a
magnetic field permeating the workpiece.

Background of the Invention

Metallic workpieces, in particular in the form of bars, ingots, billets or blooms, or rods, can
10 be heated in a magnetic field that is excited by means of at least one coil, the winding of
which carries either an alternating current or a direct current. In the first case, the
workpiece is usually at rest in the alternating-current magnetic field, but it can also be
subjected to translational or rotational movement relative to this. In the latter case, i.e.
when a direct-current magnetic field is excited, a translational and/or rotational relative
15 movement between the magnetic field and the workpiece is necessary.

Methods of this kind for induction heating of a workpiece in a direct-current magnetic field
are known, for example from WO 2004/066681 A1 and DE 10 2005 061 670 A1.

20 A basic difficulty of known methods for induction heating of moving workpieces consists
of determining the time-dependent rising temperature of the workpiece with sufficient and
reproducible accuracy, in order to terminate the heating process when a prescribed
desired temperature has been attained. Although direct contact measurements, for
example by means of a thermo-couple, yield very precise measurement values they are
25 hardly practicable because they can be performed only on a workpiece at rest. Indirect
contact measurements, for example measurements of the temperature-dependent
resistance of the workpiece material, can be performed on a moving workpiece, but they
require sliding contacts which not only are subject to wear, but also lead to very
inaccurate measurement results because of layers of oxide and scale on the surface of
30 the workpiece. This disadvantage is also present in a method known from DE 30 33 482
A1 for measuring the temperature of an induction-heated roll by measurement of the roll
diameter.

Although non-contacting measurements, i.e. those performed by pyrometry, can be
35 carried out in a substantially simple manner, they do not yield any sufficiently accurate

and reproducible measurement results, because they are based on a calculation which converts measured IR radiation to corresponding black-body temperatures by means of correction factors. However, the correction factors which express the emissivity of the material used in relation to a black body are dependent upon the material and also upon the condition of the surface of the workpiece. The condition of the surface is in turn considerably temperature-dependent, particularly owing to oxide or scale formation. Therefore the emissivity can change considerably to increase and decrease between room temperature and the desired temperature. For example, with copper the emissivity increases from about 0.3 at room temperature to about 0.7 at 600 °C owing to the formation of black copper oxide. On the other hand, with aluminum the emissivity drops with increasing temperature owing to the formation of white aluminum oxide. Independently from this, extruded blocks in particular may have a surface condition that already differs from block to block before the heat treatment. Therefore, in many cases even a pyrometric measurement of the actual temperature of a workpiece is not sufficiently accurate, and does not yield reproducible values from workpiece to workpiece.

Summary of the Invention

The invention is based on the object of providing a method which makes it possible to heat a metallic workpiece by induction to a desired temperature with sufficient and reproducible accuracy.

In a method for induction heating of a metallic workpiece to a desired temperature by rotating the workpiece relative to a direct-current magnetic field permeating the workpiece, this object is achieved in that the workpiece is clamped between two clamping jaws adapted to be rotated about a common axis, in that at least one of the clamping jaws is driven to rotate, in that at least one of the clamping jaws is adapted to be actively displaced along or parallel to the rotation axis, in that the contact force of at least one of the clamping jaws is regulated, and in that at least one mechanical parameter representative of the workpiece temperature is measured as an actual value and is compared with a desired value of this mechanical parameter as being representative of the desired temperature.

In a regular case, the induction heating is discontinued when the actual value has attained the desired value.

Preferably the actual value of the representative mechanical parameter is measured as a proportional electrical signal, or is converted to an electrical signal of this kind, the magnitude of which is then compared with the magnitude of an electrical signal corresponding to the desired value.

5

For example, for documentation purposes the actual value can be continuously measured and stored.

10

Preferably the desired value representative of the desired temperature is determined on a reference workpiece of the same kind which is induction heated according to the same method, with its temperature and the corresponding actual value of the mechanical parameter being determined, and also the value of the mechanical parameter that is measured upon attainment of the desired temperature being treated as a desired value for all workpieces of the same kind.

15

It is particularly simple to use the thermal expansion of the workpiece as a representative mechanical parameter.

20

This thermal expansion can be measured by means of a direct or indirect measurement of path. This can be effected in a non-contacting or contacting manner.

25

Because the thermal expansion is proportional to an initial value of the measured dimension of the workpiece at the starting temperature, in the case of an elongate workpiece, e.g. a billet or a bar, a measurement of its thermal expansion along its longer axis is attended by less measurement effort than a measurement along its shorter axis, such as for example a measurement of the diameter in the case of a cylindrical workpiece.

30

A substantially anisotropic uniformity of the desired temperature of the workpiece is ensured when clamping jaws of poor thermal conductivity are used.

35

When the desired temperature is within the temperature range in which the material of the workpiece begins to become plastically deformed in dependence upon the pressure exerted on the surface, the contact force is regulated in dependence upon the temperature to a value corresponding to a surface pressure that is smaller than the

temperature-dependent surface pressure at which this plastic deformation of the workpiece begins. Thereby it is ensured that the spacing between the clamping jaws increases proportionally to the increase of temperature of the workpiece as long as the coefficient of expansion remains constant regardless of temperature. This applies to
5 most workpieces with sufficient accuracy.

Particularly when the contact force of the clamping jaws is produced hydraulically and the value of the contact force is determined from the value of the hydraulic pressure, the value of the contact force can be very simply reduced, if need be, by lowering the
10 hydraulic pressure.

The contact force of the clamping jaws, effected for example by a linear displacement of one of the rotatable clamping jaws, can be set or regulated also with a linear motor, a spindle drive or a rack-and-pinion drive.
15

As the representative mechanical parameter, the mechanical work supplied to the workpiece also can be used instead of the thermal expansion.

Because in the case of a rotatably driven workpiece the mechanical work depends upon
20 the transmitted torque amongst other factors, it is expedient to measure continuously at least the torque transmitted to the workpiece.

With a constant rotation number, the mechanical work then can be calculated from this rotation number, the measured torque, and the time.
25

If on the other hand the workpiece is rotatably driven at different rotation numbers whilst being heated, the mechanical work is calculated from the time-integral of this time-dependent rotation number and the time-dependent torque. The torque can be calculated from the active current or the active power of the converter of the motor
30 characteristic. This and other methods for continuous torque measurement are familiar to a person skilled in the art.

As a rule, the temperature determined from the thermal expansion is attended by a smaller error than the temperature determined from the mechanical work. It is therefore
35 preferred to use the temperature determined from the mechanical work only for a

plausibility check of the temperature of the workpiece as determined from the thermal expansion.

The proposed method is expediently performed by process control. For this, particularly the reference values, although measured with effort but with precision on the reference
5 workpiece, and the actual values of the mechanical parameter measured on the workpieces, can be continuously stored in a process controller which compares the actual values measured on the workpieces during the induction heating with the stored reference values and emits a signal representative of the actual temperature. On the basis of this signal that can be displayed as an analog or digital value, for example on a
10 screen, the operating personnel can read the calculated actual temperature of the workpiece. However, the signal can be used, in particular, to terminate the heating operation automatically as soon as the actual temperature has reached the desired temperature.

15 A further development of this method consists in that the reference values for workpieces of different dimensions and/or for workpieces of different materials are stored in separate data files. For workpieces of changing dimensions and/or of different materials, which in the latter case as a rule also must be heated to different desired temperatures, the process control is in this case restricted to calling-up the respective relevant data file and
20 the desired temperature, either by hand or, with completely process-controlled systems, automatically from workpiece and/or material data transmitted by a higher-ranking process controller.

If alternatively or additionally the mechanical work is used as a parameter representative
25 of the workpiece temperature, at least the material and the dimensions of the workpiece to be heated can be input in the process controller and the process controller programmed so that it controls at least the contact force of the clamping jaws, the rotation number of the workpiece, and the induction in dependence of time according to a given program.

30 If the heated workpiece is not immediately further processed, then upon attainment of the desired temperature of the workpiece at least the rotation number of the workpiece can be lowered to a value at which the losses by heat radiation and heat conduction are approximately compensated.

35

Alternatively or in addition, the magnetic induction can be lowered for the same purpose.

The direct-current magnetic field can be generated by means of at least one superconducting coil.

5

Brief Description of the Drawings

In the following the method in accordance with the invention will be illustrated by way of example with the aid of the drawings. Shown by:

10 Fig. 1 is a much simplified illustration of a device for induction heating of a workpiece to a desired temperature by measuring the thermal expansion of the workpiece; and

Fig. 2 is a much simplified illustration of a device for induction heating of a workpiece to a desired temperature by measuring the mechanical work supplied to the
15 workpiece.

Detailed Description of the Drawings

In Fig. 1 two carriages 2a, 2b that are spaced from each other are disposed on a machine bed. At least one of these carriages is adapted to be moved along the direction of the
20 double arrow P1 by means of a not depicted drive means. Each of the carriages 2a, 2b carries an electric motor 3a and 3b, respectively. Each electric motor 3a or 3b drives a clamping jaw 4a or 4b, respectively. At least one of the clamping jaws 4a, 4b is adapted to be moved in accordance with the double arrow P2 relative to the respective electric motor 3a, 3b by means of a hydraulic device 5a, 5b. A workpiece in the shape of a
25 cylindrical bar 6 is clamped between the clamping jaws. The bar 6 is permeated by a magnetic field which is indicated by the arrow B and is generated by a not illustrated, direct-current carrying coil.

Each of the carriages 2a and 2b carries a path-measuring sensor 7a and 7b, respectively.
30 These path-measuring sensors measure the position of a respective carriage relative to the machine bed 1 by scanning the indicated linear measuring scales 8a or 8b, respectively, and consequently the changing, temperature-dependent length of the bar 6 between the clamping jaws 4a, 4b. Instead of the path-measuring sensors 7a or 7b as illustrated, any other path or distance measuring means operating with sufficient accuracy
35 can also be used. In particular, a laser distance-measuring means that measures the

distance between the carriages 2a and 2b directly, or a laser distance-measuring means that measures the distance between the end faces of the clamping jaws 4a and 4b directly and transmits the measurement data by radio to a receiving means also can be used.

- 5 Fig. 2 shows, also in very schematic and simplified form, a device for induction heating with which the temperature of the workpiece 6 is determined from the work supplied to the latter. The workpiece 6 rotates between the pole pieces of an iron core 20 of a coil 21 which, in particular, can have a superconducting winding. The workpiece 6 is set into rotation via an indicated driving motor 23 (in principle in analogy with Fig. 1, i.e.
10 supported between clamping jaws and, if necessary, also via two driving motors). The torque transmitted from the driving motor 23 to the workpiece 6 is transmitted by means of sensing elements, known per se, e.g. wire strain gauges disposed on the shaft, as an electrical signal to a processing unit 24 which supplies a parameter proportional to torque to the process computer 25. The process computer furthermore receives a signal, e.g.
15 derived from the driving motor 21, which is representative of the rotation number of the workpiece 6. As soon as the rotation number is different from zero, a time measurement is started in the computer. From the rotation number, the torque, and the elapsed heating time the computer determines the work supplied to the workpiece. In the computer the actual value of the quantity of the work is compared with a stored desired value, and in
20 the case of equality the driving motor 23, for example, is stopped.

- The desired value or a number of desired values are measured as sensed values for each workpiece dimension and each workpiece material on a similar or identical workpiece that is heated by induction preferably in the same way; for example by
25 repeatedly interrupting the heating by stopping the drive, and via contact with a thermocouple, or by performing a calibrated pyrometric measurement on a moving workpiece,

THE EMBODIMENTS OF THE INVENTION IN WHICH AN EXCLUSIVE PROPERTY OR PRIVILEGE IS CLAIMED ARE DEFINED AS FOLLOWS:

1. Method for induction heating of a metallic workpiece to a desired temperature by rotating the workpiece relative to a direct-current magnetic field permeating the workpiece, wherein the workpiece is clamped between two clamping jaws adapted to be rotated about a common axis, that at least one of the clamping jaws is driven to rotate, that at least one of the clamping jaws is adapted to be actively displaced along or parallel to a rotation axis, that a contact force of at least one of the clamping jaws is regulated, and that at least one mechanical parameter representative of the workpiece temperature is measured as an actual value and is compared with a desired value of the mechanical parameter as being representative of the desired temperature.
2. Method according to claim 1, wherein the induction heating is stopped when the actual value is equal to the desired value.
3. Method according to claim 1 or 2, wherein the actual value of the representative mechanical parameter is measured as an electrical signal or converted to an electrical signal, and that its value is compared with a value of an electrical signal corresponding to the desired value.
4. Method according to any one of claims 1 to 3, wherein the actual value is measured continuously and stored.
5. Method according to any one of claims 1 to 4, wherein the desired value representative of the desired temperature is determined on a reference workpiece of similar kind that is heated inductively according to a same method, with its temperature and the corresponding actual value of the mechanical parameter being determined, and also the value of the mechanical parameter measured upon attainment of the desired temperature being treated as a desired value for all similar workpieces.
6. Method according to any one of claims 1 to 5, wherein thermal expansion of the workpiece is used as a representative mechanical parameter.
7. Method according to claim 6, wherein the thermal expansion is measured by means of a path-measuring means.

8. Method according to claim 6 or 7, wherein the thermal expansion of the workpiece is measured along a longer axis of the latter.

9. Method according to any one of claims 1 to 8, wherein clamping jaws of poor thermal conductivity are used.

10. Method according to any one of claims 1 to 9, wherein the contact force is regulated in dependence upon temperature to a value corresponding to a surface pressure that is lower than a temperature-dependent surface pressure at which plastic deformation of the workpiece begins.

11. Method according to any one of claims 1 to 10, wherein the contact force of the clamping jaws is produced hydraulically, and a value of the contact force is determined from a value of the hydraulic pressure.

12. Method according to any one of claims 1 to 11, wherein mechanical work supplied to the workpiece is used as the representative mechanical parameter.

13. Method according to claim 12, wherein at least torque transmitted to the workpiece is measured continuously.

14. Method according to claim 12, wherein the mechanical work is calculated from a rotation number, torque, and time.

15. Method according any to claim 12, wherein the mechanical work is calculated from a time-integral of a time-dependent rotation number and a time-dependent torque.

16. Method according to any one of claims 12 to 15, wherein the temperature determined from the mechanical work is used for a plausibility check of the temperature of the workpiece determined from the thermal expansion.

17. Method according to claim 5, wherein reference values measured on the reference workpiece and the actual values of the mechanical parameter measured on the workpieces are

continuously stored in a process computer which compares the actual values of the workpiece measured during the induction heating with the stored reference values and emits a signal representative of the actual temperature.

18. Method according to claim 17, wherein the reference values for workpieces of different dimensions and/or for workpieces of different materials are stored in the process computer in separate data files.

19. Method according to any one of claims 1 to 18, wherein at least the material and the dimensions of the workpiece to be heated are input in the process computer, and that the process computer controls at least the contact force of the clamping jaws, the rotation number of the workpiece, and the induction in dependence upon time according to a pre-determined program.

20. Method according to any one of claims 1 to 19, wherein upon the desired temperature of the workpiece being reached, at least the rotation number of the workpiece is lowered to a value at which the losses by heat radiation and heat conduction are approximately compensated.

21. Method according to any one of claims 1 to 20, wherein upon the desired temperature of the workpiece being reached, the magnetic induction is lowered to a value at which the losses by heat radiation and heat conduction are approximately compensated.

22. Method according to any one of claims 1 to 21, wherein the direct-current magnetic field is generated by means of at least one superconducting coil.

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Fig. 1

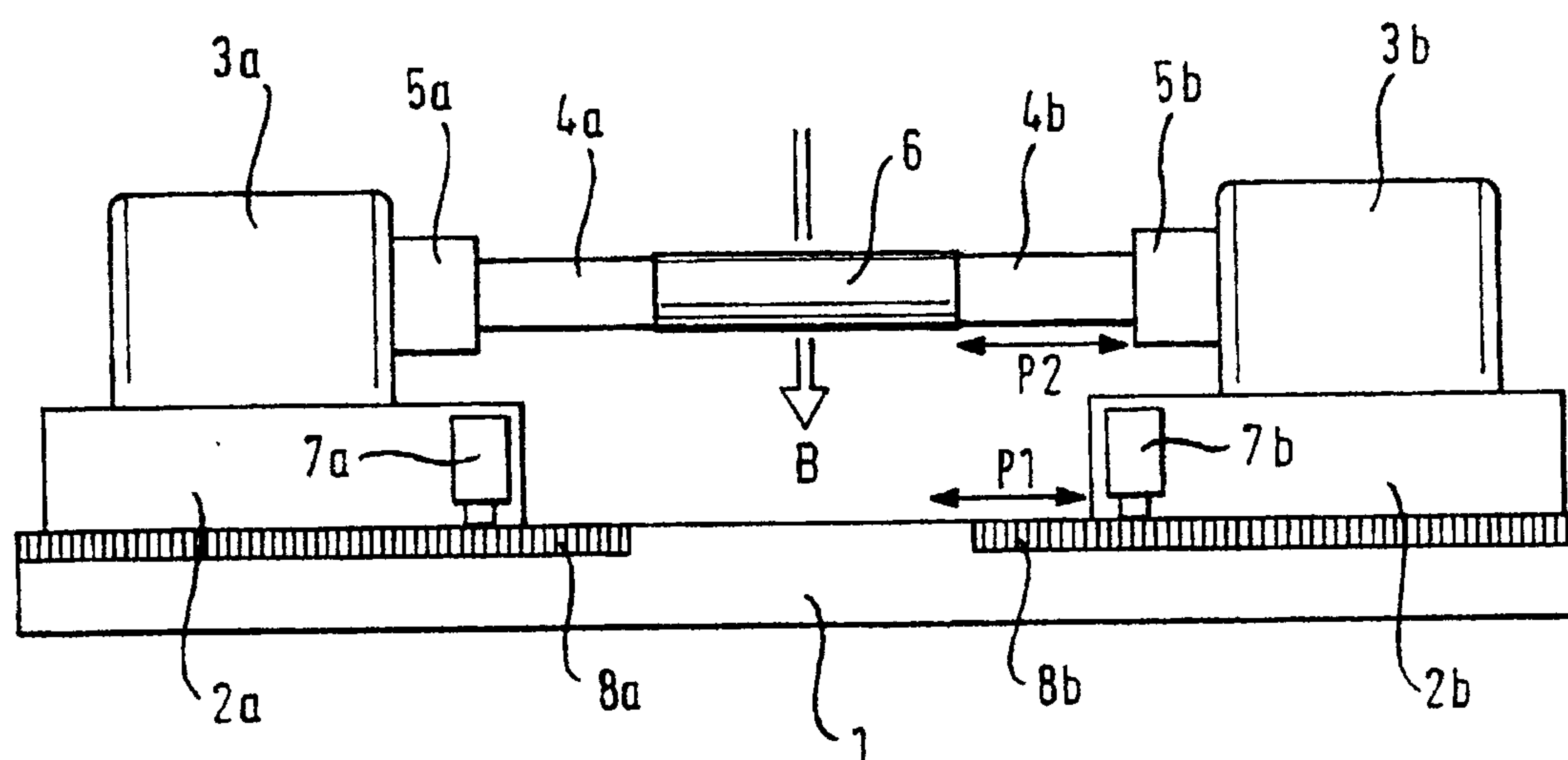


Fig. 2

