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(54) **AN INDUCTION COIL FOR HEATING LONG WORKPIECES**

(57) The invention relates to an induction coil for heating long workpieces, said induction coil comprising a connection for connection to a transformer, a central part of the coil connected with the connection through a connecting pipe and a protective copper plate on each end of the central part, a holder for the induction coil between the central part of the coil and the connection, and transport cylinders for moving the workpiece through the coil. Said central part of the coil comprises:
- a ceramic tube (31),
- dilatation insulation (32) surrounding the ceramic tube (31),
- an induction coil (33) made from copper, wrapped by insulation tape and protected with an insulating varnish,
- two protective copper plates (5) cooled with water,
- a layer of thermal concrete (34),
- and panelling (35) made from water-resistant plywood surrounding said induction coil (33) with the layer of thermal concrete (34).

For longer life span connections (22), protective copper plates (5) and the induction coil (33) are provided with channels for cooling water, which is pumped from a reservoir with a suitable pump.

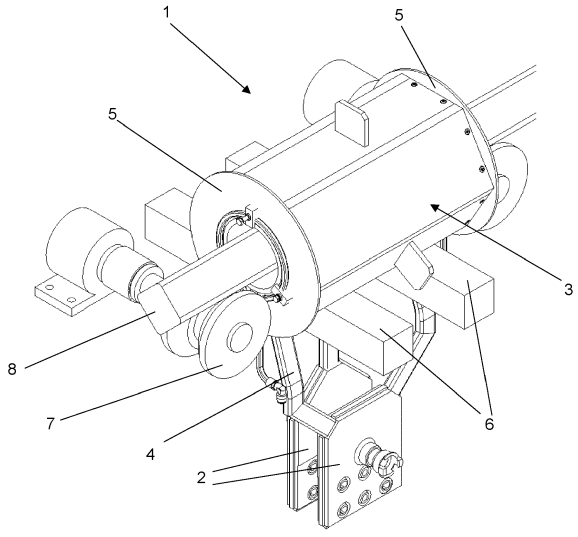

Figure 1

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Description

Field of the invention

[0001] The present invention belongs to the field of rolling and forging industries, more precisely in the field of furnaces and coils for heating workpieces for subsequent transformation or reshaping. The present invention relates to an induction coil for heating long workpieces.

Background of the invention and the technical problem

[0002] It is widely known that steel must be heated prior to further processing such as rolling, forging or pressing, in order to achieve the appropriate flexibility of the material for dimensional transformation (reshaping). The heating of the material before rolling takes place mainly in gas furnaces, which must be kept at a certain temperature. The problem of heating long steel workpieces in classic or well-known furnaces is the need to heat the furnace even when production is not in progress. In case of the opposite, the lining of the furnace would crack and frequent renovation would be needed. The problem is also the greater decarburization of the surface material. In addition, the heating temperature changes very slowly due to the wall construction. Temperature changes are necessary for ensuring different properties of the rolled materials.

[0003] Heating longer workpieces having a rectangular cross-section often is characterized in the material being heated from the outside to the inside. This usually triggers overheating of the corners of the profile, which deform, i.e., burn.

[0004] Recently, inductive heating has been proposed for long rolled profiles, mostly due to larger flexibility of manufacturing and lowering production costs. Inductive heating of steel, where the workpieces are heated in an induction coil, has been used in forging for a while. Such heating softens the processed material, which allows dimensional transformation with forging or pressing.

[0005] The heating process in induction devices for heating workpieces depend on the frequency of power voltage used for powering the inductor. Induction furnaces for heating longer steel pieces are known. These furnaces operate at high frequencies between 1000 Hz and 4000 Hz or higher. During treatment in induction furnaces with high frequencies the material is heated only on the surface, so that the temperature due to heat conductivity is slowly spreading into the interior of the material. Due to such surface heating the process should not be too intensive in order to prevent the edges to overheat and thus melt, as the workpieces usually have square cross-sections.

[0006] Induction furnace manufacturers do not use lower frequencies, as the lower frequencies increase the mechanical forces in the induction coil, thus leading to inductor deformation and their shorter lifespan. The technical problem, which is addressed by the present invention, is thus construction of an induction coil for heating long workpieces, which will enable initial heating of the workpiece in the centre and then on the exterior. At the same time, the induction coil should have a longer lifespan as the existing low-frequency inductors. It is further desirable that the inductor construction is suitable for high-frequency inductors for induction furnaces.

Prior art

[0007] Chinese utility model CN212486829 discloses an induction heating device for heating a workpiece. The induction coil is powered with an alternating current, and has two coils, one coiled to the right and the other to the left. Both coils are connected in series. The length of the induction coil is equal to the workpiece length. The construction of this induction coil differs from the present invention.

Description of the solution to the technical problem

[0008] The present invention addresses the problem of short lifespan of low-frequency induction coils and solves the problems of existing solutions. The aim of the invention is to minimize the effect of forces caused by the low frequency voltage. In addition, the invention aims to design an induction coil for heating long workpieces from inside to the outside, which will prevent unwanted deformations of the workpiece. The technical problem is solved as defined in the independent claim, wherein the preferred embodiments are defined in dependent claims. The workpiece is usually a blank, material having a rectangular or square cross-section, usually having a length from 2 to 4 m and with dimensions of square sides from 90 to 150 mm, which is heated and then directed to a rolling track for transformation (reshaping).

[0009] The essence of the invention is in that the coil comprises:

- a console for connection to a transformer for ensuring required voltage,
- a central part of the coil connected to the console through electric connections and a protective copper plate on each end of the central part,
- holders of the induction coil arranged between the central part and the console, said holders supporting the central part, and
- transport cylinders or rollers with holders for attachment on both ends of the central part, wherein the transport cylinders or rollers enable movement of the workpiece through the coil.

[0010] Said central part of the coil comprises:

- a ceramic tube for preventing the coil against the workpiece and scale falling from the workpiece as the latter moves through the coil, to prevent short

circuits.

- dilatation insulation surrounding the ceramic tube, wherein said insulation is formed by a plurality of insulation segments, which are rings of insulation material inserted between individual threads of the coil to prevent a direct contact between the threads and thus prevent sparking due to differences in electric potential of the threads,
- an induction coil (inductor) made from copper, wrapped by insulation tape and protected with an insulating varnish, wherein the threads of the induction coil are axially compressed with screws for preventing clearance between threads and thus caused vibration,
- two protective copper plates cooled with water, said copper plates protecting panelling against temperature radiation and preventing electric disturbances between individual coils,
- a layer of thermal concrete,
- and panelling made from water-resistant plywood surrounding said induction coil with the layer of thermal concrete.

[0011] The induction coil (inductor) is made from or coiled from copper pipes with a rectangular cross-section, wherein the first and second end of the coil are provided with contact plates made from two copper plates welded together with a copper insert to form a space for the cooling liquid cooling said contact plates. Preferably, the coil is made from mutually connected copper plates, so that a channel is formed in between. The plates are then bent into the said shape of the coil. In a preferred embodiment all edges of the coil in higher voltage zones, particularly threads of the coil, are made by bending and not welding. The cooling channel is thus provided in the interior of the copper forming the coil, so that the cooling liquid can travel in the interior, wherein the inlet opening and the outlet opening are provided on connecting parts or connecting plates. The coil and the protective copper plates are cooled with cooling water, wherein the supply and discharge of the cooling water, a reservoir for the cooling water and a pump for ensuring pumping of the water are provided. Preferably, the cooling system as described also comprises flow sensors and temperature sensors.

[0012] The transport cylinders are also heated with cooling water, and namely in a similar manner as the coil and protective plates. Cooling is needed to prevent the transport cylinders from being overheated by the heated workpiece, as the overheated transport cylinders lose their carrying capacity.

[0013] The inductor has two or three connections connected to two contact connection plates, to allow changes in its inductivity and thus optimization of the electric circuit. In the embodiment with two connections, the first end of the coil is connected to a first contact of the console and the second end of the coil is connected to a second contact of the console. In the embodiment according to which three connections are provided, both ends of the coil are short-circuit connected and connected to a first contact of the console, and a central connection on the coil is connected to a second contact of the console.

[0014] The inductor according to the invention may be a low-frequency or high-frequency inductor. Preferably, the construction of the inductor is adapted to low frequencies, as these exhibit problems in their lifespan. The advantage of using lower frequencies is that they can heat the centre of the workpiece, as lower frequencies allow larger depths at which the material is mostly heated.

[0015] The inductor coil may be installed in any induction furnace for heating workpieces, particularly long workpieces. In the embodiment of induction furnace with more low-frequency inductors, the latter are arranged in several zones, wherein the inductors are powered in the following manner:

- in a first heating zone with voltage having frequency from 50 Hz to 600 Hz for fast heating up to the Curie temperature;
- in a second heating zone with voltage having frequency from 300 to 600 Hz for heating from Curie temperature to the temperature slightly below hardening temperature;
- in a third heating zone with voltage having frequency from 600 to 1200 HZ for heating to the hardening temperature; and
- in a fourth heating zone with voltage having frequency from 600 to 1200 Hz for maintaining the hardening temperature until the workpiece fulfils conditions for entering the rolling track.

[0016] In each frequency zone several inductors are provided, which depends on the maximal length of the workpiece and the material for heating. Usually, the number of inductors in each zone is from 3 to 6, possibly more.

[0017] The invention as described above allows:

- higher speed of heating the workpiece,
- faster heating of the blank to temperature of 1280 °C, resulting in smaller grains in the structure of the blank (workpiece) and thus better mechanical properties of the rolled material, which is the final product from at least part of the workpiece,
- lowering the frequency of the induction coil to 50 Hz or more, as the coils are more resilient to lower frequencies and have a longer lifespan,
- faster heating of the blank to the temperature of 1280 °C so that in the first heating period (in the beginning of heating) the workpiece is heated in the centre of the cross-section, while in the next three heating periods the workpiece is heated on the circumference of the square or circular cross-section;
- preventing overheating of the edges in workpieces with square cross-section,
- less heat loss due to radiation and higher furnace

efficiency.

[0018] The induction coil for heating long workpieces and the method of heating long workpieces using said induction coil will be described in further detail based on an exemplary embodiment and figures, which show:

Figure 1 The induction coil according to a possible embodiment
Figure 2 Cross-section of the induction coil shown in figure 1
Figure 3 The induction coil shown in figure 1 with depicted inlets and outlets of cooling water

[0019] The induction low-frequency coil 1, as shown in figure 1 and figure 2 in cross-section, comprises:

- a console 2 with electric connections 22 for connecting the coil 1 to a transformer for ensuring required voltage,
- a central part 3 of the coil 1 connected to the console 2 through connecting pipes 4 and a protective copper plate 5 arranged on each end of the central part 3, wherein said central part 3 of the coil 1 comprises:
    - ◦ a ceramic tube 31 for preventing the coil 1 against the workpiece and scale falling from the workpiece as the latter moves through the coil, to prevent short circuits,
    - ◦ dilatation insulation 32 surrounding the ceramic tube 31,
    - ◦ an induction coil 33 made from copper, wrapped by insulation tape and protected with an insulating varnish,
    - ◦ two protective copper plates 5 cooled with water, said copper plates protecting panelling 35 against temperature radiation and preventing electric disturbances between individual coils,
    - ◦ a layer of thermal concrete 34,
    - ◦ and panelling 35 made from water-resistant plywood surrounding said induction coil 33 with the layer of thermal concrete 34,
- holders 6 of the induction coil arranged between the central part 3 and the console 2, said holders supporting the central part 3, and
- transport cylinders 7 or rollers with holders for attachment on both ends of the central part 3 of the coil 1, wherein the transport cylinders 7 or rollers enable movement of the workpiece 8 through the coil 1.

[0020] For longer lifespan the components of the coil 1 according to the invention are cooled with water, wherein the following components are cooled:

- transport cylinders 7,
- threads of the induction coil 33 and consoles 2 with connecting pipes 4 leading to the coil 33,
- copper protective plates 5,

wherein said components are provided with channels for cooling water and connections for supplying and discharging cooling water, to which suitable pipes connected to the reservoir for cooling water, from the water is pumped along the pipes into the cooling channels using a suitable pump.

[0021] Figure 3 shows the supply inlet 51 and the discharge outlet 52 of the cooling water for cooling the right and left copper protective plate 5 and the supply 21 and discharge (not visible in the figure due to being hidden in the back) for the cooling water for cooling the coil 33. The cooling water and the electric current travel through connecting pipes 4 and through the coil 33 through the second pipe 4 to the second console 2.

[0022] The described coil has been tested in a known induction hardening device for hardening cylinders connected to a transformer with power of 750 kW, wherein loads were simulated at different frequencies. The induction coil endured all electromechanical loads, even at the frequency of 50 Hz. Temperature measurements in the centre of the workpiece cross-section and at the depth of ¼ of the cross-section as well as on the surface of the test workpiece showed that the core of the material is heated almost as quickly as the outer surface, wherein the temperatures are equal after a particular time, particularly around the Curie temperature at which steel changes its magnetic properties. The edges of the workpiece with a square cross-section did not overheat.

Claims

1. An induction coil (1) for heating long workpieces (8), wherein the coil (1) comprises:

- a console (2) with electric connections (22) for connecting the coil (1) to a transformer for ensuring required voltage
- a central part (3) of the coil (1) connected to the console (2) through connecting pipes (4) and a protective copper plate (5) arranged on each end of the central part (3), wherein said central part (3) of the coil (1) comprises:
    - ◦ a ceramic tube (31) for preventing the coil (1) against the workpiece and scale falling from the workpiece as the latter moves through the coil, to prevent short circuits,
    - ◦ dilatation insulation (32) surrounding the ceramic tube (31),
    - ◦ an induction coil (33) made from copper, wrapped by insulation tape and protected with an insulating varnish,
    - ◦ two protective copper plates (5) cooled with water, said copper plates protecting

panelling (35) against temperature radiation and preventing electric disturbances between individual coils,
◦ a layer of thermal concrete (34),
◦ and panelling (35) made from water-resistant plywood surrounding said induction coil (33) with the layer of thermal concrete (34),

- holders (6) of the induction coil arranged between the central part (3) and the console (2), said holders supporting the central part (3), and
- transport cylinders (7) or rollers with holders for attachment on both ends of the central part (3) of the coil (1), wherein the transport cylinders (7) or rollers enable movement of the workpiece (8) through the coil (1).

2. The induction coil (1) for heating long workpieces according to claim 1, wherein said insulation (32) is formed by a plurality of insulation segments, which are rings of insulation material inserted between individual threads of the coil to prevent a direct contact between threads and thus sparking due to differences in electric potential of the coil threads.

3. The induction coil (1) for heating long workpieces according to claim 1 or claim 2, wherein the threads (33) of the induction coil are axially compressed with screws for preventing clearance between threads and resulting vibrations.

4. The induction coil (1) for heating long workpieces according to any of the preceding claims, wherein the protective copper plates (5) are provided with channels for cooling water and with connections for supplying (51) and discharging (52) the cooling water, said connections allowing installation of suitable pipes connected to a reservoir for cooling water, from which water is pumped through the pipes into cooling channels using a suitable pump.

5. The induction coil (1) for heating long workpieces according to any of the preceding claims, wherein the transport cylinders (7) are cooled.

6. The induction coil (1) for heating long workpieces according to any of the preceding claims, wherein the induction coil (33) is made from a copper pipe with a rectangular cross-section, wherein the copper pipe is made from mutually connected copper plates so as to form a channel between them.

7. The induction coil (1) for heating long workpieces according to any of the preceding claims, wherein the threads (33) of the coil are made by bending and are not welded.

8. The induction coil (1) for heating long workpieces according to any of the preceding claims, wherein the induction coil has two or three connections connected to two contact connection plates (2), to allow changing the inductivity of the coil and thus optimization of the electric circuit.

9. The induction coil (1) for heating long workpieces according to claim 8, wherein two connections are provided and the first end of the coil is connected to a first contact of the console and the second end of the coil is connected to a second contact of the console.

10. The induction coil (1) for heating long workpieces according to claim 8, wherein three connections are provided, a wherein both ends of the coil are short-circuit connected and connected to a first contact of the console, and a central connection on the coil is connected to a second contact of the console.

11. The induction coil (1) for heating long workpieces according to any of the preceding claims, wherein the induction coil (1) is a low-frequency or a high-frequency induction coil.

12. The induction coil (1) for heating long workpieces according to claim 11, wherein the induction coil (1) is a low-frequency induction coil.

13. The induction coil (1) for heating long workpieces according to any of the preceding claims, wherein the workpiece (8) has a rectangular or a square cross-section, usually having a length from 2 to 4 m and with dimensions of square side from 90 to 150 mm.

14. An induction furnace with at least one induction coil (1) according to any of the preceding claims.

15. The induction furnace according to the preceding claim, wherein the induction coils (1) are arranged in several zones, where the coils are powered in the following manner:

- in a first heating zone with voltage having frequency from 50 Hz to 600 Hz for fast heating up to the Curie temperature;
- in a second heating zone with voltage having frequency from 300 to 600 Hz for heating from Curie temperature to the temperature slightly below hardening temperature;
- in a third heating zone with voltage having frequency from 600 to 1200 HZ for heating to the hardening temperature; and
- in a fourth heating zone with voltage having frequency from 600 to 1200 Hz for maintaining the hardening temperature until the workpiece fulfils conditions for entering the rolling track.

16. The induction furnace according to claim 14 or claim 15, wherein the number of inductor coils (1) in each zone is three or more, preferably from 3 to 6.

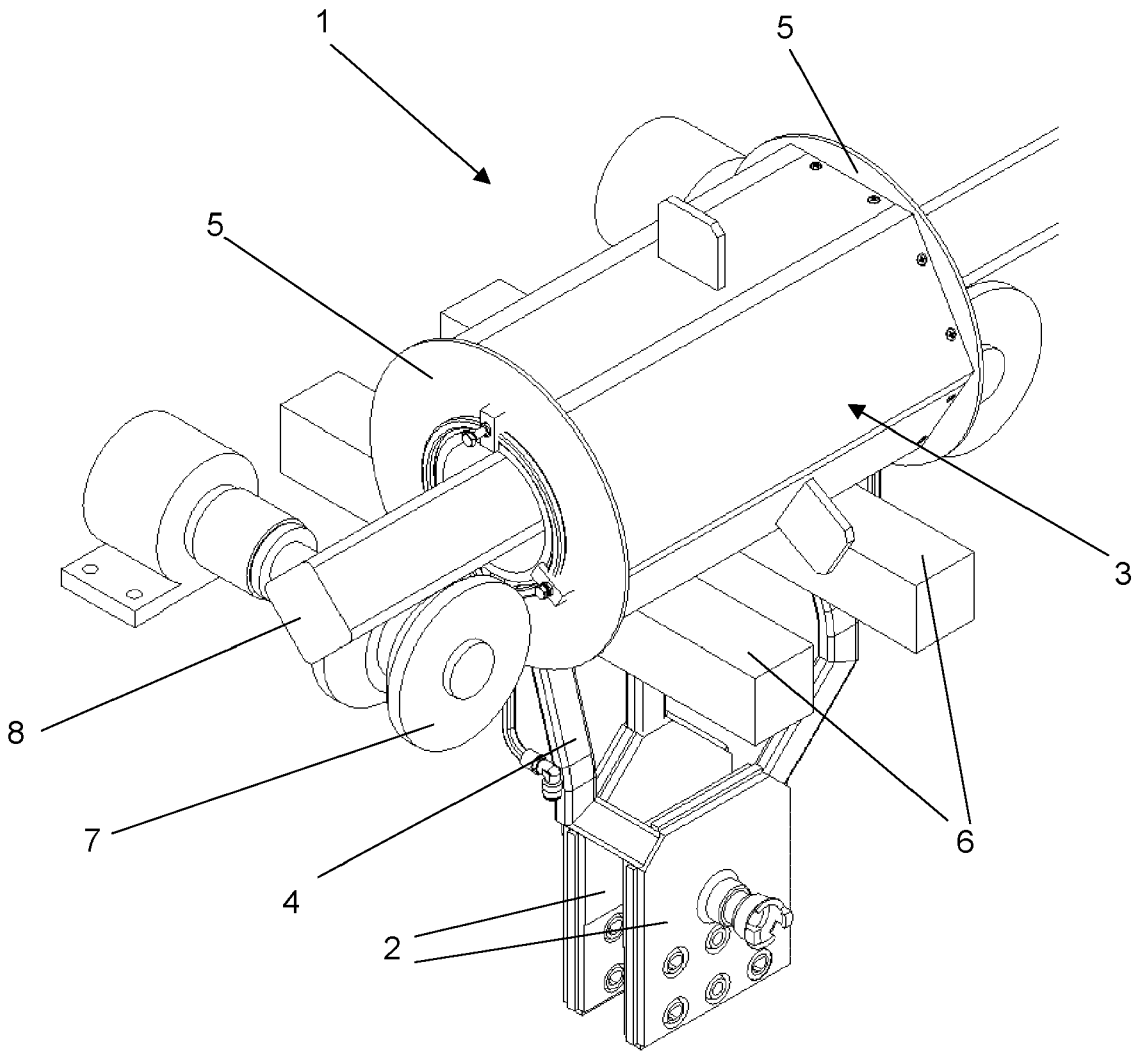

Figure 1

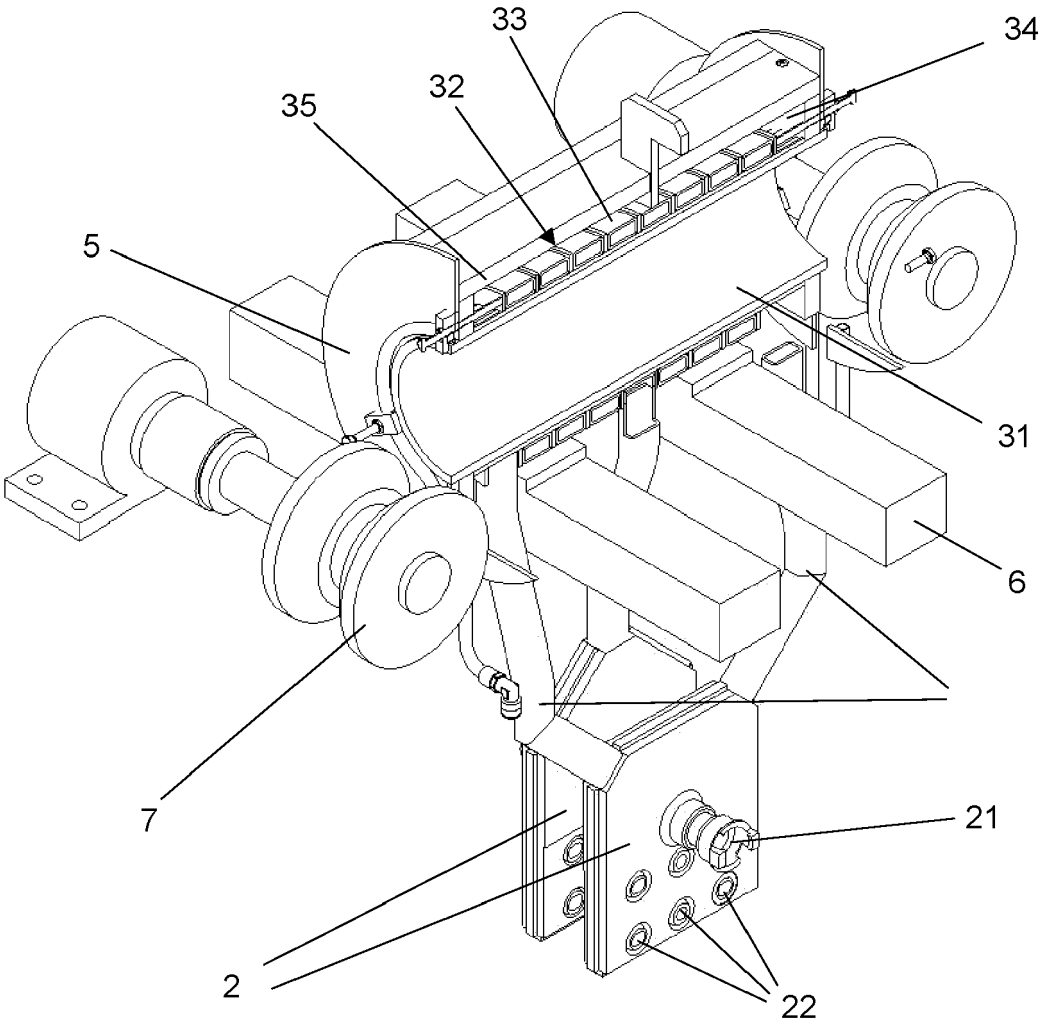

Figure 2

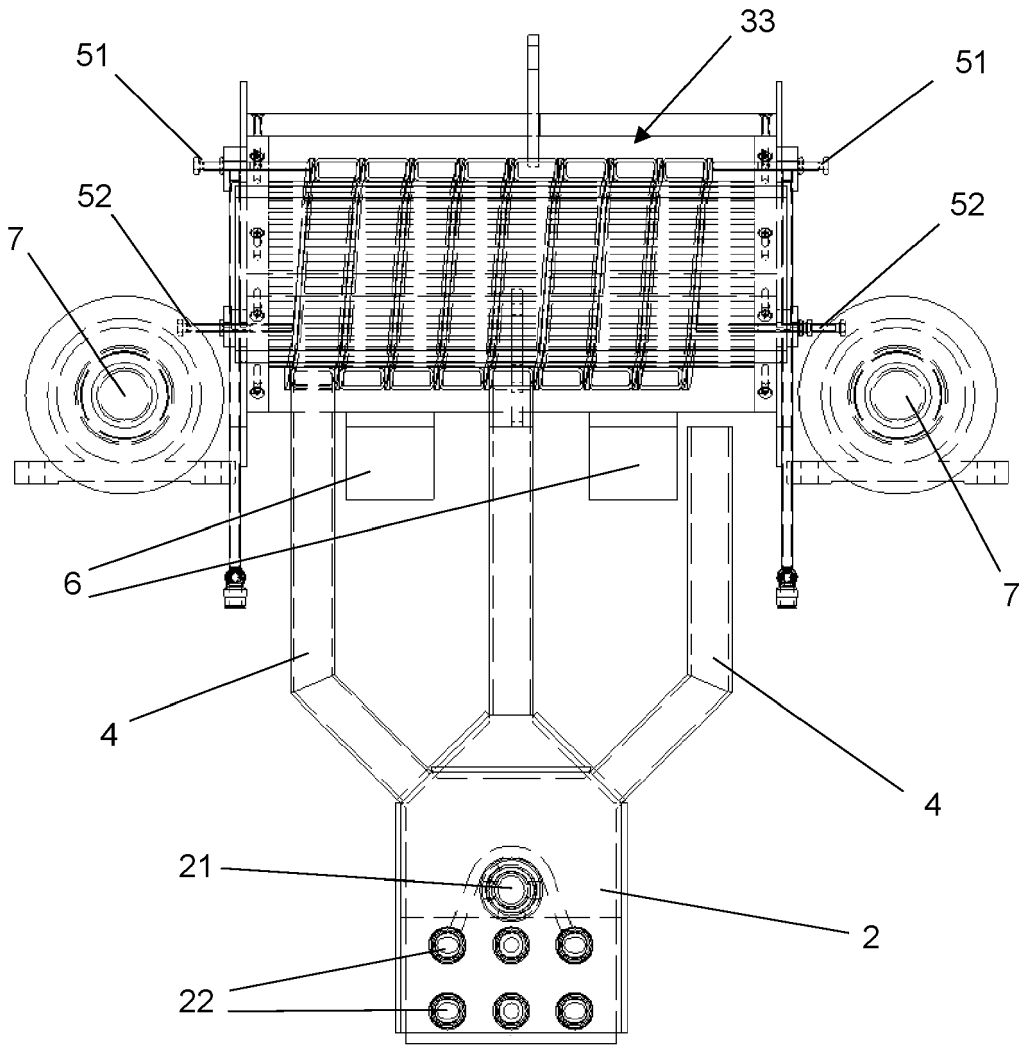

Figure 3

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EUROPEAN SEARCH REPORT

Application Number
EP 23 20 3358

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
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A	US 4 532 398 A (HENRIKSSON BENGT [SE]) 30 July 1985 (1985-07-30) * column 1, line 5 - line 12 * * column 1, line 28 - line 35 * * column 2, line 9 - line 19; figure 1 * * column 2, line 35 - line 44; figure 1 *	1-16	
			TECHNICAL FIELDS SEARCHED (IPC) H05B

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
Munich	26 March 2024	Barzic, Florent

CATEGORY OF CITED DOCUMENTS

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EPO FORM 1503 03.82 (P04C01)

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