(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
7 January 2010 (07.01.2010)

PCT

(10) International Publication Number
WO 2010/001330 A2

(51) International Patent Classification:
C23C 2/00 (2006.01) *C23C 2/30* (2006.01)

(21) International Application Number:
PCT/IB2009/052817

(22) International Filing Date:
30 June 2009 (30.06.2009)

(25) Filing Language: Italian

(26) Publication Language: English

(30) Priority Data:
MI2008A001207 30 June 2008 (30.06.2008) IT

(71) Applicant *(for all designated States except US)*: **DANIELI & C. OFFICINE MECCANICHE S.P.A.** [IT/IT]; Via Nazionale, 41, I-33042 Buttrio (IT).

(72) Inventors; and

(75) Inventors/Applicants *(for US only)*: **GUASTINI, Fabio** [IT/IT]; Via Restocina, 9/A, I-34070 Dolegna Del Collio (IT). **CODUTTI, Andrea** [IT/IT]; Via Baldasseria Bassa 83/4, I-33100 Udine (IT). **KOLESNICHENKO, Anatoly** [UA/UA]; Rusanovskaya Neberezahnaya, 18/1, Kiev, 252147 (UA). **BURYAK, Victoria** [UA/UA]; app. 20, 19/2 Serafimovicha St, Kiev, 02147 (UA). **KOLESNICHENKO, Anastasia** [UA/UA]; app. 134,5 Rusanivsky Boulevard, Kiev, 02154 (UA). **PAVLICEVIC, Milorad** [HR/IT]; Via Maniago 4/C, I-33100 Udine (IT). **POLONI, Alfredo** [IT/IT]; Via G. Paolini, 29, I-34070 Fogliano Redipuglia (IT).

(74) Agents: **BORSANO, Corrado** et al.; Corso di Porta Vittoria 9, I-Milano 20122 (IT).

(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PE, PG, PH, PL, PT, RO, RS, RU, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, SE, SI, SK, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

[Continued on next page]

(54) Title: ELECTROMAGNETIC DEVICE FOR COATING FLAT METAL PRODUCTS BY MEANS OF CONTINUOUS HOT DIPPING, AND COATING PROCESS THEREOF

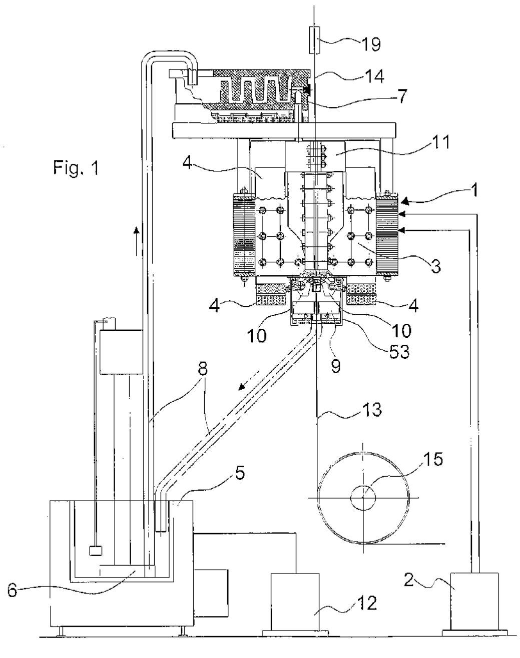

Fig. 1

(57) Abstract: An electromagnetic device for coating flat metal products by means of continuous hot dipping in a small molten coating bath, arranged over strip guiding rollers, the device being adapted not only to contain the molten coating metal in the bath but further to substantially eliminate leakages and dripping through the lower opening at the bottom of the container, for the strip passing, by means of particular electromagnetic components.

WO 2010/001330 A2

Published:

— *without international search report and to be republished upon receipt of that report (Rule 48.2(g))*

"Electromagnetic device for coating flat metal products by means of continuous hot dipping, and coating process thereof"

Field of the invention

The present invention relates to an electromagnetic device for coating flat metal products, such as steel strips, by means of continuous hot dipping, with a coating metal, which may be for example Zn or Zn-containing alloys, and further relates to a continuous hot dipping coating process for flat metal products.

State of the art

A known process for coating a steel strip includes vertically passing the strip through a molten metal bath kept in semi-levitation by means of a alternating magnetic field.

The conventional hot galvanizing process is continuous and normally requires, as a preliminary stage, to pre-treat and pre-heat the steel strip by carefully controlling the temperature of the strip before applying the coating. The pre-treatment - chemical and thermal - improves the adhesion of the coating on the strip, and the pre-treatment stage may be either a preliminary heating operation under controlled atmosphere or a fluxing operation in which the strip is dipped in a reducing inorganic flux to coat the surface of the strip with a protective film which prevents oxidation thereof.

When the steel strip is subjected to a preliminary heating under controlled atmosphere, it may enter the coating bath at high temperature which, in the case of a coating bath consisting of Zn or Zn alloys, may also be equal to that of the metal bath, e.g. 450°C.

This type of hot galvanizing process includes the step of coating carried out in a semi-levitated bath contained in a container with an opening at the bottom to allow the strip to pass towards the top. The strip is guided by means of one or more guiding rollers arranged under the molten coating bath. The strip normally enters the bath from underneath with a substantially vertical direction and then crosses the molten coating material. The strip is then extracted from the metal bath in a vertical direction.

The known systems which use magnetic levitation of the bath disadvantageously present interferences of the lower meniscus of the bath and consequent leakages of liquid through the opening at the bottom of the container containing the bath.

Some attempts have been made to eliminate lower meniscus interferences and the consequent possible leakages of liquid.

The strip passing opening is typically arranged on the bottom of a container containing the bath or on a side wall thereof in case of a horizontal passing of the strip, and contrivances are used to prevent the release of liquid metal from the strip passing opening.

Some contrivances use freezing the molten metal coating by means of cooling in proximity of the strip passing opening, where the partial solidification of the coating causes the partial closing of the opening. The position of the solid/liquid interface, in this case, should be controlled by means of an induction heating system and a controlled intensity cooling system by adjusting the cooling water flow rate.

The subsequent development of a system employing a freezing closure of the coating metal and an electromagnetic sealer near the strip passing opening has shown that the position of the solid/liquid interface in the strip passing opening may not be stable in principle, and that the stability thereof may only be ensured by induction heating due to Joule effect and water cooling at very high levels: the thermal gradients of the solid/liquid interface should not be lower than 1000°C/mm.

As a result of the instability of the position of the solid/liquid interface, either the instantaneous solidification or the melting of the coating material occurs in the strip passing opening: no intermediate position may be maintained if the temperature gradients on both sides of the interface are lower than the value mentioned above. These freezing seals cause adhesion of the surfaces of the strip moving through the opening, thus causing wear or breakage of the seal, which causes solidified coating to stick to the strip, or otherwise the leakage of molten material through the opening.

Another problem associated with electromagnetic sealers includes the intense rotational component of the electromagnetic forces used for providing the semi-levitation of the mass of molten coating metal in the bath. The vortical component of the electromagnetic force in the melt is normally used to compensate for the forces of hydrodynamic origin - viscosity and dynamic forces - which appear in the motion of a conductive molten metal in alternating magnetic field. Another component of the electromagnetic forces - the potential one - is normally used to compensate for the hydrostatic pressure, e.g. to support the molten coating metal in levitating state. The $f_{potential}/f_{vortical}$ ratio should not usually be lower than 1; only in this case an even only partial levitation of the coating molten metal may be obtained. Thus the problem, associated with this requirement, leads to the instability of the lower meniscus, which results in leakages of coating liquid through the lower opening.

Another problem associated with electromagnetic devices arranged in a position adjacent to the strip passing opening is that attraction forces are developed on the ferromagnetic steel of the strip by the magnetic poles which produce the alternating field. The attraction on the strip causes its oscillation, even in resonance, and thus irregularities appear on the thickness of the coating deposited on the strip and even the breakage of the strip itself. The possibility of leakages of molten material through the lower meniscus increases along with the oscillation of the strip. If the electromagnetic devices which are arranged adjacent to the strip passing opening do not result in a stabilization of the strip in a central position inside the opening, there will still be some leakages or dripping of liquid metal from the bath through said opening, in particular along the edges of the strip and along the opening. In some cases, the containment of the liquid mass may reach 98% or 100%, but in all cases the leakages represent a significant, if not relevant annoyance.

Another problem associated with the known mechanical or electromagnetic devices for coating a steel strip by means of continuous hot dipping is the uncontrolled creation of inter-metal compounds of the $Fe_n Zn_m$ type, which appears as the result of the chemical reactions between Fe and Zn. $Fe_n Zn_m$ alloys are mainly placed between the surface of the steel strip and the Zn coating and represent the reciprocal junction region. $Fe_n Zn_m$ particles either detach from the strip or are directly created in the bath due to the always present dissolved Fe, and mix into the molten coating Zn. These $Fe_n Zn_m$ particles, named “hard dross”, are a problem for the quality of the coated strip. The creation of hard dross must either be eliminated from steel strip coating systems or these particles must be extracted from the molten bath.

Another problem, associated with the known mechanical or electromagnetic devices for coating a steel strip by means of continuous hot dipping is the permanence of the strip in the metal coating bath, typically longer than or equal to 1 second. In this case, inter-metal $Fe_n Zn_m$ compounds of considerable thickness are rapidly developed on the surface of the strip; in particular, the layer γ, which is required for the good adhesion of the coating and for obtaining a hard surface, should not exceed certain thicknesses otherwise it will make the coating brittle, which coating may be no longer subjected to a deep forming process.

It is thus felt the need to provide an electromagnetic device for coating flat metal products by means of continuous hot dipping and a corresponding coating process which allow to overcome the aforesaid drawbacks.

Summary of the invention

It is a primary object of the present invention to provide an electromagnetic device for coating flat metal products by means of continuous hot dipping in a small molten coating bath arranged over strip guiding rollers, adapted not only to contain the molten coating metal in the bath but further to substantially eliminate leakages and dripping through the lower opening of the container containing the bath by means of particular electromagnetic components.

A further object of the invention is to provide a corresponding process of coating flat metal products by means of continuous hot dipping which does not require a large-sized bath and does not require one or more rollers dipped into the bath to direct the strip, in said process the strip being directed into a small-sized, semi-levitated coating bath and the induced currents on the whole bottom of the bath being rectified to prevent leakages and dripping.

The present invention thus proposes to achieve the above-discussed object by providing an electromagnetic device for coating a flat metal product by means of hot dipping in a molten metal bath which, in accordance with claim 1, comprises:

- a longitudinal container for containing said metal bath, provided with a longitudinal opening at the bottom thereof for introducing the metal product into said bath along a feed plane of said product,
- an electromagnetic inductor arranged about the container and adapted to generate a magnetic flux across the metal bath, the inductor having an internal profile, facing the feed plane of the metal product, adjacent to the external profile of said container, said profiles being such that they concentrate said magnetic flux in a lower part of the container, thus inducing induced currents crossing the

bottom of the container in a longitudinal direction, so as to produce electromagnetic forces of maximum intensity at the bottom of said bath, thus obtaining a levitation of the bath itself with respect to the bottom of the container and defining a lower meniscus,

wherein there are provided rectifying means for rectifying the induced currents at ends of the lower meniscus whereby said electromagnetic forces are made uniform along the whole extension of said lower meniscus.

According to a further aspect of the invention, a process of coating a flat metal product by means of continuous hot dipping in a molten metal bath is provided, which, in accordance with claim 17, comprises the following stages:

- introducing the flat metal product into said molten metal bath along a feed plane, through a longitudinal opening provided on the bottom of the longitudinal container containing said bath,

- generating a magnetic flux across the metal bath, concentrated in a narrower lower part of the container so as to induce induced currents crossing the bottom of the container in the longitudinal direction and produce electromagnetic forces of maximum intensity at the bottom of said bath, thus obtaining a levitation of the bath itself with respect to the bottom of the container and defining a lower meniscus of the bath,

wherein a rectification of said induced currents at ends of the lower meniscus is provided whereby said electromagnetic forces are made uniform along the whole extension of said lower meniscus.

The device object of the present invention, including a small coating bath arranged over the guiding rollers of the strip, has all the advantages which accompany the elimination of a large-sized bath, usually a bath containing up to 400 tons of molten coating, with guiding rollers dipped in the molten material.

The advantages include:

- more flexibility of the system, e.g. in the case in which replacing the container which contains the bath is needed;

- better control over formation of inter-metal compounds, because the strip permanence in a smaller bath is shorter;

- more homogenous temperature and bath composition;

- longer life of the roller or rollers because they are not dipped in the bath, since greater wear of the bearings and of the roller itself with consequent vibrations of the strip are avoided,

- less maintenance required, and therefore higher productivity.

Furthermore, such a device not only obtains the containment of the molten coating metal in the bath but also substantially eliminates leakages and dripping through the lower strip passing opening. The leakage is reduced by means of the present system by virtue of the particular electromagnetic components described below.

The container containing the molten metal coating bath has a through shape with side walls converging downwards in the direction of the strip passing opening provided at the bottom of the container. The electromagnet associated with the container has a pair of reciprocally facing, opposite polar expansions or magnetic poles, each adjacent to a respective side wall of the container and substantially following the shape of said respective side wall.

The configurations of the magnetic poles and side walls of the container containing the molten metal are advantageously shaped so that the magnetic induction generated by the electromagnets across the container is maximized at the bottom of the container, thus generating magnetic forces of maximum intensity in the vertical direction at the bottom of the coating bath which push the molten metal away from the strip passing opening.

These magnetic forces in the vertical direction simultaneously are of the substantially potential type and uniformly created along the whole length of the strip passing opening so as to obtain the suppression of the liquid metal circulation near the lower meniscus, thus maintaining such a meniscus more stable, i.e. at the inlet zone of the steel strip in the coating bath.

The action of the electromagnets normally agitates the bath and that agitation motion contributes to the leakage problem: the local vortical motion of the bath contributes to the pressure on the lower meniscus, which is transformed into a supplementary head which must be locally supported.

In accordance with the present invention, damping means are advantageously included for separating and interrupting the vortexes in the volume of molten metal produced by the electromagnets. These damping means comprise baffles or planar members, which modify the circulation of molten metal in the container and suppress the agitation thereof.

These baffles, which are substantially perpendicular to the feed plane of the strip, are made of dialectic ceramic material and are arranged on the upper and lower parts of the container for containing the molten metal coating. They produce low speeds in the molten metal at both the upper meniscus and the lower meniscus. At the same time, the baffles eliminate the intense local loops of current induced by the electromagnets in the molten metal coating and join them in a single, large-scale current loop. The lower part of this single current loop is straight and parallel to the lower meniscus, which allows to obtain supporting electromagnetic forces uniformly distributed along such a lower meniscus.

Despite the presence of mechanical guiding elements, arranged underneath the container with semi-levitation of the molten coating material, which keep the steel strip centered in the opening of the container, the electromagnets attract the strip towards one of the two reciprocally facing, opposite poles and generate a side-to-side motion of the strip in its motion within the container, an oscillation motion which is not desired. The periodical attraction of the strip towards one of the two poles may lead to its resonance, and even tearing it. This attraction occurs under the lower meniscus and depends on the intensity of the magnetic flux dispersed there. A system of shields made of high electrical conductivity material is used to suppress the dispersion of magnetic flux and decrease the attraction of the strip.

The conductive shields prevent the magnetic flux from penetrating in the steel strip and reduce the Maxwell attraction forces.

According to a first advantageous variant of the invention, a current shunt is included, provided with a current conducting part configured so as not to come in contact with the metal bath, said conducting part being connected to current conducting terminals, provided at two respective ends of the longitudinal opening of the bottom of the container so as to be at least partially in galvanic contact with the molten metal bath, said terminals being made of a molten metal bath-resistant material.

The conductive terminals and a high-conductivity current conductor or shunt, not in contact with the bath, which electrically connects the terminals, surround the main magnetic flux and the container containing the molten metal coating. The current conductor or shunt conducts all the induced currents generated by the magnetic flux of the electromagnets, when these are supplied by time-variant current. The above-described electric currents flow among the conductive terminals along the bottom of the molten metal coating bath. The electric currents cooperate with the magnetic flux produced by the electromagnets at the bottom of the bath, in order to produce a magnetic force which pushes the bottom of the bath upwards, apart from the opening at the bottom of the container, thus defining a lower meniscus. The use of these conductive terminals eliminates the current distortions on the edges of the lower meniscus and ensures the existence of vertical components of levitation forces only there. Thereby, leakages of molten material are advantageously eliminated from the edges of the strip passing opening. At the same time, the terminals and the shunt connecting them concentrate the electric current in desired places at the bottom of the bath, and here substantially increase the effectiveness of the magnetic forces directed upwards as compared to the magnetic forces produced without using these electric conductors.

Instead, in a second advantageous variant of the invention, appropriately shaped magnetic components are provided and reciprocally configured so as to define "magnetic windows" in order to rectify the induced currents at the ends of the free surface or lower meniscus of the molten coating bath, thus increasing the effectiveness of the upward directed magnetic forces.

Another feature of the present invention is to provide continuous cleaning of the molten coating material by means of a closed recirculation circuit of said molten material, which includes at least one melting furnace for preparing the molten metal coating, a recirculation pump, either of mechanical or of magnetic-hydrodynamic type, and a ceramic sedimentation filter, where the hard dross particles are advantageously separated from the molten coating alloy before this is unloaded into the container of the galvanizer.

Another feature and advantage of the present invention is represented by a closing mechanism arranged under the container to contain the molten coating close to the strip passing opening. Such a closing mechanism allows to fill the container with molten coating before starting up the coating line.

The dependent claims describe preferred embodiments of the invention.

Brief description of the drawings

Further features and advantages of the present invention will be more apparent in the light of the detailed description of preferred, but not exclusive, embodiments of an electromagnetic device for coating flat metal products by means of continuous hot dipping in a molten coating bath shown, by way of non-limitative example, with the aid of the accompanying drawings, in which:

Fig. 1 depicts a diagrammatic view of a first embodiment of the system according to the invention;

Fig. 2 depicts a perspective view showing a container and an electromagnet used in the electromagnetic device according to the invention;

Fig. 3 depicts a front view of a device according to the invention;

Fig. 4 depicts a section view of the device in Fig. 3;

Fig. 5 depicts a perspective view of a portion of a container used in the device according to the invention;

Fig. 6 depicts a partially sectioned side view of the container in Fig. 5;

Figs. 7 and 8 depict two section views of the container;

Fig. 9 depicts a front view of the container with current shunt;

Fig. 10 depicts a perspective view of an embodiment of the magnetic yoke of the inductor of the device according to the invention;

Fig. 11 depicts a perspective view of a half-container with current shunt partially shown in section;

Fig. 12 depicts the effect of the current shunt and conductive terminals at the ends of the strip passing opening;

Fig. 13 depicts a perspective view of a further embodiment of a half container provided with “magnetic windows”;

Fig. 14 depicts an enlarged front view of the device according to the invention.

Same reference numbers in the figures identify same elements or components.

Detailed description of preferred embodiments of the invention

Figure 1 shows an embodiment of a system for coating flat metal products by means of continuous hot dipping in a molten coating metal bath. Such a system comprises:

- an electromagnetic device 1, object of the present invention, known as galvanizer in case the coating is zinc-based, which includes an inductor 3 and a container 11 for containing the molten metal bath;
- electric feeding means 2 for feeding the inductor 3 through the coils 4 wound

thereabout;

- a heating/melting furnace 5 provided with a recirculation pump 6 arranged in the crucible so as to be dipped in the molten coating material fed into the furnace;
- an appropriately heated sedimentation filter 7 for purifying the molten coating material;
- appropriately heated pipes 8 for a recirculation of the molten coating material from the galvanizer 1 to the melting furnace 5, from the melting furnace 5 to the sedimentation filter 7 and then from the sedimentation filter 7 back to the galvanizer 1;
- a closing mechanism 10 for closing the container 11 of the device, which is filled with the molten coating material when the process is started;
- an absorber 9 for the coating material lost at the process start-up, arranged under the closing mechanism 10;
- a control unit 12 for controlling the individual heating of each element of the closed recirculation circuit, which includes the pipes 8, the heating/melting furnace 5 with the recirculation pump 6, the sedimentation filter 7 and the absorber 9.

The system in Fig. 1 may be used for continuously coating a metal strip with Zn or Zn alloys, or Al, Al alloys, Mg, Si, Sn, Pb and alloys thereof.

With reference now to figures 1, 3 and 4, a continuous strip 13 is unwound from a skein (not shown) and subjected to a conventional pre-treatment. After the pre-treatment, the strip 13 is directed by means of guiding rollers 15 towards a longitudinal opening or slit 16, provided on the bottom of the container 11 of device 1.

Such a container 11, of elongated shape, has a through shape with respect to the inductor and contains a bath 17 of a molten metal coating, e.g. Zn. The bath 17 defines an upper surface or upper meniscus 18. The opening 16 allows the strip 13 to pass within the bath 17, and the strip moves along a direction which extends through the bath 17. The motion of the strip 13 through the bath 17 allows the strip itself to be coated with a layer of molten metal material forming the bath. A coated strip 14 exits from the bath 17 downstream of the upper surface 18 thereof. The container 11 has an open upper end, through which the coated strip 14 moves upwards.

A coating thickness control device 19, of either pneumatic or electromagnetic type, typically used to obtain the desired basic weights on the strip 14, is placed over the container 11. Downstream of the control device 19, a reel (not shown) is placed, on which the cooled strip 14 is rewound in a skein which it is then removed from the reel.

The container 11 will be described now in greater detail with reference to Figures from 3 to 9.

As shown in figures 6 and 9, for example, the molten material level in the container 11 is controlled by means of one or more overflows 51, which are connected to the heating/melting furnace 5 by means of a heated pipe (not shown).

As shown in Figure 4, which depicts a section view along a vertical plane perpendicular to the plane defined by the strip 13, the container 11 is substantially shaped as an elongated funnel.

The container 11 has a relatively narrow part 20, which extends downstream of the opening 16 defining a passage 27 for the strip 13, and a relatively wide part 21, arranged downstream of said narrow part 20.

The narrow part 20 of the container 11 has longitudinal grooves 49, arranged on the bottom at the edges with the side walls of said narrow part, which when the bath levitation system is turned on, i.e. when the aforesaid feeding means 2 are activated, serve to direct the vortical motion components of the molten metal coating (or liquid metal simply) upwards, said components descending along the side walls of the container 11, whereby the local dynamic components of the pressure on the lower meniscus of the liquid metal are reduced, thus promoting a more uniform lifting of such a lower meniscus by virtue of a more uniform distribution of the upward acting electromagnetic forces. Said grooves 49 have a depth ranging from 10 to 100 mm with respect to the bottom of the container 11, and are preferably arranged at a distance one from another in the range from 30 to 60 mm, in order to obtain a better stability of the lower surface of the bath 17 and thus limit or annul the phenomenon of dripping of the material from said lower surface.

With reference to Figures 2, 3, 4 and 9, the container 11 consists of two half-containers 22 held together at respective opposite edges along vertical flanges bolted with one another. When joined together, the two half-containers 22 define the elongated container 11 with through shape.

As shown in Figures from 6 to 8, the container 11 has a pair of longitudinal side walls 23 and a pair of end walls 24, each of which extends between the corresponding ends of the side walls 23. The side walls 23 define the elongated funnel shape.

An intermediate part 25 of the container 11, shown in Fig. 4, is placed between the upper, relatively wide part 21 and the lower, relatively narrow part 20, and comprises a pair of longitudinal side walls 26, included in the walls 23, converging towards the relatively narrow part 20. The configuration and geometry of the converging walls 26 are an important feature of the present invention because, along with the shape of the polar expansions, it allows the magnetic induction generated by the inductors through the container to be maximized at the bottom of the container, thus generating electromagnetic forces of maximum intensity in the vertical direction at the bottom or lower meniscus of the coating bath, said forces pushing the molten metal away from the opening for the strip passing.

The materials of which the container 11 may be made may comprise refractory ferromagnetic dielectric materials, such as ceramic mixtures with Fe powder with relative magnetic permeability $\mu^*=25\text{-}30$, in addition to ceramic dielectric materials or non-magnetic metal materials at low electrical conductivity, such as for example 316L stainless steel. The usable materials can also be composite materials with glass, ceramic or silica fibers held together by ceramic binders or cements resistant to the high temperature and to the thermal shocks. The container 11 can also be made of metal parts and ceramic parts.

With reference to Fig. 6, which partially shows the interior of the container 11, the narrow part 20 of the container includes the passage 27 for the strip, which comprises at one end thereof the opening 16 of the container bottom. The passage 27 is defined by a pair of opposite longitudinal walls 28 (only one of which is shown in Fig. 6) and by a pair of opposite end walls 29, each of which extends between the corresponding ends of the walls 28.

The inductor 3 of the galvanizer 1 will now be described in greater detail with reference to figures 2, 3, 10, 14.

The magnetic yoke of the inductor 3 of the galvanizer comprises an external member 31, having in plan view the shape of a rectangular frame, made of ferromagnetic material and comprising a pair of opposite, facing longitudinal side walls 32 and a pair of end walls 33, each of which extends between the corresponding ends of the side walls 32. The side walls 32 and the ends walls 33 define a vertically arranged inner spacer 34, delimited by the upper 35 and lower 36 open edges, respectively.

The magnetic yoke of the inductor 3 of the galvanizer also comprises a pair of polar expansions or magnetic poles 37, each expansion being made of ferromagnetic material and mounted to a respective side wall 32 of the external member 31, inside the vertically arranged space 34. Each polar expansion 37 extends inside the space 34 towards the other polar expansion and ends at at least one end face 38 of the pole, which is opposite to and facing at least one corresponding end face 38 of the other polar expansion 37 (Fig. 10). The polar expansions 37 define an opening 39 for placing the container 11 therebetween, and the opposite faces 38 define part of the opening 39 therebetween, in which part the narrow part 20 of said container is inserted.

As shown in Figure 2, 3 and 14, the coils 4 to which the electrical current is supplied are wound about each polar expansion 37. In accordance with a preferred embodiment of the present invention, a time-varying electrical current is delivered by the feeding means 2 to each coil 4 in order to generate a magnetic field in the polar expansion 37 on which the coil 4 is wound. The feeding means 2 may be adjusted in current, voltage, frequency and power, and allow to vary the electric power delivered to the coil 4, thereby they allow to control the force and quality of the magnetic field generated by the inductor 3 of the electromagnetic galvanizer.

The coils 4 may consist of a plurality of sections and are assembled together to provide openings for the penetration of the cooling air. The coils consist of a plurality of turns, each winding about the respective polar expansion 37 and each made of an appropriate conductive material, e.g. copper. The turns are insulated from one another and also with respect to the polar expansion 37 by means of an electro-insulating material (not shown). In the embodiment shown in Fig. 14, the coil 4 is made of solid wire because the current density in the wires is lower than 5 A/mm^2.

The polar expansions 37 and the outer member 31 define a path 40 for the magnetic field generated by the current fed to the coils 4. The path 40 is shown with a dashed line and arrows in Fig. 10. More in particular, the magnetic field extends through the opening 39, from the end face 38 of a first polar expansion 37 to the end face 38 of the second polar expansion 37. The magnetic field then extends in sequence through the second polar expansion 37, then in opposite directions through the longitudinal side wall 32 to which said second polar expansion 37 is mounted, then through both end walls 33 of the external member 31, then through the longitudinal side wall 32 to which the first polar expansion 37 is mounted, and finally through the first polar expansion 37 back to the end face 38 of said first polar expansion.

The direction of the current flow through each coil 4 of each polar expansion 37 is controlled so that the magnetic field generated by each coil on each polar expansion extends through the opening 39 in the same direction.

The magnetic yoke of the inductor 3 of the galvanizer is made of a conventional ferromagnetic material such as ferrite or other magneto-dielectric materials, but preferably of electric steel foils.

As shown in Fig. 10, the magnetic yoke of the inductor 3 of the galvanizer consists of two half-magnets 41 each of which has a substantially E-shaped section along a horizontal plane.

As shown in Figures 7 and 10, each end face 38 of a polar expansion or pole 37 is arranged adjacent to the respective longitudinal side wall 23 of the container 11, substantially very close to said side wall at the narrow part 20 of the container and at the converging side wall 26. Each face 38 of a pole is shaped such that, in this embodiment, it substantially follows the shape of the adjacent portion of side wall 23, in particular along the converging side wall 26 and along the narrow part 20 of the container.

The distance between the opposite, reciprocally facing polar faces 38 is minimal at the narrow part or zone 20 of the container close to the opening 16 at the bottom of the container. Such a minimum distance defines the minimum value of the opening 39, at which the intensity of the magnetic field (magnetic induction) is maximum. Instead, the intensity of the magnetic field is lower downstream of the zone 20 where the opening 39 between the polar expansions 37 is wider.

Moreover, since the resistance to the magnetic flux passing (reluctance) is lower in the free space than in the liquid metal of the bath 17, the magnetic flux tends to pass through the polar faces 38 and concentrates right under the bottom of the bath 17 in the passage 27, that is the prosecution of the opening 16 at the bottom of the container (Fig. 4). Therefore, for a given time-varying current across the coils 4, the magnetic force exerted on the bath 17 by the inductors 3 is more intense at the narrow part 20 of the container, close to the opening 16 at the bottom of the container, as compared to any other zone of the molten metal bath 17. In general, the power of the magnet (and the magnetic flux) may be adjusted by varying the amperage of the time-varying current, used to supply the inductor, and the frequency thereof.

In order to generate the described concentration effect of the magnetic field in the lower narrow part 20 of the container at the bottom of the bath, the ratio between the minimum value and the maximum value of the opening 39 between the magnetic poles 37 is advantageously between 0,1 and 0,7, preferably between 0,3 and 0,4. Furthermore, the largest dimension of the magnetic opening in the upper part of the inductor 3 should be constant for a vertical segment equal to a fraction of 0,2-0,6, preferably 0,35-0,45, of the height of the polar expansion 37.

The lower part of the magnetic opening 39, corresponding to the lower narrow part 20 of the container, must have an overall area, in cross section, between 5% and 20%, preferably between 8% and 12%, of the maximum cross section area of the magnetic opening between the polar expansions 37. Above this lower part of the magnetic opening 39, with substantially vertical walls, the magnetic opening expands with the walls on the poles 37, at the converging walls 26 of the container 11, inclined by an angle between 25° and 89°, preferably between 40° and 80°, with respect to a horizontal plane. The relative vertical extension of the latter zone with respect to the total height of the polar expansion 37 is between 3% and 15%, preferably between 7 and 10%.

The longitudinal extension or width of the polar expansion 37 must be higher than or at least equal to the longitudinal extension of the opening 16 and, thus, of passage 27.

The magnetic flux generated by the time varying current extends through the opening 39 and induces currents inside the bath 17. With reference to Fig. 11, the path 42 for conveying the induced currents includes a lower portion in which the current is directly induced into the metal alloy or molten coating metal, thus conductive.

Figures 5, 6, 9 and 11 show a first embodiment of the electromagnetic device for coating strips, which is the object of the present invention.

This first embodiment includes the use of a current shunt or bypass for rectifying the induced currents along the lower free surface of the bath. Said shunt comprises substantially vertical conductive parts or conductors 44, substantially horizontal conductive parts or conductors 43 which join the substantially vertical conductive parts 44 to one another, and conductive terminals 47 in contact with the molten metal bath, arranged at the ends of the longitudinal passage 27.

The horizontal conductors 43 are either external or in contact with the external walls of the container 11, thus outside the bath, and made of electro-conductive material, e.g. copper. In addition to conveying the induced current, they may be used to shield the magnetic flux dispersed by the magnetic yoke close to the upper meniscus, thus reducing the interferences on said upper meniscus and the possible attraction of the strip by the polar expansions 37.

The vertical conductors 44 are arranged between the two half-containers 22 and, along with the horizontal conductors 43, connect the conductive terminals 47 to one another. The vertical conductors 44 either can be electrically insulated from the bath 17 by a refractory wall 50, shown in Fig. 6, or can be in contact with the bath 17.

With reference to Figures 5 and 6, the vertical conductors 44 of the shunt are generally L-shaped elements made of electro-conductive material, e.g. either copper if the conductors 44 are insulated from the bath or stainless steel or graphite or other electro-conductive material, little reactive with the bath material, if the conductors 44 are in contact with the bath.

The vertical conductors 44 comprise a pair of vertical arms, each arm being arranged adjacent to a respective end wall 24 of the container 11, and connected to each other by means of a crossing expansion defined by the horizontal conductors 43.

The vertical conductors 44 are provided with a pair of molten coating material-resistant, conductive terminals 47, e.g. advantageously made of silicon or copper carbide, or made of graphite or pyrolytic graphite, at the end which defines the short segment of their L-shape. These terminals or electrodes 47 allow the electric contact with that part of the bath 17 in the zone 20 of the container, close to the passage 27.

Advantageously these electrodes 47 do not need to be cooled, thus avoiding problems of local freezing of the molten coating material in the passage 27, which could also involve the strip by making it stick to the solidified coating and thus blocking it to the container with consequent breakage of the container itself or strip.

In the embodiment shown in Fig. 11, the induced current flows through the current conductors 44, 43 rather than circulate through the bath 17, and the induced current is directed by the conductor 44 into the terminal space of the container 11, i.e. inside the part of molten bath 17 at the lower meniscus of the bath itself.

These conductive parts 43, 44 and 47 directly concentrate the induced currents close to the lower meniscus to increase the potential part of the electromagnetic forces. The suppression of the induced currents in other parts of the mass of molten coating material and the concentration of the induced currents very close to the lower meniscus leads to damping the movement of the bath. Moreover, the effect of the concentration of current on the lower meniscus is useful during filling the container 11, when the amount of liquid metal in the bath would not be sufficient to develop the levitation forces.

The common current induced in the molten material and in the horizontal 43 and vertical 44 conductors of the current shunt combines along the lower meniscus of the molten mass and extends along the bottom of the bath 17, horizontally in the longitudinal direction of the container 11, close to the opening 16 provided at the bottom of the container. The direction of the currents here induced is orthogonal to the direction of the local magnetic flux. As a result, the magnetic flux and the induced currents intersect on a horizontal plane, thus producing upwards directed electromagnetic forces. These electromagnetic forces push the part of bath 17 which is close to the opening 16 at the bottom of the container, e.g. the lowermost part of the bath 17, in an upward direction apart from the opening 16. This effect is known as magnetic levitation and defines a lower meniscus of the bath 17.

The magnetic induction increases towards the bottom so as to obtain the maximum on the lower edges of the magnetic poles.

The progressive increase of the density of the downward magnetic flux and the existence of a lower meniscus of the conductive mass of molten coating material produce the positive effect that the electromagnetic supporting force progressively increases when the molten mass moves downwards.

Magnetic levitation, resulting from the upward force exerted on that part of the molten metal bath next to the opening 16, represents an important factor for containing the mass of molten metal of the bath.

The above-described magnetic levitation may produce a containment of the bath 17 higher than 98%. The containment of the bath 17 produced by the magnetic levitation, of the above-described type, may be effective to prevent major losses of molten coating metal through the strip passing opening 16 and for partially reducing dripping along the longitudinal side walls 28 and end walls 29 of the passage 27 (Figures 6 and 11).

The operation of the inductor 3 creates electromagnetic forces substantially adapted to compensate for the hydrodynamic pressure (potential part of the electromagnetic forces) of the molten coating material moving in the bath 17. At the same time, the electromagnetic forces produce a circular agitation motion; this motion implies the creation of a pair of molten coating vortexes within the container 11, which wash the steel strip from the bottom to the top.

These vortexes have a common lifting branch along the strip which implies the decrease of the intensity of the thermal and chemical diffusion on the exchange surface between strip and coating. At the same time, the double vortex has two descending fluxes directly onto the edges of the strip. The dynamic pressure of these molten coating fluxes decreases the lifting forces on the edges of the strip and contributes to the dripping or leakage through the opening 16 at the bottom of the container 11, and specially increases the probability of dripping of the molten material on the edges of the passage 27 of the strip shown in figures 4 and 6.

The breakage of the double vortex in the container 11 advantageously occurs by implementing two pairs of longitudinal planar members 45 and 46, shown in Figures 4, 6 and 7, each pair of said members protruding from the longitudinal side walls 23 of the container 11.

In particular, the pair of upper planar members 45 may be arranged in an upper zone of the wider part 21 of the container, e.g. close to the upper ends of part 21.

In a first variant (Fig. 7), the pair of lower planar members 46 is instead arranged close to the lower ends of the wider part 21 of the container. In a second variant (not shown), the lower planar members 46 may be arranged inside the narrower part 20 of the container 11.

The influence of the correction effect of the vortexes in the container 11 is two-fold: local, of magneto-hydrodynamic nature, and global, of hydrodynamic nature. Both factors cause a considerable change in the distribution of flow rates of the mass of coating metal.

By virtue of the shunting of the magnetic flux exerted by the upper planar members 45 on the wide part 21 of the container 11, downward facing electromagnetic forces appear in the opening between the members 45, 46 and the vortex between said members 45 and 46 changes the rotation direction: the molten coating thus flows in a direction contrary to the motion of the strip in the zone between the upper and lower planar members. Furthermore, said members 45 and 46 work as flow rate baffles, which confine the vortex in the wide part 21 of the container and insulate it from the influence on the lower meniscus.

The lower planar members 46 can be provided with a vertical longitudinal part or projection 46', an example of which is shown in Fig. 8, that extends in vertical direction from the upper surface of the member 46 up to a maximum extension equal to the width of said member 46. Said vertical part 46' serves to deviate and distribute the steel jet, promoting the filling step of the container 17.

The members 45 and 46 have a longitudinal extension L higher than the width of the steel strip L_{strip}, so that L is equal to at least (L_{strip} + 0,1H), where H is the depth of the molten coating confined in the container 11. The members 45 and 46, made of dielectric material, modify the loop of current induced in the molten material by the main magnetic flux. They define a straight passage zone of the induced current along the lower meniscus. Therefore, these members 45, 46 also contribute to rectifying the induced currents along the lower meniscus of the bath.

The members 45 and 46, containing the turbulences, are made of either non-magnetic or slightly ferromagnetic ceramic material. They can also be made of metal material having an electric conductivity lower than that of the molten material in the bath 17, for example 316L stainless steel.

Both the longitudinal planar members 45 and the longitudinal planar members 46 are substantially parallel and horizontal, and preferably have transversal dimensions so as to allow a minimum opening for the steel strip to pass between the two members 45 and the two members 46.

The lower planar members 46 advantageously eliminate the influence of the double vortex in the molten coating which is formed above it on the lower meniscus. The upper planar members 45 cover the molten coating material thus preventing splashing, and push such a material along the ascending steel strip.

The upper diagram in Fig. 12 explains the dripping mechanism on the end walls 29 of the passage 27 at the bottom of the container 11. When the end walls 29 are dielectric, the induced current lines are curved near the dielectric wall 29 and here the vertical component of the electromagnetic force decreases accordingly: the probability of a leakage of liquid material thus occurs.

The presence of conductive terminals or electrodes 47 at the end walls 29 is required to start the process of the invention, when the molten coating material fills the container up to the bottom and is contained by a closing mechanism or mechanical seal 10, an embodiment of which is shown in Fig. 14. A good galvanic contact between the conductive wall 29 and the molten metal allows the induced current to have a flux which is substantially orthogonal to the wall 29 in the bath 17, and to cross said wall 29 obtaining a uniform level of electromagnetic supporting forces, as shown in the central diagram in fig. 12.

The conductive terminals 47, defining the end walls 29 of the passage 27 in this case, belong to the shunt and define a low-resistance conductive path which is followed by that part of induced current flowing along the bottom of the bath 17. As a result, the electromagnetic forces only have vertical, uniform components along the whole opening 16 of the bottom of the container and decrease the vortical component of the electromagnetic forces, thus reducing the movement of the bath near the lower meniscus.

When the current is sufficiently increased on the coils 4, the position of the lower meniscus will move over the electrodes 47 and the current will flow so as to partially avoid the electrodes and to partially enter the electrodes themselves at the top, as shown in the lower diagram in Fig. 12. Again in this case, uniform electromagnetic forces will be obtained.

Filling the container 11 can also be carried out without the closing mechanism 10 shown in Fig. 1 and Fig. 14 exploiting the conductive terminals 47 by moving the position of the lower meniscus over said terminals 47, accepting some initial leakage that is intercepted by the absorber 9.

Moreover, due the presence of the lower planar members 46, and possibly of vertical projections thereof, it is possible to fill the container 11 also without the presence of the shunt consisting of the electro-conductive elements 47, 43 and 44, and without the closing mechanism 10, but the magnetic field required for lifting the position of the lower meniscus is about twice with respect to that used in presence of the shunt.

By providing both conductive terminals 47 and conductors 44 made of graphite and in direct contact with the bath it is possible to benefit from the lower electric conductivity of the graphite itself with respect to that of the bath material because only during filling the container 11 the electric current and, consequently, the electromagnetic supporting force particularly concentrate on the lower surface of the bath in proximity of the terminals 47 and, when the container is filled, more evenly redistribute promoting the stability of the levitated lower surface.

In fact, it is possible either to concentrate the electromagnetic forces in proximity of the end walls 29 of the passage 27 with respect to the centre or to make uniform said electromagnetic forces along all the passage 27 by using different electro-conductive materials to make the terminals 47. For example, in order to concentrate said forces it is possible to use stainless steel or other metals having electric conductivity similar or higher than that of the bath material; while in order to make uniform said forces it is possible to use graphite or other materials having a lower electric conductivity.

With reference to a second embodiment shown in Fig. 13, the same function of rectifying the induced currents along the whole bottom of the bath or the lower free surface or meniscus is exerted by appropriately shaped magnetic components, reciprocally configured so as to define “magnetic windows”. These electrically insulating, magnetic components are arranged inside the container 11 and configured so as to define a substantially quadrangular magnetic circuit, adapted to concentrate the magnetic flux within the mass of metal bath inside said circuit and to concentrate the induced currents outside about said circuit.

The lower edges of said magnetic circuit are arranged over the bottom of the container 11 at a distance between 0 and 50 mm, preferably between 10 and 15 mm.

These "magnetic windows" may be made, in a first preferred variant, in the form of two pairs of magnetic components 54, 55 (Fig. 13), the components 54, 55 of each pair being integral, fixed or anchored, with a half-container 22 and having a surface parallel to the feed plane of the strip, either in contact or not in contact with the reciprocally facing surface of the component corresponding to the other pair of components 54, 55 (not shown) provided on the other half-container 22.

In the variant shown in Fig. 13, the magnetic circuit or "magnetic window" is defined by said two pairs of magnetic components 54, 55 and by the two pairs of longitudinal planar members 45, 46.

Other variants of said magnetic windows may comprise:

- two solid elements, one on the right and one on the left of the feed plane of the strip, integrally connected to the container, e.g. embedded between the two half-containers 22,

- or tubes configured so as to define a rectangular-shaped frame and integral, fixed or anchored, e.g. embedded between the two half-containers 22.

These magnetic windows may be made either of the same materials as the container 11 and the planar members 45 and 46 or of different materials, in any case of materials which do not conduct electricity.

If ceramic materials are used, the magnetic components 54, 55 are cast and solidified along with the container 11 or may be added as separate parts. The magnetic components 54 and 55 may be at least partially made of mild ferromagnetic material, e.g. by inserting straight parts of ferromagnetic material wire, electrically insulated from one another and arranged mainly parallel to the main direction taken by the magnetic flux in the bath 17.

The induced current advantageously avoids both magnetic windows, each arranged at one side of the feed plane of the strip, and the lower part of the induced current loop is straight due to these windows so that the induced current is concentrated close to the lower meniscus, thus increasing the potential component of the electromagnetic forces.

The height of the magnetic windows is either equal to or smaller than the distance between a planar member 45 and the corresponding planar member 46 and the magnetic windows are placed so that their reciprocally facing inner walls 56 and 57 are either close to or in contact with the side edges of at least one pair of planar members 46. The distance between these reciprocally facing inner walls 56 and 57 may be either equal to or greater than the width of the metal strip 13 to be coated. The walls 56', 57' opposite to these reciprocally facing inner walls 56 and 57 may have a maximum reciprocal distance equal to the longitudinal extension of the polar expansions 37, increased by an amount equal to the minimum value of the opening 39 between the reciprocally facing polar faces 38.

The solution, shown in Fig. 13, suppresses the need to use the previously described current shunt 43, 44 and 47.

Alternatively, the two systems for rectifying the induced currents may be used together close to the lower meniscus of the bath 17, i.e. current shunt and magnetic windows, so that the use of the current shunt is only needed during a first step of the process, in which the lower surface of the bath 17 is inside the passage 27 defined by the pairs of walls 28 and 29 (Fig. 6): when such a lower surface moves over the passage 27, the current shunt is deactivated and the "magnetic windows" work alone.

As previously noted, the magnetic force produced by the cooperation between the magnetic field, generated by the inductor 3, and the induced currents, developed in the bath 17, pushes the molten metal bath 17 away from the opening 16 at the bottom of the container and contains the bottom of the bath 17 over the passage 27.

The upward directed magnetic force exerted at the bottom of the bath 17, in any position along the longitudinal extension of the container 11, depends on both (a) the amount of local magnetic flux and (b) the local intensity of the current induced on the place. The polar faces 38 ensure the magnetic flux on the place. As previously noted, the current conductors 43 and 44 direct the induced current generated by the inductor 3 towards the terminals or electrodes 47, adjacent to the bottom of the container 11. By using the current conductors 43 and 44, the induced current is more concentrated on the edges of the passage 27 as compared to when these conductors are absent. This increases the magnetic force directed upwards at the ends of the passage 27, which in turn contributes to reducing the dripping or leakages from the container, in particular along the edges of passage 27.

As previously noted, the density of the magnetic flux generated by the inductor 3 is maximum in those places where the opening 39 between the polar expansions 37 is minimal. Similarly, the induced currents generated in the bath 17 are relatively intense in those places where the opening 39 is relatively small, in particular near the bottom of the bath 17. Additionally, the terminals 47 concentrate the induced current along the bottom of the bath 17 near the upper part of the passage 27.

Along with the magnetic forces, the operation of the inductor 3 generates a heating, due to Joule effect, of the mass of molten coating material and ferromagnetic strip 13, 14. Such a heating of the molten material is strong despite major heat leakages, in particular in the pipes of the sedimentation filter 7.

The container 11 of the galvanizer advantageously includes a refrigerator 48 (Fig. 6) which uses an appropriate cooling fluid, either gaseous or liquid, for extracting the exceeding heat from the steel strip and from the molten mass produced by the alternating magnetic field of the electromagnetic galvanizer 1. The refrigerator 48 is activated by a constant fluid flow rate. The tubes of the serpentine of the refrigerator 48 are made of non-magnetic steel and covered with a high-temperature resistant coating, e.g. metal oxide- or carbide-based, to protect them against the interaction with the liquid coating metal. The cooling fluid passes through the tubes of the serpentine to cool the molten material within the container 11, thus solidifying a certain amount of metal coating to form a crust or layer about the surface of the tubes. The solidified crust protects the tubes against the corrosion caused by the molten coating bath 17.

Advantageously, the vertical longitudinal part or projection 46' of the planar members 46 can be used to house the lower part of the tubes of the refrigerator 48.

A further advantage is represented by the fact of providing electro-conductive shields 53, shown in Figures 1 and 14, which prevent the magnetic flux from penetrating into the steel strip and reduce the Maxwell attraction forces. These shields 53 are arranged about the closing mechanism 10 and are shaped so as to support the absorber 9.

In the embodiment of the present invention shown in Fig. 14, the sealed closing mechanism used for starting the continuous hot dipping coating process is shown. With reference to Fig. 14, the closing mechanism 10 comprises two pushing tables 52 and a tube made of soft refractory material which may be crushed by pressure applied by both tables 52 which move in reciprocal opposite directions and which simultaneously push the tube made of soft refractory material on both the inlet of the opening 16 at the bottom of the container 11 and the steel strip 13, so as to operate a mechanical closing of the container 11 while this is filled with molten coating material before starting the motion of the strip 13 or in emergence situations, for example the absence of power supply to the inductor.
Once the inductor 3 has been activated for operating the semi-levitation of the bath by means of magnetic field, the closing mechanism 10 is opened and the strip 13 is moved in a vertical direction through the bath 17.
Since the soft refractory material tube, preferably made of ceramic, may be partially coated with a solidified coating material when the closing mechanism 10 is activated, before the subsequent closing and after emptying the container 11 of molten coating material through the absorber 9, the feeding means 2 must be activated at high frequency, e.g. up to 400 Hz, in order to heat by induction and melt the solidified coating material remained on the soft ceramic tube. The flux dispersed by the inductor 3 is exploited to achieve this result.

CLAIMS

1. An electromagnetic device for coating a flat metal product by means of hot dipping in a molten metal bath (17), comprising

- a longitudinal container (11) for containing said metal bath, provided with a longitudinal opening (16) at the bottom thereof for introducing the metal product into said bath along a feed plane of said product,

- an electromagnetic inductor (3) arranged about the container (11) and adapted to generate a magnetic flux across the metal bath (17), the inductor having an internal profile, facing the feed plane of the metal product, adjacent to the external profile of said container (11), said profiles being such that they concentrate said magnetic flux in a narrower lower part (20) of the container, thus inducing induced currents crossing the bottom of the container (11) in a longitudinal direction, so as to produce electromagnetic forces of maximum intensity at the bottom of said bath (17), thus obtaining a levitation of the bath itself with respect to the bottom of the container and defining a lower meniscus,

wherein there are provided rectifying means for rectifying the induced currents at ends of the lower meniscus whereby said electromagnetic forces are made uniform along the whole extension of said lower meniscus.

2. A device according to claim 1, wherein said rectifying means for rectifying the induced currents comprise a current shunt, provided with a current conducting part (43, 44) configured so as not to come in contact with the metal bath (17), said conducting part being connected to current conducting terminals (47), provided at two respective ends (29) of said longitudinal opening (16, 27) so as to be at least partially in contact with the molten metal bath, said terminals (47) being made of a molten metal bath-resistant material.

3. A device according to claim 2, wherein said molten metal bath-resistant material may comprise at least one of the following materials: silicon carbide, copper carbide, graphite, pyrolytic graphite.

4. A device according to claim 2 or 3, wherein said current conducting part comprises a pair of substantially vertical conductors (44), arranged between the corresponding ends of two half-containers (22) defining the container (11), each vertical conductor being arranged adjacent to a respective end wall (24) of the container (11), said vertical conductors being connected to each other by means

of a pair of substantially horizontal conductors (43) placed outside the container (11).

5. A device according to claim 4, wherein the substantially vertical conductors (44) are substantially L-shaped and the current conducting terminals (47) are provided at the ends of the short arm of said L.

6. A device according to claim 4, wherein the substantially horizontal conductors (43) may be in contact with external walls of the container (11).

7. A device according to any one of the preceding claims, wherein the container (11) has a wider upper part (21) and two pairs of longitudinal planar members (45, 46) are provided, each pair of said members protruding from longitudinal side walls (23) of the container (11).

8. A device according to claim 7, wherein the longitudinal extension (L) of each of said longitudinal planar member (45, 46) is larger than the width of the flat metal product (13) by an amount of at least 0,1H, where H is the depth of the molten metal bath provided in the container (11).

9. A device according to claim 8, wherein said longitudinal planar members (45, 46) are substantially parallel to one another and horizontal, and have transversal dimensions such as to define a minimum opening suitable for the passing of the flat metal product between each pair of members.

10. A device according to claim 1, wherein said rectifying means for rectifying the induced currents comprise electrically insulating magnetic components arranged inside the container (11) and reciprocally configured so as to define a magnetic circuit adapted to concentrate the magnetic flux within the mass of the metal bath inside said circuit and to concentrate the induced currents outside about said circuit.

11. A device according to claim 10, wherein the magnetic circuit is substantially quadrangular and the lower edges of said magnetic circuit are arranged over the bottom of the container (11) at a distance between 0 and 50 mm, preferably between 10 and 15 mm.

12. A device according to claim 10 or 11, wherein two pairs of magnetic components (54, 55) are provided, the components of each pair (54, 55) being integral with a half-container (22) and having a surface parallel to the feed plane of the flat metal product either in contact or not in contact with the reciprocally

facing surface of the corresponding component of the other pair of components (54, 55) provided on the other half-container (22).

13. A device according to claim 12, wherein said magnetic circuit is defined by said two pairs of magnetic components (54, 55) and by two pairs of longitudinal planar members (45, 46), each pair of said members protruding from longitudinal side walls (23) of the container (11) and being arranged close to the upper and lower ends of a wider part (21) of the container (11), respectively.

14. A device according to claim 13, wherein the longitudinal extension (L) of each of said longitudinal planar member (45, 46) is larger than the width of the flat metal product (13) by an amount of at least 0,1H, where H is the depth of the molten metal bath provided in the container (11).

15. A device according to claim 14, wherein said longitudinal planar members (45, 46) are substantially parallel to one another and horizontal, and have transversal dimensions such as to define a minimum opening suitable for the passing of the flat metal product between each pair of members.

16. A device according to claim 1, wherein said rectifying means for rectifying the induced currents comprise:

- a current shunt, provided with a current conducting part (43, 44) configured so as not to come in contact with the metal bath (17), said conducting part being connected to current conducting terminals (47), provided at the two respective ends (29) of said longitudinal opening (16, 27) so as to be at least partially in contact with the molten metal bath, said terminals (47) being made of a molten metal bath-resistant material,

- and electrically insulating magnetic components arranged inside the container (11) and reciprocally configured so as to define a magnetic circuit adapted to concentrate the magnetic flux within the mass of the metal bath inside said circuit and to concentrate the induced currents outside about said circuit.

17. A process of coating a flat metal product by continuous hot dipping in a molten metal bath (17), feasible by means of an electromagnetic device according to any one of the preceding claims, comprising the following stages:

- introducing the flat metal product into said molten metal bath (17) along a feed plane, through a longitudinal opening (16) provided at the bottom of the longitudinal container (11) containing said bath,

- generating a magnetic flux across the metal bath (17), concentrated in a narrower lower part (20) of the container so as to induce induced currents crossing the bottom of the container (11) in the longitudinal direction and produce electromagnetic forces of maximum intensity at the bottom of said bath (17), thus obtaining a levitation of the bath itself with respect to the bottom of the container and defining a lower meniscus of the bath,

wherein a rectification of said induced currents at ends of the lower meniscus is provided whereby said electromagnetic forces are made uniform along the whole extension of said lower meniscus.

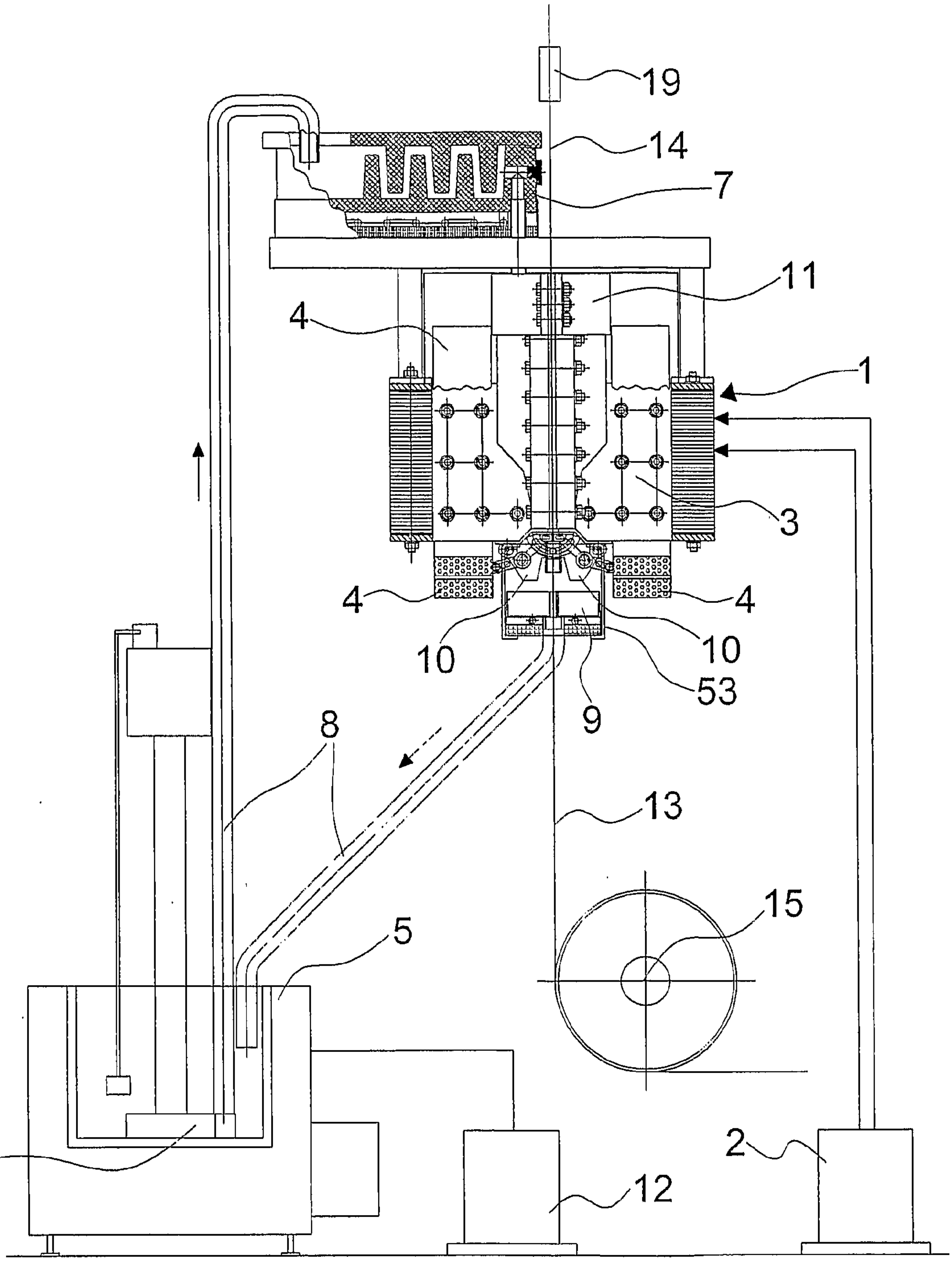

Fig. 1

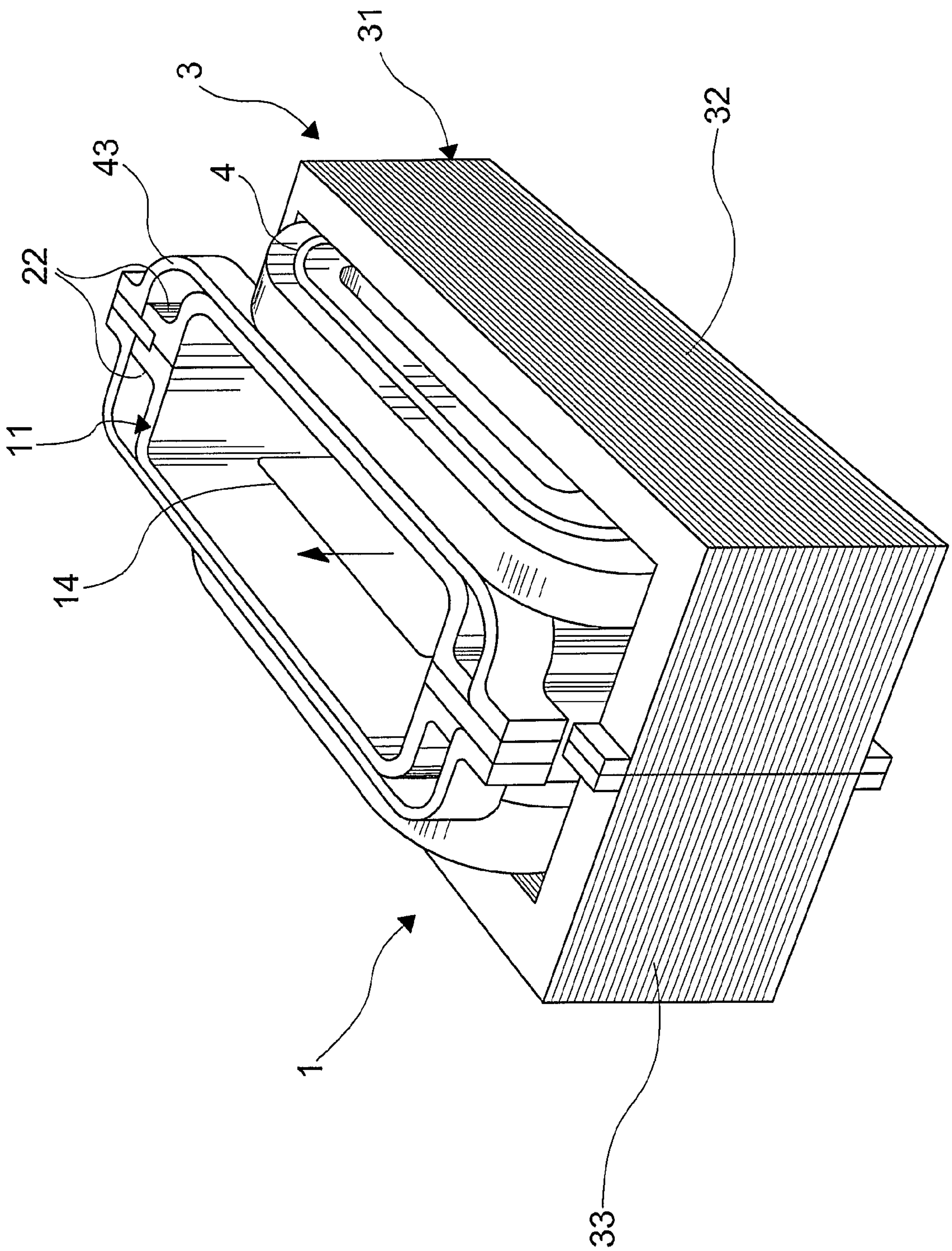

Fig. 2

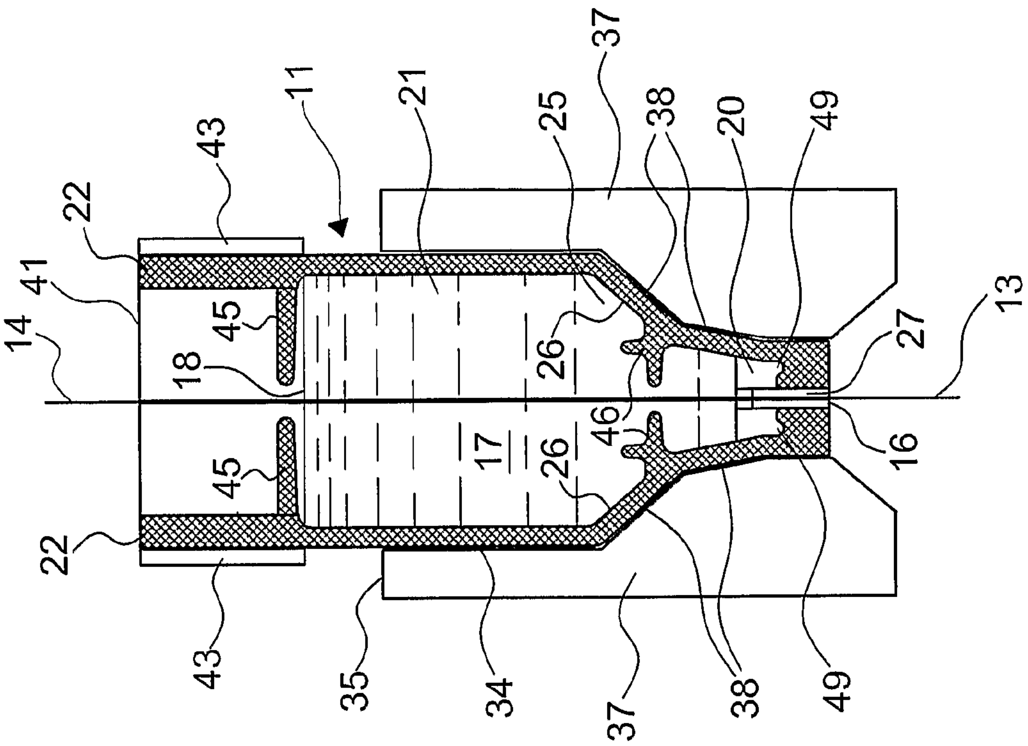
11
21
37
25
38
20
49
43
22
41
14
45
18
26
46
17
27
13
16
35
34
38
49

Fig. 4

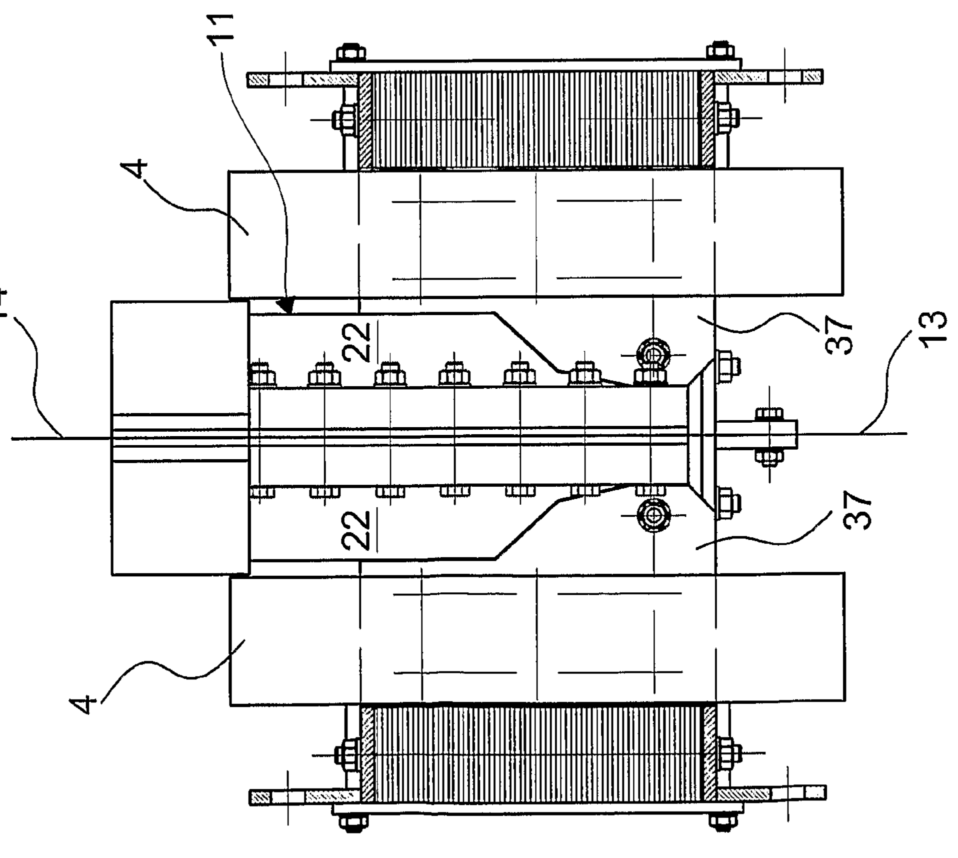
11
4
14
22
37
13

Fig. 3

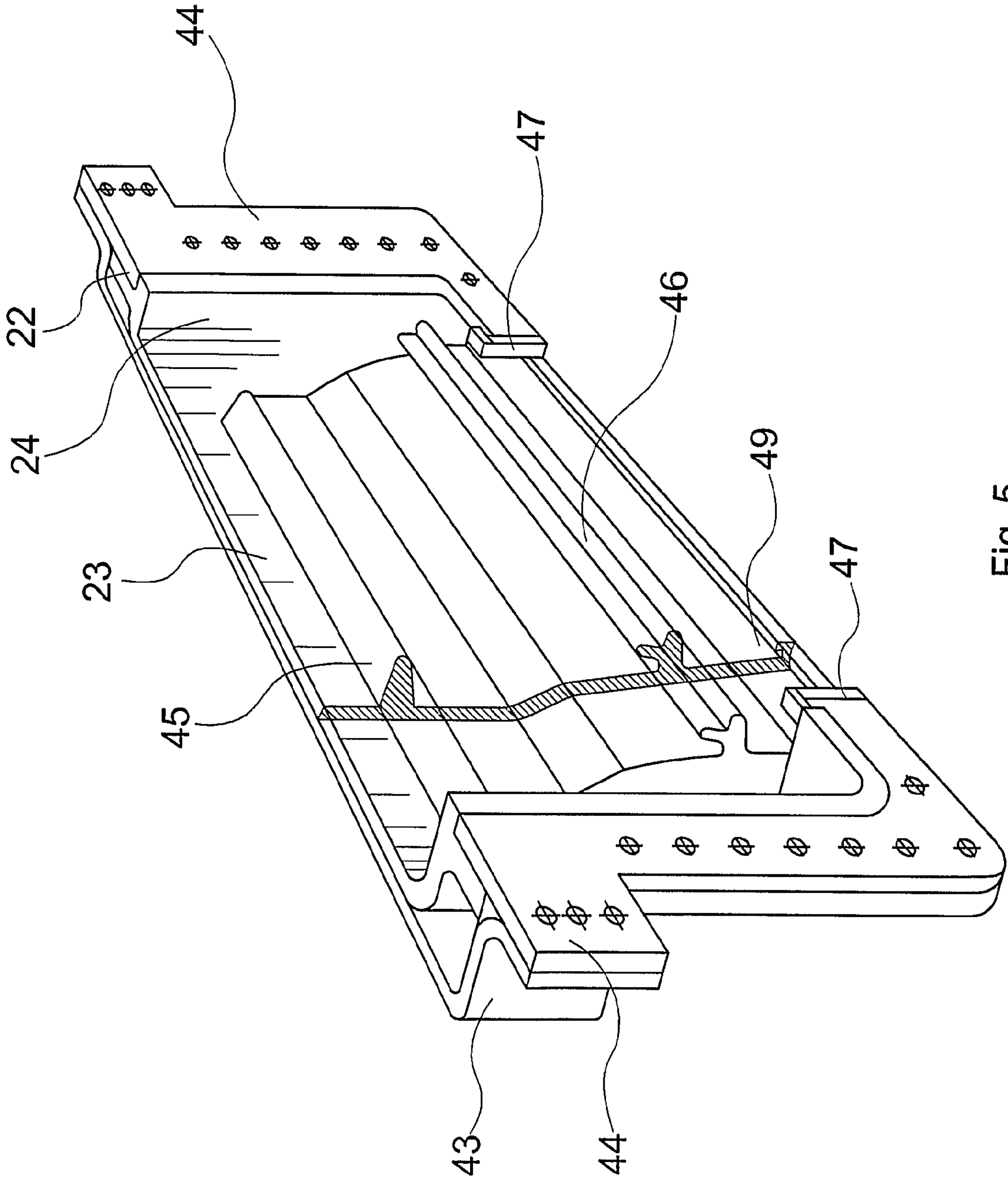

Fig. 5

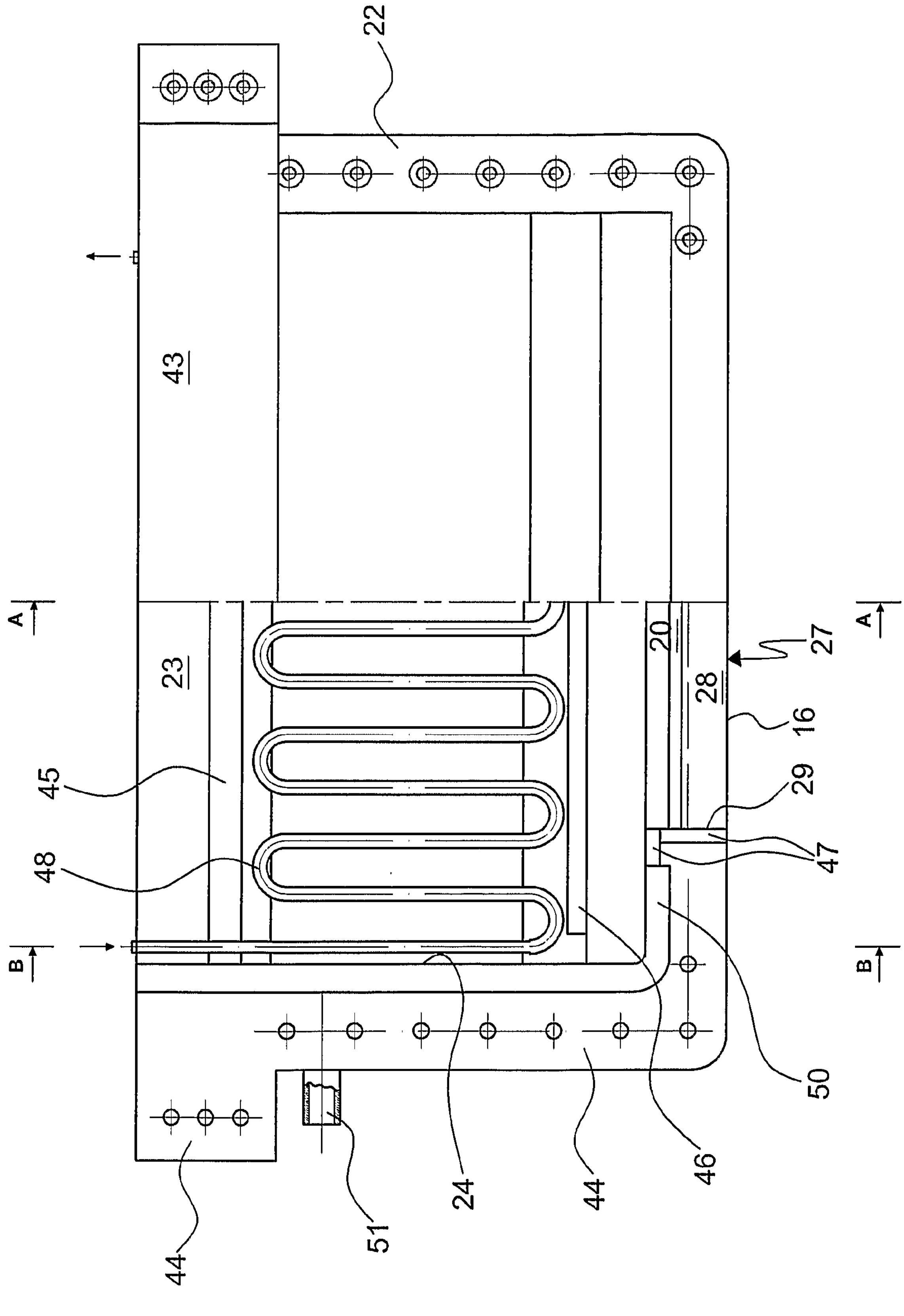

Fig. 6

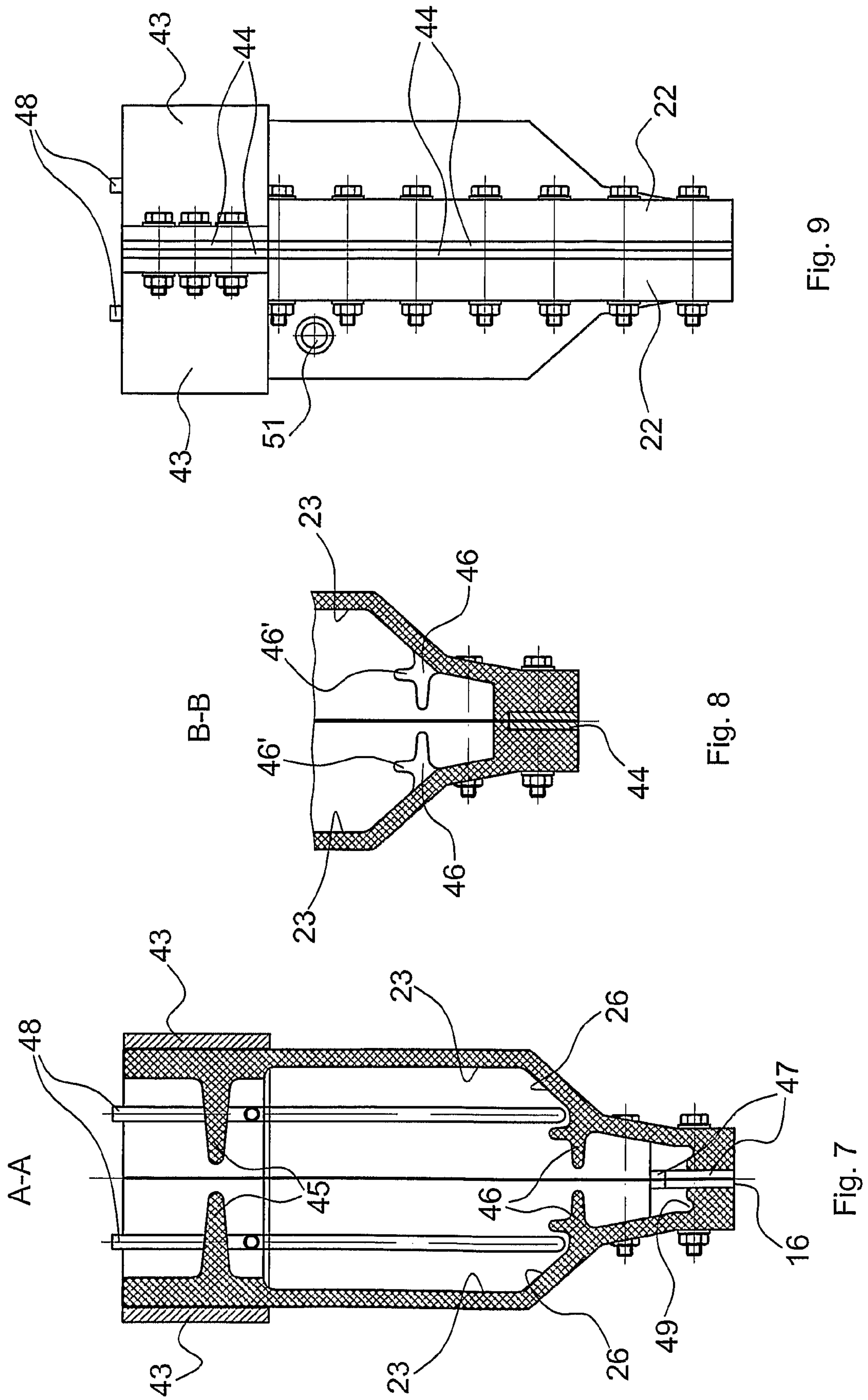

Fig. 9

Fig. 8

Fig. 7

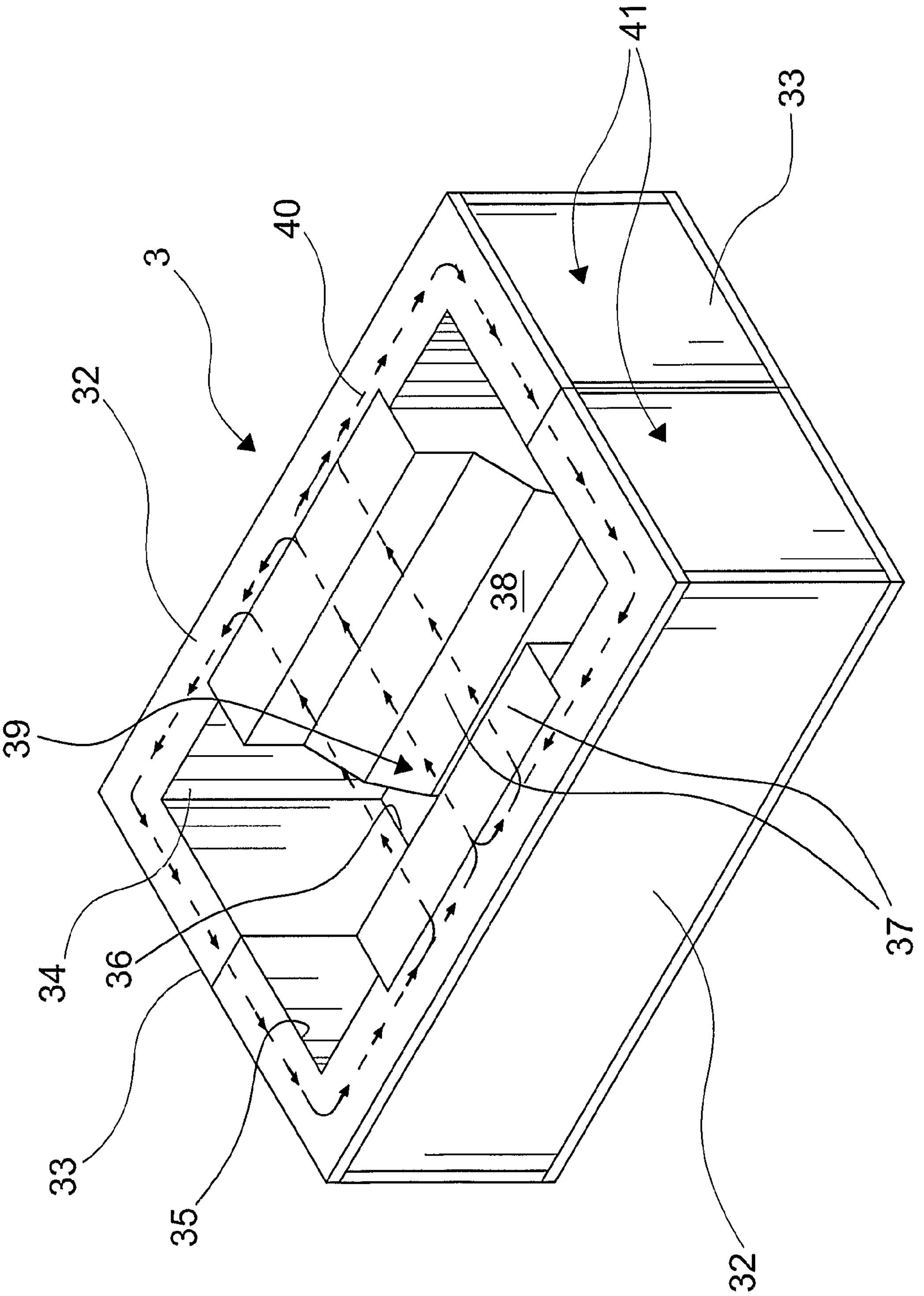

Fig. 10

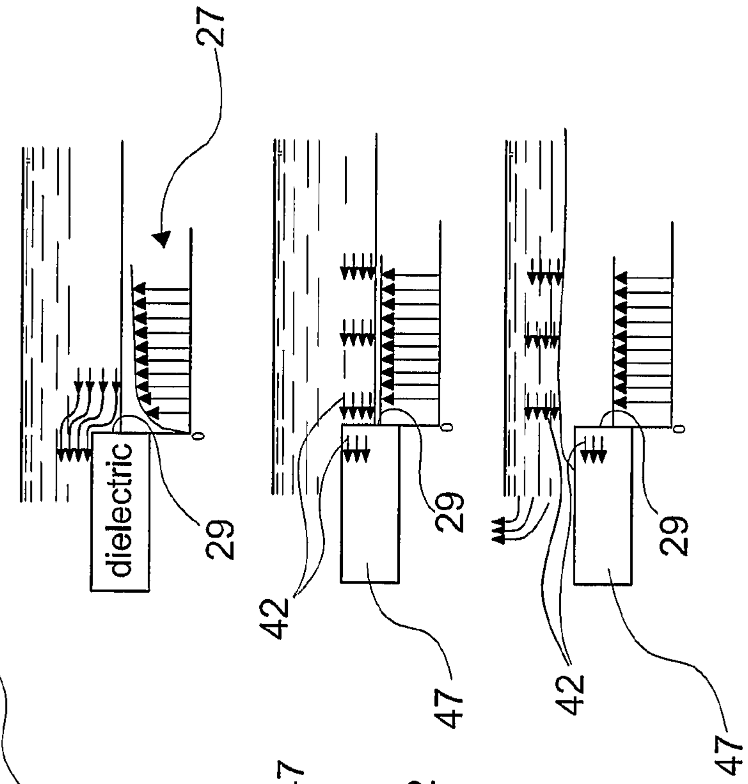

Fig. 12

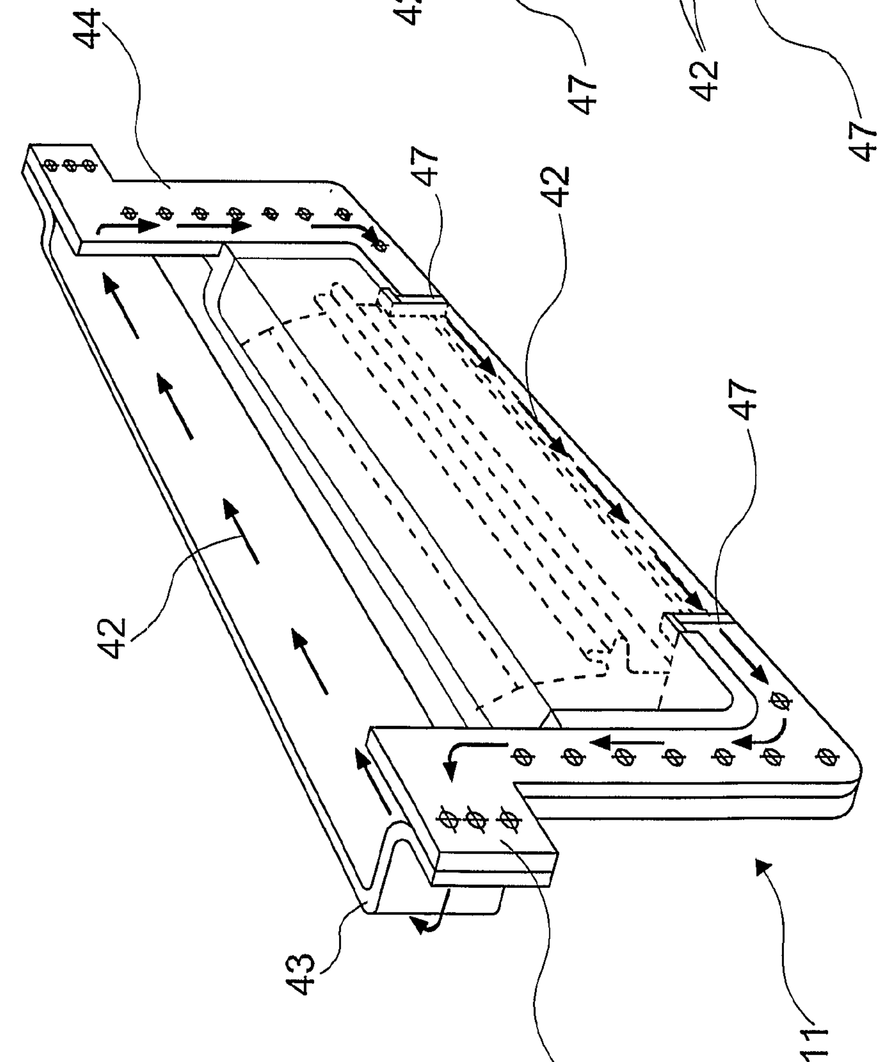

Fig. 11

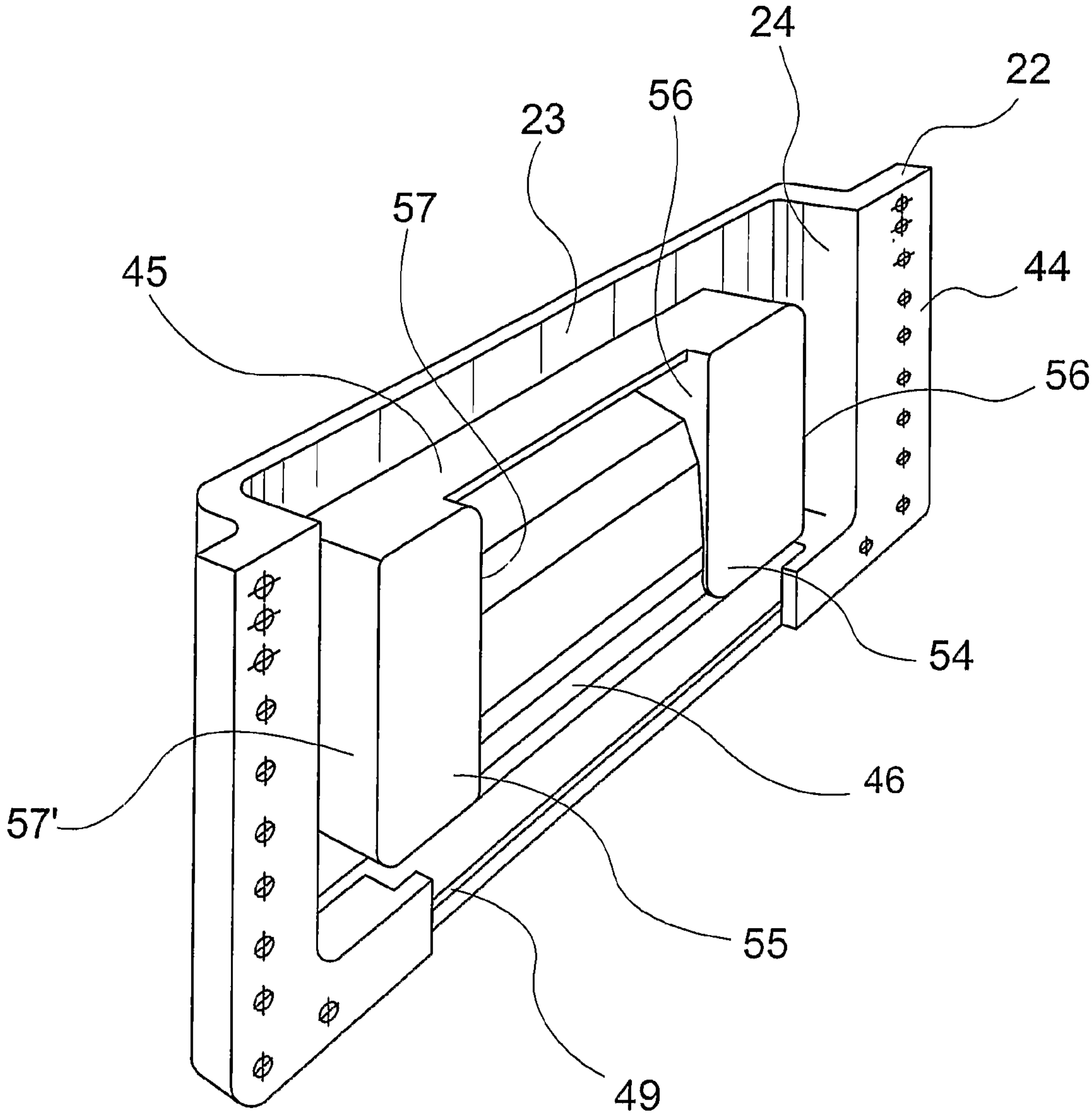

Fig. 13

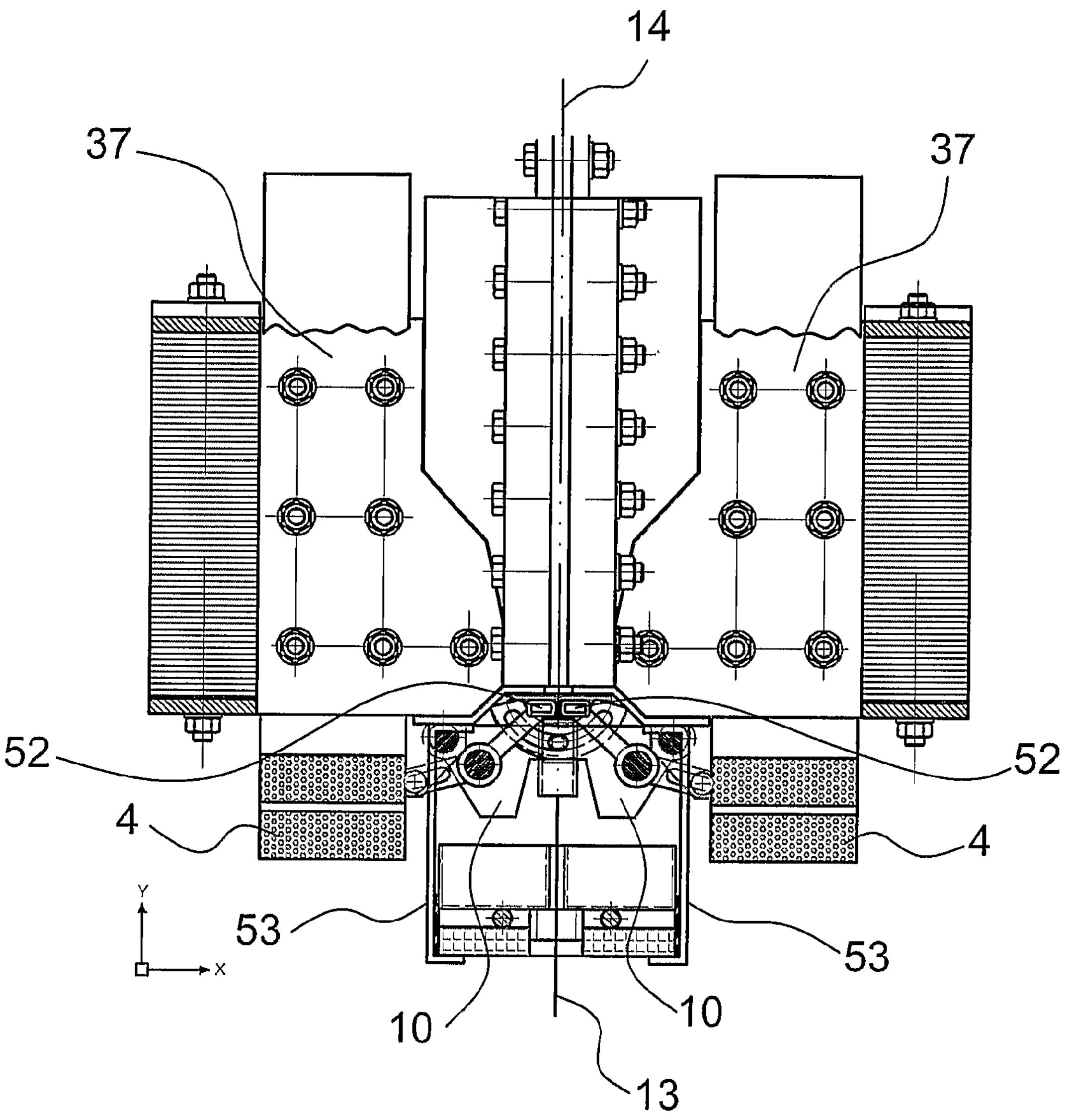

Fig. 14