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(54) METHOD AND DEVICE FOR CONTROLLING THE THICKNESS OF A COATING ON A FLAT METAL PRODUCT

VERFAHREN UND VORRICHTUNG ZUR STEUERUNG DER DICKE EINER BESCHICHTUNG AUF EINEM FLACHEN METALLPRODUKT

PROCÉDÉ ET DISPOSITIF POUR CONTRÔLER L'ÉPAISSEUR D'UN REVÊTEMENT SUR UN PRODUIT MÉTALLIQUE PLAT

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Description

Field of the invention

[0001] The present invention relates to a method and a device for controlling the thickness of a coating on a flat metal product, such as a steel strip, during the continuous galvanizing process of the strip by-hot immersion, also referred to briefly "hot dip" by the English term.

Prior Art

[0002] In the galvanizing process by immersion in a hot bath, a metal strip, suitably thermally pre-treated in a non-oxidising /reducing atmosphere is dipped in a bath of melted Zn (440°C-470°C) and is guided out in a vertical direction by rollers immersed in the bath.

[0003] The amount of liquid Zn extracted by the strip during the passage through the melted bath is determined by the balance between the force of gravity and the viscous forces, and the thickness of the layer of liquid Zn which is deposited on both surfaces of the strip, results as proportional to the speed of the strip and the physical properties of the melted Zn, such as kinematic viscosity and surface tension.

[0004] In order to reduce the thickness of the Zn layer deposited on the strip to those values required by final application specifications of the strips, jets or blades of air, known in English as "Air Knives", or of some other gas, usually steam or N_2, are commonly used.

[0005] The devices employed generally comprise two nozzles having a rectangular section or a section having some other form, positioned at the sides of the strip at a predetermined distance from both the strip and the free surface of the Zn bath, from which a gas jet exits advantageously at room temperature. These gas jets act to reduce the thickness of the zinc layer that covers the surface of the strip, forcing part of the liquid metal to return towards the bath.

[0006] The same type of process can be used to coat metal strips with Zn-Al, aluminium and tin alloys.

[0007] The air knife is characterised by very narrow pressure distribution on the zone of impact, only a few millimetres wide, such as 3-5 mm, for example, and by the presence of a larger shear stress zone of action. The main effect of the pressure distribution is to generate a force, due to the gradient of pressure on the thickness of the liquid zinc, that abruptly cuts the fluid vein and reduces the thickness of the coating, sending back any quantities of Zn in excess to the bath. The value of this force is at its maximum when the gas jet is perpendicular to the strip surface.

[0008] The value of the final coating thickness is also determined by the action of the shear stress generated on the strip by the gas. This value is at its minimum when the gas jet is perpendicular to the strip surface. The gas that hits the galvanized strip, and then flows on its surfaces, cools the zinc and the strip, especially in the zone of impact of the gas.

[0009] Since the final thickness of the coating is proportional to the speed of the strip, in order to obtain the same thickness at increasing speed, the pressure exercised by the air knives must be increased. This effect is obtained by an increase in the gas flow rate or the reduction of the-opening of the air knife nozzles.

[0010] International standards and market demand have established a discrete number of admissible coating thicknesses and the respective tolerances suitable for successive industrial applications. As well as producing the required thickness, it is also necessary to obtain constant thickness levels and maximum uniformity in the galvanized surface to guarantee coating quality and to reduce to a minimum the amount of Zn required to obtain a determined coating, thus providing an economical advantage.

[0011] Main disadvantage of the air knife technology is that of provoking a strong cooling and therefore the premature solidification of the Zn under the action of the air knife, especially when the supply pressure is increased with the purpose of obtaining increasingly thinner coatings. This signifies diminishing the efficacy of Zn thickness reduction.

[0012] Other drawbacks with air knife technology are represented by the lack of uniformity of the applied coating and the limited strip speed resulting in a limited productivity.

[0013] A very important problem is caused by the different fluid dynamics and thermal situation present on the centre of the strip with respect to the strip edges. In fact, this situation leads to a lack of uniformity in the thickness of the coating along the total width of the strip, but this is greater at the edges. In fact, the edges of the strip cool more rapidly than the centre of the strip creating variations in the physical properties of the liquid Zn, in particular in the kinematic viscosity, that generate surface forces (Marangoni effect) provoking an accumulation of coating near the edges. The problem is resoived only partially using knives or masks to deflect-the gas jet at the edges of the strip, or using butterfly nozzles that increase the gas flow rate on the edges.

[0014] The accumulation of the coating near the edges, in addition to create problems about winding and successively problems of flatness of the galvanized strip, causes also problems of uniformity in the coating properties when the strip is subjected to successive treatments, for example a heating and a holding for an appropriate time at a temperature close to the melting point of the zinc, a treatment referred to as "galvannealing" in English. Furthermore, this accumulation does not permit to reduce to a minimum the amount of Zn necessary to obtain a given coating, with the consequential economical disadvantages.

[0015] Another problem is represented by the fact that, because of the very limited application zone for pressure force, the variation in the Zn thickness is very abrupt and, according to the gas flow rate and the shear stress which depends strongly also on the inclination angle of the jet with respect to the strip surface, for a given final thickness of Zn deposited on the strip, there is a speed limit for the strip feeding over which the surface of the coating layer is subject to instability and wave formation to the point of releasing liquid and solid drops in the environment in proximity of the air knives. This phenomenon, referred to as "splashing", is generally amplified by the vibrations and oscillations that always occur on the strip. "Splashing" provokes large problems both for product quality by forming "jet lines", as well as environmental safety because of the dust released, and this represents one of the main causes that limits productivity in actual galvanizing plants.

[0016] A limit in air knife technology is also represented by the fact that the airflow produces a coating oxidation that increases in intensity in proportion to the increase in speed and gas flow rate. This generates defects in the final product and contributes towards releasing dust into the environment. The realization of cutting systems using inert gas, such as N_2, used to prevent this drawback, are only able to resolve the problem partially and in any case at a higher -cost when compared to common air knife systems.

[0017] A further limit relates to the fact that, once the feeding speed of the strip is fixed, the final thickness of the coating depends on the peak of the pressure gradient force, but the pressure of the air, or gas, must be maintained within certain limits in order-to prevent reaching supersonic air speeds with the consequential problems of vibration, beating and instability in the strip position, and excessive noise levels in the plant.

[0018] Therefore, in the case where the final thickness of the coating is fixed at a relatively reduced value, since it is not possible to increase the air pressure too much, the strip speed must be reduced, and therefore also the production line productivity, and this is in contrast with current needs in sales competitiveness, which require speeds over 200 metres/min.

[0019] EP525387 discloses a method for controlling coating weight on a hot-dipping steel strip, with the provision of flowing a high-frequency current strong enough to magnetically saturate the steel strip through a pair of high-frequency current conducting paths to induce a high-frequency current of an opposite phase in the steel strip, so that a magnetic pressure acting on surfaces of the steel strip is generated by interaction of the induced high-frequency current with a high-frequency current of the high-frequency current conducting paths.

[0020] US4273800 discloses a method for removal of excess metal coating by means of a stationary pulsating or alternating magnetic flux. The frequency and intensity of the flux are controlled to exert on the coating surface a force opposing the viscous drag forces exerted on the coating by the moving substrate.

[0021] For this reason a method and relative device must be realised for controlling the thickness of a coating on metal products, exiting from a hot bath which are able to overcome the aforesaid drawbacks.

Summary of the invention

[0022] A first object of the present invention is to provide a method and relative device to realise an operation of controlled removal of the excess coating during the final continuous galvanizing stage by hot dipping of a flat metal product, such as a steel strip for example, by means of the combined use of alternate monophase or pulsed electromagnetic fields and gas jets so as to efficiently control the coating weight and the uniformity of coating distribution, compensating the cooling effect of the air knives by means of a localised induction heating of the coating.

[0023] A second object is that of using the combination of air knives and magnetic fields, generating electromagnetic forces cooperating with the forces of pneumatic pressure, in order to reduce the air supply pressure and thus to reduce the problems of "splashing" and coating oxidation.

[0024] A third object of the invention is that of using magnetic fields, in cooperation with the air knives, to heat the liquid zinc in order to locally reduce the kinematic viscosity and surface tension thereof and, thus, furtherly reduce the "splashing" phenomena caused by air knives.

[0025] Another object of the invention relates to the possibility of increasing the strip feeding speed and, therefore, the maximum productivity of the current galvanizing lines.

[0026] In order to achieve the objects mentioned, according to a first aspect of the present invention, there is provided a method for controlling the thickness of coating on a flat metal product, with the features of claim 1.

[0027] A second aspect of the invention provides a device for implementing the aforementioned method of controlling the thickness of coating on a flat metal product, according to claim 12.

[0028] According the law of electromagnetic induction, by applying at least one alternate magnetic field of induction, in proximity of the surfaces of major extension of a strip, there are induced electromotor forces into the strip material and into the coating material, still in liquid state, and thus electric induction current with an intensity depending, among the other things, on the resistivity of the materials. The direction of these currents is always such that it opposes to the cause producing itself, in particular the variation in the magnetic flux due both to the field variation and to the displacement of the strip, with respect to-the field, over time.

[0029] The induced currents generate a heating in the Zn coating and in the strip whose entity depends on the intensity and the frequency of the imposed magnetic field. The heating of the strip also depends on the geometrical trend of the magnetic flux tubes reclosing in the strip.

[0030] The method according to the present invention advantageously allows to modify the paths that the magnetic fluxs follow when closing in the magnetic yoke, crossing the strip subject to the galvanizing process. Therefore it is possible to dose in the strip the phenomenon of heating by electromagnetic induction, in both concentration and distribution, varying the module and the frequency of the magnetic induction and the path of the field fluxes. The flux tubes can be produced substantially in different configurations by means of the control of the currents that supply the magnetic circuit in question.

[0031] The difference in flux distribution influences the different distribution of the induced currents in the strip and consequently also the induced heating. Using the method according to the invention, it is possible in this way to control the heating areas on the strip and the intensity of this heating.

[0032] Advantageously this method provides a heating that, under certain conditions, concentrates more on the edges because of the return of the electric currents. In this case it is possible to compensate the natural overcooling of the strip edges with respect to the strip centre.

[0033] Furthermore, since also the forces generated on the Zn coating are proportional to the frequency and intensity of the imposed magnetic field, it is possible to optimise these parameters in such a manner to obtain the maximum of the forces on the Zn, inducing limited heatings in the Zn and in the strip that favour the action of the volume force, as they make the liquid Zn more fluid, locally reducing the kinematic viscosity and the surface tension. Furthermore, in this way, there is not produced overheating such to cause metallurgical problems, such as the undesirable production of Fe-Zn alloy, during the coating process.

[0034] Thanks to the alternate monophase or pulsed magnetic field, advantageously a heating is generated by induction on the strip and the coating material or directly in the gas jet action zone or in a zone adjacent and above said action zone, thus avoiding an intensive cooling of the coating material by the gas and avoiding the risk of its premature solidification. In addition to increasing the surface temperature of the coating material, induction heating advantageously reduces the surface tension and the kinematic viscosity of said material, in particular at the edges of the strip. Furthermore, thanks to the heating, kinematic viscosity and surface tension are modified locally in order to make more difficult to provoke "splashing" phenomena.

[0035] The present invention also resolves the problem of the accumulation of Zn on the edges of the strip since the temperature of the Zn and of the strip are more uniform along the thickness of the strip.

[0036] In this manner it is obtained a strip with a uniform coating thickness on all its surface, consequently avoiding problems with winding and successively with the flatness of the galvanized strip, as well as uniformity problems in the properties of the coating when the strip is subjected to successive treatments, for example a "galvannealing" treatment. Furthermore the amount of Zn, required for a determined coating, is reduced to a minimum with consequential economic advantages.

[0037] The alternate or pulsed magnetic fields can be applied in directions substantially parallel or in directions substantially perpendicular to the strip. Possibly the aforesaid magnetic fields can be applied in both directions, parallel and perpendicular to the strip.

[0038] The method according to the present invention can be applied to control the thickness of coating on steel strips in exit from a hot bath of zinc, Zn-Al alloys, aluminium, Al and tin alloys, for example.

Brief description of the figures

[0039] Further characteristics and advantages will be made clearer from the detailed description of preferred, but not exclusive, embodiments of the method and device according to the invention with the help of the appended drawings wherein:

Figure 1 shows a diagram of the dip process for a strip in a melted metal bath with the successive application of air knives;

Figure 2a shows a portion of strip on which a first magnetic field having a first direction is applied;

Figure 2b shows a top view of the strip with a diagram of the currents induced by the magnetic field in Fig. 2a;

Figure 3 shows a first schematic embodiment of the device according to the invention;

Figure 3a shows the device in Fig. 3 in greater detail;

Figure 3b shows a variant of the device in Fig. 3a;

Figure 3c shows a further variant of the device in Fig. 3a;

Figure 4 shows a second schematic embodiment of the device according to the invention;

Figure 4a shows the device in Fig. 4 in greater detail;

Figure 5a shows a portion of strip on which a second magnetic field having a second direction is applied;

Figure 5b shows a side view of the strip with a diagram of the induced currents induced by the magnetic field in Fig. 5a;

Figure 6 shows a third schematic embodiment of the device according to the invention;

Figure 6a shows the device in Fig. 6 in greater detail;

Figure 7 shows a fourth schematic embodiment of the device of the invention;

Figure 8a shows a portion of strip on which a third magnetic field having the same second direction is applied;

Figure 8b shows a side view of the strip with a diagram of the currents induced by the magnetic field in Fig. 8a;

Figure 9 shows a fifth schematic embodiment of the device of the invention;

Figure 9a shows the device in Fig. 9 in greater detail;

Figure 10 shows a sixth schematic embodiment of the device of the invention;

Figure 11 a shows a portion of strip on which at the same time said second and third magnetic fields are applied;

Figure 11b shows a side view of the strip with a diagram of the induced currents induced by the magnetic fields in Fig. 11 a;

Figure 12 shows a seventh schematic embodiment of the device of the invention;

Figure 13 shows an eighth schematic embodiment of the device of the invention;

Figures 14a, 14b and 14c show ways of positioning the air knives with respect to the heating areas produced on the moving strip;

Figure 15 shows a variant of the embodiment of the device in Fig. 12;

Figure 16 shows a section of a variant of the device according to the present invention.

Detailed description of preferred embodiments of the invention

[0040] A diagram illustrating the galvanizing process of a metal strip by immersion in a hot bath is shown in Fig. 1. The metal strip 1, suitably thermally pre-treated in a non-oxidising/reducing atmosphere is immersed in the bath 2 of melted Zn and is guided out from the bath in a vertical direction, at a predetermined speed, by three rollers immersed in the bath.

[0041] Above the bath 2, at each side of larger extension of the strip, means for generating gas jets are provided, comprising nozzles or air knives 4 suitable to produce jets or blades of air or other gas, such as steam or N_2, and therefore pneumatic forces to reduce the thickness of Zn deposited on the strip. The supply pressure for the nozzles 4 preferably ranges between 0,1 bar and 1 bar.

[0042] In order to perform the method according to the present invention, a relative device comprises means for generating alternate monophase or pulsed electromagnetic fields in order to remove the excess coating material by means of the induction heating on the coating layers 11 of the strip, said means being advantageously combined with the aforesaid means for generating gas jets.

[0043] The means for generating alternate magnetic fields can comprise one or more magnetic yokes whose magnetic poles have predetermined geometries, or one or more wound coils or turns, placed in proximity of the strip and supplied with alternate or pulsed monophase current.

[0044] A first embodiment of the method according to the present invention provides the generation of a longitudinal alternate magnetic field B having a direction substantially parallel to the feeding direction of the strip, that is the vertical direction, as illustrated in Fig. 2a.

[0045] The heating action obtained is uniform and the heating area 5 corresponds with a substantially rectangular area at the zone of impact 12 of the gas jets. The heating area 5 advantageously covers the total width of the strip 1, edges included.

[0046] The heating induced by the uniform longitudinal field B depends on the intensity and the distribution of the induced currents 6, which are function of the penetration depth of the current in the strip, depending on the magnetic induction frequency, and function of the thickness of the strip itself.

[0047] Advantageously, in order to obtain an optimal heating, the frequency of the generated magnetic induction is varied in a manner to obtain a predetermined ratio between thickness of the strip and depth of the penetration of the induced currents in the strip itself, ranging between 0,5 and 20. For example, for strips having a thickness ranging between 0,2 mm and 4 mm it is appropriate to work with a frequency ranging between 500 Hz. and 500000 Hz, preferably between 10kHz and 300kHz.

[0048] Instead, the intensity of the alternate magnetic field is comprised between 0,05 and 1 T in the air at the "wiping" zone, that is at the air knife action zone.

[0049] This first embodiment of the method according to the invention can be realised by means of a device comprising, in a first variant, one or more coils or turns 7, wound around the strip 1 and supplied with alternate or pulsed current in order to create a longitudinal magnetic field B, alternate or pulsed, inside said coils or turns, as illustrated in Fig. 3,
or comprising, in a second variant, magnetic yokes provided with poles 8, 8', placed at each of the surfaces of major extension of the strip, having the same function, arranged according to the diagram in Fig. 4. In the latter case the generated magnetic flux moves, parallel to the strip feeding direction, from the upper poles 8 to the lower poles 8' of the respective magnetic yoke.

[0050] In the first variant of the device, advantageously nozzles 4 are provided placed in proximity of the coil 7, preferably at half-height of the winding, as illustrated in Fig. 3a. The turns of the coil 7 can also be arranged closer to the strip at the top, and gradually further away from the strip at the bottom, as shown in Fig. 3b, or alternatively they can be provided in a decreasing number along the vertical plane towards the melted coating material bath, that is from top to bottom as shown in Fig. 3c. In the embodiment illustrated in Fig. 3b the flare angle β of the coil 7 with respect to the vertical plane is between 0° and 60°.

[0051] The second variant of the device, illustrated in Fig. 4a, on the other hand, provides means for generating electromagnetic fields comprising two inductors, each one for example composed of one or more windings or coils-30 wound around a ferromagnetic core or yoke 31, substantially having a C shape, while the means for generating gas jets comprise, for each inductor, a support and supply structure for supporting and supplying nozzle 4, the structure comprising a gas feed manifold 32 and the same nozzles, placed in proximity of each surface 11 of major extension of the steel strip 1 in exit from the melted coating material bath.

[0052] The ferromagnetic cores 31, having a substantially C shape, are lamination stack or compact type and produced in ferromagnetic or magneto-dielectric or ferritic material, while the coils 30 are positioned opposite one another on each side of the steel strip 1 and can be cooled with water. The control of the alternating magnetic field frequency is provided according to the type and quality of the coating to be removed.

[0053] Advantageously since the support structure, comprising the feed manifold 32 and the nozzles 4, is positioned inside the ferromagnetic cores 31, the superposition of the gas jets over the action zone of the induction heating is always guaranteed. The nozzles 4, positioned placed in proximity of the magnetic yoke poles 8, 8' of each ferromagnetic core 31, can be placed inside or outside the inductors.

[0054] In order to realise the alternate or pulsed magnetic field B, having a direction substantially parallel to the feeding direction of the strip, an alternate or pulsed current flows through the coils 30 with a phase shift angle between currents equal to 180° in a manner such there is only one longitudinal magnetic flux generated by the magnetic flux loops 33, 33' circulating on each inductor.

[0055] All the variants of the first embodiment of the invention are characterised by a vertical distribution of the coils or of the terminal parts of the magnetic yokes, in proximity of the strip feeding plane, ranging between 10÷100 mm in order to advantageously concentrate the heating along a strip zone that extends in longitudinal direction for 5÷30 mm and that is at least partially superimposed over the zone most intensely cooled by the air knives, extending longitudinally for about 3÷10 mm, thus reducing the necessary heating power, equal to approximately 1÷50 kW for metre of strip width.

[0056] Contrarily, the devices that exploits a " travelling magnetic field" require the use of power two or three times higher in order to obtain the same result.

[0057] A second embodiment of the method according to the invention, instead, provides the generation of a non-uniform alternate magnetic field B' having a direction substantially perpendicular to the feeding direction of the strip, as shown in Fig. 5a.

[0058] The heating action obtained is not uniform on the strip. In particular, the field B' has a gradient which causes a distribution of induced current represented by the curved line 6' such to heat both the edges and centre of the strip. The heating is localised in several heating areas:

- a first area 9, substantially elliptical, central with respect to the strip surface and arranged at the zone of impact 12 of the gas jets;
- and two second side heating areas 9', placed above the first central area 9, at the edges of the strip.

[0059] The gradient of the magnetic field B' can be obtained, in a first variant, by supplying a magnetic yoke in which the poles 10 in the- magnetic gap have a geometry that is similar to that illustrated in Fig. 6, said poles being provided with a surface 20 inclined by an angle between 0° and 60° with respect to a vertical plane.

[0060] This first variant, illustrated in Fig. 6a, comprises two inductors, each one for example composed of one or more windings or coils 30 wound around a ferromagnetic core or yoke 31'. The two parts of the yoke 31', each one placed at a surface of major extension of the strip 1, are advantageously connected on the horizontal plane perpendicular to the sheet in order to close and maximise the magnetic flux. The means for generating gas jets comprise, for each inductor, a support and supply structure for supporting and supplying nozzles 4', the structure comprising a gas feed manifold 32' and placed outside the ferromagnetic yoke 31'. The nozzles 4' are placed immediately above said inductors and slightly inclined in a downward direction to ensure that the gas jet zone coincides with the action zone of magnetic field B'. This solution allows an easier access for nozzle cleaning since the upper part of the nozzles is unencumbered.

[0061] The gradient of the magnetic field B' can be obtained, in a second alternative variant, by adopting a series or winding of non-uniformly distributed turns 7' of the type illustrated in Fig. 7. The turns 7', arranged on one side only with respect to the feeding direction of the strip, are wound in a manner to define axes perpendicular to said direction and an internal surface inclined, with respect to a vertical plane, of an angle preferably comprised between 0° and 60°.

[0062] A third embodiment of the method according to the invention is obtained by inverting the gradient of the non-uniform alternate magnetic field B", as illustrated in Fig. 8a.

[0063] In this case, the gradient of the magnetic field B" causes a distribution of induced current represented by the curved line 6" such to heat both the edges and centre of the strip. The heating is localised in- several heating areas:

- a first area 9, substantially elliptical, central with respect to the surface of the strip and arranged at the zone of impact 12 of the gas jets;
- and two second side heating areas 9"; arranged under the first central area 9, at the edges of the strip.

[0064] The gradient of the magnetic field B" can be obtained, in a manner similar to that described above, in a first variant, by supplying a magnetic yoke whose poles 10 in the magnetic gap have a geometry similar to that illustrated in Fig. 9, said poles being provided with a surface 20' inclined of an angle preferably comprised between 0° and 60° with respect to a vertical plane.

[0065] This first variant, illustrated in Fig. 9a, comprises two inductors, each one for example composed of one or more windings or coils 30' wound around a core or ferromagnetic yoke 31'. The two parts of the yoke 31', each one arranged at one surface of major extension of the strip 1, are advantageously connected on a horizontal plane perpendicular to the sheet in order to close and maximise the magnetic flux. The means for generating gas jets comprise, for each inductor, a support and supply structure for supporting and supplying nozzles 4', the structure comprising a gas feed manifold 32' and placed outside the ferromagnetic yoke 31'. The nozzles 4' are placed immediately above said inductors and slightly inclined in a downward direction to ensure that the gas jet zone coincides with the action zone of the magnetic field B". This solution allows an easier access for nozzle cleaning since the upper part of the nozzles is unencumbered.

[0066] The gradient of the magnetic field B" can be realised, in a second alternative variant, by adopting a series or winding of non-uniformly distributed turns 7" of the type illustrated in Fig. 10. The turns 7", arranged on one side only with respect to the feeding direction of the strip, are wound in a manner to define axes perpendicular to said direction and an internal surface inclined, with respect to a vertical plane, of an angle preferably comprised between 0° and 60°.

[0067] A fourth embodiment of the method according to the invention is obtained by generating two non-uniform alternate magnetic fields B', B", having a direction perpendicular to the feeding direction of the strip and directions opposite to one another, that is by combining the second and third embodiments, as illustrated in the Figures from 11 a to 13.

[0068] In this case, the distribution of the induced- currents 6', 6" on the surfaces 11 of the strip 1 are such to generate a heating at the centre of the surfaces 11 higher with respect to the edges. Therefore a central heating area 9"' wider than the central area 9 of the previous cases is provided; and second side heating areas 9', 9" are provided both above and below the area 9"'.

[0069] The gradients of the magnetic fields B', B" can be realised by providing the combination, as illustrated in Figures 12 and 13, of the magnetic yokes shown in Figures 6 and 9, arranged symmetrically with respect to a horizontal plane, or the combination of the series or windings of the non uniformly distributed turns 7', 7" shown in Figures 7 and 10, each winding being arranged to be placed at a respective side with respect to the feeding direction of the strip.

[0070] In particular this fourth embodiment of the method according to the invention can be realised by means of a device, such as that illustrated in Fig. 15, totally identical to that already described above and illustrated in Fig. 4a.

[0071] In order to realise the alternate or pulsed magnetic field B', crossing the feeding direction of the strip in a substantially orthogonal direction, an alternate or pulsed current flows through the coils 30 with a phase shift angle between the currents equal to 0° in a manner such there is only one magnetic flux crossing the strip twice in opposite directions, said flux being generated by the magnetic flux loop 33" common to the two inductors.

[0072] The use of ferromagnetic yokes or cores with appropriately shaped poles allows to model the shape of the magnetic field. In particular the inclination of the poles with respect to the vertical direction, that is the feeding direction of the strip, must be between 0° and 60° in order to be efficacious.

[0073] The heating induced by field B' and/or B" depends on the intensity and the distribution of the induced currents 6' and/or 6", which are function of the intensity of the magnetic induction and its frequency. For example, for strips with a thickness ranging between 0,2 mm and 4 mm it is appropriate to work with frequencies ranging between 5 and 1000 Hz, preferably between 50 and 500 Hz. The intensity of the alternate magnetic field B', B" is, instead, comprised between 0,05 and 1 T, in the air.

[0074] Advantageously, the induced heating is such that it contrasts the cooling- effect due to the gas jet or air knife action, whereby the heating areas 5, 9, 9', 9", 9"' must be provided underneath or at most at the zone of impact of said jets. In this way the strip can be maintained in motion at a temperature that is substantially equal to that at the exit from the bath 2 until it reaches the impact zone of the jets, thus avoiding surface solidification of the zinc in proximity of the nozzles 4. In fact the strip surface that could be subject to the risk of solidification is the part just below the nozzles 4, that is below the air jet impact zone, having a width approximately equal to that of the strip and having a height ranging between a few millimetres and 10 mm that corresponds with the pressure peak of the gas jet. The thermal power that can be removed from the strip in the gas jet impact zone, having a height equal to 1÷10 mm, caused by the cooling of the gas jets, is variable between 1 and 50 kW according to the working conditions of the air knives. Advantageously, intensity and frequency of the magnetic field are regulated in order to provide the strip with a thermal power equivalent to that removed, thus being able to avoid premature solidification of the liquid coating before the excess coating is removed.

[0075] The figures 14a to 14c show possible arrangements of the nozzles 4 with respect to the heating areas generated on the strip during feeding.

[0076] In the case shown in Fig. 14a the gas jet can be advantageously applied at or above the heating area 5. It must not be applied under this area 5 because the coating could have already attained the solid state when it reaches this area, therefore making the heating action, generated by the magnetic field B, ineffective. In the case of the other embodiments of the method according to the invention, the induced heating will have a different effect according to whether the nozzles are placed in proximity of the central elliptical heating area or in proximity of the heating areas at the edges.

[0077] In the case shown in Fig. 14b the gas jet can be applied at or above the side heating areas 9'. It must not be applied under these areas 9' because the coating could have already attained the solid state when it reaches these heating areas, therefore making ineffective the heating action generated by the magnetic field B' at the edges. Therefore, in this case the nozzles 4 are preferably placed at or above the side heating areas 9', because, if they are placed at the central heating area 9, the thermal power supplied to heat the edges could become superfluous, as the coating at the edges could have already solidified by the time it reaches the areas 9'.

[0078] In the case shown in Fig. 14c the gas jetcan be applied at or above the central-heating area 9. It must not be applied under this area because the coating could have already attained the solid state when it reaches this area 9, therefore making ineffective the heating action generated by the magnetic field B" at the centre of the strip.

[0079] Therefore, in this case the nozzles 4 are preferably placed at or above the central heating area 9, because, if they are placed at the side heating areas 9", the thermal power supplied to heat the central surface of the strip could become superfluous, as the coating in the centre could have already solidified by the time it reaches the central area 9.

[0080] In all embodiments of the method according to the invention the gas jet generation occurs above the heating area or the heating areas furthest from the melted coating material bath. Therefore, the nozzles 4 are arranged above or at the coils or the magnetic poles that cause the localised heating.

[0081] The localised heating of the strip coating, performed by induction using electromagnetic fields, therefore allows to compensate the cooling effect of the air knives in the zone where they perform.

[0082] Thanks to this localised heating, which maintains the coating in liquid state, the pneumatic "wiping" action of the air knives is facilitated. Therefore less pressure and less air knife flow rate are required in order-to obtain the same result, with the consequential reduction in noise produced by the jets and in the "splashing" problems. Alternatively, it is possible to work with the same air pressure or flow rate to obtain thinner coating thicknesses or a higher production line speed. Furthermore, the fact of concentrating the heating in the air knife zone of action limits the electrical power necessary and also limits the risk of overheating the strip and its coating. In fact, by supplying with monophase current, alternate or pulsed, the windings or the coils of the device according to the invention, in all variants of said second embodiment, in order to produce the magnetic fields B', B" it is possible to concentrate the-heating in a restricted zone that extends along the strip feeding plane in a vertical direction for- about 5÷100 mm. In this manner, the overlapping of the heating zone with the cooling zone (which extends for about 3÷10 mm), that is the air knife action zone, is optimized, thus improving the efficiency of the device and the method of the invention.

[0083] Contrarily, the known travelling field "wiping" systems produce heating zones, or thermal action zones, which extend for a much greater longitudinal distance, longer than at least 100 mm, and consequently are less efficient.

[0084] Furthermore, by supplying the windings or coils of the device of the invention, in all embodiments, with alternate or pulsed monophase current in order to produce the magnetic fields B,B',B", with the aforesaid predetermined frequency and intensity, it is possible to avoid local strip overheating to prevent the undesired formation of Zn-Fe alloys. An overheating lower than 50°C, could be acceptable and it can be efficaciously obtained by transferring specific power to the strip, lower than 0,9 MW/m^2. In reference to the devices illustrated in Figures 4a and 15, a variant can provide that the magnetic core or yoke 31 can also perform the function of air knife. This is possible because the polar expansions or magnetic poles 8, 8' can be appropriately shaped to define the nozzles 4 adapted to generate gas jets, as in the example in Fig. 16. In this variant, advantageously there are provided bulkheads 40, or slots, at the inlet section of said nozzles 4 which are conceived to equalise the flow rate inside the nozzles themselves. In this case, therefore, the nozzles 4 are defined by the configuration of the polar expansions 8, 8' and have a passage orifice which, when seen in transversal section (Fig. 16), has a shape tapering along the feeding direction of the strip. In the embodiment shown in Fig. 16, in particular, said passage orifice comprises two successive tapering stretches defining directions incident with one another. In this case the distance between the magnetic yoke poles 8, 8', respectively the upper one and the lower one, is comprised between 0,5 and 5 mm.

[0085] Advantageously, in order to reduce the induction heating of the support and supply structure of the gas knives, placed inside each ferromagnetic core 31 and comprising the manifold 32 and possibly the nozzles 4, it can be provided at least one high electrical conductivity electromagnetic shield, placed between said structure and the core 31, that performs two functions:

- preventing air knife overheating by induction,
- and concentrating the magnetic flux directly in the zone where the gas jet acts. Said at least one shield can also act as a magnetic field concentrator in the space between strip and magnetic core, partially increasing the local action efficacy of said field on the strip.

[0086] According to a further variant, said electromagnetic shield, placed inside the magnetic cores, can be shaped so that it forms the nozzle for the gas jets. In this case, therefore, the nozzles will be defined by the configuration of the electromagnetic shield or shields.

Claims

1. Method for controlling the thickness of a coating on a flat metal product, the product defining a feeding direction when it exits from a melted coating material bath in a continuous hot dip galvanizing process, wherein there are provided first means for generating

at least one alternate or pulsed monophase magnetic field, and second means, for generating gas jets, suitable for producing gas jets directed on the surfaces of major extension of said product, both said means being placed in proximity of said surfaces, the method comprising the following stages:

a) generating by said first means at least one alternate or pulsed monophase magnetic field (B, B', B"), in proximity of said surfaces of the product, said magnetic field, having an intensity between 0,05 and 1 T in air and a frequency between 5 Hz and 500 KHz, inducing a distribution of currents (6, 6', 6") on the surfaces thus producing, depending on the intensity and frequency of the magnetic field and on the geometry of the magnetic flux tubes, a concentration and distribution of heating on said surfaces, in order to generate at least one heating area (9, 9', 9", 9"') on said surfaces,
b) transferring power lower than 0,9MW/m^2 to the product in order to reach a product overheating lower than 50 °C,
c) generating gas jets, by said second means, at said at least one heating area in order to obtain a predetermined uniform coating thickness along the total width of the product.

2. Method according to claim 1, wherein the alternate or pulsed magnetic field (B) is uniform and has a direction substantially parallel to the feeding direction of the product.

3. Method according to claim 2, wherein the heating area (5), produced on each of said surfaces of the product, is substantially rectangular and covers the total width of said surfaces, including the edges.

4. Method according to claim 3, wherein said alternate or pulsed magnetic field has a frequency between 0,5 and 500kHz.

5. Method according to claim 4, wherein said alternate or pulsed magnetic field has a frequency between 10 kHz and 300 kHz.

6. Method according to claim 1, wherein the alternate or pulsed magnetic field (B', B") is not uniform and has a direction substantially perpendicular to the feeding direction of the product.

7. Method according to claim 6, wherein on said surfaces several heating areas are produced including a first central area (9, 9"'), substantially elliptical, and second side areas (9', 9") which are smaller than the first area in proximity of the edges of the product, said second heating area being produced above (9') and/or under (9") the first central heating area (9).

8. Method according to claim 7, wherein said alternate or pulsed magnetic field (B', B") has a frequency between 5 and 1000 Hz.

9. Method according to claim 8, wherein said alternate or pulsed magnetic field (B', B") has a frequency between 50 Hz and 500 Hz.

10. Method according to claim 4, 5, 8 or 9, wherein the thermal power supplied at the heating area or areas is variable between 1 and 50 kW.

11. Method according to claim 4, 5, 8 or 9, wherein the generation of the gas jets occurs above the heating area or areas furthest from the melted coating material bath.

12. Device for controlling the thickness of a coating on a flat metal product (1) according to the method of claim 1 comprising first means for generating (4) at least one alternate or pulsed monophase magnetic field and second means for generating gas jets suitable for producing gas jets directed on the surfaces of major extension of said product, both said means for generating the gas jets and the magnetic field being placed in proximity of said surfaces, the first means comprising at least one magnetic yoke, the magnetic poles thereof (10,10') in the magnetic gap having a surface inclined (20, 20') by an angle between 0° and 60° with respect to a vertical plane, or comprising a winding of non-uniformly distributed turns (7', 7") in order to define an internal surface inclined with respect to the vertical plane by an angle between 0° and 60 °.

13. Device according to claim 12, wherein there are provided two magnetic yokes, respectively provided with first poles (10) and second poles (10') arranged on both sides with respect to the feeding direction of the flat metal product (1) or there are provided two windings of non-uniformly distributed turns (7', 7") arranged on both sides with respect to the feeding direction of the strip in order to generate two alternate or pulsed magnetic fields (B', B") having opposite directions.

14. Device according to claim 13 wherein the two magnetic yokes have one common magnetic flux crossing the flat metal product twice in opposite directions.

Patentansprüche

1. Verfahren zum Überprüfen der Dicke einer Beschichtung auf einem flachen Metallprodukt, wobei das Produkt eine Transportrichtung definiert, wenn es von einem Beschichtungsmaterial-Schmelzbad in einem kontinuierlichen Feuerverzinkungs-Verfahren austritt, worin darin bereitgestellt werden erste Mittel zum Erzeugen wenigstens eines alternierenden oder gepulsten einphasigen Magnetfeldes, und zweite Mittel zum Erzeugen von Gasströmen, die geeignet sind zur Herstellung von Gas strömen, die auf die Oberflächen einer Haupt-Erstreckung des Produktes gerichtet sind, wobei beide der Mittel in der Nähe der Oberflächen platziert sind, wobei das Verfahren die folgenden Abschnitte umfaßt, daß man

(a) durch die ersten Mittel wenigstens ein alternierendes oder gepulstes einphasiges Magnetfeld (B, B', B") in der Nähe der Oberflächen des Produktes erzeugt, wobei das Magnetfeld eine Intensität zwischen 0,05 und 1 T in Luft und eine Frequenz zwischen 5 Hz und 500 kHz aufweist, eine Verteilung der Ströme (6, 6', 6") auf den Oberflächen induziert, und somit, abhängig von der Intensität und Frequenz des magnetischen Feldes und der Geometrie der Magnetflußröhre, eine Konzentration und Verteilung des Heizens auf den Oberflächen produziert, um wenigstens eine Heizfläche (9, 9', 9", 9'") auf den Oberflächen zu erzeugen;

(b) eine Energie, die niedriger ist als 0,9 MW/m^2, zu dem Produkt überführt, um eine Überhitzung des Produkts zu erreichen, die niedriger ist als 50 °C;

(c) Gasströme durch die zweiten Mittel an der wenigstens einen Heizfläche erzeugt, um eine vorbestimmte einheitliche Beschichtungdicke entlang der gesamten Breite des Produktes zu erhalten.

2. Verfahren nach Anspruch 1, worin das alternierende oder gepulste Magnetfeld (B) einheitlich ist und eine Richtung aufweist, die im Wesentlichen parallel zu der Transportrichtung des Produktes ist.

3. Verfahren nach Anspruch 2, worin die Heizfläche (5), hergestellt an jeder der Oberflächen des Produktes, im Wesentlichen rechteckig ist und die gesamte Breite der Oberflächen bedeckt, einschließlich der Ecken.

4. Verfahren nach Anspruch 3, worin das alternierende oder gepulste Magnetfeld eine Frequenz zwischen 0,5 und 500 kHz aufweist.

5. Verfahren nach Anspruch 4, worin das alternierende oder gepulste Magnetfeld eine Frequenz zwischen 10 kHz und 300 kHz aufweist.

6. Verfahren nach Anspruch 1, worin das alternierende oder gepulste Magnetfeld (B', B") nicht einheitlich ist und eine Richtung aufweist, die im Wesentlichen senkrecht zu der Transportrichtung des Produktes ist.

7. Verfahren nach Anspruch 6, worin auf den Oberflächen einige Heizflächen erzeugt werden, einschließlich einer ersten zentralen Fläche (9, 9'"), die im Wesentlichen elliptisch ist, und zweiten Seitenflächen (9', 9"), die kleiner sind als die erste Fläche, in der Nähe der Kanten der Produkte, wobei die zweite Heizfläche erzeugt wird oberhalb (9') und/oder unterhalb (9") der ersten zentralen Heizfläche (9).

8. Verfahren nach Anspruch 7, worin das alternierende oder gepulste Magnetfeld (B', B") eine Frequenz zwischen 5 und 1.000 Hz aufweist.

9. Verfahren nach Anspruch 8, worin das alternierende oder gepulste Magnetfeld (B', B") eine Frequenz zwischen 50 Hz und 500 Hz aufweist.

10. Verfahren nach Anspruch 4, 5, 8 oder 9, worin die thermische Energie, die an der Heizfläche oder den Heizflächen zugeführt wird, variabel ist zwischen 1 und 50 kW.

11. Verfahren nach Anspruch 4, 5, 8 oder 9, worin die Erzeugung der Gasströme oberhalb der Heizfläche oder den Heizflächen geschieht, die am weitesten weg von dem Beschichtungsmaterial-Schmelzbad sind.

12. Vorrichtung zum Überprüfen der Dicke einer Beschichtung auf einem flachen Metallprodukt (1) nach dem Verfahren von Anspruch 1, umfassend erste Mittel zum Erzeugen (4) wenigstens eines alternierenden oder gepulsten einphasigen Magnetfelds und zweite Mittel zum Erzeugen von Gasströmen, die geeignet sind zur Herstellung von Gasströmen, die auf die Oberflächen der Haupt-Erstreckung des Produktes gerichtet sind, wobei beide der Mittel zum Erzeugen der Gasströme und des magnetischen Feldes in der Nähe der Oberflächen platziert sind, wobei die ersten Mittel wenigstens eine magnetische Spule umfassen, die magnetischen Pole davon (10, 10') in dem Magnetspalt eine Oberfläche (20, 20') aufweisen, die, bezogen auf eine vertikale Ebene, in einem Winkel zwischen 0 ° und 60 ° geneigt ist, oder eine Wicklung von nicht einheitlich verteilten Windungen (7', 7") umfassen, um eine innere Oberfäche zu definieren, die, bezogen auf die vertikale Ebene, in einem Winkel zwischen 0 ° und 60 ° geneigt ist.

13. Vorrichtung nach Anspruch 12, worin zwei magnetische Spulen bereitgestellt werden, die jeweils mit ersten Polen (10) und zweiten Polen (10') versehen sind, die an beiden Seiten angeordnet sind, bezogen auf die Transportrichtung des flachen Metallproduktes (1) oder zwei magnetische Wicklungen von nicht einheitlich verteilten Windungen (7', 7") bereitgestellt werden, die an beiden Seiten angeordnet sind, bezogen auf die Transportrichtung des Streifens, um zwei alternierende oder gepulste Magnetfelder (B', B") zu erzeugen, die gegensätzliche Richtungen aufweisen.

14. Vorrichtung nach Anspruch 13, worin die zwei Magnetspulen einen gemeinsamen Magnetfluss aufweisen, der das flache Metallprodukt zweimal in gegensätzlichen Richtungen kreuzt.

Revendications

1. Procédé pour contrôler l'épaisseur d'un revêtement sur un produit métallique plat, le produit définissant une direction d'amenée lorsqu'il sort d'un bain de matériau de revêtement en fusion dans un processus de galvanisation à chaud continu, dans lequel sont prévus des premiers moyens pour produire au moins un champ magnétique monophasé alternatif ou pulsé, et de deuxièmes moyens pour produire des jets de gaz, aptes à produire des jets de gaz dirigés sur les surfaces d'extension majeure dudit produit, lesdits deux moyens étant placés à proximité desdites surfaces, le procédé comprenant les étapes suivantes :

a) produire par lesdits premiers moyens au moins un champ magnétique monophasé alternatif ou pulsé (B, B', B"), à proximité desdites surfaces du produit, ledit champ magnétique ayant une intensité entre 0,05 et 1 T dans l'air et une fréquence entre 5 Hz et 500 KHz, induisant une distribution de courants (6, 6', 6") sur les surfaces en produisant ainsi, en fonction de l'intensité et de la fréquence du champ magnétique et de la géométrie des tubes de flux magnétique, une concentration et distribution de chauffage sur lesdites surfaces, pour produire au moins une zone de chauffage (9, 9', 9", 9'") sur lesdites surfaces,
b) transférer une puissance inférieure à 0,9 MW/m^2 au produit pour atteindre une surchauffe de produit inférieure à 50 °C,
c) produire des jets de gaz, par lesdits deuxièmes moyens, à ladite au moins une zone de chauffage pour obtenir une épaisseur de revêtement uniforme prédéterminée sur la largeur totale du produit.

2. Procédé selon la revendication 1, dans lequel le champ magnétique alterné ou pulsé (B) est uniforme et a une direction sensiblement parallèle à la direction d'amenée du produit.

3. Procédé selon la revendication 2, dans lequel la zone de chauffage (5), produite sur chacune desdites surfaces du produit, est sensiblement rectangulaire et couvre la largeur totale desdites surfaces, incluant les bords.

4. Procédé selon la revendication 3, dans lequel ledit champ magnétique alternatif ou pulsé a une fréquence entre 0,5 et 500 kHz.

5. Procédé selon la revendication 4, dans lequel ledit champ magnétique alternatif ou pulsé a une fréquence entre 10 kHz et 300 kHz.

6. Procédé selon la revendication 1, dans lequel ledit champ magnétique alternatif ou pulsé (B', B") n'est pas uniforme et a une direction sensiblement perpendiculaire à la direction d'amenée du produit.

7. Procédé selon la revendication 6, dans lequel sur lesdites surfaces, plusieurs zone de chauffage sont produites, incluant une première zone centrale (9, 9'"), sensiblement elliptique, et des deuxièmes zones latérales (9', 9") qui sont plus petites que la première zone à^2 proximité des bords du produit, lesdites deuxièmes zones de chauffage étant produite au-dessus (9') et/ou en dessous (9") de la première zone de chauffage centrale (9).

8. Procédé selon la revendication 7, dans lequel ledit champ magnétique alternatif ou pulsé (B', B") a une fréquence entre 5 et 1000 Hz.

9. Procédé selon la revendication 8, dans lequel ledit champ magnétique alternatif ou pulsé (B', B") a une fréquence entre 50 Hz et 500 Hz.

10. Procédé selon la revendication 4, 5, 8 ou 9, dans lequel la puissance thermique fournie à la ou les zones de chauffage est variable entre 1 et 50 kW.

11. Procédé selon la revendication 4, 5, 8 ou 9, dans lequel la génération des jets de gaz a lieu au-dessus de la ou des zones de chauffage à la plus grande distance du bain de matériau de revêtement en fusion.

12. Dispositif pour contrôler l'épaisseur d'un revêtement sur un produit métallique plat (1) selon le procédé de la revendication 1, comprenant des premiers moyens pour produire (4) au moins un champ magnétique monophasé alternatif ou pulsé et des deuxièmes moyens pour produire des jets de gaz aptes à produire des jets de gaz dirigés sur les surfaces d'extension majeur dudit produit, les deux desdits moyens pour produire les jets de gaz et le champ magnétique étant placés à proximité desdites surfaces, les premier moyens comprenant au moins une culasse magnétique dont les pôles (10, 10’) dans l’entrefer magnétique ont une surface inclinée (20, 20’) selon un angle d’environ 0° et 60° relativement à un plan vertical, ou bien comprenant un enroulement de tours distribués non uniformément (7’, 7") pour définir une surface interne inclinée relativement au plan vertical selon un angle entre 0° et 60°.

13. Dispositif selon la revendication 12, dans lequel sont prévus deux culasses magnétiques, munies respectivement de premiers pôles (10) et de seconds pôles (10’) agencés sur les deux côtés relativement à la direction d’amenée du produit métallique plat (1), ou bien sont prévus deux enroulements de tours distribués non uniformément (7’, 7") agencés sur les deux côtés relativement à la direction d’amenée de la bande pour produire deux champs magnétiques alternatifs ou pulsés (B’, B") ayant des directions opposées.

14. Dispositif selon la revendication 13, dans lequel les deux culasses magnétiques ont un flux magnétique commun croisant le produit métallique plat deux fois dans des directions opposées.

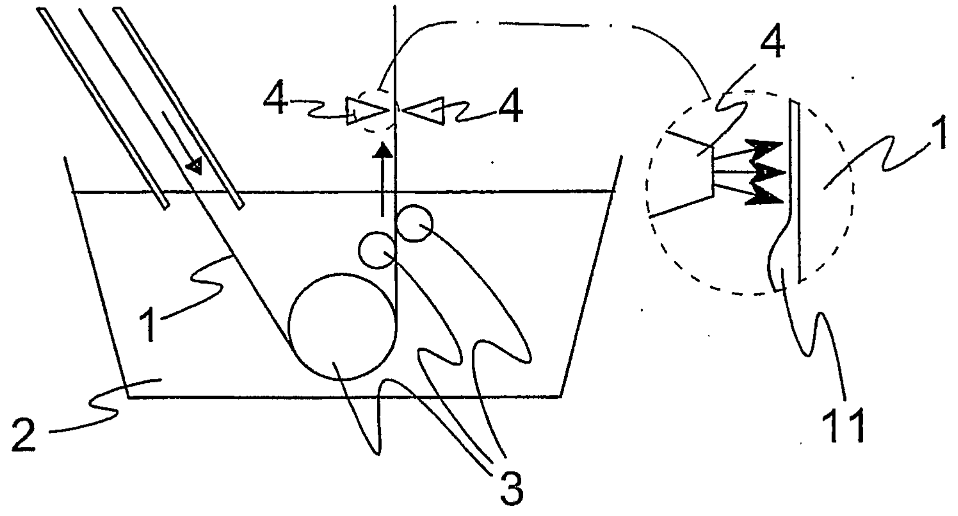

Fig. 1

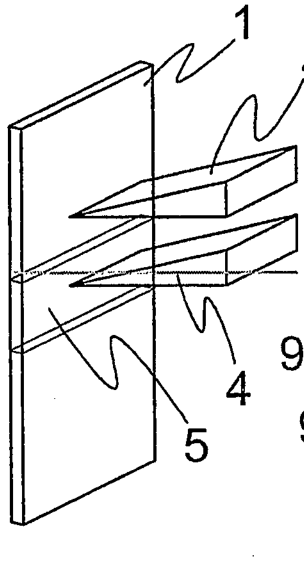

Fig. 14a

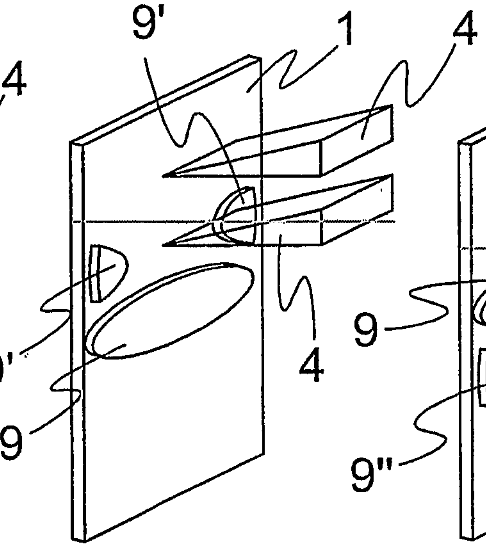

Fig. 14b

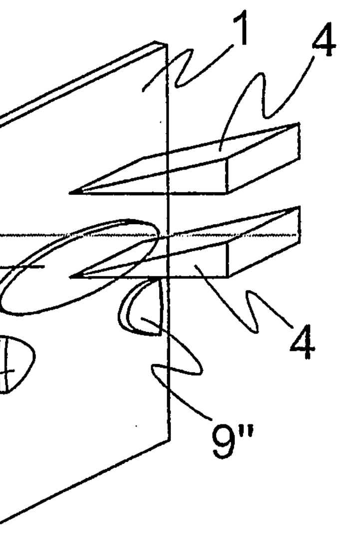

Fig. 14c

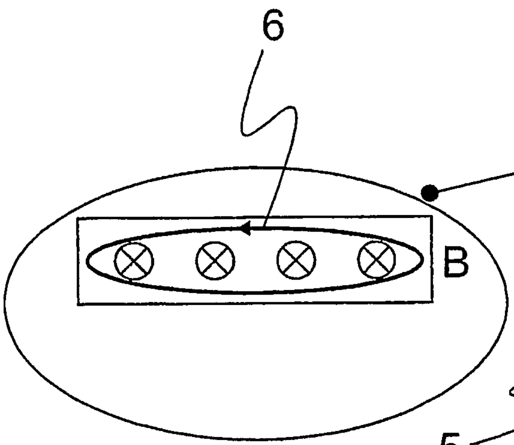

Fig. 2b

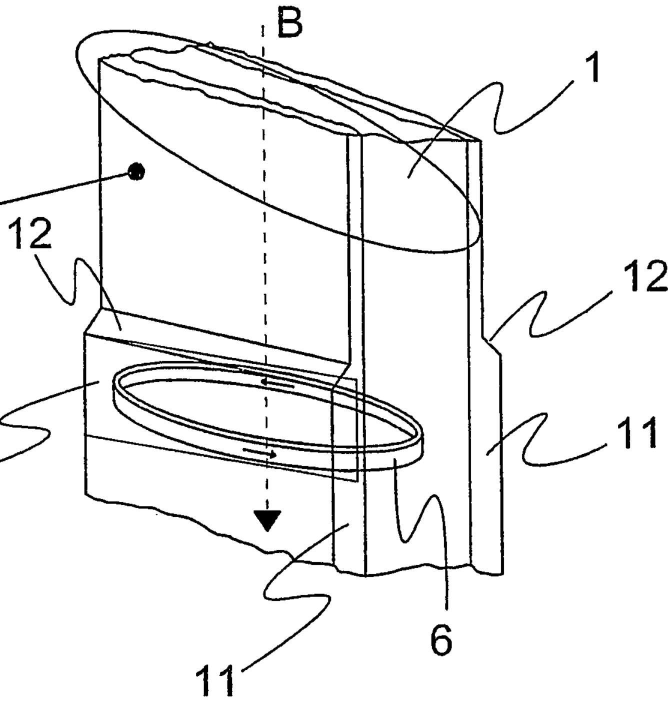

Fig. 2a

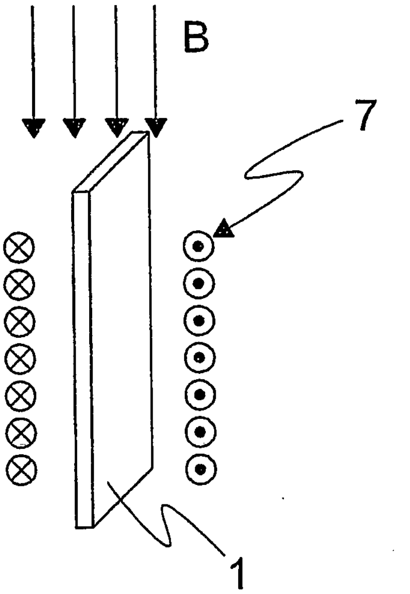

Fig. 3

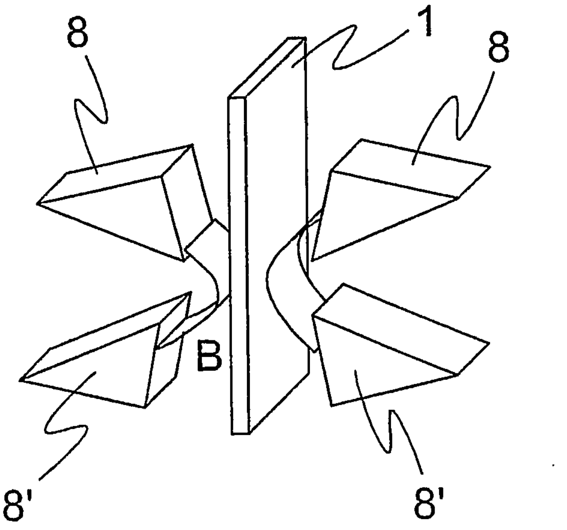

Fig. 4

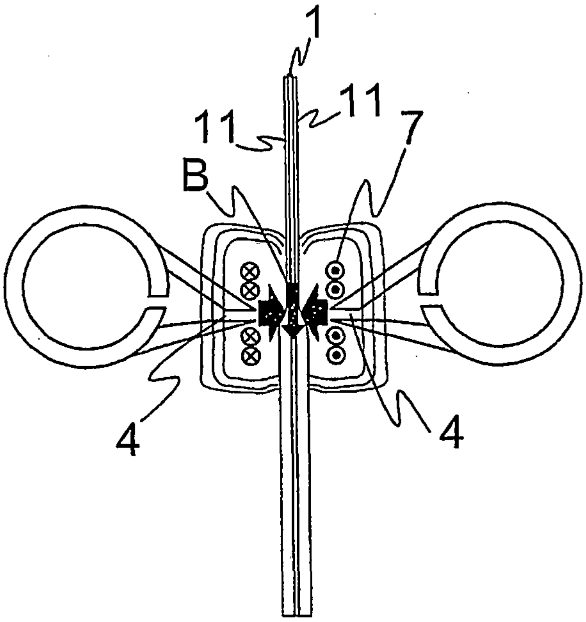

Fig. 3a

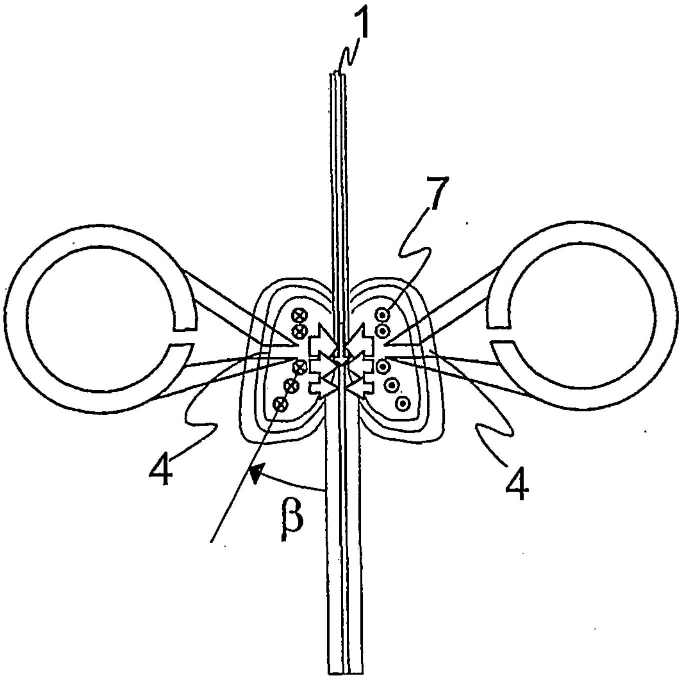

Fig. 3b

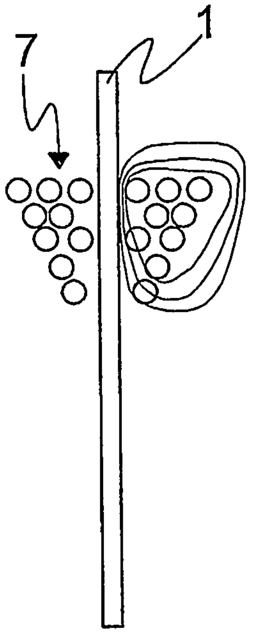

Fig. 3c

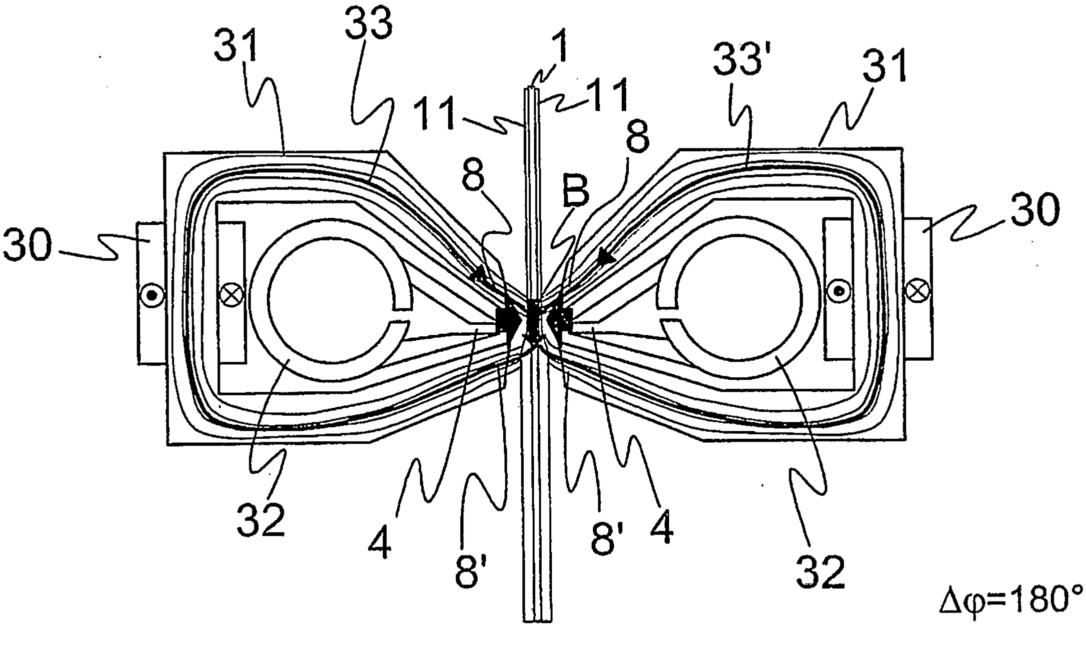

Fig. 4a

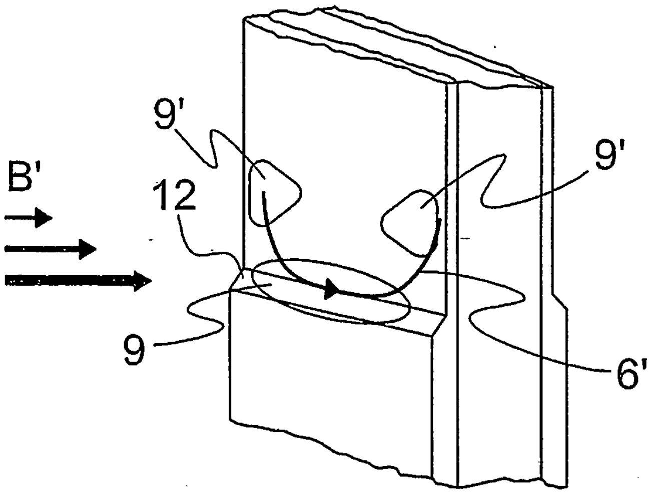

Fig. 5a

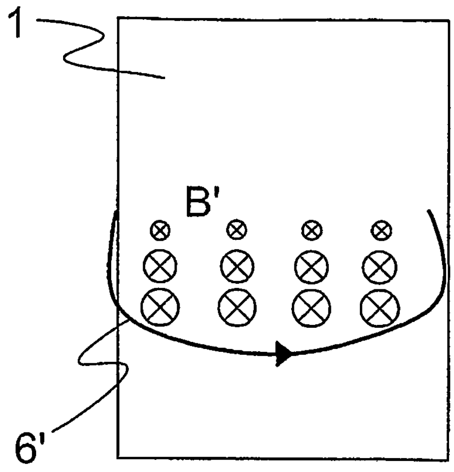

Fig. 5b

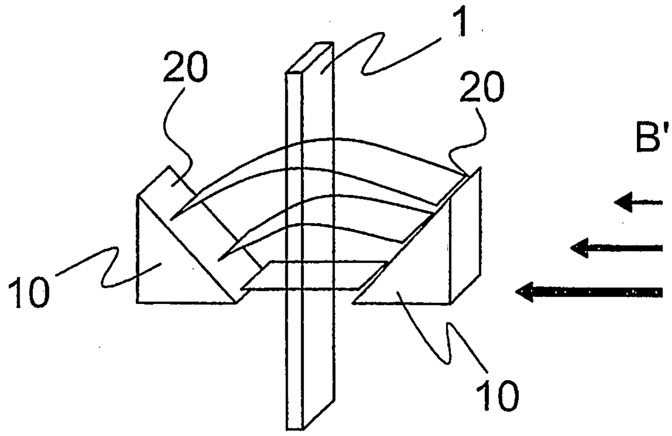

Fig. 6

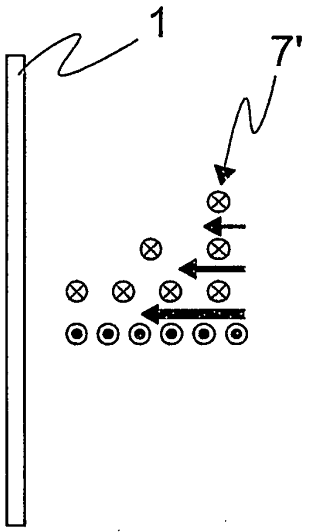

Fig. 7

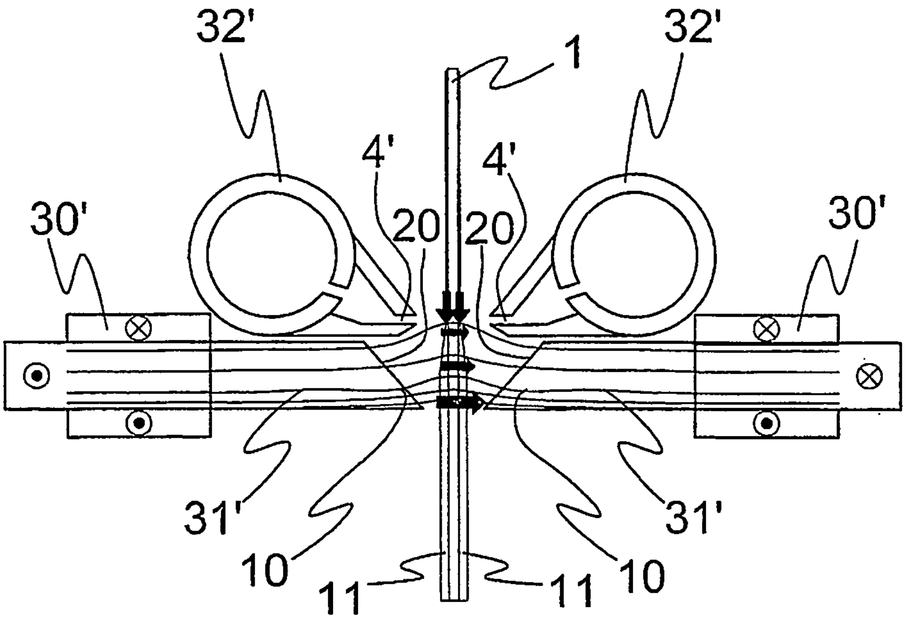
32'
1
32'
4'
4'
30'
20
20
30'
31'
31'
10
10
11
11

Fig. 6a

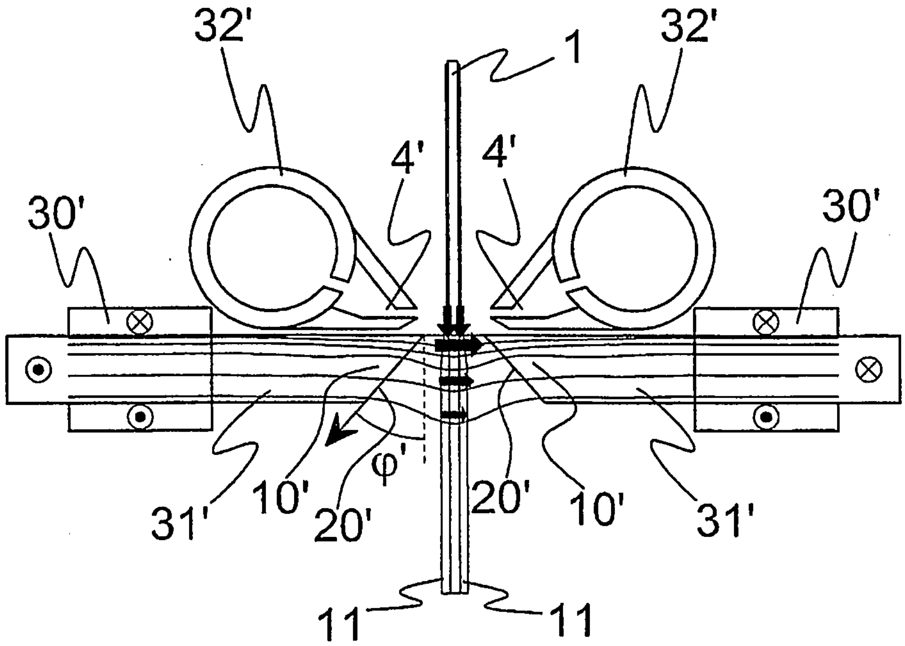
32'
1
32'
4'
4'
30'
30'
φ'
31'
10'
20'
20'
10'
31'
11
11

Fig. 9a

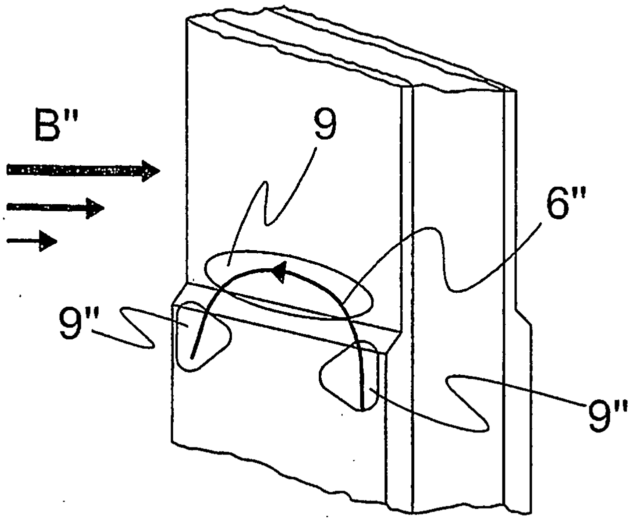

Fig. 8a

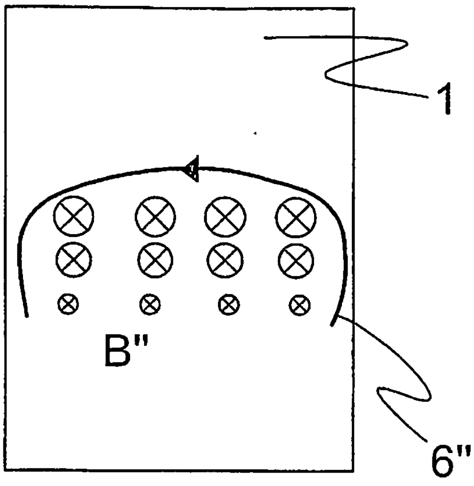

Fig. 8b

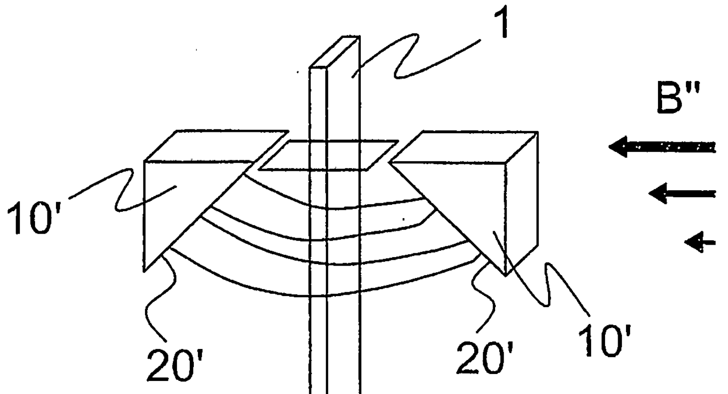

Fig. 9

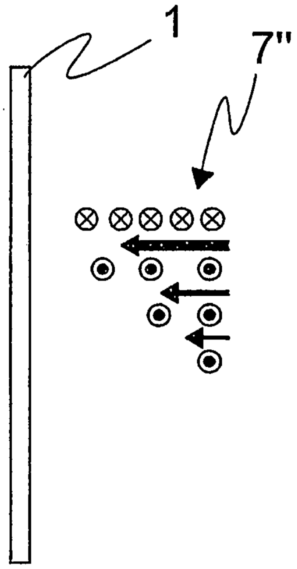

Fig. 10

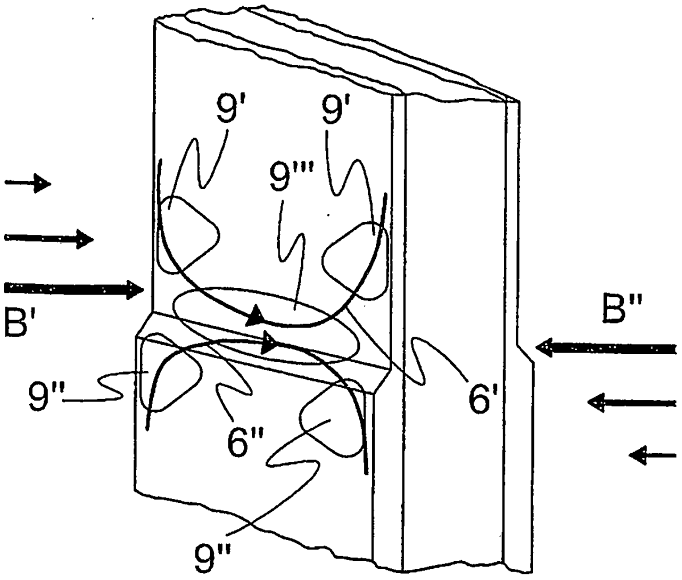

Fig. 11a

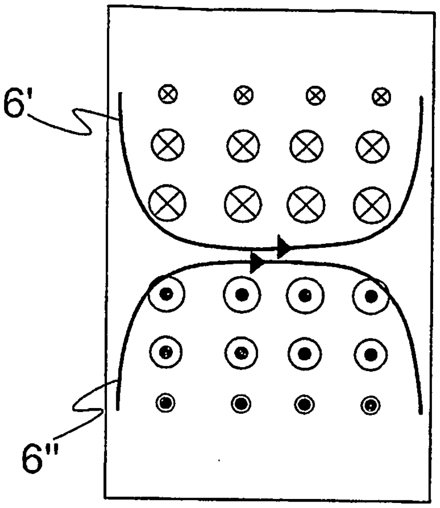

Fig. 11b

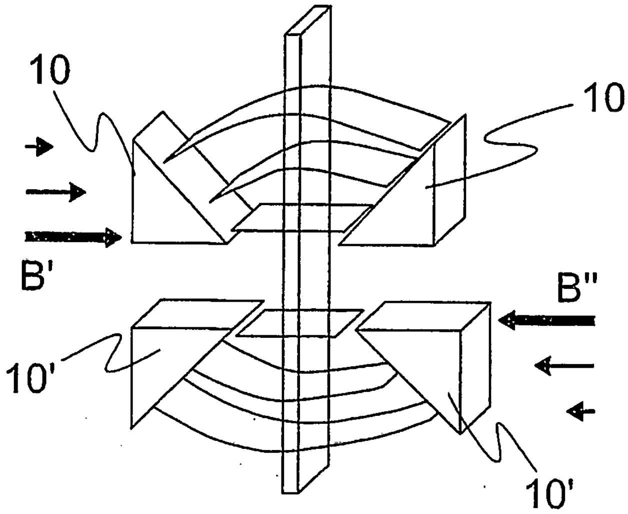

Fig. 12

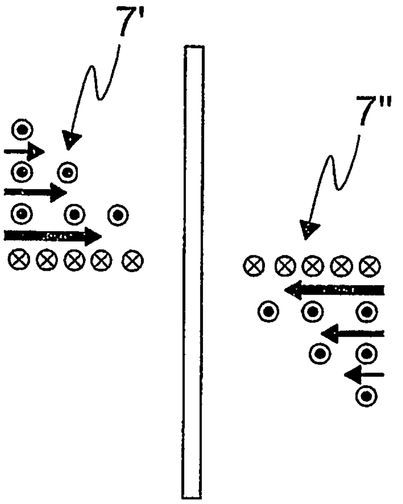

Fig. 13

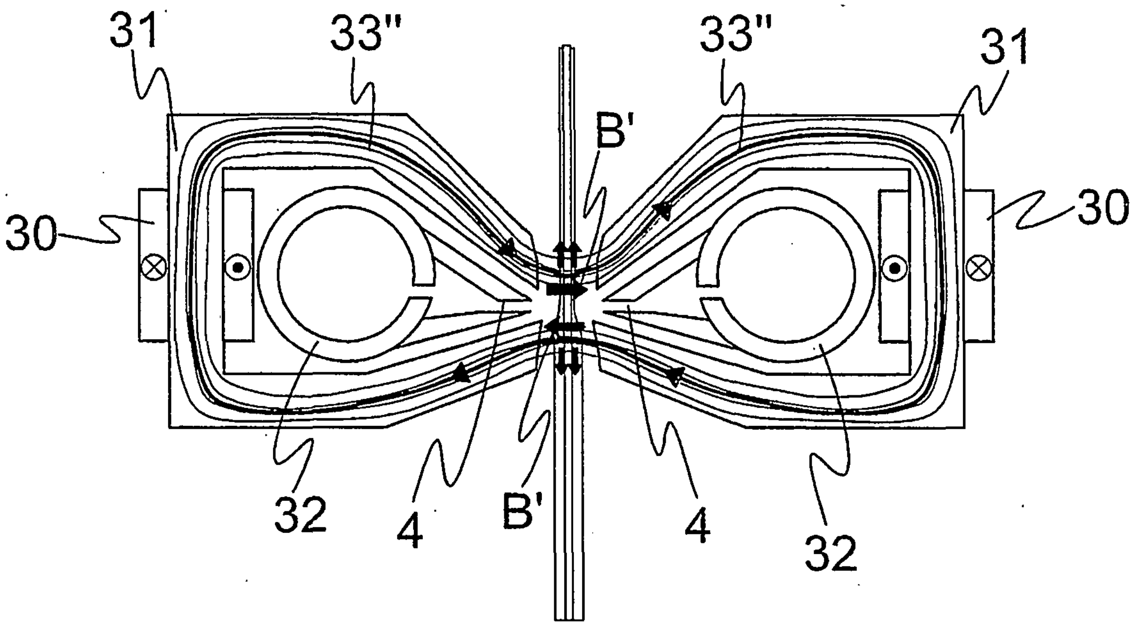

Fig. 15

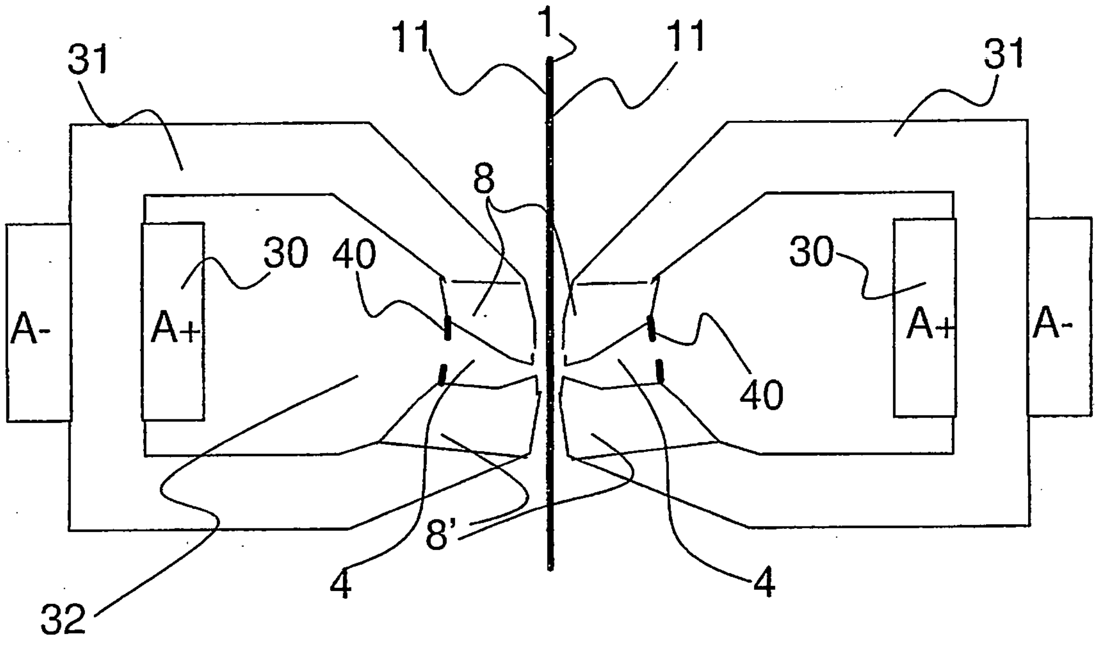

Fig. 16

REFERENCES CITED IN THE DESCRIPTION

Patent documents cited in the description

- EP 525387 A **[0019]**
- US 4273800 A **[0020]**