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ELECTROMAGNETIC PUMPS FOR PUMPING MOLTEN METAL

Filed Aug. 26, 1963

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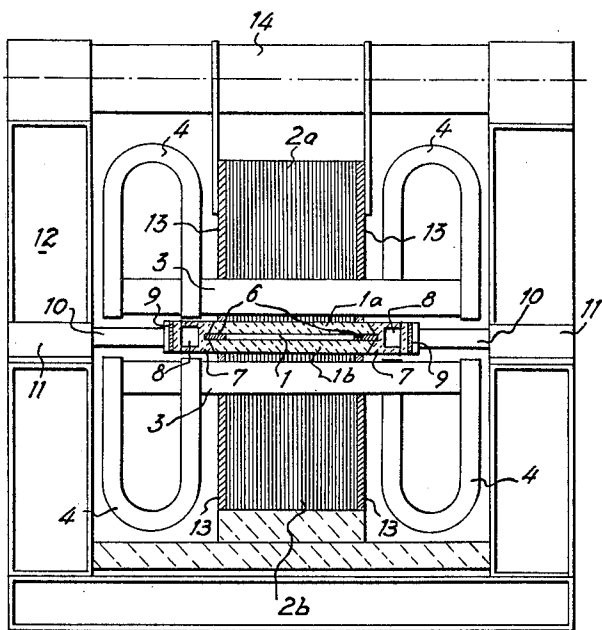
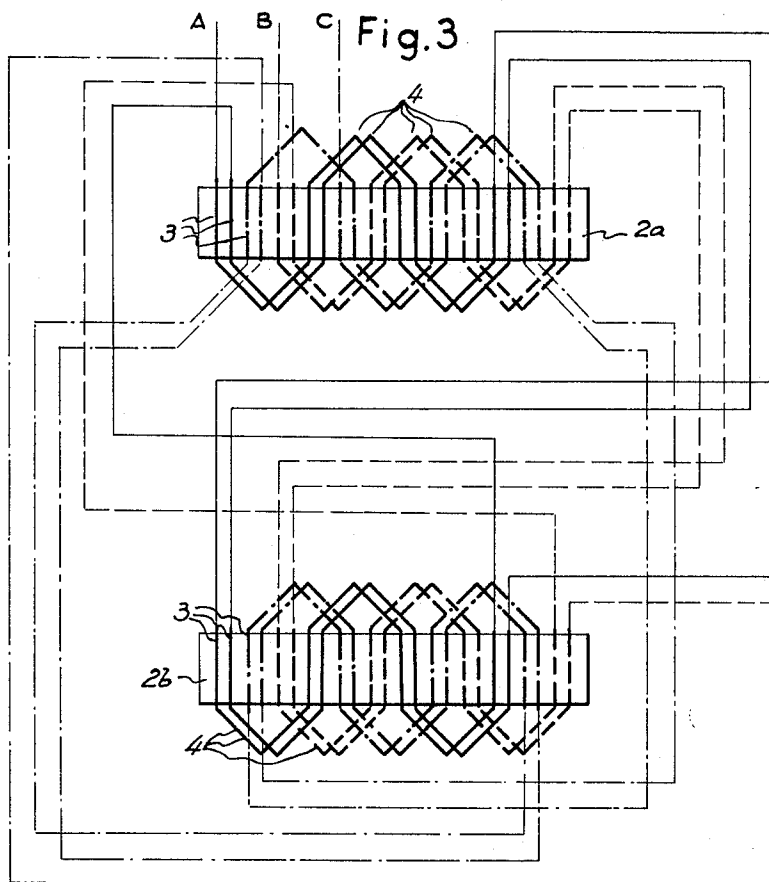


Fig. 1

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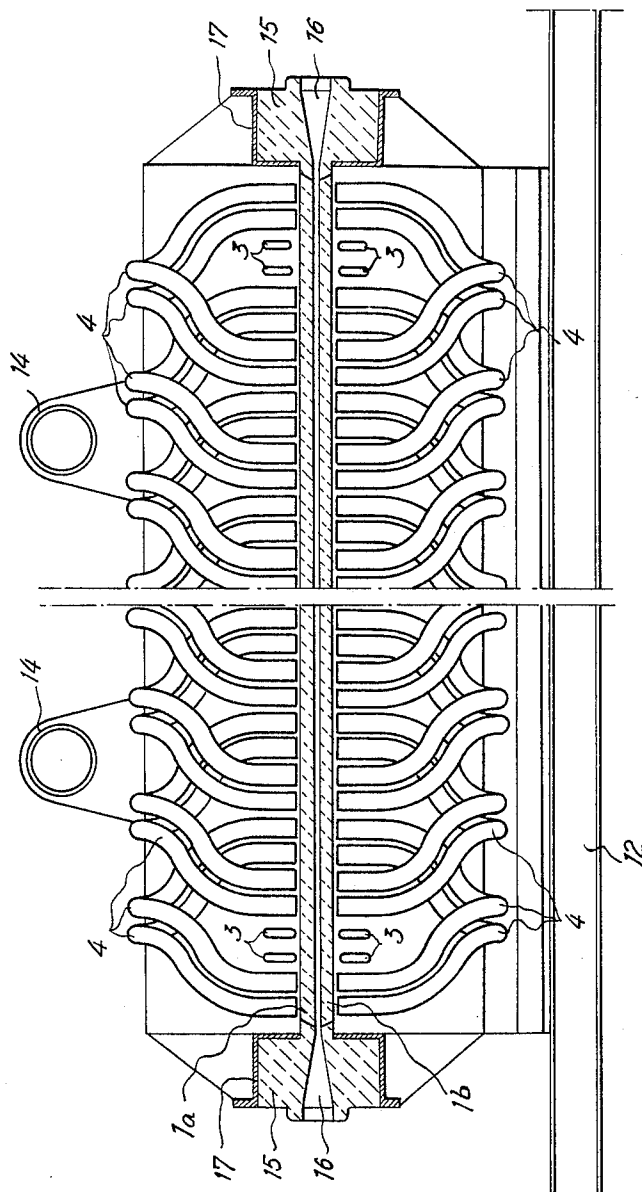
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Fig. 2



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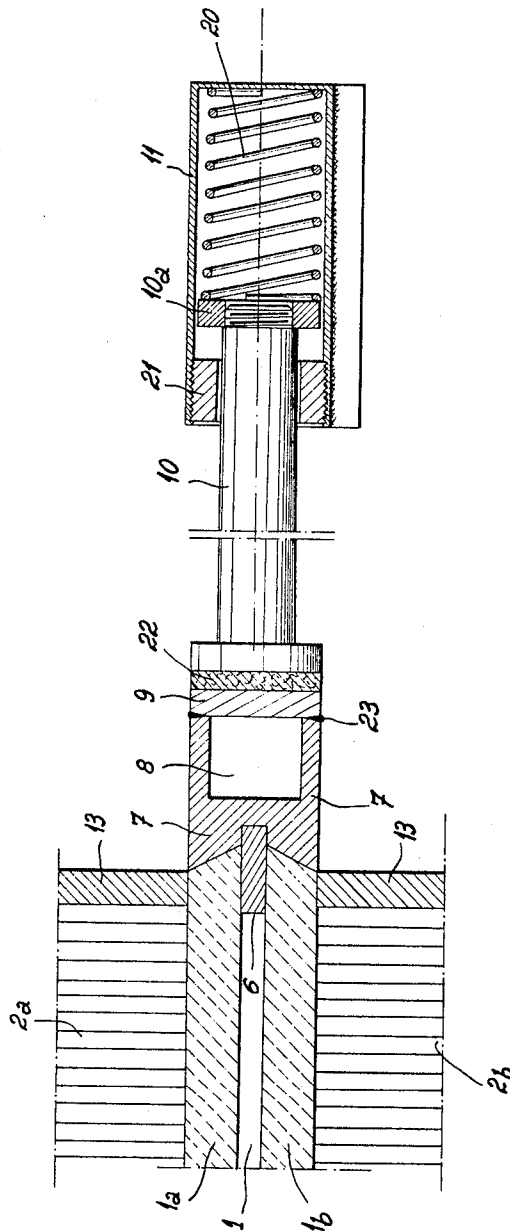
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FIG. 4



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**ELECTROMAGNETIC PUMPS FOR PUMPING
MOLTEN METAL**

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16 Claims. (Cl. 103—1)

The present invention relates to the transportation of molten metal.

In particular, the present invention relates to the pumping of molten metal.

For some time now electromagnetic devices of different types have been used for pumping molten metals. Devices of this type have been used, for example, to circulate metals of relatively low melting points, such as sodium or potassium, and these devices have been used for cooling purposes in certain nuclear reactors.

While attempts have been made to use such devices for metallurgical purposes in order to transport or cast molten metals of relatively high melting points, great difficulties have been encountered in such applications, and up to the present time very little practical use has been made of electromagnetic pumping devices for molten metals of high melting points.

In general these devices use the same general principle of operation, which is to say the action of magnetic field on an electric current, in this case a current traversing a stream of liquid metal, this principle being according to the well known law of Laplace. The force which acts on the liquid is in a direction normal to the direction of the lines of force of the field and the current which passes through the liquid element.

There are in fact two types of electromagnetic devices which are used for transporting liquid metals, one of the types of devices acting by conduction (action) and the other acting by induction (reaction). The devices of the first type involve the circulation of a strong intense current transversely through the stream of liquid metal, at a region where the stream of metal is in an intense magnetic field, the lines of force of this field are normal to the lines of current and to the longitudinal axis of the stream of metal, so that in this way a force acts on the stream of metal parallel to the longitudinal axis thereof. If the magnetic field is continuous, either as the result of a magnet or of a winding through which current flows continuously, the current which traverses the metal will also be continuous. Both the current and the field can be equally alternating and of the same frequency, and in this case the phases are adjusted in such a way that the mean force acting on the metal is a maximum in the desired direction. Devices of this general type are satisfactory for metals of low melting points, provided that there is available a material which is a good electrical conductor, sufficiently refractory, and incapable of being attacked by the molten metal so that it can constitute contacts for the passage of electric current through the molten metal. The problems encountered in such situations are often very difficult to solve.

With the second type of devices referred to above, the windings are traversed by an alternating current providing suitable magnetic fields which give rise to induced currents in the stream of metal, and the reaction of these currents on the magnetic fields creates the pumping forces provided that the induced currents are suitably oriented. Within this latter group of devices it is possible to distinguish between repulsion devices in which a ring of liquid metal constitutes the short-circuited secondary of a transformer of which the primary is a winding traversed

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by an alternating current, and devices having a "shifting" field in which the windings are situated along the stream of metal and are traversed by a suitable alternating current in general three-phase, providing a magnetic field which shifts or slides in the direction in which the stream of metal extends while passing normally therethrough. This inductive type of shifting field is analogous to the field of an asynchronous induction motor, particularly of the squirrel-cage type, and the present invention is particularly applicable to an electromagnetic, liquid metal pump which utilizes such a shifting field.

In devices of this type the reaction of the current induced in the metal on the inductive field transforms itself into a pressure within the molten metal itself. Such an arrangement is extremely simple because it is unnecessary to circulate an electrical current in the metal by means of an exterior source. However, in order to obtain a pumping pressure which is sufficiently high for practical industrial purposes it is essential to orient the induced currents in the stream of metal, and this problem is difficult to solve. Thus, elongated bars which have very high electrical conductivity may be placed in contact with the stream of metal extending in the same general direction as the stream of metal for the purpose of orienting the induced currents. If such measures are not taken the induced currents would necessarily close upon themselves and since they do not find a path of least resistance in the stream of metal they form instead an infinite number of small eddy currents which oppose each other. Thus, by placing at each side of the stream of molten metal elongated bars of very low electrical resistance in contact with the stream, it is possible for the lines of current to close upon themselves at the exterior of the stream of metal while these lines of current become oriented normally to the longitudinal axis of the stream of metal taking the shortest path from one electrically-conductive bar at one side of the stream of metal through the stream to the other electrically-conductive bar at the other side of the stream of metal. Thus, such electrically-conductive bars have with respect to the stream of metal the same relationship as the short-circuiting rings connecting the rotor bars of a squirrel-cage motor.

Thus, the problem of making electrical contact between such bars and the molten metal is common to devices of the above groups. However, the problem is a difficult one to solve inasmuch as the molten metal has a high melting point. For example, it is desirable to be able to electromagnetically pump a metal such as steel, and with induction devices of the above type it is essential that the lateral, electrically-conductive bars have an extremely low resistance relative to the resistance of the molten metal itself. It is highly desirable to be able to use such metals as copper or silver for the electrically-conductive bars, but unfortunately these materials do not have high melting points and thus they cannot be placed in contact directly with molten steel, for example.

It is accordingly a primary object of the present invention to provide a process and apparatus which make it possible to electrically interconnect a molten stream of metal which has a high melting point with electrical conductors of relatively low melting points and very low electrical resistances, so that in this way it becomes possible to provide the desired pumping efficiency which makes the electromagnetic pumping of molten metal of high melting points economically feasible.

In particular, it is an object of the invention to provide a process and apparatus which can reliably maintain over a long period of time an electrical connection between a molten metal of high melting point and electrical conductors of low resistance and low melting points.

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Also, it is an object of the invention to provide a process and apparatus which will make electrical connections of this type without producing any undesired physical or chemical reactions between the molten metal and structure in contact therewith.

It is furthermore an object of the present invention to provide a process and apparatus which make it possible to electromagnetically pump molten steel while maintaining an electrical connection between such molten steel and electrically-conductive bars made of copper, for example.

It is furthermore an object of the invention to provide a structure capable of accomplishing the above objects while at the same time being composed of relatively simple rugged elements which can be quickly and easily assembled and disassembled and which will have a long operating life.

With these objects in view the invention includes, in an electromagnetic pump for pumping a molten metal, an elongated outer electrically-conductive bar of low resistance extending in the same general direction as and spaced from but located adjacent a stream of molten metal, and an inner bar of substantially the same properties as the molten metal in contact with the latter as well as with the outer bar to provide an electrical connection between the molten metal and the outer bar, the structure of the invention also including a cooling means which provides for the portion of the inner bar which engages the outer bar a temperature sufficiently low to maintain the inner bar at least partially in a solid state. The process of the invention includes the steps of maintaining, in an electromagnetic pump for pumping molten steel, a copper bar in electrical connection with the molten steel by way of a ferrous metal bar located between and engaging both the copper bar and the molten steel while maintaining the portion of the ferrous bar which engages the copper bar at a temperature on the order of 25° C.

The novel features which are considered as characteristic for the invention are set forth in particular in the appended claims. The invention itself, however, both as to its construction and its method of operation, together with additional objects and advantages thereof, will be best understood from the following description of specific embodiments when read in connection with the accompanying drawings, in which:

FIG. 1 is a partly schematic transverse sectional view of one possible embodiment of an electromagnetic pump according to the present invention;

FIG. 2 is a fragmentary schematic longitudinal partly sectional elevation of the electromagnetic pump of FIG. 1;

FIG. 3 is a schematic illustration of the windings and electrical connections of the pump of the invention; and

FIG. 4 is a fragmentary view on an enlarged scale of part of the structure of FIG. 1.

The figures illustrate an electromagnetic pump designed to pump liquid steel at a rate of flow which can attain 50 tons per hour under a pressure of approximately 10 atmospheres.

The stream of molten steel flows along a passage 1 which has a rectangular cross section and which has an extremely small depth while being of a width which is very great in relation to its depth. The passage 1 for the stream of molten metal is formed in part by a pair of plates 1a and 1b which are made of materials which have extremely high melting points, much higher than the melting point of steel, and which have an extremely great electrical and mechanical resistance. For example, the plates 1a and 1b which are spaced from each other as shown particularly in FIGS. 1 and 4 may be made of a ceramic material, and zirconia has proved to be particularly suitable for the plates 1a and 1b. It will be noted that the plates 1a and 1b have outer side edges which are bevelled. These ceramic plates 1a and 1b are clamped between two groups of transformer laminations 2a and 2b, which form the magnetic armatures. Above and below

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the passage 1 are located horizontal electrically-conductive bars 3 which extend perpendicularly across the stream of metal, these bars 3 being situated within corresponding insulated notches of the magnetic armatures 2 and being maintained within these notches by means of wedges identical with those utilized for maintaining the windings of electric motors in their notches, and these wedges are not illustrated in the drawings for the sake of clarity.

The bars 3 are connected in series by means of exterior connections 4 having a special form as shown particularly in FIG. 2, and they are formed into an undulating, imbricated, three-phase series winding according to the diagram shown in FIG. 3. In FIG. 3 the upper and lower bars are shown in a plan view, although normally the two parts shown in FIG. 3 are placed one above the other. The connections are similar to those of an induction motor, and the entire construction is the same as if the stator of an asynchronous, three-phase induction motor is unrolled so as to have a flat configuration. The rotating field of such an asynchronous motor is thus replaced in this case by the sliding or shifting field which shifts perpendicularly to the plane of FIG. 3 and which becomes displaced in a direction parallel to itself and parallel to the longitudinal axis of the stream of molten metal. The shifting field induces in the molten metal currents on which it exercises forces which entrain the metal and cause it to flow in the same direction as the direction of displacement of the field. The windings are supplied at A, B, and C with current from a three-phase network. The bars 3 as well as the exterior connections 4 therebetween are hollow and are traversed by a cooling liquid.

The molten metal which flows through the pump has a high temperature on the order of 1600° C. or more, so that the cooling is particularly important. For this reason the disposition of electrically-conductive bars above and below the passage 1 is of particular advantage. In effect, besides reinforcing the field, which results from this arrangement, this device has the advantage of producing a symmetrical cooling of the two magnetic masses against which the refractory plates 1a and 1b are located.

As has been indicated above, the ceramic plates 1a and 1b are spaced from each other and define part of the passage 1 through which the molten metal flows, and a particular feature of the invention resides in the structure which completes the passage 1 and which provides the electrical connection between the molten metal and electrically-conductive bars of low resistance as referred to above. Thus, there are situated between the plates 1a and 1b, a pair of inner elongated electrically-conductive bars 6 (FIGS. 1 and 4), and in the case of molten steel, these bars 6 are also made of steel or at least of a ferrous metal so that they will not have any undesired physical or chemical reaction with the molten metal. The inner bars 6 are in engagement at their outer side edges, which project beyond the plates 1a and 1b, with a pair of outer bars 7 which are preferably made of copper and which serve to orient the current in the manner described above. As is apparent from FIGS. 1 and 4, the copper bars 7 are formed with substantially V-shaped grooves which receive the bevelled side edges of the refractory plates 1a and 1b, and in addition the copper bars 7 are formed with additional groove portions which receive the outer side edge portions of the inner bars 6 which project beyond the plates 1a and 1b, and these bars 6 may be brazed to the outer bars 7, if desired. Thus, it will be seen that the inner side edges of the bars 6 which are directed toward each other define with the inner surfaces of the plates 1a and 1b, which are also directed toward each other, the passage 1 through which the molten metal flows in the form of a ribbon or sheet of molten metal of extremely small thickness and of relatively great width, and furthermore it will be noted that with this arrangement the bars 6 which are of the same properties as the molten metal are directly in contact with the molten metal. Because of the high temperature of the molten metal it is

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necessary to provide an extremely effective cooling for the bars 6, and in accordance with the present invention a cooling means is provided, this cooling means acting on the bars 6 for maintaining them at least at their portions which engage the outer bars 7 at temperatures low enough to maintain the bars 6 in a solid state at least in part. The cooling means is formed by the outer portions of the outer bars 7. Thus, these outer portions of the bars 7 are hollow so as to form the elongated hollow conduits 8 through which a cooling liquid is adapted to circulate. As is apparent particularly from FIG. 4 the passages 8 are closed by plates 9 also of copper and brazed, as indicated at 23 in FIG. 4, to the bars 7 so as to close the passages 8 through which the cooling liquid flows.

In order to maintain the bars 7 in the illustrated positions in engagement with the plates 1a and 1b, pushers 10 engage the bars 7 and push them toward each other. A series of pushers 10 are arranged on each side of the assembly with one row engaging one of the bars 7 and the other row engaging the other bar 7, and the details of each of the pushers 10 are shown most clearly in FIG. 4. Thus, it will be seen from FIG. 4 that each pusher bar 10 acts on a fiber shim 22 to push the latter against the closure plate 9 which in turn pushes the bar 7, and a spring 20 acts on each bar 10. Thus, the bar 10 extends slidably through a suitable sleeve 21 located within a tubular housing 11, and at its end within the tubular housing 11 the bar 10 threadedly carries a ring 10a on which one end of the spring 20 presses, the other end of the spring 20 engaging the closed end of the tubular housing 11 which is fixed to the frame of the apparatus, so that in this way the several springs 20 act on the several pushers 10 on both sides of the apparatus to urge one row of pushers toward the other row of pushers and thus in this way the pair of bars 7 are urged toward each other. Because of the bevelled side edges of the refractory plates 1a and 1b and the substantially V-shaped grooves of the bars 7 which receive these bevelled side edges, the pushing of the bars 7 toward each other by the rows of pushers 10 urges the refractory plates 1a and 1b toward each other so that they press against the bars 6 which maintain the plates 1a and 1b spaced from each other, and in addition it is to be noted that the laminations 2a and 2b also press against the plates 1a and 1b. The dimensions and location of the inner ferrous bars 6 are such that they are situated just outside of the magnetic field.

During the normal functioning of the apparatus they are directly in contact with the molten steel and thus assure the desired electrical connection between the copper bars 7 and the molten metal. The heat of the molten metal is of course transferred to the bars 7 through the inner bars 6, and the copper bars absorb the heat which is very effectively carried away by the circulation of the cooling water or other liquid in the conduits 8, the portion of the bars 7 which are formed with the conduits 8 forming the cooling means for cooling the outer edge portions of the bars 6 which are situated distant from the molten metal. Thus, the steel or other ferrous metal bars 6 are in contact with the molten metal which is at a relatively high temperature (on the order of 1600° C.) while at their outer edge portions these bars 6 are maintained at a relatively low temperature on the order of 25° C., so that in this way with the cooling action properly regulated a very effective cooling is provided which guarantees that the bars 6 will be maintained in the solid state. Actually, with proper cooling there exists a boundary layer separating the molten steel and the solid steel of the bars 6, and with proper cooling it has been found that the bars 6 do not melt.

The entire assembly is mounted on a frame 12 composed of members such as angle bars of H section, and the polar masses are maintained in place by means of sheets 13 which are fixed to the frame 12. A pair of

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transverse bars 14 are connected to the top of the frame so that the entire assembly can be conveniently handled.

In order to obtain a magnetic field which is as intense as possible, the thickness of the ribbon of molten metal which flows through the device is maintained at a minimum. In an actual construction of the type illustrated in the drawings the thickness of the passage 1 is in the neighborhood of 1 cm., and the width of the passage 1 is in the neighborhood of 20 cm., the space between the polar masses 2a and 2b being on the order of 5 cm. In other words, each of the plates 1a and 1b will have a thickness of approximately 2 cm. and these plates will be spaced from each other by a distance of 1 cm. so that the total distance between the laminations 2a and 2b is 5 cm. At each end of the device the passage 1 (FIG. 2) communicates with a conduit for the molten metal by way of a refractory fitting 15 having the general form of a parallelepiped, each fitting 15 being formed with a flared passage 16 communicating at its small end with the passage 1 and at its large end with a suitable conduit which is not illustrated and which may have a circular section, the fittings 15 being situated within metallic casings 17 which are fixed to the frame of the apparatus.

At its small end each passage 16 of course has a cross sectional configuration corresponding to the cross sectional configuration of the passage 1 so that the molten metal flows into and out of the passage 1 from the passages 16 of the fittings 15 shown in FIG. 2 in a very smooth manner.

As was pointed out above, the device which is illustrated by way of example in the drawings is designed to provide a flow of molten steel at a rate of 50 tons per hour and at a maximum pressure in the neighborhood of 10 atmospheres. The construction which is designed for this purpose is provided with 60 bars 3 above the passage 1 and an equal number below the passage 1, and these bars are traversed by electrical current whose intensity can attain 3000 amperes. The total power required ranges between 150 and 200 kw.

It will be understood that each of the elements described above, or two or more together, may also find a useful application in other types of pumps differing from the types described above.

While the invention has been illustrated and described as embodied in electromagnetic pumps, it is not intended to be limited to the details shown, since various modifications and structural changes may be made without departing in any way from the spirit of the present invention.

Without further analysis, the foregoing will so fully reveal the gist of the present invention that others can by applying current knowledge readily adapt it for various applications without omitting features that, from the standpoint of prior art, fairly constitute essential characteristics of the generic or specific aspects of this invention and, therefore, such adaptations should and are intended to be comprehended within the meaning and range of equivalence of the following claims.

What is claimed as new and desired to be secured by Letters Patent is:

1. In an electromagnetic pump for pumping molten metal, in combination, an outer elongated electrically-conductive bar extending in the same general direction as and located along a stream of molten metal which is pumped by the electromagnetic pump; an inner elongated electrically-conductive metallic bar of substantially the same composition as the stream of molten metal, said inner bar being located between and engaging both the stream of molten metal and the outer electrically-conductive bar for electrically connecting the latter to the stream of metal, the material of said outer electrically-conductive bar having a lower melting point and a higher electrical conductivity than the material of said inner bar; and cooling means for cooling at least that portion of said inner bar which engages said outer bar for maintaining

said portion of said inner bar at a temperature sufficiently low to maintain at least said portion of said inner bar in a solid state.

2. In an electromagnetic pump for pumping molten metal, in combination, an elongated outer electrically-conductive bar extending in the same general direction as and located along a stream of molten metal which is pumped by the electromagnetic pump; an inner elongated electrically-conductive metallic bar of substantially the same composition as the stream of molten metal and located between and engaging both the stream of molten metal and the outer bar for placing the latter in electrical communication with the stream of molten metal, the material of said outer electrically-conductive bar having a lower melting point and a higher electrical conductivity than the material of said inner bar; and cooling means for cooling that portion of said inner bar which engages said outer bar for maintaining said portion of said inner bar at a temperature sufficiently low to maintain said inner bar at least partially in a solid state.

3. In an electromagnetic pump for pumping molten metal, said pump providing a magnetic field which participates in the pumping of the molten metal, in combination, an outer elongated electrically-conductive bar extending in the same general direction as and located along a stream of molten metal which is pumped; an inner electrically-conductive bar located between and engaging both the stream of molten metal and the outer bar for placing the latter in electrical communication with the stream of molten metal, said inner bar being located at least partially beyond the magnetic field of the pump; and cooling means for cooling that portion of said inner bar which engages said outer bar for maintaining said portion of said inner bar at a temperature low enough to maintain said inner bar at least partially in a solid state.

4. In an electromagnetic pump for pumping molten metal, in combination, an outer elongated electrically-conductive bar extending in the same general direction as the stream of molten metal which is pumped and located adjacent but spaced from the stream; an inner electrically-conductive bar of substantially the same composition as said stream of molten metal, said inner bar being located between and engaging both the stream of molten metal and the outer bar for placing the latter in electrical communication with the stream of molten metal, the material of said outer electrically-conductive bar having a lower melting point and a higher electrical conductivity than the material of said inner bar; and cooling means for cooling that portion of the inner bar which engages said outer bar for maintaining said portion of said inner bar at a temperature sufficiently low to maintain at least said portion of the inner bar in the solid state, said cooling means including part of said outer bar which is hollow and through which a cooling fluid is adapted to flow for maintaining the portion of the inner bar which engages the outer bar at said sufficiently low temperature.

5. In an electromagnetic pump for pumping molten metal, in combination, a pair of outer elongated hollow electrically-conductive bars; and a pair of inner electrically-conductive metallic bars of the same composition as the molten metal, said pair of inner bars engaging and located between the outer bars and adapted to engage also a stream of molten metal which is pumped by the pump so as to place said outer bars in electrical communication with the stream of molten metal, the electrical conductivity of said hollow outer bars being greater than the electrical conductivity of said inner bars and said hollow outer bars being adapted to have a cooling fluid flowing therethrough for maintaining the portions of said inner bars which respectively engage said outer bars at temperatures sufficiently low to maintain said inner bars in the solid state.

6. In an electromagnetic pump for pumping molten metal, in combination, a pair of spaced parallel plates of a material which has very little electrical conductivity and

very high melting points substantially higher than the temperature of the molten metal which is pumped; a pair of inner bars located between said plates at side edge portions of the latter for maintaining said plates spaced from each other and for defining with said plates an elongated passage through which a stream of molten metal is adapted to flow; a pair of outer elongated electrically conductive bars engaging the outer side edges of said plates and also engaging said inner bars to be placed by the latter in electrical communication with the stream of molten metal; and cooling means for cooling those portions of said inner bars which engage said outer bars for maintaining said portions of said inner bars at temperatures sufficiently low to maintain said inner bars at least partially in a solid state.

7. In an electromagnetic pump for pumping molten metal, in combination, a pair of mutually spaced parallel plates of a material of electrical conductivity substantially lower than the electrical conductivity of the molten metal and a very high melting point substantially higher than the temperature of the molten metal which is pumped; a pair of inner electrically-conductive bars located between said plates at side edge portions thereof and maintaining said plates spaced from each other, said bars defining with said plates an elongated passage through which a stream of molten metal is adapted to flow; a pair of outer elongated electrically conductive bars engaging said plates at side edge portions thereof and also engaging said inner bars to be placed by the latter in electrical communication with the stream of molten metal, said outer bars being hollow so that a cooling fluid can flow through said outer bars for maintaining the portions of said inner bars which engage said outer bars at temperatures sufficiently low to maintain said inner bars at least partially in a solid state.

8. In a pump as recited in claim 7, said inner bars respectively having edge portions which project beyond said plates and said outer bars being respectively formed with grooves which receive said portions of said inner bars.

9. In a pump as recited in claim 7, said outer bars being respectively formed with substantially V-shaped grooves which receive said side edge portions of said plates, said side edge portions of said plates being bevelled and mating with said grooves of said outer bars.

10. In a pump as recited in claim 9, spring means urging said outer bars toward each other so that the outer bars urge through said grooves and bevelled edges of said plates, said plates toward each other to press against said inner bars.

11. In a pump as recited in claim 10, said inner bars having outer edge portions projecting beyond said plates and said outer bars having groove portions which receive said outer portions of said inner bars.

12. In a pump as recited in claim 11, said inner bars being made of a material which has substantially the same properties as the stream of molten metal.

13. In a process for electromagnetically pumping a molten metal, the steps of maintaining in engagement with the molten metal a bar of a material which is electrically conductive and whose properties prevent any chemical or physical reaction between the molten metal and the bar; maintaining in engagement with the first-mentioned bar, but out of contact with the molten metal, a second bar of a material exhibiting a greater electrical conductivity but having a lower melting point than the material of said first mentioned bar; and cooling the first-mentioned bar to a temperature sufficiently low to maintain said first-mentioned bar at least partially in a solid state.

14. In a process for pumping molten steel, the steps of maintaining in engagement with a stream of molten steel during pumping thereof a ferrous bar while also maintaining in contact with the ferrous bar but out of contact with the stream of steel an elongated additional bar of a material of high electrical conductivity; and

cooling the ferrous bar to an extent sufficient to maintain the ferrous bar in the solid state.

15. In a process as recited in claim 14, said bar of high electrical conductivity being made of copper.

16. In a process as recited in claim 15, the portion of said ferrous bar which engages said copper bar being maintained at a temperature of approximately 25° C.

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