

Feb. 7, 1961

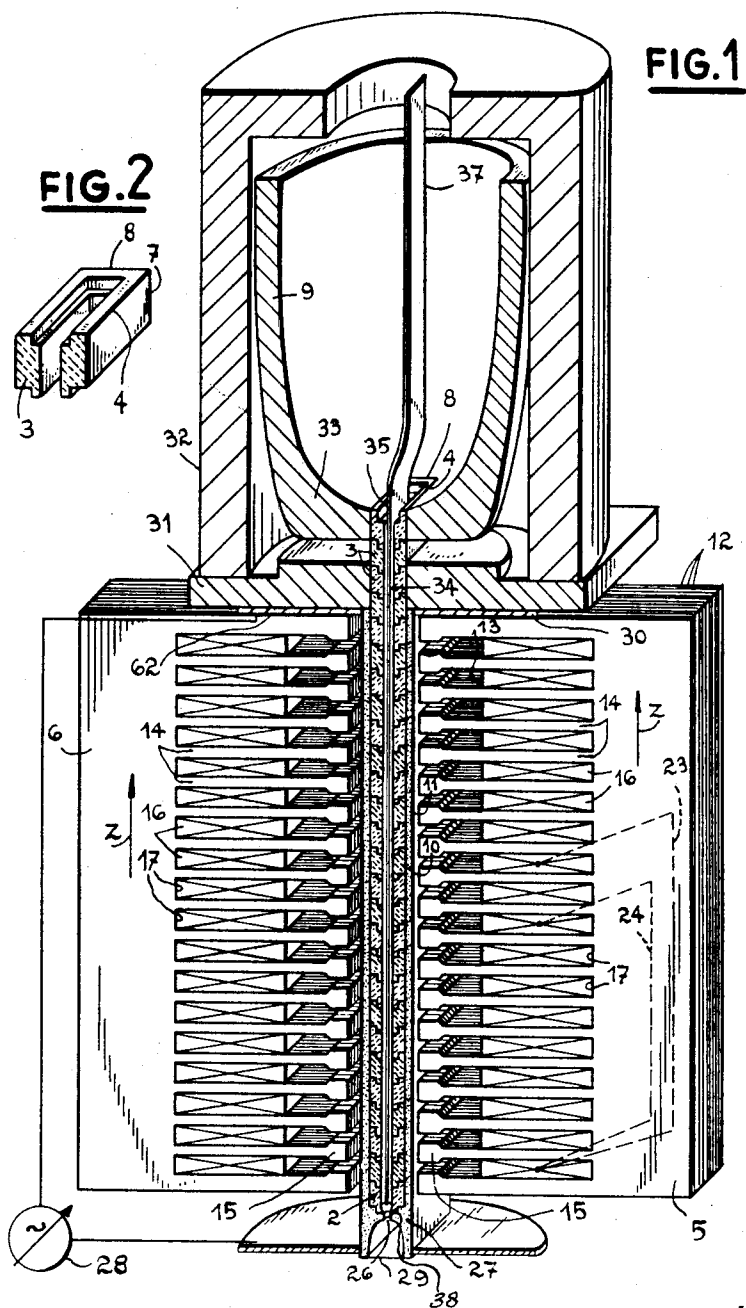
W. SIEGFRIED

2,970,830

VARYING THE FALLING SPEED OF A STREAM OF MOLTEN METAL

Filed March 10, 1958

4 Sheets-Sheet 1



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4 Sheets-Sheet 2

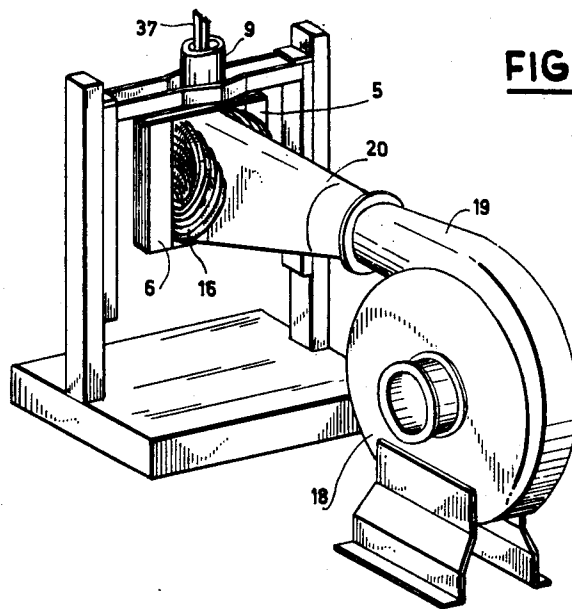


FIG. 3

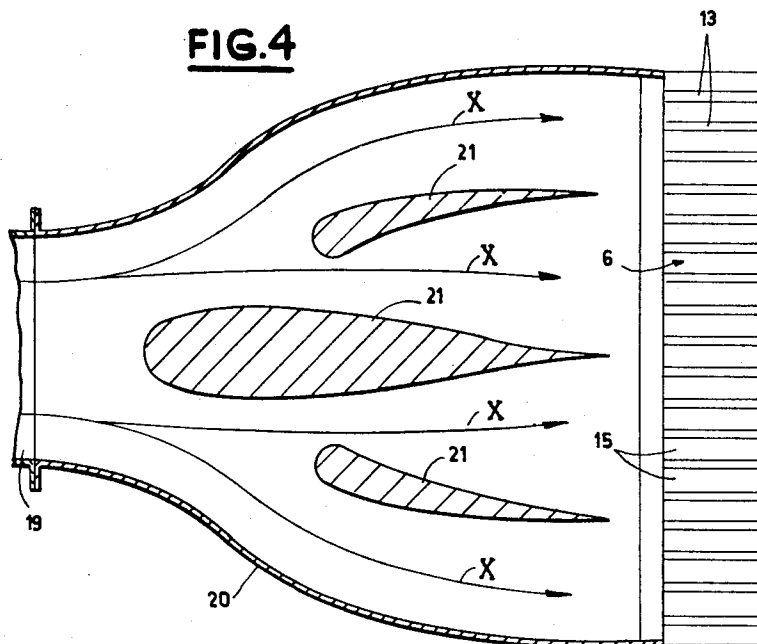


FIG. 4

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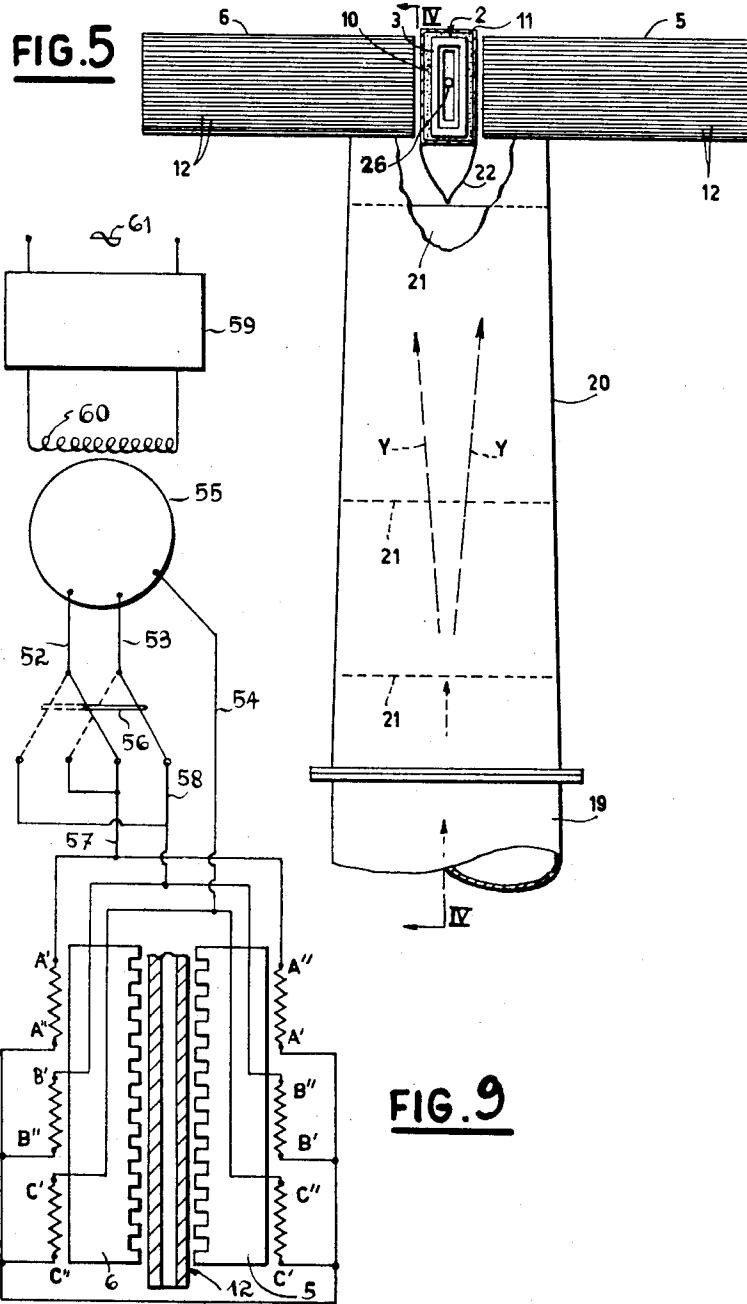
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4 Sheets-Sheet 3



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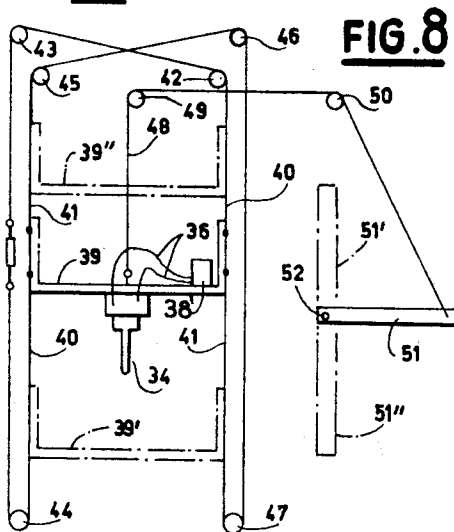
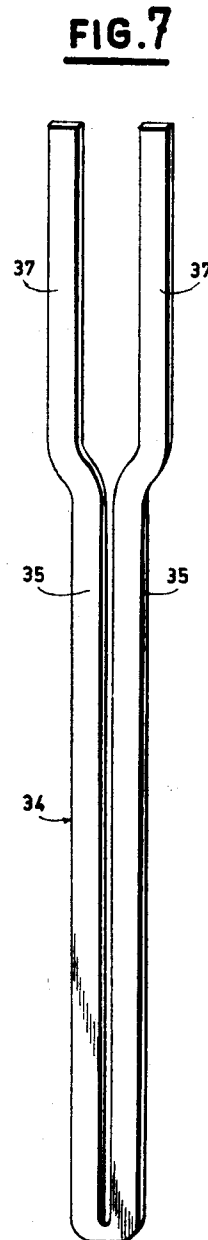
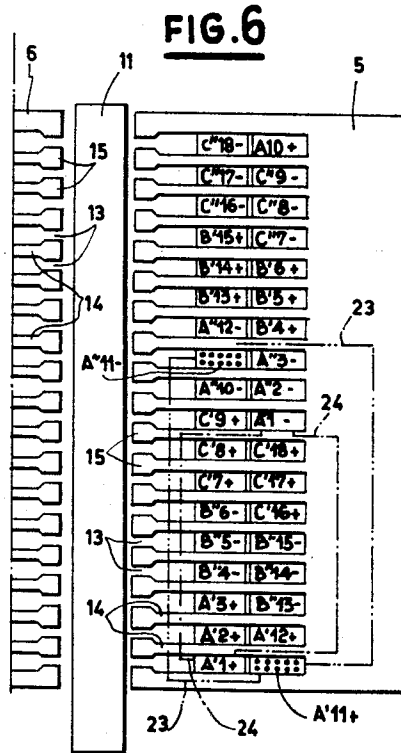
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VARYING THE FALLING SPEED OF A STREAM OF MOLTEN METAL

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4 Sheets-Sheet 4



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2,970,830

VARYING THE FALLING SPEED OF A STREAM OF MOLTEN METAL

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Filed Mar. 10, 1958, Ser. No. 720,419

Claims priority, application Belgium Mar. 21, 1957

7 Claims. (Cl. 266—38)

The present invention relates to an installation to vary the falling speed of a stream of molten metal in a tube made of refractory material, comprising, as known in a pump to circulate molten metal in a closed circuit, an electromagnetic device arranged alongside the tube and creating across the stream of metal a magnetic field sliding parallelly to the axis of the tube when three-phase current is supplied to coils wound around magnetic pole pieces.

It has been already proposed to use electromagnetic pumps of the above type to circulate low-melting metals, such as sodium, in metallic conduits. In such pumps, the coils creating the sliding magnetic field are similar to those of the stator in three-phase induction motors, which produce rotating fields but, instead of being arranged around an axis, the coils are arranged alongside the axis of the stream of metal to pump.

The coils of these pumps are located very close to the metallic conduit guiding the liquid metal and this tubing is relatively thin, so that, by placing on the opposite side of the conduit a pole piece of magnetic material intended to close the electromagnetic field, one creates, across the stream, a magnetic field of sufficient intensity to circulate the molten metal. The force required for this purpose is of course less than the one needed to establish a circulation in an open circuit subject to gravity action.

When metals having a high melting point have to be circulated in a closed circuit, and particularly so for metals attacking and/or corroding the metallic tubes they contact, pumps of this kind can no longer be used.

If the melting point of the metal is high, such as for iron, steel and their alloys as well as for metals such as nickel, cobalt, manganese, chromium, vanadium and their alloys, the tube acting as a guide for the liquid stream would be brought externally to a temperature so high that the coils would have to be located at some distance from the tube to avoid the destruction of their insulators.

It should be noted that the external temperature of the tube could not be reduced by artificial cooling to a temperature compatible with good conservation of the insulation of the coils, because such cooling would cause a solidification of the metal in the tube.

Furthermore, the pole pieces would have to be kept at a distance from the high temperature tube to avoid heating said pole pieces to a temperature above the Curie point, at which magnetic properties disappear.

Finally, if the molten metal would corrode the metallic conduit rapidly, this conduit would have to be replaced by another in a refractory material, having a thickness always much larger than that of the metallic conduit, and this would also compel the increase of the distance between the pole pieces and the axis of the stream.

It becomes clear that, for these various reasons, the distance, called magnetic gap, between the coils and the yoke of the magnetic circuit opposite said coils, would have to be increased considerably. With this yoke no longer in the region of concentrated magnetic lines, and

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with a gap greater than the air gap usually accepted in induction motors (seldom over 1 millimeter) the major portion of the magnetic lines would jump from one pole to the adjacent pole without crossing the molten metal stream. It would be vain to increase the ampere-turns of the coils because the iron is already saturated. Under such conditions, the dispersion of the magnetic field would not be compensated by an increase in the ampere-turns.

The present invention concerns an installation which remedies this difficulty and in which the magnetic field can be made sufficiently strong in the molten metal stream to permit, either to maintain the flowing speed at a constant value despite changes in the level of the metal in the container, or to vary said speed according to the desired output of metal, for instance when said metal feeds directly into a rolling mill.

In the installation according to the invention, a second electromagnetic device identical to the first one is located alongside the said tube, opposite the first device and at the same level. Furthermore, the windings opposite each other in both devices are energized with currents having the same phase. Finally, the pole pieces have channels to circulate a stream of cooling air between the end adjacent to the refractory tube and the said windings.

The combination of two electromagnetic devices arranged and energized in the manner described constitutes a first method to concentrate the magnetic field upon the molten metal stream, while the cooling of the portion of the pole pieces located between the refractory tube and the windings makes it possible to place the latter closer to the tube and therefore to further concentrate the field in the molten metal stream.

Thanks to these two means used simultaneously, the falling speed of the molten metal stream can be easily controlled, even when the thickness of said stream is substantially greater than the air gap in an induction motor. The device according to the invention operates therefore as a valve.

Furthermore, no matter what molten metal is used, the installation according to the invention allows for wider limits in the regulation of the falling speed.

In a form of realization particularly suitable for the regulation of the falling speed of molten steel stream, the pole pieces have cavities in which the windings are fitted, and portions between the notches, not in contact with the windings, and shaped as teeth to act as cooling fins for these pole pieces.

Preferably, the tips of said teeth nearest to the refractory tube are broadened to equalize the field along the tube. Furthermore, these broadened tips also act as a partial screen between the tube and the spaces cooled by air circulation.

In order to further increase the braking effect upon the liquid stream by an increase of the speed of the sliding field, the windings can be energized at a higher frequency than the usual industrial frequency of 50 or 60 cycles per second depending upon the country. Since an increase in the frequency also increases at the same time the eddy current losses in the molten metal stream, an additional heating effect results in the metal stream, which contributes in preventing freezing. This arrangement also permits shortening the valve because of the increased braking power. This double advantage resulting from an increase in frequency is possible because of the arrangement of identical windings energized by currents with the same phase on both sides of the refractory tube. Experience has shown that the use of a three-phase current with a frequency of about 500 cycles per second is very advantageous. Furthermore, it was observed that, between 50 and 500 cycles per second, there

is a linear relationship between the frequency and the braking force and, therefore, between the frequency and the square of the flowing speed.

Much higher frequencies, up to 1,000 cycles per second, can be employed. In such case, the braking force created by the valve is much increased and can stop completely the metal flow. In addition, the valve can then operate as an induction furnace keeping the metal in a molten state, even when the flow has stopped.

By switching the connections of two phases of the three-phase current, the direction of motion of the sliding field is reversed and, therefore, the free fall speed is increased instead of being reduced. A reversing switch is thus a simple means to broaden the limits between which the falling speed can be controlled by varying the field intensity.

To reduce the length of the cracks which might occur in the refractory material of the tube guiding the molten metal stream, under the thermal shock suffered by said tube at the beginning of the flow, it is proposed, under this invention, to form this tube by stacking rings on top of each other, joining them by a refractory cement.

Such method of assembling the tube from small rings provides some flexibility because the stresses can be absorbed by some deformation. Furthermore, cracks occurring in one ring cannot propagate in the other rings.

Just in case cracks would occur in one of these rings, it is advisable to surround the rings with a mass of refractory material to stop and solidify the molten metal. This mass of refractory material is therefore self-healing. Preferably, this material is also a heat insulator, to reduce the amount of heat passing from the inner face of the tube to the outer face.

The danger of tube cracking is also reduced if the refractory tube is heated from the outside while the inside is brought to a temperature close to the melting point of the metal. This is the reason why the invention also provides an electrical heating resistor around the refractory tube. Such resistor is better made as an envelope containing the refractory mass surrounding the refractory tube.

As will be easily understood, the use of a heating resistor of this type can even become necessary when the air used to cool the pole pieces of the installation as per the invention for the purpose of protecting the insulation of the windings, can come in contact with said tube or with the mass of refractory material surrounding it. In such case, the shaping of this heating resistor as a shield prevents direct action of the cooling air upon the refractory tube.

Since the pole pieces are necessarily heated by said resistor, the intensity of the air flow used to cool them must be increased correspondingly to prevent overheating the insulation of the windings beyond a safe value, and to prevent also the pole pieces from reaching the Curie point.

According to another feature of the installation according to the invention, a heating resistor may be introduced temporarily into the refractory tube before pouring a metal having a high melting point, in order to bring the inside of this tube to a temperature close to the melting point of the metal, while the outside is kept at a temperature only 300 or 400 degrees C. below said melting point.

In the case where the frequency used is sufficiently high to have the valve behaving like an induction furnace, pre-heating can be obtained by introducing a steel bar inside the tube. This rod warms up progressively and finally melts.

Other features and details of the invention will appear during the description of the drawings attached to this specification, showing diagrammatically and as examples only, one form of realization according to the invention.

Figure 1 shows schematically, in perspective, and after a vertical section, an installation according to the inven-

tion, in which the electric supply and some parts have been omitted.

Figure 2 shows, in perspective, after a vertical cross-section, one of the parts of the installation shown in Figure 1.

Figure 3 shows in perspective means to cool the pole pieces of the installation.

Figure 4 is, at a much larger scale, a vertical section along line IV—IV of Figure 5 in the distributor shown in Figure 3.

Figure 5 is, after partial horizontal section, a plan view of this distributor.

Figure 6 is a vertical section showing part of Figure 1 with some additional details.

Figure 7 is a view in perspective of a resistor for the temporary preheating of the tube used to guide the molten metal stream.

Figure 8 shows diagrammatically in front view a device for moving rapidly up and down the resistor shown in Figure 7.

Figure 9 is a schematic view of the electrical supply of the installation according to the invention.

In the various figures, identical reference markings designate identical elements.

In Figure 1, a tube 2 of refractory material is made of a stack of rings 3 joined by refractory cement. The thickness of the cement is too small to be visible in this drawing.

The cross section of tube 2 is rectangular. The long sides 4 of the rectangle defining this section externally equal the thickness of two pole pieces 5 and 6 which will be described later and which are placed parallel to the opposite faces of the tube.

To facilitate the correct location of these rings when assembled and to keep them properly located in service, said rings were given a shape conducive to mutual interlocking, such as is shown in Figure 2. Their height 7 (Figure 2) is about equal to the length of the two small sides 8 of the cross section of tube 2.

The above rings are preferably made in corundum. This material was chosen after numerous tests made with many refractory materials.

The tube 2 is intended to guide a stream of molten metal, such as steel, iron or their alloys, pouring from a crucible 9 into a mill to produce a wire by continuous casting.

The rings of tube 2 are surrounded with a refractory mass 10, preferably a heat insulator. This mass is made, for instance, of powdered alumina contained in a shield 11. It could also be made of an alumina-base refractory cement.

The rectangular shape of the tube results in equalizing the magnetic field in the molten metal stream, said field being created as explained later, by three-phase currents energizing windings supported by the pole pieces 5 and 6. The arrangement of the long sides parallel to the adjoining faces of said pieces permits increasing the output without increasing the distance between the coils of the pole pieces.

The design of tube 2 in rings of limited height is intended to prevent the propagation over considerable length of any crack which might occur in the tube because of thermal shock.

Should such a crack occur, and should steel flow through that crack, it would then be stopped by the refractory mass surrounding it. If that mass is alumina in powder, the same will sinter partially by contact with the steel which will solidify at the same time, and the leak is under control. If the refractory mass is an alumina base refractory cement, the same result is obtained with the added advantage of better mechanical strength.

The pole pieces 5 and 6 arranged along the opposite faces of tube 2 are at the same level. They comprise iron sheets 12 with horizontal slots 13 extending over the entire height and across all the sheets. These notches are,

for instance, about $\frac{1}{4}$ " high and they are separated from each other by comb teeth 14 about $\frac{3}{16}$ " high.

The tips 15 of teeth 14 nearest to the tube 2 are broadened to about twice the width of the body of the tooth. The slots 13 are thus shaped nearly as conduits. The broadening of the free ends of teeth 14 has several advantageous effects. It equalizes the magnetic flux along the tube. It forms between tube 2 and windings 16 pressed against the opposite end 17 of notches 13 a partial shielding protecting the windings against direct radiant heat from tube 2 or from the layer of material surrounding tube 2, or from the envelope 11. The broadening of tips 15 of teeth 14 also prevents the cold air shot at great speed across the notches 13 from hitting the envelope 11 directly with excessive cooling action on said envelope.

This cold air is shot into the notches 13 by a blower 18 (Figure 3) having an outlet 19 connected to a distributor 20 (Figures 3, 4 and 5). In said distributor, vanes 21 are installed to divide the air flow equally between the various notches on the entire height of the pole pieces, as shown by arrows X. In Figure 5, an asbestos sheet 22 is also shown, which surrounds the envelope 11 and is shaped to divide the air flow between the notches of the two pole pieces, as shown by arrows Y.

By shooting air at great speed across the pole pieces 5 and 6, the latter are cooled sufficiently to protect the insulation of the windings 16 against the heat and to keep the iron of the sheets 12 below the Curie point, although the external surface of envelope 11 reaches a temperature of about 1200° C.

Considering the room occupied by the windings 16, the temperature of the portion of teeth 14 at $\frac{1}{16}$ inch from the broadened tips 15 can be easily lowered to 70 degrees C., although the tips are heated at 450 degrees C., provided cold air is circulated in the free spaces of the notches 13 at a speed of about 81 feet per second.

Each winding is bipolar and, as visible in Figure 6, is also spread in two layers, as commonly known, in order to better equalize the magnetic field created by the current. There are three notches per pole and per phase because this choice is favorable to the making of the winding. There are therefore $2 \times 3 \times 3 = 18$ notches in total per pole piece. There are also three coils per pole and per phase, or 18 coils in total for each pole piece. Each coil comprises a certain number of turns, for instance, ten. The turns have been shown for one of the coils only, to avoid complicating Figure 6. Some of the coils have a length corresponding to ten times the distance between two adjacent slots and others have a length corresponding to eight times the distance between two adjacent slots. These coils are called respectively "long" coils and "short" coils. They have been shown by the dot and dash lines 23 and 24. The manner in which all the coils have been made can be easily understood by the letters printed at the location of the turns of these coils, affected by the sign ' or " and by an index number.

Each coil shown in section, in one layer, by a letter, a number and the sign ' also passes in the other layer, at the location indicated by the same letter, the same number, but the sign ". As can be verified, the winding shown comprises ten short coils and eight long ones.

There is interest in keeping the height of the slots 13 as small as possible, in order to reduce the height of the pole pieces and therefore the length of motion of the metal while it cools. It is however difficult to reduce this height of the slot below $\frac{1}{4}$ " because of the room taken by the coils. As for the thickness of the teeth 14, which must also remain small to keep the pole pieces as short as possible, it is determined by the necessity to provide sufficient cooling under the action of the cold air stream, between the enlarged heads 15 and the portion where the coils begin.

If the coils of the pole pieces 5 and 6 are connected to a source of three-phase current so that opposite coils

coincide in phase, the concentrated magnetic field which, at a given time, crosses the molten metal stream guided by tube 2, for instance from right to left, will move parallel to said stream. If we suppose that this motion is upward as shown by arrows Z in Figure 1, there will appear in the molten metal stream a current perpendicular to the plane determined by the direction of the field and by the direction of motion of said field. Applying the rule of the three fingers of the left hand, the direction of said current can be found. This current reacts with the field, resulting in a force acting upon the conductor, namely the molten metal stream, perpendicularly to the plane determined by the direction of the current and by the direction of the field, namely parallel to the axis of the stream. By the application of the rule of the three fingers of the right hand, the direction of said force can be determined and verified as being the same as the direction of motion of the field. Said force therefore opposes the fall of the molten metal.

During experiments, a retarding effect of about 32% of the free fall has been obtained easily in the fall of a stream of steel $\frac{1}{4}$ inch thick, at a temperature of about 1600 degrees C. This result was obtained with a three-phase current supply at 500 cycles per second after developing enough power to saturate the pole pieces. With three-phase current at 50 cycles per second, the reduction in the output was only 10%.

By reversing the connections of two out of the three phases of the three-phase current supply, for instance in the manner explained later, the direction of motion of the field was reversed and the falling speed was accelerated as compared to the speed when no magnetic field is applied. With a frequency of 500 cycles per second and with the same power of saturation, the increase in output has been about 32%. With such an installation, we have therefore the possibility of varying the output by about 64%, this variation between the extreme limits being possible by varying the intensity of the magnetic field, in a manner well-known per se.

To prevent the cracking of the rings 3 of refractory material, it is not only useful to surround them with a layer of poor heat-conducting material such as 10 but also to reduce to several hundred degrees C. the difference in temperature between the inner and outer faces of these rings during the pouring of a high-melting metal such as steel.

To do so, the tube 2 of refractory material can be surrounded with an electric heating device 11 which could be advantageously selected from metals used as heating resistors. This envelope can, for instance, be made of an alloy commercially known as "Inconel," comprising 80% nickel, 15% chromium and 5% iron, all percentages being by weight. With such an envelope, a temperature of 1200 degrees C. can be easily obtained, which protects the refractory rings against cracking when steel at 1600 degrees C. is poured through them.

The heating Inconel envelope is advantageously extended a few centimeters lower than a hole 26 provided at the bottom of the tube 2 and in its center. This hole is located in a refractory ring 27 having the same composition as the rectangular rings 3. When the hole 26 is $\frac{3}{4}$ inch above the lower edge of the Inconel envelope 11, it is inside the zone which is preheated before beginning to pour, by connecting the ends of said envelope to a source of current 28.

The portion 38 of the tube 2 immediately above the hole 26 is preferably tapered toward the bottom, with a longitudinal section of this portion 38 opening upward. This arrangement results in a jet of metal flowing through hole 26 as a vertical jet instead of being sometimes slightly slanted as happens when the inner passage in tube 2 is not constricted progressively nearing the hole 26.

Since during the preheating of tube 2, there appears in said tube an air draft which is better avoided, said tube

is obstructed by means of a thin sheet 29 of steel or other ferrous metal, affixed to the Inconel envelope 11, and melting rapidly when hit by the jet of steel at 1600 degrees C.

The heating envelope 11 expands at the top into a table 30 which supports the bottom 31 of a sleeve 32 of refractory material. The table 30 is insulated electrically from the pole pieces 5 and 6 by an insulating layer 62 in order to use the table extension as one connection of the heating circuit of the Inconel envelope 11. The sleeve 32 surrounds the crucible 9 which is supported by the refractory tube 2, reaching through its bottom 33. The latter is held a few millimeters above the bottom 31 to avoid being hit by the envelope 11 which expands under heat during the preheating of tube 2.

To heat the inside of tube 2 before beginning to pour the steel, a graphite electrode such as 34 in Figure 7 is used with advantage. It is shaped as a U and the two upper ends 35 of both projections are connected by conductors 36 (Figure 8) to a source of suitable current shown at 38'. These conductors can in reality connect to portions 37 (Figure 7) intended to penetrate inside the crucible 9 during preheating of the latter.

When the proper temperature is reached inside the refractory tube 2, it becomes necessary to extract the resistor 34 rapidly and without shock outside the tube 2. To do so, this resistor has been mounted on a frame 39 guided vertically by flexible wires 40 and 41 supported by pulleys designated respectively by 42, 43, and 44 and by 45, 46 and 47. This frame 39 is further connected to another wire 48 running over pulleys 49 and 50 and to an arm 51 pivoting around 52. This arm can occupy two positions opposed to each other and called respectively 51' and 51''. To each position corresponds a position of the frame 39 called respectively 39' and 39''. The rotation of arm 51 from position 51' to position 51'' can take place rapidly and at the same time the resistor 34 can be extracted from the tube 2 in a perfectly straight path.

The current supply for the windings of pole pieces 5 and 6 is made for instance in the manner shown in Figure 9.

Three leads 52, 53 and 54 can be seen supplying three-phase current from an alternator schematized in 55. The leads 52 and 53 are connected to a reversing switch 56 which, in the position marked in solid lines, connects these leads to two other leads designated respectively by 57 and 58. For each of both pole pieces 5 and 6, only one winding has been illustrated for each phase, this winding being designated in the same manner as in Figure 6 for the coils, except that the numbers of the coils are no longer shown. The connection of the three phases is of the star type.

By moving the switch 56 to the position shown by the dotted lines, two out of the three phases are reversed, and the direction of motion of the magnetic field is consequently reversed.

To vary the intensity of this field, a voltage regulator 59 is used to feed the field coil 60 of alternator 55 from a source of A.C. current 61.

The regulation of the flowing speed of the metal by changing the intensity of the field is very effective because the action of the field upon the speed varies as the square of the field intensity.

It should be noted that the braking effect increases not only with the frequency, as already mentioned, but, for a given frequency, it also increases with the voltage. The level variation of a metallic column in a U tube and subjected to the action of the electromagnetic valve as per the invention is approximately proportional to the square of the voltage applied. There is therefore an additional method to vary the flowing output.

The supply voltage of the electromagnetic valve must preferably be kept low to avoid insulation difficulties. A

voltage between 100 and 200 volts appears to be the most suitable. When raising the frequency from 200 to 1,000 cycles per second, it might be advisable to subdivide the wires to reduce the losses by skin effect (Kelvin effect). For instance, at 1,000 cycles per second, two insulated wires connected in parallel are used with advantage.

It is easy to control the metal flowing speed according to a present program, since it is sufficient to vary the field intensity accordingly.

In view of my invention and disclosure variations and modifications to meet individual whim or particular need will doubtless become evident to others skilled in the art, to obtain all or part of the benefits of my invention without copying the structure shown, and I, therefore, claim all such insofar as they fall within the reasonable spirit and scope of my claims.

Having thus described my invention what I claim as new and desire to secure by Letters Patent is:

1. A device for controlling the falling speed of a molten metal stream with a high melting point, comprising a rectangular refractory downwardly extending tube, first electromagnetic means disposed alongside one large face of the refractory tube and setting up across the metal stream a magnetic field sliding parallel to the axis of the tube; said first electromagnetic means including three phase windings and a first magnetic pole piece in flux transfer relation with the windings, in combination with second electromagnetic means disposed alongside the opposite large face of the refractory tube at the same level as the first electromagnetic means and setting up across the metal stream a magnetic field sliding parallel to the axis of the tube, said second electromagnetic means including three phase windings and a second magnetic pole piece in flux transfer relation with said latter three phase windings, means for supplying the windings of the first electromagnetic means and the second electromagnetic means with three phase current having coinciding phases in windings at the same level, elongated notches in said pole pieces parallel to planes perpendicular to the axis of the rectangular refractory tube, and separated from one another by teeth, the windings being located at the bottom of the notches and the windings extending less than the full lengths of said notches and thereby having space for circulation of fluid between said teeth, and means for circulating cooling fluid through the part of these notches along the part of the teeth between the windings and the refractory tube for cooling said windings and said teeth.

2. A device of claim 1, in which said notches are partially closed at their ends near the refractory tube, and thereby reduce on the one hand a direct heating of the windings by radiation from said tube and on the other hand the passage of cooling air along the latter.

3. A device of claim 1, in combination with electric heating means surrounding the refractory tube.

4. A device of claim 1, in which the refractory tube comprises a stack of refractory rectangular rings having a height approximately equal to the length of the small side of the cross section of the refractory tube, refractory cement between these rings, a refractory pulverulent self-healing mass around said rings, and an envelope containing said mass.

5. A device of claim 3, in which the refractory tube comprises a stack of refractory rings, a refractory pulverulent self-healing mass around said rings, a metallic envelope surrounding the refractory pulverulent mass, in combination with means for passing electric current through the metallic envelope and heating the same as a resistor.

6. A device of claim 4, in which the refractory pulverulent self-healing mass is alumina powder.

7. A device of claim 4, in which the refractory pulverulent self-healing mass comprises a refractory cement with an alumina base.

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