June 30, 1970 J. W. HALLEY 3,518,109

APPARATUS AND METHOD FOR CONTROLLING THICKNESS OF MOLTEN METAL COATING BY A MOVING MAGNETIC FIELD

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Fig. 1.

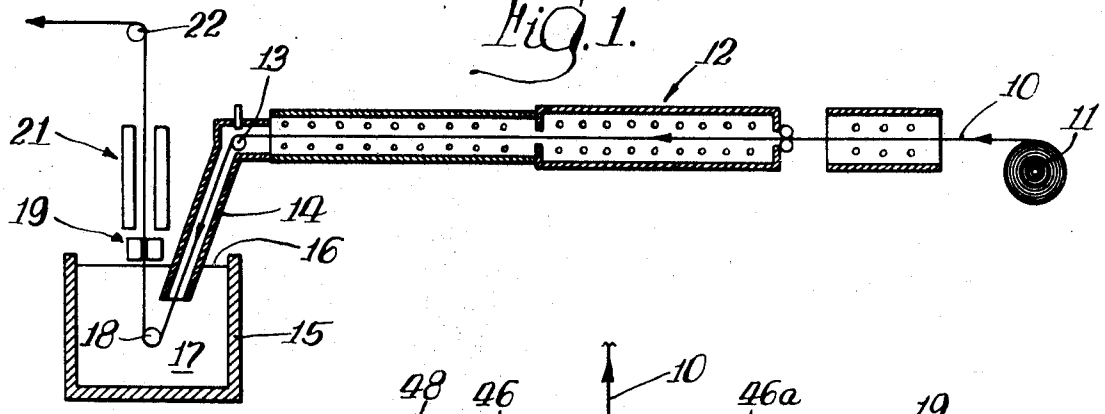



Fig. 2.

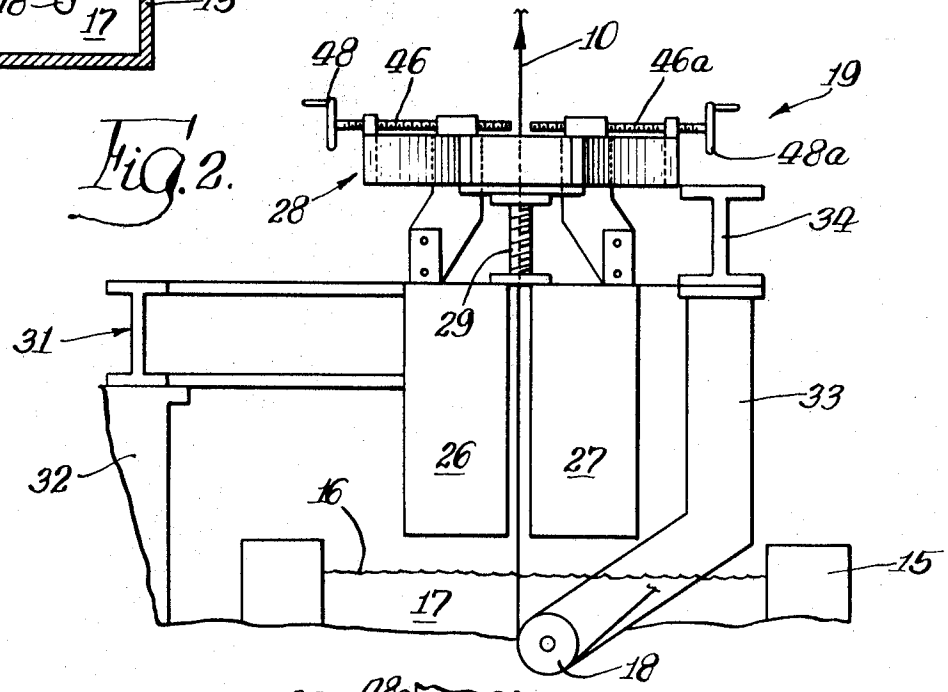
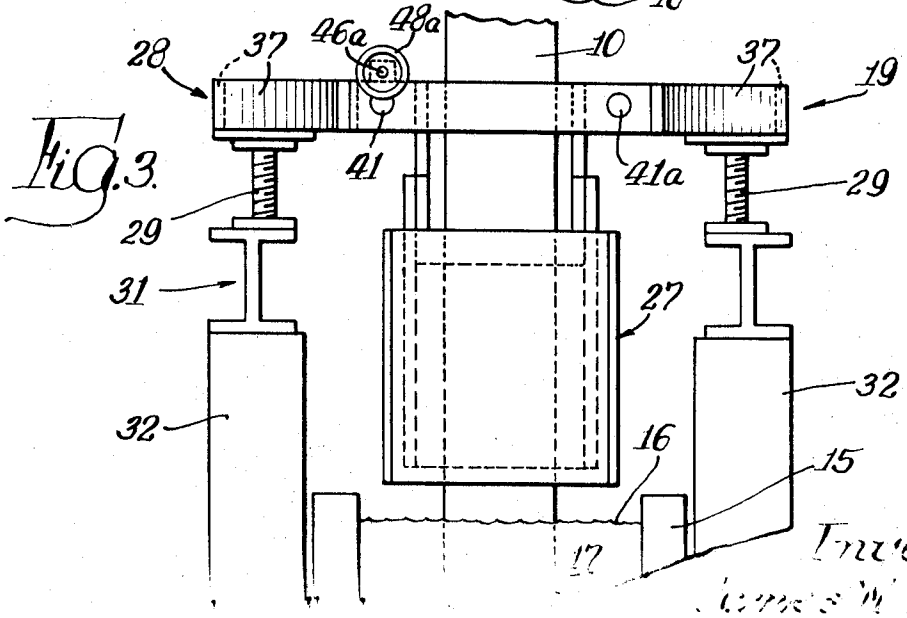



Fig. 3.




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Fig. 4.

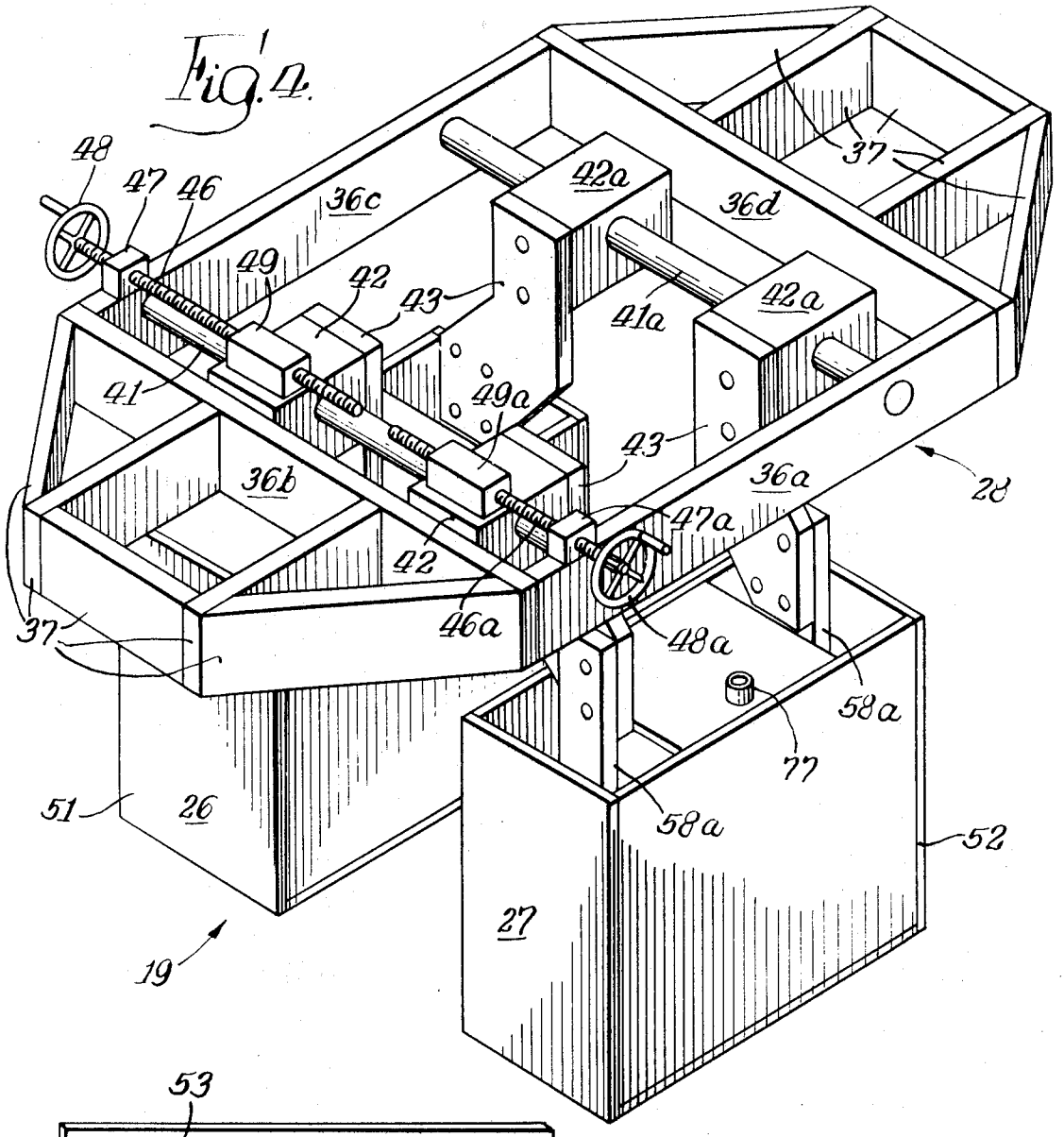
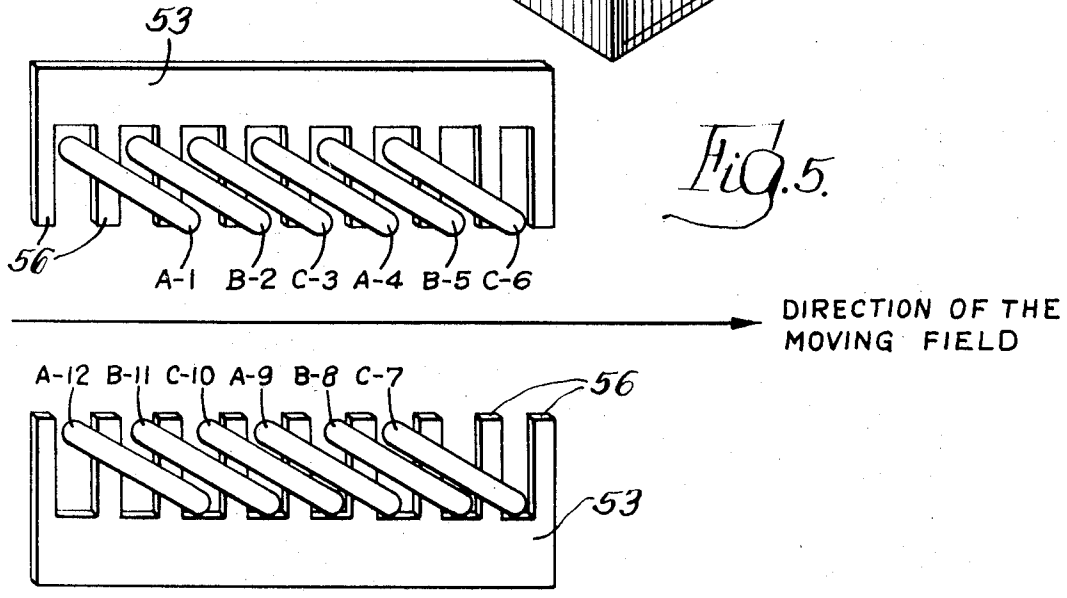



Fig. 5.



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Fig. 6.

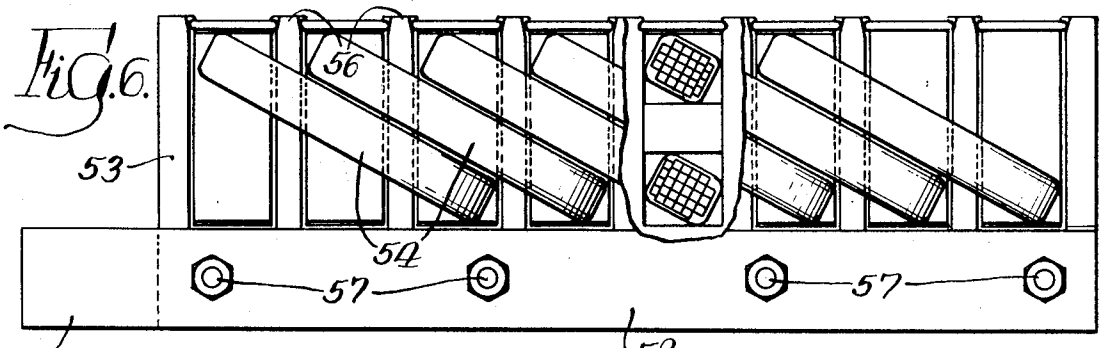



Fig. 7.

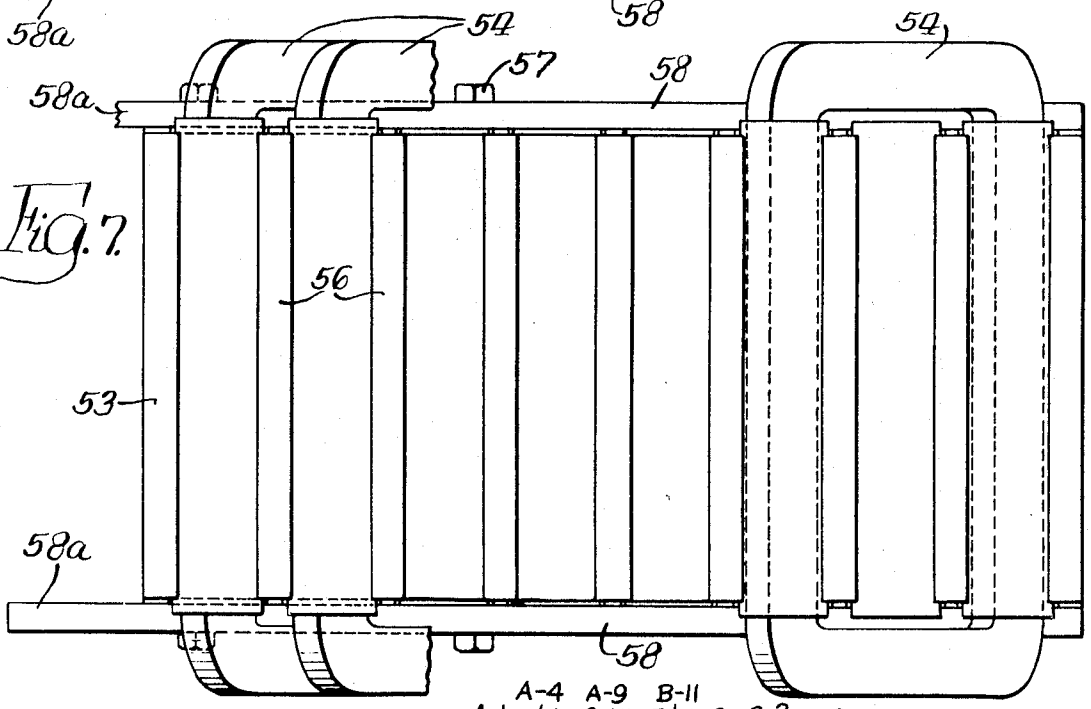
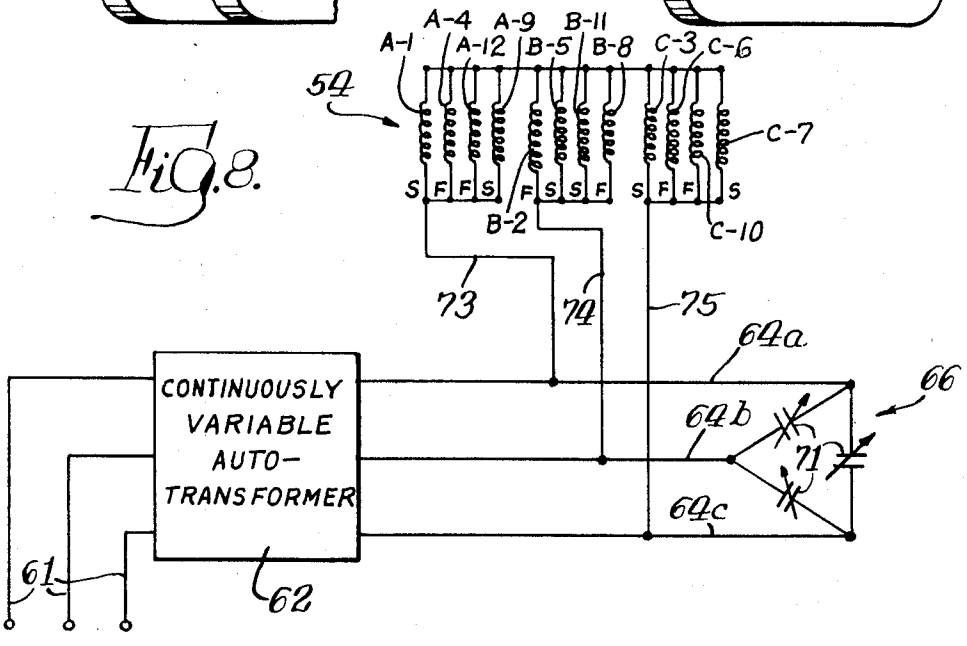



Fig. 8.



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3,518,109

# APPARATUS AND METHOD FOR CONTROLLING THICKNESS OF MOLTEN METAL COATING BY A MOVING MAGNETIC FIELD

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Int. Cl. C23c 1/02
U.S. Cl. 117—93.2 9 Claims

## ABSTRACT OF THE DISCLOSURE

This disclosure deals with apparatus for controlling the thickness of a metal coating applied to a strip by a hot dip coating process. The coating control apparatus includes means for setting up a strong magnetic field, and the strip, with the metal coating still in its molten state, is passed through the magnetic field. The resulting interaction between the magnetic field and the metal coating results in a force on the coating which wipes the coating to a desired thickness.

Metal coated strips, such as galvanized steel and aluminum coated steel, are usually manufactured by the "hot dip" process wherein the strip is drawn through a pot of molten coating metal. The coating thickness has usually been controlled in the past by a pair of grooved coating rolls between which the strip passes, a desired coating thickness being obtained by adjusting the distance between the rolls and other well known operating variables. The use of coating rolls for this purpose is, however, disadvantageous because the rolls require continuous maintenance, and coating thicknesses less than .001 inch are difficult to produce and control with such rolls. High pressure jets of steam or other gas have also been used either alone or in conjunction with rolls to control thickness but this method is effective only at certain strip speeds.

The coating thickness is controlled in accordance with the present invention by magnetic means which sets up a magnetic field adjacent the strip. The magnetic means preferably comprises an electromagnet positioned relative to the path of movement of the strip such that the lines of magnetic flux are cut by the coating of the strip. As the strip is moved in the magnetic field, the magnetic field induces electric currents in the moving metal coating, which currents also set up a magnetic field. The resulting interaction between the field of the magnetic means and the field of the coating currents causes a force to be exerted on the current carrying coating, the force being in a direction opposite to the direction of movement of the strip. The magnetic means is located to exert the force on the coating before it has solidified, and the force, in effect, wipes the coating to produce the desired coating thickness.

Objects and advantages of the invention will become apparent from the following detailed description taken in conjunction with the accompanying figures of the drawings, in which:

FIG. 1 is an illustration of coating apparatus embodying the invention;

FIG. 2 is an enlarged fragmentary view of a portion of the apparatus shown in FIG. 1;

FIG. 3 is another view of the portion of the apparatus;

FIG. 4 is a perspective view of the portion of the apparatus;

FIGS. 5, 6 and 7 are still further enlarged views of a portion of the apparatus; and

FIG. 8 is a schematic wiring diagram of the apparatus.

While apparatus embodying the invention may be used in connection with other coating processes, it is described herein in connection with a hot dip galvanizing process. In such a process, a strip **10** of low or medium carbon cold reduced steel is fed from a supply coil **11** through treating devices **12** which prepare the strip for coating. The treating devices are similar to those shown in Pat. No. 3,322,560, and comprise an oxidizing furnace, a furnace having a reducing section, and a cooling section. At the downstream end of the treating devices **12**, the strip **10** is passed over a turndown roll **13** and then moved downwardly through a snout **14** which extends below the surface level **16** of a molten metal bath **17** in a pot **15**. In a galvanizing process, the metal bath **17** is of course primarily zinc. Within the metal bath **17**, the strip **10** passes around the underside of a sinker roll **18** and then extends upwardly past apparatus **19** for controlling the thickness of the metal coating. Above the apparatus **19** may be provided banks **21** of cooling sprays of air, water, wet steam or combinations thereof, for rapidly cooling the strip **10** and the coating thereon, and the strip **10** is then passed over a guide roll **22** and out of the coating apparatus.

During the operation of the process, the strip **10** is drawn off of the supply coil **11**, passed through the treating devices **12** where it is prepared for the coating operation, drawn downwardly through the snout **14** and into the molten metal **17** in the pot **15** and pulled upwardly through the apparatus **19** for controlling the coating thickness and through the cooling banks **21**.

With reference to FIGS. 2, 3 and 4, the apparatus **19** for controlling the thickness of the metal coating on the strip comprises a pair of electromagnetic devices **26** and **27** including housings, to be described hereinafter. The devices **26** and **27** are supported by a support frame **28** above the level **16** of the molten bath **17**. The devices are on opposite sides of, and preferably at equal distances from, the strip **10** which is pulled from the roll **18** substantially vertically upwardly out of the bath **17**. The support frame **28** is mounted on a pair of vertically adjustable jacks **29** (FIG. 3) and an I-beam frame **31**. The I-beam frame **31** is supported by piers **32** adjacent the pot **15**, the I-beam frame **31** extending at least partially around the pot **15** and also supporting the sinker roll **18**. The sinker roll **18** is rotatably mounted between a pair of spaced apart sinker roll arms **33** (FIG. 2) which have the sinker roll **18** fastened to their lower ends and extend upwardly out of the pot **15**. The upper ends of the arms **33** are secured to a beam **34** which in turn is supported by the I-beam frame **31**.

The support frame **28** comprises four metal bars **36***a* to **36***d* (FIG. 4) which are rigidly secured together at their ends to form a rectangle. At opposite ends of the frame **28**, a plurality of structural members **37** are rigidly secured to the outsides of the bars **36***b* and **36***d*, and the jacks **29** engage the members **37** to support the frame **28**.

The electromagnetic devices **26** and **27** are suspended from the frame **28** such that they may be adjusted toward or away from the strip **10**. The frame **28** further includes a pair of shafts **41** and **41***a* which extend perpendicularly to the strip **10** and are secured to the bars **36***a* and **36***c*, and the devices **26** and **27** are slidably mounted on the bars **41** and **41***a* by slide blocks **42** and **42***a*. Brackets **43** are rigidly secured to the blocks **42** and **42***a* and extend downwardly to support the electromagnetic devices. To adjust the positions of the blocks **42** and **42***a* on the shafts **41** and **41***a*, respectively, a pair of adjusting screws **46** and **46***a* are provided adjacent and parallel to the shaft **41**. The screw **46** is associated with the device **26** and is fastened to the bar **36***c* by a support **47** and to the block **42** for the device **26** by a nut **49**. Similarly, the screw **46***a* is associated with the device **27**

and is fastened to the bar **36***a* by a support **47***a* and to the block **42** for the device **27** by a nut **49***a*. The supports **47** and **47***a* permit rotative movement of the screws but prevent axial movement. Thus, rotative movement of the screws **46** and **46***a* causes the nuts **49** and **49***a* to travel along the length of the screws, and handwheels **48** and **48***a* are fastened to the screws **46** and **46***a* to facilitate such movement. Movement of the nuts **49** and **49***a* of course causes sliding movement of the blocks **42** and **42***a* along the shafts **41** and **41***a* and movement of the devices **26** and **27** toward or away from the strip **10**, depending upon the direction of rotation of the screws.

Thus, the location of the devices **26** and **27** may be vertically adjusted relative to the level **16** of the molten bath **17** by the jacks **29**, and the two devices **26** and **27** may be laterally adjusted toward or away from the strip **10** by the handwheels **48** and **48***a*.

With reference to FIGS. 4 through 7, each electromagnetic device **26** and **27** includes a housing **51** and **52**, respectively, a magnetic core **53** formed of a plurality of stacked laminations, and a plurality of electrical coils or windings **54**. In the present instance, the devices are constructed for use with a three phase AC power supply. The laminations forming each core **53** are punched to form pole faces **56** and are secured together by bolts **57** and bars **58**. The bars **58** are positioned on opposite vertically extending sides of the laminations and the bolts are positioned through holes in the laminations and the bars to tightly secure them together. The bars **58** further include extensions **58***a* which extend upwardly above the cores **53** and are secured to the brackets **43** as seen in FIG. 4.

FIG. 8 illustrates schematically the coils **54** and the power supply therefor. The power supply comprises three power input lines **61** connected to the input terminals of a continuously variable autotransformer **62** which is provided to permit adjustment of the voltage to the coils **54**. The input voltage on the lines **61** may, for example, be 480 volts, three phase. The output terminals of the autotransformer **62** are connected by three power lines **64***a*, **64***b* and **64***c* to a power factor correcting variable capacitor bank **66** and to the coils **54** of the two electromagnetic devices **26** and **27**. The power factor correcting capacitor bank **66** includes a plurality of adjustable capacitors **71** connected, for example, in a delta configuration.

The coils **54** (FIG. 8) are connected in a Y configuration, and four parallel connected windings are provided for each phase. Four windings **A–1**, **A–4**, **A–12** and **A–9** are connected to the power line **64***a* by a conductor **73**; four windings **B–2**, **B–5**, **B–11** and **B–8** are connected to the power line **64***b* by a conductor **74**; and four windings **C–3**, **C–6**, **C–10**, and **C–7** are connected to the power line **64***c* by a conductor **75**. The letter S adjacent the windings in FIG. 8 indicates the start end of a winding and the letter F indicates the finish end of a winding, and it will be noted that the connections to the windings **A–1**, **A–9**, **B–5**, **B–11**, **C–3** and **C–7** are opposite the connections to the other windings, and the connections to the power supply are such that the phase sequence is from conductor **73** to conductor **74** to conductor **75**.

With reference to FIGS. 5 to 7, the windings are fastened to the core **53** such that each winding encircles two pole faces **56**, and the windings are assembled on the cores such that the start end of each winding faces toward the center line of the machine. With the arrangement of the windings as shown and described, a moving magnetic field will be set up by the two devices **26** and **27** similar to the field set up by a linear polyphase induction motor. The lines of flux of the magnetic field extend substantially perpendicularly to the plane of the portion of the strip **10** between the devices **26** and **27**, and the field moves downwardly as seen in FIGS. 1 to 3. Thus, the total relative rate of movement between the field and the strip is the rate of movement of the field plus the rate of movement of the strip. Such relative movement induces currents in the metal coating, and consequently forces are exerted on the coating in a direction opposite the direction of movement of the strip similar to the force exerted by the stator of a polyphase induction motor on the rotor of the motor. The devices **26** and **27** are mounted sufficiently close to the level **16** of the bath **17** that the coating passes between the devices before it has solidified, and consequently the force on the coating wipes the coating downwardly to produce the desired coating thickness. Each core, shown in dashed lines in FIG. 3, should be sufficiently wide that it extends beyond the edges of the strip **10**.

The thickness of the coating on each side of the strip **10** may be varied by adjusting the magnitude of the voltage applied to the windings, using the autotransformer **62**. It will be obvious that as more power is delivered to the windings, the magnetic field will become stronger and the wiping force on the molten metal will increase. The thickness of the coating may also be varied by adjusting the distances between the strip **10** and the electromagnetic devices using the handwheels **48** and **48***a*. It will be apparent that the force on the molten metal coating will increase as the electromagnetic devices are moved closer to the strip **10**. Still another way of controlling the coating thickness is by adjusting the vertical distance between the electromagnetic devices and the level **16** of the molten bath **17**. Since the molten metal coating cools and becomes less fluid as the strip is drawn from the molten bath **17**, the electromagnetic field will have a greater wiping effect on the coating when it is positioned relatively close to the bath level **16**.

In one construction including apparatus embodying the invention, the two electromagnetic devices **26** and **27** were positioned approximately 6 inches above the level **16** of the bath **17**, and the strip speed was between 20 and 50 feet per minute. The total air gap between the two devices **26** and **27** was approximately ½ inch to 1 inch, and the strip was centered in the gap. The current in the coils was at least 320 to 365 amps. The strip was 6 inches wide and was 20 gauge stock.

In the event the strip tends to move toward one of the two devices **26** and **27**, means should be provided to hold the strip centered between the devices **26** and **27**. Such means may comprise devices for holding the strip taut, or edge holding slides or rollers may be used.

The housings **51** and **52** are preferably provided around the cores **53** and the coils **54** to protect them from the molten metal. The housings may be provided with means for cooling the cores and coils, and such cooling means may comprise a duct **77** at the top side of each housing, the ducts **77** being adapted to be connected to a source of cooling air. The interior of each housing may include baffles (not shown) for directing the cooling air downwardly around the center of the core and then upwardly at the sides of the cores and out of the housing at the top side thereof.

The apparatus disclosed herein may be used with any electrically conductive coating material such as tin, terne or lead, aluminum, zinc-magnesium alloy or zinc-magnesium-aluminum alloy. The material being coated may be an electrical conductor or nonconductor.

I claim:

**1**. Apparatus for coating a strip with metal and controlling the thickness of the coating, comprising means for applying a coating of molten metal to at least one side of the strip, means for generating a moving magnetic field, and means for moving said strip through said magnetic field before the coating has solidified such that said coating cuts the lines of magnetic flux of said field, whereby said magnetic field induces currents in said moving coating and said magnetic field reacts with said currents to exert a wiping force on said coating in a direction which is substantially opposite to the direction of movement of the strip.

2. Apparatus as in claim 1, wherein said magnetic field generating means comprises an electromagnet including polyphase windings wound to produce a moving magnetic field when connected to a polyphase power supply, said magnetic field moving in said opposite direction.

3. Apparatus as in claim 1, wherein said strip is moved relative to said field such that said coating is substantially normal to said lines of flux.

4. Apparatus as in claim 1, wherein said means for generating a magnetic field comprises two portions, one of said portions being on each side of the plane of said strip and said lines of flux extending between said two portions.

5. Apparatus as in claim 1, and further including means for adjusting the position of said field generating means toward or away from the plane of said strip.

6. Apparatus as in claim 1, and further including means for adjusting the position of said field generating means toward or away from said coating applying means.

7. A strip coating process, comprising the steps of coating at least one side of a strip with molten metal, generating a moving magnetic field, and while said metal is still molten moving said strip through said magnetic field such that said strip cuts the lines of magnetic flux of said field, whereby said magnetic field exerts a force on said



coating in the direction opposite the direction of movement of the strip.

8. A process as in claim 7, and further including the step of adjusting the position of said strip in said magnetic field to obtain a desired coating thickness.

9. A process as in claim 7, wherein said magnetic field is generated such that it moves in the direction which is opposite the direction of movement of the strip.

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117—114, 131; 118—620, 639; 219—10.61, 10.75