ABSTRACT

A method of correcting planar disconformities in moving metal (e.g., ferromagnetic) sheet, in which a said disconformity from a predetermined plane is detected, (e.g., by a magnetic field detector), and in which the sheet is flexed (e.g., by electromagnets) in dependence on the degree of disconformity from the plane, the flexing being of such sense and magnitude as to urge the sheet to conform to the plane.

13 Claims, 5 Drawing Figures
This invention relates to a method of, and apparatus for correcting planar distortions in moving metal sheet, especially ferromagnetic sheet. The distortions for example may be due to the "shape" of the sheet or due to momentary twisting or flexing of the sheet. The term "metal sheet" is used in this specification to include metal strip.

In the production of galvanised strip, the strip issues from a bath of molten zinc at a high speed and the thickness of the zinc coating is controlled by a series of jets or a knife edge jet (air or super-heated steam) directed on to each side of the strip to blow the excess zinc back into the bath. The closer these jets are to the surface of the strip the thinner is the coating of zinc, but it is difficult to produce a thin coat because deviations of the strip from the intended plane alter the strip/nozzle distance and in extreme cases the strip can scrape against the jet assembly and fowl the orifice. The deviations from the intended plane can arise from the natural modes of vibration of the strip or from bad shape or from a combination of both. As a result, the galvanised strip is damaged, and further, the thickness of the coating is non-uniform.

It is an object of the hereafter specifically described and illustrated embodiment of the invention to overcome or at least mitigate this problem, but in its broad aspects the invention is not limited to this object.

From one aspect the present invention provides a method of correcting planar distortions in moving metal sheet in which a said distortion from a predetermined plane is detected, and in which the sheet is flexed in dependence on the degree of the distortion from the plane, the flexing being of such sense and magnitude as to urge the sheet to conform to the plane. The sheet may be ferromagnetic sheet and may be flexed by a magnetic field.

From another aspect, the invention provides apparatus for correcting planar distortions in moving metal sheet comprising means for detecting a said distortion from a predetermined plane, and means for flexing the sheet in dependence on the degree of the distortion from the plane so that the sheet is urged to conform to the plane.

When the means for flexing are adapted to flex the sheet by means of a magnetic field, the means for detecting may comprise a plurality of distortion detectors arranged so that in operation they are distributed laterally of the sheet and closely spaced therefrom, the detectors being independently operative to detect said distortions, the means for flexing comprising a plurality of electromagnets selectively energisable by the detectors to develop said magnetic field.

There may be two banks of detectors and electromagnets, the banks being arranged so that in operation the sheet passes between them, the detectors in one bank controlling the electromagnets in the other bank.

The detectors may conveniently be magnetic field detectors, but alternatively they may be capacitance detectors or ultrasonic transducers, back-pressure air gauges, etc. Alternatively, optical or microwave techniques may be employed.

A said magnetic field detector may be arranged to compare the reluctance of a magnetic circuit in operation containing the sheet and the reluctance of a magnetic circuit containing a dummy load, the reluctance of the magnetic circuit containing the sheet varying according to the distortion of the sheet from the predetermined plane.

Alternatively a said detector may be arranged to compare the reluctances of two magnetic circuits on opposite sides of the sheet, the difference between the reluctances varying according to the distortion of the sheet from the predetermined plane.

A detector may be connected to a bridge circuit such that a distortion in the sheet unbalances the bridge circuit to energise one or more said electromagnets.

Alternatively, a detector may be connected to electronic feedback amplifier such that a distortion in the sheet alters the amplifier output to energise one or more said electromagnets.

When the detectors are capacitance detectors, they may be connected in tuned circuits such that a distortion in the sheet de-tunes a said circuit to energise a said electromagnet.

The invention is of particular utility when incorporated in apparatus for coating moving sheet or strip material where it is necessary for the strip to be momentarily maintained in an accurately planar configuration. For example, it may be incorporated in galvanising lines as mentioned above, to avoid fouling jet nozzles, and to control the coating thinness. It may also be advantageously employed in spray or powder coating plants where uniform depositon is required.

Thus, the thickness of a coating on the sheet may be controlled by urging the sheet to conform to the predetermined plane.

Normally, the strip would be maintained in a plane equidistantly spaced between the jet nozzles or other coating controlling apparatus so as to have a uniform coating applied but it could conveniently be displaced so that a differential coating is applied on the two sides of the strip.

Thus the coating apparatus may be adapted for coating both sides of the sheet, one with a thicker coating than the other, the means for flexing being adapted to urge the sheet to conform to a said plane which is unequally spaced from means for controlling the coating thickness on respective sides of the sheet. For example, when two banks of electromagnets are provided, the electromagnetic field of one bank may be biased (made stronger) so that the sheet or strip is displaced towards that bank.

In order that the invention may be fully understood one embodiment thereof will now be specifically described, by way of example only, in connection with a hot dip galvanising line with reference to the accompanying drawings in which:

FIG. 1 illustrates a schematic side elevation of a hot dipping plant in a galvanising line;
FIG. 2 illustrates an end elevation of this plant;
FIG. 3 schematically illustrates the detectors and electromagnets and their associated circuitry, and
FIGS. 4 and 5 show alternative forms of detectors.

Referring now to FIGS. 1 and 2 in the drawings, preheated strip steel 1 issuing from a gaseous heating chamber passes through a sealed muffer 2 into a molten zinc plating bath 3. The strip passes around a roller 4 and bears against a further roller 5 before issuing upwardly out from this bath towards a cooling and drying zone.
As the strip issues from the bath steam issuing from a series of jets 6 plays upon it from opposite sides to control the zinc coating and blow any excess zinc back into the bath so as to provide a uniform coating on the strip.

The apparatus thus far described is conventional.

In order now to constrain the strip to lie in a predetermined median or mid-plane equidistantly between these jets as it passes by them there is located adjacent to these jets two opposed banks of magnetic members, between which the strip passes. The members comprise proximity detectors 7 and electro-magnets 8. The detectors and magnets are distributed laterally of the strip side-by-side on each side thereof with a detector and an associated magnet lying opposite one another on opposite sides of the strip, e.g., as shown in FIG. 3.

In particular, referring now to this figure, a detector 7 is in the form of a ferrite core 10 shaped in the manner of a letter H (two back-to-back U-shaped cores may suffice here). The core is energised by an A.C. source 11 and two A.C. windings 12, 13 are wound in opposite senses on one of its side limbs on either side of the centre limb about which, in turn, is wound a centre-tapped detector coil 14. This coil is connected to a processing circuit 15 for energising the electro-magnet 8 associated with this detector in dependence on the output from the detector as will be described.

A dummy load 16 is located adjacent the detector core, the latter being equidistantly spaced between this load and the steel strip 1.

With this arrangement, then with the strip 1 lying centrally in the magnetic circuits created by the detectors, there is no output from the detector coils 14 and the electro-magnets remain de-energised. Should the strip pass these detectors exhibit "bad shape," however, so that it bows outwardly from the mid-plane, e.g., as shown in the chain-dotted outline, the reluctance of the magnetic circuit including the strip differs from the reluctance of the circuit including the dummy load and, as a result, a finite output signal is developed across the detector coil.

This signal is applied to the processing circuit 15 which, for a signal of one sign, i.e., indicative of the strip bowing towards the detector, develops a d.c. output of a magnitude directly related to this signal for energising the associated electro-magnet 8. The processing circuit 15 includes an electronic bridge circuit or a feedback amplifier which if the deformation of the strip exceeds a threshold value, energises the electromagnet and adjusts the energisation according to the extent of the deformation. On energisation, the attractive force developed by the electromagnet 8 is operative on the strip to draw it back towards the mid-plane whereupon the detector output falls to zero, realising the equilibrium condition again so that the strip tends to remain in this position as it passes by the jet nozzles. As a result any tendency for the strip to foul these nozzles is minimised. Because each electromagnet 8 is energised only if the strip bows towards the detector 7 controlling the electromagnet, the detectors are arranged alternately on opposite sides of the strip so that bowing in either sense can be corrected.

An alternative form of proximity detector is shown in FIG. 4. The detector comprises a pair of U-shaped nickel-iron laminated cores 20, 21 disposed one on each side of the strip 1. The cores are energised by an A.C. source (not shown) via drive windings 22, 24. A detector coil 26, 27 is provided on each core 20, 21 the coils being connected in series and such that voltages induced in the coils are subtracted from each other. The strip 1 forms a magnetic circuit with each of the cores as indicated by the arrows 23, the reluctance of each magnetic circuit being dependent on the distance between the strip and the cores 20, 21. When the strip is in its median plane equidistant from each core 20, 21 the reluctances of the two magnetic circuits are equal and opposite. When the strip is deformed out of the median plane, the reluctances of the magnetic circuits becomes unequal and the induced voltages in the coils 26, 27 also are no longer equal. Thus an A.C. voltage appears at output terminals 29.

There is a phase shift of 180° between the voltage produced by a leftward deformation of the strip and by a rightward deformation. This enables the output voltage to be electronically processed to provide a D.C. signal whose magnitude indicates the size of the deformation and whose polarity indicates the direction of the deformation.

The D.C. signal is then fed to a bridge circuit or a feedback amplifier which controls the energisation of the electromagnet according to the degree of deformation of the strip, as mentioned in connection with the FIG. 3 apparatus.

A suitable arrangement of electromagnets for the FIG. 4 detector is in groups of six, three on each side of the strip, each group of six being provided with a detector. Correction of the strip shape in either direction then is available by energising either the three electromagnets of the group on one side of the strip, or the three electromagnets on the other side.

FIG. 5 shows another form of detectors, similar to that of FIG. 4 except that the cores 20, 21 are E-shaped, and a single drive coil 30 is provided on the centre arm of each core. The detectors coils 26, 27 are connected in series as in FIG. 4, to provide an output which has the same characteristics as the output 29 in that figure.

Although the invention has been described with reference to the particular embodiment illustrated it is to be understood that various modifications and alterations may be made without departing from the scope of this invention. For example, it is not essential to use magnetic proximity detectors and, as mentioned above, a variety of other forms of detectors may be used. A bank of capacitive probes may be employed, for example, each probe comprising an inner earthed guard ring. The disc and the strip may be connected in a tuned circuit so that any change in the capacitance occasioned by movement of the strip out of the mid-plane de-tunes the circuit causing an associated electromagnet to be energised.

Another scheme which may be employed is to focus a light beam on to the strip and then monitor the area of the spot if the strip bows then the area will increase and corrective action may be taken by energising the electromagnets as before. Alternatively, back-pressure air gauging or even ultra-sonic or micro-wave measuring techniques may be utilised.

It is not necessary furthermore for these banks of detectors and electro-magnets to be disposed on both sides of the strip — they may be located on one side only provided that they are biased so as to detect not only the magnitude but the sense of any strip move-
We claim:
1. A method of controlling a moving ferromagnetic sheet to conform to a predetermined plane, comprising: detecting in the sheet a disconformity from the plane, and flexing the sheet by means of a magnetic field in dependency of the degree of the disconformity from the plane, the flexing being of such sense and magnitude as to urge the sheet to conform to the plane.
2. Apparatus for controlling a moving ferromagnetic sheet to conform to a predetermined plane and to correct planar disconformities, comprising: means for detecting in the sheet a disconformity from the plane, and means comprising a magnetic field for flexing the sheet in dependency on the degree of the disconformity from the plane so that the sheet is urged to conform to the plane.
3. A method for controlling a moving metal sheet to conform to a predetermined plane comprising: detecting disconformity of the sheet from the predetermined plane, applying directly to the sheet at the region of the disconformity a force which has a component normal to the sheet surface and which is dependent on the degree of disconformity, the force being of such size and magnitude as to urge the sheet to conform to the plane.
4. Apparatus for controlling a moving metal sheet to conform to a predetermined plane, comprising: means for detecting disconformity of the sheet from the plane together with means for applying directly to the sheet at the region of the disconformity a force which has a component normal to the sheet surface and which is dependent on the degree of disconformity, so that the sheet is urged to conform to the plane.
5. Apparatus for correcting planar disconformities in a moving ferromagnetic sheet, comprising: means for detecting in the sheet a disconformity from a predetermined plane, said means comprising a plurality of disconformity detectors distributed laterally of the sheet and closely spaced therefrom, the detectors being independently operative to detect said disconformities; and means for flexing the sheet in dependence on the degree of the disconformity from said plane by subjecting it to a magnetic field so that the sheet is urged to conform to said plane, the magnetic field being developed by a plurality of electromagnets selectively energisable by said detectors.
6. Apparatus as claimed in claim 5 wherein there are two banks of detectors and electromagnets, the sheet passing between the banks, the detectors in one bank controlling the electromagnets in the other bank.
7. Apparatus as claimed in claim 5 wherein the detectors are magnetic field detectors.
8. Apparatus as claimed in claim 7 wherein a said detector comprises means to compare the reluctance of two magnetic circuits on opposite sides of the sheet, the difference between the reluctances varying according to the disconformity of the sheet from the predetermined plane.
9. Apparatus as claimed in claim 7 wherein a said detector comprises means to compare the reluctance of a magnetic circuit in operation containing the sheet and the reluctance of a magnetic circuit containing a dummy load, the reluctance of the magnetic circuit containing the sheet varying according to the disconformity of the sheet from the predetermined plane.
10. Apparatus as claimed in claim 9 wherein a bridge circuit is connected to a said detector such that a disconformity in the sheet unbalances the bridge circuit to energise one or more said electromagnets.
11. Apparatus as claimed in claim 9 wherein an electronic feedback amplifier is connected to a said detector such that a disconformity in the sheet alters the amplifier output to energise one or more said electromagnets.
12. Apparatus as claimed in claim 5 wherein the detectors are capacitance detectors.
13. Apparatus as claimed in claim 12 wherein the detectors are connected in tuned circuits such that a disconformity in the sheet de-tunes a said circuit to energise a said electromagnet.

* * * * *