METHOD AND APPARATUS FOR CONTROLLING FLATNESS IN SHEET METAL

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The present invention relates to the art of cold-rolling sheet metal, and its primary object is to provide a new and improved method and apparatus for determining and controlling the flatness of sheet metal while it is being rolled on a cold mill.

Non-flatness in sheet metal rolled on a cold mill is caused by portions of the sheet being longer than the rest, forming bands of different lengths running the length of the sheet. This extra length causes buckles when the sheet is relaxed. When the sheet is under tension as it comes off the mill, the buckles, unless very gross, disappear due to elastic stretching of the sheet, but reappear when tension is released. To use such sheet commercially, it is necessary in most cases to continually stretch the sheet beyond the yield point, or the sheets must be cut and stretched individually. Stretching requires the quality of the sheet except for flatness, and develops "Luder" lines if excessive stretching is required.

A cold mill operator, by looking at and feeling the sheet as it comes off the cold mill at high speed and under tension, can only make gross corrections for sheet flatness. This is true in particular with aluminum mills, where years of experience are of limited help. A cold mill has at least one row of cooling oil nozzles for each roll, and sometimes more, where the mill is a two-high or a four-high mill. Each nozzle is usually individually controlled, giving the operator an almost unlimited number of cooling patterns for roll shape control.

As the sheet metal passes through the cold mill and is reduced in thickness, the work of reducing the metal causes the rolls to be heated up, and this heat is removed by cooling oil applied in bands by the individually controlled coolant nozzles. Thus, the amount of heat removed and the resultant roll temperature in one band can be controlled by the amount of coolant at that location, and by differentially controlling the temperature of the body of the roll, the shape of the roll body can be controlled. However, this capability of controlling the flatness of the sheet is of little or no value to the operator, since he has no accurate way of knowing the condition of the sheet without slowing the mill or relaxing the tension, which, if done, would spoil the strip. Thus, if the operator knew precisely where buckles were forming in the sheet, he could take corrective action by regulating the temperature of the roll during its differential setting on the strip. If so, he might increase the diameter of the roll at the location of the buckle and thereby increase or decrease the amount of reduction at that point, so as to eliminate the buckle.

One of the important objects of the invention, therefore, is to provide a new and improved method of determining the location and degree of non-flatness in a strip of sheet metal as it issues from the work rolls of a cold mill, by elongating stress variations in internal stress across the width of the sheet, and then converting the internal stress variations into a visual profile of the sheet, showing the non-flatness of the sheet in an exaggerated manner, thereby enabling the operator to take corrective action.

Another object of the invention is to provide apparatus for determining the location and degree of non-flatness in a strip of sheet metal under tension by applying pressure against the sheet on one side thereof at a plurality of closely spaced, transversely arranged pressure points, measuring the deflection of the sheet at each of said pressure points, and converting the deflection of the sheet at each of said pressure points into an oscilloscope trace representing an exaggerated profile of the non-flatness of the sheet.

Still a further object of the invention is to provide a method and apparatus for continuously monitoring the sheet across its full width, to sense variations in the internal stress of the sheet, and converting the variations in internal stress into an electrical signal that is utilized to apply differential heating or cooling to the work rolls of the cold mill at spaced points along the length thereof, so as to cause localized expansion or contraction of the work roll diameter, and thereby eliminate the variations in internal stress in the sheet.

These and other objects and advantages of the present invention will become apparent to those skilled in the art upon consideration of the following detailed description of the preferred embodiment thereof, reference being had to the accompanying drawings, wherein:

FIGURE 1 is a schematic side elevation view of a four-high cold mill and apparatus associated therewith embodying the principles of the invention;

FIGURE 2 is a partially cut-away plan view of the same;

FIGURE 3 is an enlarged plan view of one of the roller sensing units of the invention;

FIGURE 4 is a side elevation of the unit shown in FIGURE 3, the supporting structure upon which it is mounted being shown in section;

FIGURE 5 is an enlarged fragmentary sectional view, taken at S—S in FIGURE 4;

FIGURE 6 is an enlarged fragmentary sectional view, taken at T—T in FIGURE 4;

FIGURE 7 is a fragmentary sectional view taken at U—U in FIGURE 3, showing a number of the sensing rolls and the manner in which they follow the sheet, the amount of deflection of the sheet being greatly exaggerated for purposes of illustration;

FIGURE 8 is a schematic circuit diagram of the electrical circuit of the invention; and

FIGURE 9 is a schematic drawing of a transducer associated with one of the roller sensing units.

In the drawings, the reference numeral 10 designates a four-high cold mill having the usual frame 11, upon which are journaled small-diameter work rolls 12 and 14. Backing up the work rolls 12, 14 on opposite sides thereof are back-up rolls 16 and 18.

The sheet metal S passes between the work rolls 12, 14, and over a detector 20, with which the present invention is primarily concerned. Beyond the detector 20, the sheet S passes over a breaker roll 22, and is wound onto a re-wind coil 24.

The detector 20 comprises a plurality of roller sensing units 26, preferably fifty-four in number for a 40-inch wide strip, although any number of roller sensing units might be used, depending upon the spacing between the units and the width of the strip.

The units 26 are mounted on a transverse supporting structure 28 which is fixed to the frame 11, and each of the units 26 has an elongated steel base bar 29, the ends of which are drilled through to receive mounting screws 31. Standing on top of the base bar 29 near one end thereof and secured by screws 32 and 33 is a short block 34. A vertical leaf spring 35 is attached at its lower end by screws 36 to the outer end of the block 34, and projects upwardly therefrom. A cover plate 37 is interposed between the heads of the screws 36 and the leaf spring 35 to distribute the clamping pressure of the screws uniformly over the surface of the leaf spring. The
upper portion of the leaf spring 35 is confined between two strips 38 and 39, which are drawn together by screws 40. Attached to opposite sides of the strip 39 and project ing downwardly from the two spaced-apart, parallel side plates 41. A roller 42 is disposed between the side plates 41 and is rotatably supported on a shaft 43, the ends of which are seated in holes drilled in the plates. Each of the rollers is crowned slightly on its outer surface to prevent marking the sheet.

Mounted between the side plates 41 below the roller 42 is a horizontal lever arm 44, the free end of which projects laterally beyond the right-hand edges of the plates, as seen in FIGURE 4. The lever arm 44 is preferably in the form of a cylindrical rod, and its left-hand end is received within a cylindrical socket 45 (FIG. 6) and is clamped in the bottom of the end strip 39. The bottom end of the strip 39 is split up the center at 46 for a portion of its length, and the two sides of the strip are drawn together by a screw 47 to clamp the end of the lever arm 44 between them.

The projecting right-hand end of the lever arm 44 passes through a hole 48 in an upright post 49, which is mounted on the base bar 29 a short distance beyond the end of the block 34. Attached by screws 50 to the right-hand edge of the post 49 above the projecting end of the lever arm 44, is a housing 51 containing a transducer 52. The transducer 52 is preferably in the form of a differential transformer, and comprises three vertically spaced cores 53, 54 and 55 (see FIG. 5), through which a movable core 56 passes. The core 56 may conveniently consist of a split sleeve of soft iron or other magnetic material, which is slipped over a stem 57 of brass or other non-magnetic material and cemented thereto. The stem 57 is clamped at its bottom end to the outer end of the lever arm 44, and projects upwardly therefrom, through a bore 58 in a bobbin 59, which is slidable received within a cylindrical aperture 60 in the housing 51. The bobbin 59 is made of non-magnetic material, and has three axially spaced, circumferentially disposed grooves formed therein, within which are received the coils 53, 54 and 55.

The center coil 54 is the primary winding of the differential transformer, which is supplied with high-frequency power from a power supply 61 and amplifier 62 (FIG. 8). The top and bottom coils 53 and 55 are secondary windings which are connected together as shown in FIG. 9, and these deliver an output signal that is a function of the position of the core 56 with respect to the primary and secondaries of the transformer. The core 56 is normally centered within the bobbin 59, as shown in FIGURE 5, and when the leaf spring 35 is deflected one way or the other as the roller 42 follows the sheet 4, the free end of the lever arm 44 is raised or lowered, and this causes the core 52 to move up or down within the bore 58, thereby changing the electrical output signal of the secondary windings 53 and 55.

At the top end of the housing 51 is an upper section 63, which is covered by a cover plate 64. The upper housing section 63 has a vertical bore 65 formed therein directly above and in line with the bore 58. Disposed within the bore 65 and movable vertically therein is a cylindrical member 66 having a shoulder flange 67. Projecting downwardly from the bottom end of the member 66 is a stud 68 of reduced diameter, which is inserted down into the top end of the bore 58 and is a snug fit therein. The member 66, together with bobbin 59, is adjustable within the housing 51 by means of an adjusting screw 69, the bottom end of which is threaded into a tapped hole in the top end of the member 66. The screw 69 passes upwardly through a hole 70 in the cover plate 64, and the head 71 at the top end of the screw bears against the top surface of the plate. A spring 72 bears against one end against the underside of the plate 64, and at the other end against the shoulder flange 67, to exert a downward spring pressure against the member 66 so that when the screw 69 is backed off, the member 66 and bobbin 59 are pushed downwardly along the bore 60. The screw 69 thus allows the coils 53, 54, 55 to be adjusted vertically with respect to the core 56, which is necessary when the machine is first set up, to provide uniform zero readings from all of the transducers 52 when the rollers 42 are under no load.

Mounted in a shallow recess in one side of the base 29 and projecting upwardly therefrom is a printed circuit card 74 having a miniature solid-state preamplifier 75 mounted on one side thereof, including an adjustable potentiometer 76 which functions as an individual gain control, and an MX switch 77 (see FIG. 8). The bottom edge of the card 74 is received within a printed circuit card socket 78, which is mounted on a plate 79 covering a longitudinally extending opening 80 in the supporting member 28. The socket 78 makes electrical contact with the copper strips 81 on the card 74, and wires 82 pass downwardly from the socket into the interior of the supporting member. The wires 82 of all fifty-four of the sensing units 26 come together and terminate in disconnectable connectors 83, which pass through the bottom of the member 28. The conductors 84 are connected by multi-conductor wires 84 to a 54-channel Multiplexer 85, which is preferably mounted on a stand closely adjacent the mill 10.

The Multiplexer 85 is a solid-state flip-flop system, which successively samples the voltage coming from each transducer preamplifier 75 at the rate of 37 times per second, and feeds the sampled voltage to an oscilloscope 86 having a tube face 87, upon which the oscilloscope trace is presented. The power supply unit 61 which feeds high frequency alternating current to the transducer 52 includes a 20 kc. oscillator 88, and with 54 transducers being scanned at the rate of 37 times per second, each individual sample is almost exactly 1 cycle. The scanning rate of 37 times per second is controlled by a sampling rate generator 89, which feeds 2000 pulses per second to the Multiplexer; each pulse acting to switch the circuit from one of the 54 transducers to the next in line.

As shown in FIGURE 8, each of the MX switches 77 has two output lines 90 and 91, the former being connected to the Multiplexer 85, and the latter being connected to a common line 92. The line 92 goes to a band pass filter 93, then into a demodulator 94, and then through a master gain control 95 to the oscilloscope 86. With the circuit described above, the transducers 52 are scanned at the rate of 37 times per second, and the output signals from the transducers are integrated and converted into an oscilloscope trace which represents an exaggerated profile of the non-flatness of the sheet. With a perfectly flat sheet 8, all of the rollers would deflect the sheet upwardly by the same amount, and the transducers 52 would all produce identical signals. This would result in a trace on the oscilloscope tube 87, which rises abruptly at one end and then extends horizontally across the face of the tube to the other side thereof, where it again drops down to the initial starting point. Any minute localized difference in the internal stress of the sheet, which would produce an objectionable buckle, would result in the sheet being deflected upwardly by the spring pressure of the roller 42 a slight amount above the level of the sheet on either side thereof. The concept described is illustrated to a greatly exaggerated degree in FIGURE 7. This upward deflection of the strip results in an electrical output signal from the transducer 52 which is converted by the circuit into a dip in the oscilloscope trace.

Upon seeing the dip in the trace, the mill operator would note from the graduations on the face of the oscilloscope tube 87, the exact location of the roll sensing units 26 which were responsible for the dip. Since a buckle in the sheet indicates that a narrow band of the
metal is being reduced slightly more than the band on either side, the corrective step required to eliminate the buckling is to reduce the diameter of the work rolls 12, 14 at that particular point, which would lessen the reduction in the sheet and thereby eliminate the buckle. To reduce the diameter of the rolls, the operator would adjust one or more of the coolant flow control valves 96 spraying coolant onto the work rolls 12, 14 and back-up rolls 16, 18 at the point in question, so as to increase the volume of flow. This would cool the work rolls at that particular point slightly more than the remainder of the length of the roll, causing a localized contraction in diameter. As soon as the condition producing the buckle had been corrected, the trace on the oscilloscope tube 87 would show that the sheet is now coming off the work rolls flat.

When the sheet S is under maximum tension, it presses downwardly against each of the rollers 42 with a pressure of approximately 5 pounds, and this causes the roller to be deflected downwardly a distance of about .005" below the normal unloaded position. As a buckle area in the sheet passes over the rollers, the lesser tension of the sheet in that particular area allows the sheet to yield slightly under the spring pressure of the 4 to 6 rollers spanning the buckle area. The rollers follow the sheet as it is yields upwardly, and assume positions relative to one another, more or less as shown in FIG. 7, wherein adjacent rollers may have as much as .001" to .002" difference in deflection. The sensitivity of the invention is such that a roller deflection as little as one ten thousandth of an inch produces a marked displacement of the trace on the oscilloscope tube.

For automatic control of sheet flatness, an automatic control system 97 may be added to the circuit, which is connected to the output of the Multiplexer 85. The automatic control system 97 is essentially a computer which responds to the electrical signal of the Multiplexer to operate solenoid actuators 98, which open and close the valves 96. The automatic control system 97 acts in response to a signal from one or more of the transducers 52 to energize the corresponding solenoid actuator 98, thereby causing the associated valve 96 to be opened to a greater extent. The increased cooling effect due to the additional flow of coolant onto the work rolls 12, 14, and back-up rolls 16, 18 causes the work rolls to be contracted slightly in diameter at that particular point, thereby correcting the condition responsible for non-flatness of the sheet, without any attention from the operator. This has the advantage of freeing the operator from the task of constantly watching the oscilloscope and making adjustments of the coolant valves, and allows him to devote his entire attention to the operation of the mill.

 Provision is made for adjusting each of the sensing units 26 to raise or lower the level of the roller 42, so that the top surfaces of the rollers all lie in the same horizontal plane. This is accomplished by means of two screws 33 and 99, which act against the right-hand end of the block 34. Screw 33 extends upwardly from the bottom of the base bar 29 through a smooth, oversize hole 100 in the latter, and is threaded into a tapped hole in the block 34. Screw 99 is parallel to screw 33 and closely adjacent thereto. Screw 99 also extends upwardly from the bottom of the base bar 29, but is threaded into a tapped hole therein, and its top end abuts against the bottom surface of the block 34. Thus, screw 99 pushes upwardly against block 34, while screw 33 pulls downwardly against the same, and acts as a lock screw. When the right-hand end of the block 34 is raised slightly from the base bar 29 by the screw 99 as shown in FIGURE 4, the base bar bends at 101 in the manner of a spring hinge. To permit such bending, the base bar 29 is slotted at 102, and a hole 103 is drilled through the bar at the inner end of the slot to reduce stress concentration and also to reduce the thickness of material at 101 so that all of the bending will take place at this local area.

At the time the machine is set up, the units 26 are first adjusted by means of the screws 33, 99, to bring the top surfaces of all of the rollers 42 into tangency with a common horizontal plane. With the pre-amplifiers 75 connected into the circuit, as in FIG. 8, each of the adjusting screws 71 is turned to raise or lower the differential transformer windings 53, 54, 55, with respect to the core 56, so as to bring the output voltage of each of the units 26 to a predetermined "no-load" value. Each of the rollers 42 is then loaded with a standard weight, preferably of about 5 lbs., and the output voltage is adjusted to a predetermined "full load" value by turning an adjusting screw on the adjustable potentiometer 76. With these adjustments completed, the apparatus of the present invention is ready to go into operation.

All 54 of the roller sensing units 26 are partially covered by a hood 104 of steel plate, which shields the transducers 52 and printed circuit cards 74 from coolant and other foreign material that might adversely affect the units, and protects them from damage. The hood 104 is swingably mounted on the supporting member 28 by a hinge pin 105. A skirt 106 depending from the underside of the hood 104 adjacent the roller 42, acts to keep any coolant spray from being thrown by the rollers 42 back into the transducers, and printed circuit cards. The inverted position of the transducers 52 also helps to keep them dry and free of contamination.

While I have shown and described in considerable detail what I believe to be the preferred form of my invention, it will be understood by those skilled in the art that various changes may be made in the shape and arrangement of the several parts without departing from the broad scope of the invention as defined in the following claims.

1. The method of determining and controlling the flatness of sheet metal while being rolled on a cold mill, comprising the steps of:
applying longitudinal tension to the sheet between the work rolls of a cold mill and the rewind coil upon which the sheet is being wound;
applying pressure against one side of the sheet and normal to the surface thereof at a plurality of transversely spaced points across the width of the sheet;
sensing the deflection of the sheet at each of said points of pressure application;
converting the deflection of said sheet at each of said plurality of points of pressure application into an electrical signal;
integrating said electrical signals and converting them into a visual oscilloscope trace representing an exaggerated profile of the flatness of the sheet; and
varying the temperature of the work rolls of said cold mill in a plurality of narrow contiguous, zones along the length thereof, so as to counteract by thermal expansion any localized variations in the work roll diameter responsible for non-flatness in the sheet.

2. The method of determining and controlling the flatness of sheet metal while being rolled on a cold mill, comprising the steps of:
applying longitudinal tension to the sheet between the work rolls of a cold mill and the rewind coil upon which it is being wound;
applying pressure against one side of the sheet and normal to the surface thereof at a plurality of transversely spaced points across the width of the sheet;
sensing the deflection of the sheet at each of said points of pressure application;
converting the deflection of said sheet at each of said plurality of points of pressure application into an electrical signal;
integrating said electrical signals; and
utilizing said integrated electrical signals to vary the temperature of the work rolls of said cold mill at spaced points along the length thereof, so as to
counteract by thermal expansion any transverse variations in the work roll diameter responsible for non-flatness in the sheet.

3. Apparatus for determining and controlling the flatness of sheet metal while being rolled on a cold mill, comprising:

means for applying longitudinal tension to the sheet as it issues from the work rolls of the cold mill, said tension being less than the yield point of the metal;

means for applying pressure against one side of said sheet at a plurality of spaced points across the width of the sheet;

means for sensing the deflection of the sheet at each of said points of pressure application;

means for converting the deflection of the sheet at each of said points of pressure application into an exaggerated visual profile of the flatness of the sheet; and

means for varying the temperature of the work rolls of said cold mill at spaced points along the length thereof, so as to counteract by thermal expansion any localized variations in the work roll diameter responsible for non-flatness of the sheet.

4. Apparatus for determining and controlling the flatness of sheet metal while being rolled on a cold mill, comprising:

means for applying longitudinal tension to the sheet as it issues from the work rolls of the cold mill, said tension being less than the yield point of the metal;

a plurality of spring-pressed rollers bearing against one side of said sheet at closely spaced points across the width of the sheet;

each of said rollers being displaced from a given position as the sheet deflects locally under the pressure of the roller;

means for sensing the displacement of each of said rollers; and

means responsive to displacement of said rollers for regulating the temperature of the work rolls on said cold mill at spaced points along the length thereof, so as to cause localized expansion or contraction of the work roll diameter to counteract transverse variations in the work roll diameter responsible for non-flatness in the sheet.

5. Apparatus for determining and controlling the flatness of sheet metal while being rolled on a cold mill, comprising:

means for applying longitudinal tension to the sheet as it issues from the work rolls of the cold mill, said tension being less than the yield point of the metal;

a plurality of spring-pressed rollers bearing against one side of said sheet at closely spaced points across the width of the sheet;

each of said rollers being displaced from a given position as the sheet deflects locally under the pressure of the roller;

a transducer associated with each of said rollers and operable to produce an electrical output signal responsive to displacement of the rollers;

means for supplying an alternating current to said transducers; and

means responsive to the output signals from said transducers for regulating the temperature of the work rolls on said cold mill at spaced points along the length thereof, so as to vary the diameter of the work rolls to counteract the condition responsible for non-flatness in the sheet.

6. Apparatus for determining and controlling the flatness of sheet metal while being rolled on a cold mill, comprising:

means for applying longitudinal tension to the sheet as it issues from the work rolls of the cold mill, said tension being less than the yield point of the metal;

a plurality of spring-pressed rollers bearing against one side of said sheet at closely spaced points across the width of the sheet;

each of said rollers being displaced from a given position as the sheet deflects locally under the pressure of the roller;

a differential transformer associated with each of said rollers and operable to produce an electrical output signal responsive to displacement of the rollers;

means for supplying an alternating current to said differential transformers;

means for converting the combined output signals from said differential transformers into a visual oscilloscope trace representing an exaggerated profile of the flatness of the sheet; and

means responsive to the output signals from said differential transformers for regulating the flow of coolant into the work rolls of said cold mill at spaced points along the length thereof, so as to vary the diameter of the work rolls to counteract the condition responsible for non-flatness in the sheet.

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