AUTOMATIC CONTROL SYSTEM FOR CONTINUOUS STRIP MILL

FIG. 1b

X-Ray Gage

Mixer & Discriminator

Screw-down Control

Amplifier & Control Initiation

Rotating Amplifier

Amplifier

Magnetic Amplifier

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AUTOMATIC CONTROL SYSTEM FOR CONTINUOUS STRIP MILL

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Filed Feb. 12, 1956, Ser. No. 714,782
3 Claims. (Cl. 90—56)

This invention relates to a system for automatically controlling the thickness of hot-rolled metal strip produced by a multi-stand continuous strip mill. In particular, it provides a system for controlling the tension applied to the strip between stands and the adjustment of the screws of some of the stands of a finishing mill in accordance with certain variable factors, to compensate for differences in the temperatures of successive bars and the differences in temperature between portions of the same bar, as well as thickness variations resulting from the breakdown rolling of starting slabs in a roughing stand or stands.

It is highly important to produce hot-rolled strip of steel, for example, which is uniform in thickness within close tolerances, because non-uniformity introduces difficulty into subsequent processing as well as further processing such as coating and fabricating. Non-uniformity in thickness of hot-rolled steel strip results from the temperature effect or progressive cooling of the strip bar (partially reduced slab) during rolling, and from variations in the temperature of the bar along its length, e.g., transverse lines less highly heated than the remainder of the bar, resulting from contact of the slab with the water-cooled skids of the slab-heating furnaces. In addition, successive strip bars rolled in a mill may differ in their average temperatures as a result of being heated in different furnaces or because of differences in their initial thickness. The compensation necessary to overcome the effect of these differences on finished strip thickness has been accomplished hereafter only by manually varying the speeds or roll settings of the several stands. The automatic control of continuous strip mills has been developed for strip rolling mills but has not been applied to hot-strip mills (where the problem is more acute) because the strip at rolling temperature, being plastic, has relatively little strength, requiring extreme accuracy in the control of varying tensions applied thereto, and the fact that acceptable tolerances in the thickness of hot-rolled strip are narrower on a percentage basis than they are for cold-rolled strip. In addition, these tolerances are being constantly narrowed by customers' demands.

We have invented a control system for a continuous hot-strip mill including means for establishing a reference function, e.g., a voltage, in accordance with the thickness of the strip bar at its leading end prior to its entry into the second finishing stand of the mill. We provide means for adjusting the screws of the second stand in accordance with departures from the reference thus established, in the continued rolling of the strip bar. We also vary the speeds of the earlier stands of the mill to maintain the desired tension in the bar between stands, despite changes in the adjustment of the screws. We further establish a reference function, e.g., a voltage, corresponding to the temperature of each bar as it enters the first finishing stand, and utilize departures in temperature of the subsequent strip bars from the reference thus established, to adjust the screws of all the stands of the mill with the possible exception of the last stand. We also provide means responsive to the thickness of the finished strip, effective when this thickness varies outside predetermined limits, to cause a further adjustment of the screws of some or all of the stands.
reheating furnaces (not shown). As the bar 21 enters stand 1, the rolling pressure thereby developed is applied to load cells 22 under the bearing seats of the bottom back rolling 11. These cells may be of any suitable type but preferably embody magnetic stress gages such as in-corporate through conductors" gages made by ASEA. The load cells apply to an amplifier 23 a voltage signal proportional to the pressure exerted by rolls 10 and 11. This pressure is proportional to the reduction in the thickness of the strip bar effected in stand 1, or, more properly, to the thickness of the entering bar since the thickness of the strip leaving stand 1 does not vary much. Amplifier 23 is of conventional character and may be a vacuum-tube amplifier or a transistor amplifier. The output of amplifier 23 is applied to a means for establishing a pressure-reference voltage, such as a motor-operated, self-balancing, bridge-type potentiometer 24. The potentiometer normally is connected by a bus contact 25a of a relay 25 so as to be operated to a setting corresponding to the thickness of the leading end of strip bar 21 as it enters stand 1.

At a predetermined time after the entry of the bar into stand 1 and preferably after the bar has entered stand 2, relay 25 is energized to open its back contact 25b and close its front contact 25b. This changes the circuit connection of device 24 so that thereafter the reference voltage previously established thereby will be opposed to the voltage from amplifier 23, developed by load cells 22. Relay 25 may be a motor-current relay, a pressure relay, or a hot-metal detector relay. That is, it may be of a conventional type responsive either to the increased current drawn by the motor 23 driving stand 1, to the increase in the pressure on the rolls of stand 1 or to the energy radiated by bar 21. Thus, after operation of relay 25, if any change occurs in the thickness of the bar from that of the leading end thereof, an error signal will be given which is opposed by the previously established reference voltage. The algebraic sum of the opposing voltages is applied to an amplifier 26, of the vacuum-tube or transistor type, the output of which is conducted through circuit 26a into the automatic control of the screw-down motor 14 of stand 2. This circuit introduces the error signal into device 28 of stand 2 to adjust the screws 29 thereof in a manner to be explained subsequently. We also apply the error signal to control the speeds of the motors 13 of stands 1 and 2 by introducing the error signal from amplifier 23 through circuit 26b and 26c to the magnetic amplifiers 17 of stands 1 and 2. This varies the speeds of stands 1 and 2 to maintain the proper tension on the material therebetween in accordance with the adjustment of the screws of stand 2.

The screw-down controller 15 of each stand is under the control of a device 27, such as a potentiometer, which may be adjusted manually or preset by punched-card apparatus, and develops a voltage proportional to the desired screw setting. This voltage is applied to a mixer and discriminator 28, the output of which is applied to an amplifier 29. The output of amplifier 29 operates a reversing controller 15 for screw motor 14. Devices 27, 28 and 29 preferably embody General Electric Company's numerical positioning control, modified to suit the requirements of screwdown operation which includes the necessary arrangements for a "Selyn" generator 30. The resulting adjustment of the screws by operation of motor 14 is reflected by generator 30, the output of which is applied through circuit 28a to mixer 28 in opposition to the voltage from the potentiometer 27. Amplifier 26 thus exerts a control over amplifier 29 by virtue of circuit 26a extending to mixer 28. By means of an added manual adjustment in amplifier 26, e.g., an additional potentiometer the increment of screw adjustment per volt of error signal may be varied. We thus adjust the amount of correction for thickness variation so as to obtain either a uniform or decreasing thickness of the bar as it emerges from stand 2. This permits compensation for the tendency of a strip bar to increase in thickness toward the trailing end and because of the aforementioned temperature cell.

The speed of one of the intermediate stands of the mill, stand 3 for example, is used as an "anchor" or reference value, i.e., the speed regulator of its motor is left unchanged, so that the motor speed is affected only to maintain that for which the regulator was originally set maintain that for which the regulator was originally set maintain that for which the regulator was originally set. Once set, the regulator remains unchanged and is not automatically adjusted in response to any of the variable functions attributable to the strip bar being rolled. With the automatic control already described, the rolling of the strip bar proceeds in stands 1, 2 and 3. As the bar enters stand 4, load cells 31 responsive to the rolling pressure thereby developed, apply a voltage to an amplifier 32. The cells 31 are similar to those shown at 22 and amplifier 32 similar to that shown at 23. The output of amplifier 32 is applied by circuits 32a and 32b to a self-balancing, bridge-type potentiometer 33 which operates to establish a reference voltage proportional to the rolling pressure initially developed in stand 4 and, therefore, to the thickness of the leading end of the bar as it leaves stand 4.

After the leading end of the bar has passed through stand 6, a relay 34 operates to change the connections of potentiometer 35 by opening back contact 34a and closing contact 34b, so that thereafter its voltage is opposed to that of amplifier 32 and the difference or error signal is applied to amplifiers 35, one for each of stands 4, 5 and 6 over a circuit 35a. Relay 34 is similar to that shown at 25. Each of these amplifiers incorporates an additional potentiometer 35b which will vary the output in accordance with the desired amount of speed change for stands 4, 5 and 6. The output of each amplifier 35 is applied by a circuit 35c to the speed-regulator of the motor of one stand through amplifier 17. By this arrangement, if the portion of the strip bar in stand 4 at any instant is thicker than the leading end of the bar on which the pressure reference was initially established, it will effect an increase in the speed of any one or all of stands 4, 5 and 6 depending on the ratio adjustment of potentiometer 35b. If any point along the strip bar is thinner than the leading end, no reduction of tension between stands below that established by the leading end will be effected. Our regulating system applies only the necessary speed-increasing adjustment to the related control field of magnetic amplifier 17, in the case of excessive strip thickness.

The progressive increase of tension between the last several stands will tend to reduce the delivery of strip of uniform thickness out of the last stand. Actually, the thickness correction is effected in the stand where roll pressure is measured, and the increase in the speeds of subsequent stands is necessary as a consequence, in order to maintain the tension on the strip as it travels through these latter stands. We provide means whereby a further increment of mill speed may be introduced to prevent an increase in thickness from "growing back in" the bar as the rolling continues, due to the temperature effect. For this purpose, an X-ray gage 36 of known construction measures the thickness of the strip emerging from stand 5. The output of the gage drives a positioning device 37, preferably a "Selyn" transmitter, which operates an additional potentiometer in device 35 preferably by action of a "Selyn" receiver, effective over circuits 37a and 37b, to effect an increase or decrease in the error signal to amplifier 32. This, in turn, by the leading end of the finished product is excessive, the positioning device 37 will increase the gain of amplifiers 35 causing a further adjustment in the speeds of the motors driving stands 4, 5 and 6 to further increase the tension on the strip therebetween.

Thickness gage 36 also applies a voltage to a thickness deviation "Selyn" transmitter 38, such as the standard equipment furnished for General Electric Company's X-ray thickness gages, equipped with adjustable tolerance...
limits. If the thickness of the strip as measured by gage 36 is outside the limits for which device 38 is adjusted, the latter applies a correcting voltage through a front contact 34c of relay 34, to all or some of the screw-down positioning controls 29 through circuits 36a and 36b connected to the mixer and discriminator 28 of each, so that the thickness of the strip rolled will be brought within the desired range by repositioning of the screws of any or all stands as necessary. This has the result of further adjusting the settings of the rolls of the several stands to compensate for relatively slow change in mill conditions such as temperature of the housings and rolls or wear of the rolls. Normally open contact 34c of relay 34 prevents screw movements due to action of device 35 when there is no strip in the mill.

The first bar of a particular series to be rolled, furnishes a temperature-reference voltage through a temperature gage 39 by closing of the reference-establishing switch 44, such as a flag switch or manually operated switch. Temperature gage 39 preferably embodies a Leeds and Northrup Company "Raytube" device which produces an output voltage proportional to measured temperature of the first bar causing a decrease in the roll set-balancing, bridge type potentiometer 40 similar to 10 for comparison with the temperatures of strip bars subsequently to be rolled. After the trailing end of the first bar emerges from stand 1 and before the next bar enters stand 1, a relay 41 operates. This relay, similar to relay 25, closes its contact in response to a reduction in the load current drawn by the motor 18 driving stand 1, to a reduction in the pressure exerted by the rolls or to the termination of radiant energy from the hot bar. Closing of the contact of relay 41, with the closing of contact 25c of relay 25, changes the connections of potentiometer 40 so that the voltages proportional to the temperatures of subsequent strip bars, as developed by gage 39, will be opposed to the reference voltage established on the potentiometer, and the algebraic sum thereof applied to an amplifier 42. The output of amplifier 42 also affects the setting of the mill screws of any or all the stands by modifying the input through mixers and discriminators 28. Temperatures lower than the established reference temperature of the first bar cause a decrease in the roll setting, and a temperature higher than the one established by the first bar will result in an increase of the roll setting. The change in the roll setting of stand 1 is performed immediately after the trailing end of the preceding bar leaves stand 1 by operation of relay 25. Similarly, the change in each of the other stands is performed immediately after the trailing end of the preceding bar has left the stand, by operation of relays (not shown) similar to relay 25.

Switch 44 is adapted to be manually closed when the operator desires to establish or check temperature reference. When the slab approaches stand 1, relay 41 is energized, but a signal to amplifier 42 is not permitted until the preceding slab has cleared stand 1 or 2 and relay 25 is deenergized, at which time a screw change signal is transmitted depending on the voltage differential of potentiometer 40 and device 39. To complete connections between devices 39, 40 and 42, relay 41 must be energized with its front contact closed and permissive relay 25 deenergized with its front contact closed.

The system described above provides for thickness control by increasing the tension on the strip between the last several stands of the mill. As a modification, we may similarly effect the desired control by decreasing the speeds of the motors driving the first several stands, thereby increasing the tension on the material between these stands. For example, a signal from potentiometer

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