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Andresen

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[54] **ROLL GAP DETECTION**

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[52] **U.S. Cl.** .... **72/31,** 72/21, 72/35, 324/34 TK

[51] **Int. Cl.** **B21b 37/08**

[58] **Field of Search** .... 72/21, 31, 8, 35; 324/34 TK

[56] **References Cited**

UNITED STATES PATENTS

2,684,001	7/1954	Wilson	72/8
3,570,288	3/1971	Fischer et al.	72/8
3,662,576	5/1972	Giriatschek	72/21

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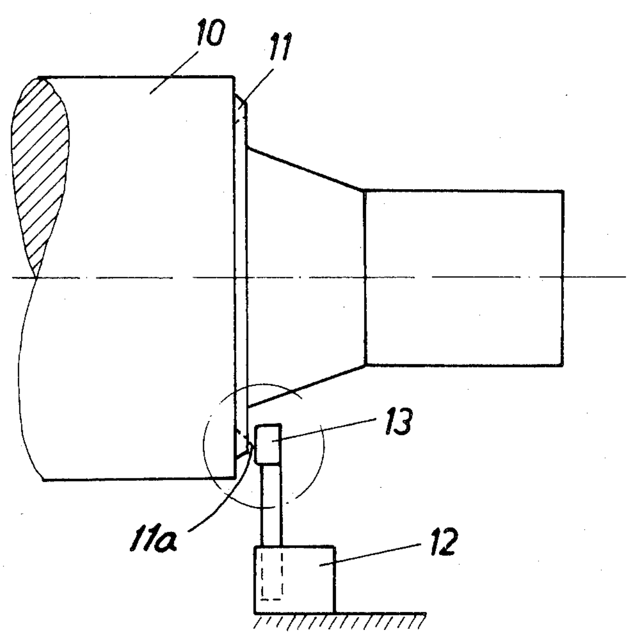
Attorney, Agent, or Firm—Ralf H. Siegemund

[57] **ABSTRACT**

The axial end faces of rolls in a rolling mill are provided with annuli cooperating with axially displaced stationary pick ups which respond to lateral (radial) displacement of the rolls. The disposition of each roll is separately detected in relation to the respective transducer, and two transducer signals are combined specifically to generate a gap error signal. Each transducer has a pair of pick ups which respond to particular axial edge alignment of the respective annulus whose rotational symmetry establishes invariable pick up conditions during rotation as long as the roll with annulus does not undergo lateral (radial) displacement.

10 Claims, 8 Drawing Figures



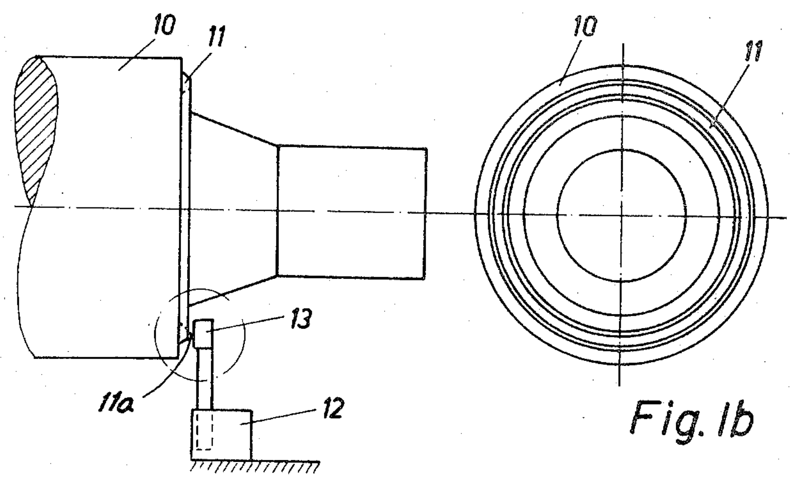


Fig. 1b

Fig. 1a

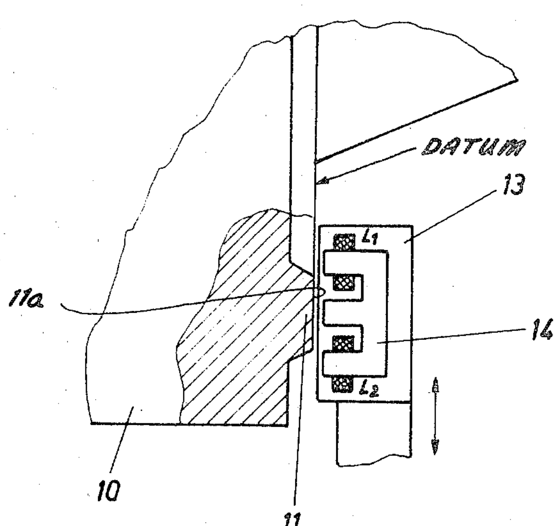


Fig. 2

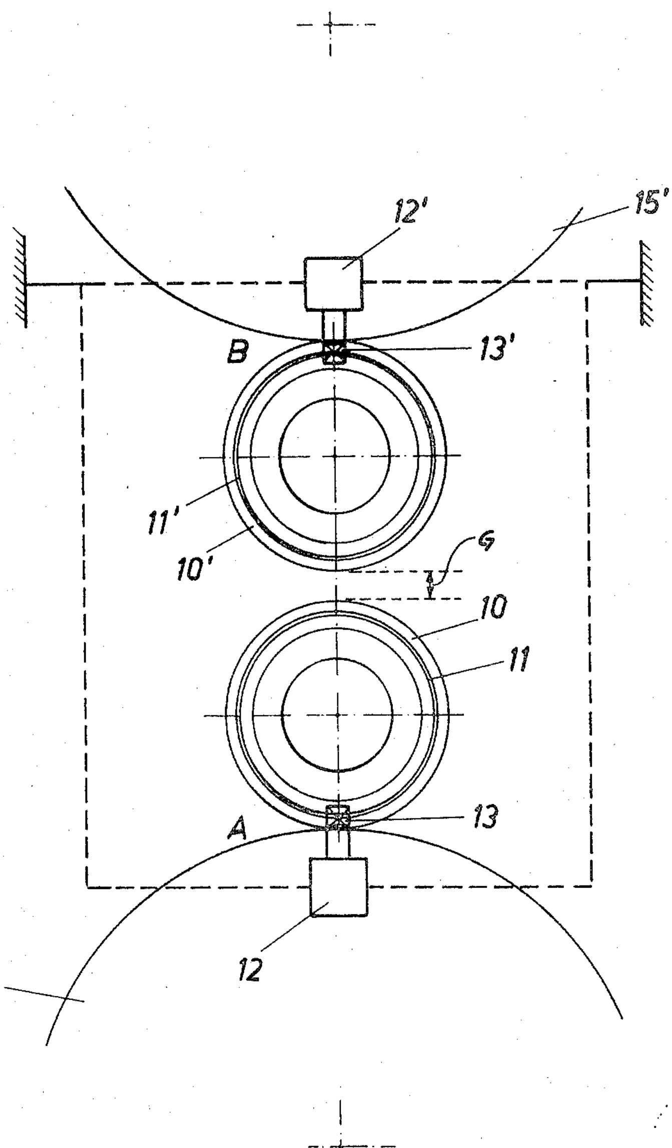


Fig. 3

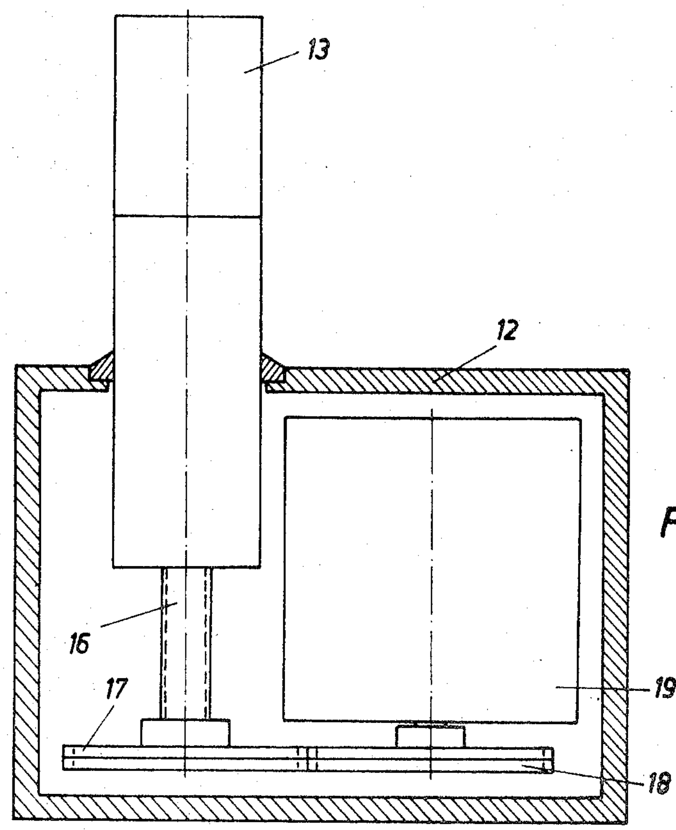


Fig. 4a

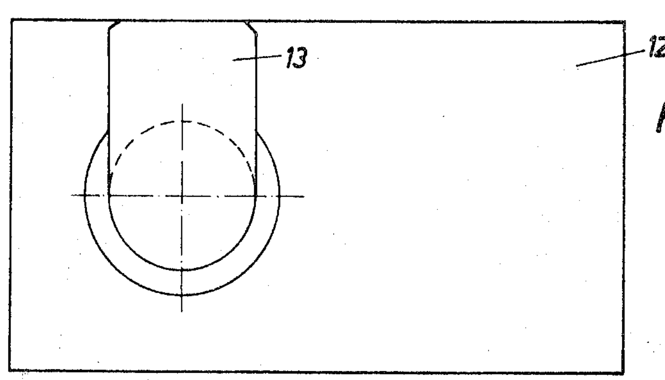


Fig. 4b

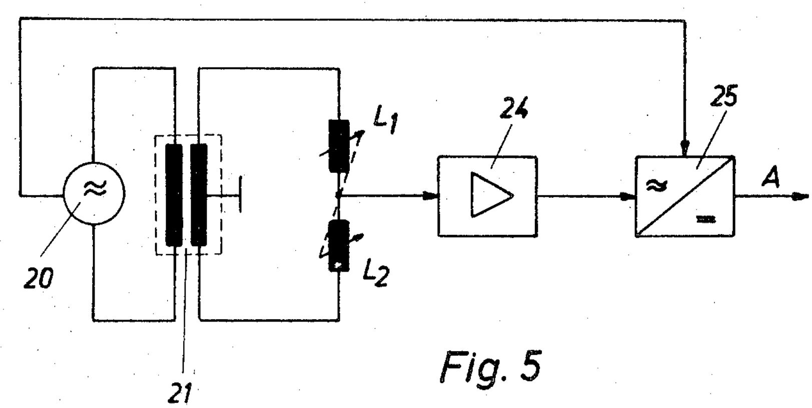


Fig. 5

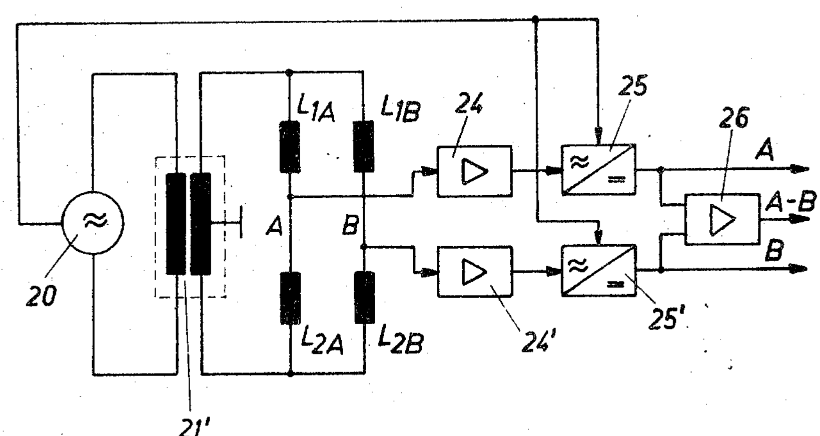


Fig. 6

ROLL GAP DETECTION

BACKGROUND OF THE INVENTION

The present invention relates to a device for measuring the gap between the working rolls of a rolling mill, so that the result of measuring may serve as input for a controller for maintaining the gap constant by means of automatic feedback control.

Rolling mills generally require control of the roll gap because the thickness of the rolled sheet stock or the like is usually to be kept within very close tolerances. The feedback control must meet significant dynamic requirements which include a fast operating actuator for adjusting the gap and which further include a pick up device detecting the thickness of the rolled stock as controlled variable in one way or another. This pick up device should operate without or with only insignificant delay so that the stock width will not vary beyond permissible limits. However, measuring strip or sheet stock thickness right at the roll gap is not accurate enough due to the deformation of the rolls during working and further due to some resilient reaction of the stock after emerging from the gap. Therefore, the strip or rolled sheet stock thickness is usually measured indirectly by detecting the roll gap in one way or another.

The different controllers for the roll gap differ primarily in the set up and design of the gap detection. A rather simple but relatively inaccurate method uses the displacement of the roll positioning plunger as representation of the gap. The inaccuracy here stems from the fact that the gap is only indirectly ascertained and roll flattening, mill stand expansion, and eccentricities in the support rolls render the relationship between the true gap and measured input rather unreliable. As a consequence, the measured value supposedly representing the roll gap must be subjected to numerous corrections as to all these disturbing influences.

Another method uses a spindle between the inserts of the support rolls, and the changes in spindle force are used as an (indirect) representation of the roll gap. The controller operates here to maintain the spindle force at a constant level, and hopefully the roll gap is maintained constant therewith. This method works actually as a first order approximation, but this system uses as command input a supplemental spindle device which does not consider roll flattening, and eccentricities of the support are entered into this pick up system with the wrong sign. Thus, it is quite impossible here to provide for an optimized controller on that basis.

U.S. Letters Pat. No. 3,662,576 of common assignee offers a significant improvement over the aforementioned control systems. This patent discloses pick up devices and uses inductive phenomena across the gap (or, more exactly, of axially displaced replica of the roll gap) to ascertain the true gap dimensions. This pick up system operates indeed satisfactorily but because of the particular inductive mode of detection, application is restricted to rolling mills with relatively low rolling speeds.

SUMMARY OF THE INVENTION

It is an object of the present invention to avoid the drawbacks of the several known pick up systems for rolling mill gaps and to provide a pick up and detector system which does not impose, e.g., speed limitations on the mill and on the delay of gap detection.

In accordance with the preferred embodiment of the present invention it is suggested to provide the working rolls with reference annuli, one on an axial end of each roll and these annuli are respectively associated with transducer heads which are affixed to the stand. The annuli each have a particular transducing surface rotating in datum plane which extends transverse to the axis of the respective roll. Upon rotation thereof, no changes occur in the pick up transducer as facing that datum plane at a particular distance. Changes in the disposition of the roll axis causes change of the rotating annulus in the datum plane, and that lateral-radial change is picked up.

Such a reference annulus cooperates with the respective head on the basis of one several possible physical principles. For example, the reference annulus may influence the respective pick up head magnetically, optically, capacitively electromechanically or otherwise. The principle of the invention is to be seen in that the annulus has a particularly surface of rotational symmetry providing constant activation of the respective head during rotation, and any shift of the annulus in the datum plane changes the effective head-annulus interaction and the resulting head output.

Each such head includes preferably a pair of pick ups responding, e.g., to concentric edges of the respective annulus and providing balanced outputs when the edges have similar disposition to the pick ups. This then establishes a zero position separately on each head. The heads are preferably motorically adjusted in radial direction as far as the respective associated annulus is concerned, so that the signals derived from the heads and combined may have characteristics of an error signal. The relative position of the transducer heads establish representation of the desired gap, and the head signals together form representation of the controlled variable (actual gap width) minus the desired gap representation.

DESCRIPTION OF THE DRAWINGS

While the specification concludes with claims particularly pointing out and distinctly claiming the subject matter which is regarded as the invention, it is believed that the invention, the objects and features of the invention and further objects, features and advantages thereof will be better understood from the following description taken in connection with the accompanying drawings in which:

FIGS. 1*a* and 1*b* are respectively generalized, somewhat schematic side and front views of a roll with reference ring and pick up head;

FIG. 2 illustrates in detail the pick up head constructed as electromagnetic transducer;

FIG. 3 is a schematic front view of the components as they detect and monitor a roll gap;

FIGS. 4*a* and 4*b* are respectively a front view partially in section and a top view of the transducer and pick up head for particularly adjusting its disposition;

FIG. 5 is a circuit diagram used in conjunction with the device of FIG. 3 for generating a signal representing the difference of desired and actual disposition of a roll; and

FIG. 6 shows two circuits of the type of FIG. 5 combined for generating a gap error signal.

Proceeding now to the detailed description of the drawing, FIG. 1 shows representatively one of the working rolls **10**, which may be the upper or the lower one in a two-high rolling mill and having a reference ring or annulus **11** provided at one of its axial end faces from which a shaft end projects for journalling the roll. The annulus **11** is concentrically disposed in relation to the working surface of the roll. Therefore, the relative disposition of annulus **11** depends on the relative disposition of roll **10** in the mill stand so that, in turn, the disposition of the annulus represents the disposition of the roll and of its working surface.

These aspects require a more detailed consideration. The annulus **11** has a particular, axially facing surface **11***a* of rotational symmetry with two edges of different radii and correspondingly different distances from the cylindrical rolling surface of these edges. This surface **11***a* defines a datum plane which extends transverse to the axis of rotation of the roll. Any displacement of the rolling surface of roll **10** in direction transverse to the rolling surface shifts the annulus so that particularly the axially facing surface **11**a shifts in the datum plane transverse to the axis of rotation.

The reference annulus **11** is associated with a stationary transducer head **13**, having a particular axial disposition to the datum plane as well as to the axis of rotation of roll **10**. The transducer head faces the annulus and is particularly responsive to the relative disposition of the said axially facing surface **11**a in the datum plane. The transducer head **13** responds particularly to any shift of the annulus in its plane of rotation, but the interaction between transducer and annulus is constant as long as such a shift does not occur, due to the rotational symmetry of annular surface **11***a*.

The transducer head generally has a pair of pick ups such as magnetic coils, capacitive probes or optical detectors responding particularly to the disposition of the axial facing surface **11***a* of annulus **11** and adjacent the edges thereof. These edges provide a discontinuity and any shift of the annulus in the datum plane changes the respective input of at least one of the pick ups. Induction, capacitance, or reflection as effective at and in the respective pick up changes when the respective closest edge passes across the respective pick up.

A magnetic pick up system is representatively shown in FIG. **2**. The transducer head **13** is provided as two inductive pick ups and includes an E-shaped core, whose three legs face the annulus but in different radial levels. Each one of the three outer legs carries a coil having inductance L_1 and L_2 respectively; these are the two pick ups. The reference annulus **11** has (radial) width in the datum plane, closest to the head, corresponding to the inner distance of the outer legs from each other. The annulus as such interacts magnetically with each of the pick up coils (L_1) and (L_2).

As annulus **11** and head **13** have relative disposition corresponding to the illustrated position of FIG. **2**, the inductances are $L_1 = L_2 = 1$. This then defines a normal or zero position. In this position, the inner edge of annulus **11** just about registers with one edge of the leg of the E-core carrying the coil with inductance L_2 and the outer edge registers with one edge of the lower leg of the E-core carrying the coil of inductance L_1. Due to rotational symmetry of the annulus **11** as such, and of its axially facing surface as facing head **13** in particular, no change in inductance occurs when the annulus rotates with the roll. The same is not true for any shifted disposition of the annulus transverse to the axis of rotation. Thus, $L_1 = L_2$ is true only in the illustrated position. In the case of a lateral shift as just mentioned, $L_1 \neq L_2$ and either $L_1 < L_2$, or $L_1 > L_2$, depending on the direction of shift.

Turning now to FIG. **5**, these inductances are connected across the center tapped secondary of a transformer **21** which is energized by an oscillator **20** of constant frequency. The junction between the two inductances L_1 and L_2 will have zero voltage relative to the grounded center tap if the inductances indeed are equal. If the inductances are not equal a non zero voltage develops as between the said junction and ground. The phase and amplitude of that voltage is indicative of a difference in the inductances. This output voltage is amplified in an amplifier **24** and rectified at **25** to provide a d.c. output A whose polarity and magnitude represents the imbalance in the inductances. The rectifier **25** is controlled by the oscillator **20** to establish phase dependent rectification.

It can be seen that the position of the roll **10** relative to head **13** is ascertained by this device and particularly the output A of rectifier **25** is a representation of the roll's position relative to the stationary position of head **13**. Neither temperature deviations, nor axial distance variations between the head and the annulus enter into the output A, because these disturbances cancel in the formation of $L_1 : L_2$.

Having described the subsystem as provided for the detection of the relative disposition of an individual roll in the stand, I proceed to the detection of the roll gap, which requires the detection of the disposition of upper and lower rolls in the stand. Turning, therefore, to FIG. **3**, the roll **10** is shown here as the lower one, there being a second roll **10'** member above roll **10** and defining a rolling gap G therewith.

Roll **10'** is provided with an annulus **11'** which cooperates with a transducer head **13'**. Elements **11** and **11'**, and **13** and **13'** correspond to other and are similar in construction and dimension. Particularly the two heads each have a pair of magnetic pick up coils and the arrangement on the upper roll will be just as was explained with reference to FIG. **2**.

The two transducer heads **13** and **13'** are not individually mounted to the rolling stand. Rather, a frame **131** is used for mounting both transducers in particular position to each other, and the frame **131** is secured to the stand within one and the same horizontal plane. Thus, forces acting on the stand during rolling do not act on the frame. This way dimensional changes which the stand may undergo during rolling are not transmitted upon the transducer mount. The frame **131** provides, so to speak, for a coarse or approximate relative disposition of the transducer heads **13** and **13'**. The fine and accurate position will be adjusted and predetermined in a manner explained later with reference to FIG. **4**.

FIG. **6** shows the circuit for the gap detection which is basically a duplication of the circuit of FIG. **5** except that FIG. **6** shows a common oscillator **20** and a transformer with a single primary winding. The circuit, therefore, shows two pairs of inductances, identified by indices -A and -B, and there is a second signal path including an amplifier **24'** and a phase dependent rectifier **25'** for providing a d.c. signal B that represents the imbalance of the two inductances L1B - L2B of transducer **13'**. Rectifiers **25** and **25'** are synchronously controlled from oscillator **20**.

The four inductances L1A, L2A, L1B, L2B establish inherently a bridge circuit, but the bridge voltage is not used directly (though it could). Rather, each of the two junctions between the coils of each pair is respectively referenced to ground. A signal representation of the difference A − B is generated by a d.c. differential amplifier **26** receiving signal A and B at oppositely poled inputs.

Generally speaking, the two signals A and B represent individually the deviation of the respective roll from arbitrarily selected positions, wherein the respective annuli face the transducers **13** and **13'** symmetrically. The signal A − B represents the relative deviation of the two rolls from those individually predetermined radial levels.

The radial levels for the two transducers may now be selected, so that the rolls **10-10'** establish a particular gap if the annuli **11, 11'** have disposition relative to the transducers **13, 13'** so that A = B (e.g., = 0). The output of amplifier **26** as providing a signal A − B can be used as representation of the error signal between controlled variable and desired value for automatic feedback control of the thickness of the rolled stock.

It should be noted that the transducer system as such does not necessarily provide a signal representation of the rolling gap as such. Assuming the transducers had disposition that A = B = 0 for gap zero, then A − B ≠ 0 will in fact develop for non zero gap and that signal will represent the actual gap width. If however, the transducers **13, 13'** have disposition that A = B = 0 the desired gap width, then A − B ≠ 0 represents an error signal, but neither A nor B is directly the desired variable or the command signal in this representation. Nevertheless, A − B could be interpreted as representation of the actual gap width with the desired gap width serving as zero point setting for that particular scale of representing gap width, but permitting positive or negative values in that kind of representation.

As just stated, the relative disposition of the transducer heads can be made subject to predetermination and can be used directly as representation of the desired gap width. FIG. **4** shows by way of example how the transducers can be adjustably mounted. The head such as **13** projects from a casing **12** containing a stepping motor **19.** The drive shaft of the motor has a gear **18** meshing with a biased gear **17.** Gear **17** in turn is mounted on a spindle or worm gear **16** for providing for elevation adjustment of head **13.** The motor **19** is separately and, e.g., step-wise controlled for accurately adjusting the level of transducer action. The motor **19** may be controlled by pulses for step action. This way the head disposition can be determined on the basis of accurately metered pulse trains.

The calibration of the device as described, following for example a replacement of worn rolls by new or refinished ones, is carried out as follows. The rolls (in running condition) are at first moved towards each other by the roll position actuator. Usually only one roll is adjustable as to relative height above (or below) the other one. Next, each of the transducers **13** and **13'** is adjusted and trimmed in its disposition until the signals A and B have separately zero value. This then establishes a zero condition as far as calibration is concerned.

As stated above, and considering open loop conditions at first, retraction of one of the rolls (e.g., roll **10'**) will produce a non zero value B (A remains zero) and that signal will in fact represent the gap as established. Conversely, and still considering open loop conditions, the transducer **13** could be moved up, and again a non zero value B will develop (but of opposite sign as before) and that signal will represent a desired gap width on the same scale and with the same accuracy and resolution as the signal B could represent an actual gap width with the transducers remaining as just described.

It should be noted here, that actually none of the transducers and heads with circuit need to develop, e.g., full scale signals for the entire range of adjustments because of follow up conditions established upon closing the loop. This actually is an advantage as maximum sensitivity is needed only for a limited range around zero as to each transducer.

Assuming generally one of the transducers, **13** or **13'** has been moved (up or down as the case may be) by a definite amount, this then establishes the desired position and defines particularly the desired gap width with reference to the position the transducer had for zero gap, and zero A,B trim adjustment. The corresponding non-zero value for A or B can be construed as a reference value or command input. The level of adjustment of the one transducer must be, of course, capable of very accurate predetermination. However, as the feedback loop is closed the respective roll (**10** or **10'**) follows that displacement of the one transducer and seeks a new disposition of the roll and of the respective annulus (**11** or **11'**) adjacent the previously adjusted head. The accuracy of determining the reference position determines the accuracy of the control system. One can see that accuracy in the determination of controlled variable and of reference and command signals correspond to each other. The system works in fact as a follower control.

It should be noted that these adjusting operations should be carried out while the rolls are turning so that any non-circularities of the annuli are offset by averaging. The processing of the signals may include filtering to remove any modulation at the roll-rotation frequency. No problem will arise here if the frequency of the oscillator **20** is sufficiently higher than the roll rotation frequency.

As stated, desired gap width is, therefore, determined by adjustment of the disposition of one of the transducer heads. The adjustment is carried out by control of motor **19** for example by means of an encoding switch, a process controller or any analog signal fed to the motor. This way, it is possible to change the command and reference value for the rolling gap and strip thickness, for example for purposes of correction.

The accuracy of the initial adjustment and of the command input depends primarily upon the accuracy of the pitch of the worn gear. This way, even large gaps can readily be adjusted as the accuracy of worm gear pitch is significant and usually constant throughout the extension. Using the system for disposition control of both roll shaft ends (four annulus-head systems in all) with separate detection and actuation accordingly, permits quite accurate parallel positioning of the rolls.

The transducer system as detecting the dispositions of the rolls separately has a number of advantages. First of all, the signals are developed in stationary transducer heads, operating without making contact with any rotating part of the rolls. Moreover no slip rings or other device for transmitting signals from a moving to a stationary part are needed. This way the system can be used in slowly as well as in fact running mills. The inventive transducer system operates with a high resolution that is quite independent from the size of the gap to be controlled. Accuracy, sensitivity and resolution are not influenced by any cooling process (or lack of it).

As was outlined above, recalibration is not difficult, so that the overall operation of replacing worn rolls is facilitated. The recalibration and zero adjustment does not require additional mounting operation; only the level adjustment of one or both of the transducers must be repeated.

As stated, the motors **19** are preferably step motors and one can use digital means for the position adjustment as well as digital indication during and for the calibration. The transducers and casings are mounted in the level of the support rolls **15** which provide adequate protection for these instrument packages.

The invention is not limited to the embodiments described above but all changes and modifications thereof not constituting departures from the spirit and scope of the invention are intended to be included.

I claim:

1. Apparatus for detecting the width of the gap between two rolls in a rolling mill comprising:

a reference annulus on a front end of each of said rolls rotating therewith, each said annulus having a planar, ring-shaped surface with concentric edges;

a pair of transducers disposed respectively adjacent the annuli but axially displaced therefrom and mounted in the stand of the mill, each transducer having a pair of pick ups of particular respective disposition to the edges, for being responsive to radial dimensions of the respective adjacent annulus and to a shift of the said surface transverse to the axis of rotation of the respective roll, and providing a constant output for constant disposition of the axis of the respective roll in relation to the respective transducer;

first circuit means respectively connected to the pick ups and providing a balanced output when the pick ups of a transducer have the desired disposition relative to the said edges, the first circuit means providing two outputs respectively for the two transducers; and

second circuit means connected to the circuit means for combining the two outputs to provide a signal representative of the gap.

2. Apparatus as in claim **1**, wherein the annuli have particular magnetic, electrostatic or optical property, the transducer being responsive to a shift on the annuli transverse to the axis of rotation of the respective roll on basis of variations of the said property as sensed.

3. Apparatus as in claim **1**, wherein the transducers each have magnetic pick up heads, the inductance of each head being changed when the respective adjacent edge shifts in one direction transverse to said axes.

4. Apparatus as in claim **3**, wherein the pick-ups of each pair of pick ups are electrically connected in circuit; the first circuit means including an oscillator connected for energizing the pick ups, so that the pick ups provide similar outputs when the pick ups have locally symmetric disposition to the respective portion of the annulus as facing directly the head; and wherein the first circuit means further includes a means for deriving a signal from the pick ups including an amplifier and a phase dependent rectifier.

5. Apparatus as in claim **4**, there being one amplifier and one rectifier for each pair of pick ups and transducer and wherein the oscillator energizes the pairs of pick ups, said second circuit means for combining including a differential amplifier connected to the respective rectifiers.

6. Apparatus as in claim **1**, at least one of the transducers including a pair of pick up coils on an E-shaped core facing the respective annulus, the spacing between the outer legs of the E being equal to the width of the ring-shaped surface.

7. Apparatus as in claim **6**, the coils being connected in series and having a junction, the apparatus including an oscillator connected for energizing the coils, an amplifier for amplifying the voltage on the junction, and a phase dependent rectifier connected to the amplifier.

8. Apparatus as in claim **7**, each transducer having a pair of pick up coils, an amplifier and a rectifier, the coils energized by the said oscillator, the second circuit means further including a differential amplifier connected to the rectifier.

9. Apparatus as in claim **1**, each transducer being mounted for individual adjustment in radial direction relative to the respective annulus.

10. Apparatus as in claim **9**, including a stepping motor and a worm gear geared to the stepping motor, for at least one transducer head, the head being geared to the worm gear for adjustment of the radial disposition of the one transducer.

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