ABSTRACT

A roll for a rolling mill, the roll having end reliefs that reduce substantially roll end spalling and increase substantially the range of roll contour control by roll bending. The end reliefs of the roll comprise two symmetrically located, smoothly curving exponential functions extending either (1) from the center line of the roll face to the two ends of the roll, or (2) from two locations intermediate the ends of the roll and the roll face center line to the ends of the roll.

7 Claims, 3 Drawing Figures
ROLL END RELIEF FOR ROLLING MILLS

BACKGROUND OF THE INVENTION

The present invention relates generally to rolls for rolling mills, and particularly to end reliefs for work and/or back-up rolls.

In four-high and other types of rolling mills employing back-up rolls, the ends of the back-up or work rolls are usually provided with a tapered relief to reduce peak contact pressure between the work and back-up rolls, which tends to concentrate at the ends, in an effort to reduce spalling of the ends of the work and back-up rolls. Parenthetically, spalling is a failure of the roll surface under the force of rolling loads, with pieces of the surface actually coming loose. The spalled roll is often damaged severely and may require replacement. Other detrimental considerations include the danger involved in spall pieces that may fly off the rolls, and possible damage to cooperating work or back-up rolls, and to the sheet being rolled.

Roll spalling, however, has remained a problem even with tapered end reliefs. The primary reason for this has been that of the nature of the tapers themselves. Heretofore, tapers have been straight, lined or bevelled so that the bevelled portion of the roll met an intermediate cylindrical or curved portion of the roll to form a fairly well defined, annular crease or edge on the roll surface, i.e., the bevelled ends and the cylindrical or curve surface of the intermediate portion of the roll forms a rather abrupt change of direction on the roll surface even though the angle of the bevel is slight. Thus, even though the bevelled end relief is designed and does tend to reduce spalling by distributing somewhat the contact pressure between the work and back-up rolls, the edge formed by the change of directions between the intermediate and bevelled end portions of the roll creates high peak pressures between the work and the back-up rolls at the location of the edge. These high peak pressures have been found to be surprisingly high, as discussed hereinafter, and are the primary cause of continued spalling of the roll ends.

In addition to the problem of roll spalling, better as-rolled sheet flatness has been a long sought after goal in the sheet rolling art. The flatness of a sheet being rolled is determined by the contour of the gap between the work rolls, which contour is controlled partly by controlled bending of the work rolls. Controlled bending of the work rolls may be accomplished by use of roll separating jacks and reverse jacks operating on the necks of the work rolls. The effectiveness of the roll jacks in controlling the roll gap contour is directly affected by the degree and extent of the taper of the roll end reliefs. The effectiveness of the jacks is maximized by allowing only point contact between the work and back-up roll at the center of the face of the rolls, i.e., at the center of the rolling mill. Such a roll contour, however, would lead to prohibitively high stresses at the point of contact so that a compromise solution is required and desired to maximize jack effectiveness while simultaneously minimizing roll contact pressures to avoid spalling.

BRIEF SUMMARY OF THE INVENTION

The present invention provides such a compromise by using a smoothly curving, exponential function for the contour of back-up or work rolls, which contour provides end relief without an annular edge or crease on the roll surface to cause roll spalling, while simultaneously increasing the length of the taper to provide increased jack effectiveness. In addition, such a function is easily employed in the process of making the roll. For example, it can be used to control roll grinding machines which provide the roll surface with a particular, finished contour.

For rolls requiring a contour other than convex (e.g., flat or concave), a compound curve may be used, and in this case the curves of the end reliefs and the curve of the center or intermediate portion of the roll face will intersect at two locations intermediate the ends of the rolls. The slopes of curves of the end reliefs, as provided by the exponential function, and the slope of the curve of the center portion of the roll are equal to zero at the two intersecting locations, as explained more fully hereinafter.

THE DRAWING

The invention, along with its advantages and objectives, will best be understood from the following detailed description in connection with the accompanying drawing in which:

FIG. 1 is a schematic end view representation of a single stand of a typical four-high rolling mill;

FIG. 2 is a diagram showing one half of the roll face of a back-up roll provided with the end relief of the present invention, and a straight-line, bevelled end relief shown in dash outline;

FIG. 3 is a graph illustrating contact pressures between a work roll and the back-up roll of FIG. 2.

PREFERRED EMBODIMENT

Referring now to the drawing, FIG. 1 shows schematically a typical four-high stand of a rolling mill 10 in which upper and lower back-up rolls 11 and 12 are located to roll against two work rolls 13 and 14 in a process of reducing the thickness of a sheet of metal 15 traveling between the work rolls.

As explained earlier, the rolling force between the work and back-up rolls tended to concentrate at the edges and ends of the rolls that resulted in spalling of the roll ends. In an effort to correct this problem, the ends of the back-up (or work) roll were provided (ground) with a straight line taper, as indicated in FIG. 2 by dash outline 16 at one end of the upper back-up roll 11. Only one half of one back-up roll is shown in FIG. 2 since the other half, as well as the lower back-up roll 12, would have essentially the same end configurations. The taper 16 joins the intermediate portion 17 of the roll face at a location 18 to provide the roll with an essentially bi-linear contour.

From a roll deformation program derived analytically, i.e., by calculations involving principles of mechanics, it has been found that extremely high peak pressures exist between the work and back-up rolls where the taper relief 16 joins the generally flat portion 17 of the roll grind, i.e., at the region or location 18 on the roll face. This high peak pressure is caused by an annular edge or crease at the location 18 where, as explained above, the tapered and intermediate portions of the roll face change directions. In FIG. 3, this peak pressure is shown by dash line curve 20 for a 38 inch diameter, 60 inch long back-up roll employed in a mill for cold rolling aluminum and aluminum alloy sheet. The curve 20 is a plot of roll pressure in kips per inch against the distance from the center line of the mill and...
the roll 11 of FIG. 2. At the end of the roll, the pressure line 20 drops to zero since the taper removes essentially all pressure between the two rolls at their ends. However, as seen in FIG. 3, in moving away from the roll end and toward the roll face center line, the pressure rises rapidly to a point approaching 70 kips per inch in comparison to a 27 to 29 kips per inch range for the remainder of the distance to the roll face center line. This peak pressure point corresponds distance-wise (in reference to the roll face center line) to the location or edge 18 on the roll face. It is this high peak pressure at 18 that is the primary cause of continued roll spalling in the rolling art.

In accordance with the present invention, the back-up rolls and/or the work rolls of a rolling mill are provided with a smoothly curving, exponential function extending from the ends of each roll to an origin at (1) the center line of the roll face for a roll having a crown consisting entirely of the exponential curve, or at (2) two locations intermediate the roll face center line and the ends of the roll having a compound crown consisting of an arbitrary central contour blending with the exponential end relief. Such a smoothly curving, exponential function blends optimally the end reliefs and the intermediate portion of the rolls to eliminate the annular edge 18, and thus the peak pressures and the roll spalling resulting therefrom. The reduction in peak pressure is illustrated by the solid line 22 in FIG. 3. In going from the center line of the mill to the end of the roll, only a slight rise in roll pressure occurs before pressure falls to zero at the very end of the roll.

The exponential function providing such advantageous results may be defined for the special case (1) above by the equation

\[ y = c(2x)^n/L \]

where, as shown in FIG. 2, \( x \) is any selected distance from the center line of the mill and roll face

\[ y \] is the relief at \( x \)

\( c \) is the maximum relief at the roll ends

\( L \) is the length of the roll, and

\( n \) is the exponent.

Rolls provided with the above exponential function and used in rolling mills to roll metal sheet have demonstrated their effectiveness in substantially reducing roll end spalling.

In addition, it can be demonstrated that for any bevel relief of an amount \( c \) over a length \( B \) (with \( B \) being the distance from the roll end to location 18 on the roll face shown in FIG. 2) the effectiveness of work roll separating jacks in controlling the gap between the work rolls by roll bending and thus control of as-rolled sheet flatness, is improved by using the above equation with \( n = L/2B \), with \( n \) being greater than one. This value of \( n \) produces a curve which is tangent to the bilinear contour of the roll face as depicted in dash outline in FIG. 2. As readily seen, for the same amount of maximum end relief \( c \), the back-up roll 11 with the curved function contacts the work roll at a location inwardly of the contact point 18 of the bevelled roll. This increases the distance that the work roll end is free of the back-up roll to provide greater leverage for the roll bending process.

With roll contours corresponding to case (1) above, the magnitude of the term \( x \) (in the above formula) at the center line of the mill is, of course, zero, and the slope of the curve at the center line is thus zero or flat.

In going from the center line toward the ends of the roll, which is a linear progression, the magnitude of \( x \) increases gradually and incrementally from zero, by finite numbers in measurement of the progression, to provide a roll with a convex shape.

However, with roll contours corresponding to case (2) above, the curve of the end relief provided by the present invention will intersect the curve of an intermediate or center portion of the roll, having the cylindrical or concave configuration, at two locations intermediate the ends of the rolls. At these two intersecting locations, the curve of the end relief exponential function begins with a zero or flat slope since the distance \( x \) originates at the intersecting locations rather than the center line of the mill.

As can be appreciated, jack effectiveness for the bending process is maximized by allowing only point contact between the work and back-up rolls at the center of the mill. Such a roll contour, however, would lead to extremely high stresses at the point of contact as explained earlier. The smoothly curving, exponential function of the present invention provides a compromise between the two by providing a very gradual decrease in contact pressure between the work and back-up rolls along a major portion of their length, for a roll having a convex crown, with relief increasing to a maximum more rapidly, though gradually, in its approach to the ends of the back-up roll. In this manner, the problem of high stress points, with resulting spalling, is essentially eliminated while simultaneously increasing jack effectiveness for increased control of roll bending to provide better as-rolled sheet flatness.

For rolls having an essentially straight cylindrical shape, or a concave configuration, the effect of the exponential function of the invention is the same, i.e., the function blends the end reliefs with the intermediate portion of the roll face to remove high stress points on the roll face and to increase jack effectiveness by increasing the distance of end relief.

While the invention has been described in terms of preferred embodiments, the claims appended hereto are intended to encompass all embodiments which fall within the spirit of the invention.

Having thus described our invention and certain embodiments thereof, we claim:

1. A roll for a rolling mill having end reliefs comprised of two smoothly curving exponential functions extending from the roll face center line to both ends of the roll, with the slope of the curve of the roll face at the center line being zero, and increasing in magnitude toward the ends of the roll from said center line.

2. The roll of claim 1 in which the exponential function is defined by the equation

\[ y = c \left( \frac{(2x)^n}{L} \right) \]

where

\( x \) is any selected distance from the center line of the mill

\( y \) is the relief at \( x \)

\( c \) is the maximum relief at the roll ends

\( L \) is the length of the back-up rolls, and

\( n \) is an exponent.

3. The roll of claim 2 in which the exponent \( n \) is greater than one.

4. A roll for a rolling mill having a center portion provided with a predetermined configuration or curve and an end relief adjacent each end of the roll, with each end relief comprising a smoothly curving, exponential function, and intersecting the center portion of the roll
at two locations intermediate the roll face center line and the ends of the roll, the slopes of the curves of the end reliefs increasing in the direction of the roll ends from said intermediate locations, with the curves of the end reliefs and the curve of the intermediate portion at the two intersecting locations having slopes equal to zero.

5. In a rolling mill having work and back-up rolls, with at least one of the rolls having end reliefs comprised of two symmetrically located, smoothly curving, exponential functions extending from the roll face center line to both ends of the roll, with the slopes of the curves increasing in the direction of the roll ends from said center line, the smoothly curving, exponential functions being effective to reduce substantially the tendency of the work and back-up rolls to spall under the force of rolling loads, while simultaneously accommodating an increased range of roll contour control by roll bending.

6. The mill of claim 5 in which the back-up rolls have end reliefs comprised of the smoothly curving, exponential functions.

7. The mill of claim 5 in which the work rolls have end reliefs comprised of the smoothly curving, exponential functions.

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