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[54] **METHODS AND APPARATUS FOR TUBE ROLLING**

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[57] **ABSTRACT**

A method and apparatus are provided for reducing the amount of out of tolerance end thickness in rolled tubing by subjecting the entering end of the tube, at least in the penultimate pass of those passes which build up tension in the tube, to a maximum tractive force.

10 Claims, No Drawings

METHODS AND APPARATUS FOR TUBE ROLLING

This invention relates to methods and apparatus for tube rolling and particularly to a method and apparatus for rolling of tubes by means of an elongating multi-pass rolling mill, in which the tube is placed under tension between the individual roller sizing gaps.

During elongation rolling of tubes, in the course of which a reduction is caused, principally in the thickness of the wall, but also in the outer diameter of the tube, considerable longitudinal portions at the leading and trailing ends of a rolled tube are produced having thicker walls than the mid-longitudinal portion of the tube. The two tube end portions whose wall thickness exceeds the permissible tolerance, must be cut off and can only be used as scrap. These longitudinal portions, termed "thickened ends," are produced as a result of the method of rolling presently followed in the art. They are formed in that, in order to achieve a specific decrease in the thickness of the wall in the finished tube, a specific tension must also be applied to the tube during rolling, which tension is adequately applied in the region of the middle longitudinal portion, it is true, but not in the region of the thickened ends of the tube. This is caused by the fact that it is not possible by present practices and equipment to achieve the strong tension which is necessary in the early stages of rolling as, for example between the first two sizing gaps of the rolling mill, since the rollers of a sizing gap produce only limited frictional forces, which are not sufficient to sustain maximum tension. It is not until the tubee has been engaged by several, e.g., six sizing gaps, that the maximum tension is built up in the middle region of the longitudinal portion of tube which has already entered, and is then maintained until the end portion of tube issues from the rolling mill at which time the number of sizing gaps which are still rolling becomes too small to continue to apply the maximum tension necessary. Since the leading and trailing portions of each tube are always grasped during the rolling process by only a smaller number of sizing gaps than is necessary to produce the maximum tension, such portions are never exposed to this force, so that thickened ends are inevitably produced.

The force which is exerted by a roller on the tube in the direction of rolling, that is the force which is applied to effect the tension basically depends on the frictional forces in the region of the contact surface between the roller and the tube. These frictional forces are influenced by the ratio of the peripheral speed of the roller to the speed at which the tube passes through. This ratio is different at the individual peripheral points of the tube, since the roller radius at the individual peripheral points of the tube which are in contact with a roller, is also different, whilst the roller angular velocity remains the same. It may therefore be the case that the peripheral speeds of the roller at all the peripheral points of the tube which come into contact with a specific roller, are greater or smaller than the speed at which the tube passes through. However, it is also possible for the peripheral speeds of a roller to be greater at certain peripheral points of the tube and to be smaller at other peripheral points of the tube than the speed at which the tube passes through. In this case there are produced on the periphery of the tube points at which the peripheral speed of the roller and the speed at which the tube passes through are the same.

The distance of these points from the axis of rotation of the roller is designated as the rolling radius. The peripheral speed, which is calculated from the rolling radius and the roller angular velocity is therefore the same as the speed at which the tube passes through.

Depending on the ratio of the roller peripheral speed to the speed at which the tube passes through at the individual peripheral points of the tube, the components of the frictional forces on the surface elements can be directed both in and against the direction of rolling once they have been resolved with respect to each other. On the other hand, they can also in part be directed against each other and thus, as before, be directed both in and against the direction of rolling. It can easily be seen that in the case of identically directed frictional forces on the individual surface elements the resultant assumes a maximum value. The direction of the frictional forces is naturally determined by the relative speed between the roller and the tube at the point in question. This leads to the roller exerting a maximum tractive force on the tube, when the relevant peripheral speed of the roller at each point of the contact surface between the roller and the tube is greater than the speed at which the tube passes through. The opposite is the case in the region of the groove base when the rolling radius is the same as or smaller than the roller radius, i.e., in the region of the deepest point of the roller working surface which is machined into the body of the roller. If instead of the radii the appropriate diameters are selected, then the following formula is produced:

$$R = \tfrac{1}{2} \cdot (WD - D) \qquad \text{(Formula I)}$$

In this formula, R represents the rolling radius, D the outer diameter of the tube, and WD the "ideal" roller diameter, which is equal to double the distance between the axis of rotation of the roller and the longitudinal axis of the tube. (Formula I) may be expressed in a more general manner as follows:

$$R = \tfrac{1}{2} \cdot (WD - C \cdot D) \qquad \text{(Formula II)}$$

In this formula, c represents a factor for determining the rolling radius. It has the value 1 when the rolling radius is identical to the roller radius in the region of the groove base. When the peripheral speed of the roller at all peripheral points of the tube which come into contact with a specific roller is greater than the speed at which the tube passes through, then the value of c becomes greater than 1. If, however, the peripheral speed of the roller at each of these peripheral points is smaller than the speed at which the tube passes through, then the value of c becomes less than 1 and assumes a maximum value of 0.5 for a three-roller pass, i.e., the pass of a stand having three rollers whose axes are at 120° to one another. If the value of c is 0.5 or less, then the maximum force exerted by the roller on the tube is in the opposite direction to the direction of rolling, whereas in the case of a c value of 1 or more, the maximum force exerted by the roller on the tube is in the direction of rolling.

If the tension is kept constant or is altered to only a small extent, the value of c in the case of a threeroller pass, is approximately 0.9, depending on the ratio of roller diameter to tube diameter and also on the reduction in diameter. The precise value is produced from the equilibrium of forces between the tube and the roller. If the tube has entered all the stands of the rolling

mill, which may, for example, number 24, then the tension is built up e.g., in the first four to six passes or sizing gaps. If the maximum possible tractive forces are utilized, the c values e.g., of the three-roller pass rolling mill, are approximately 0.5 or less. The last sizing gaps, e.g. passes 20 to 24, reduce the tractive force, which entails the rollers exerting force on the tube in the direction of rolling and their c values being 1.0 and over. Beyond passes 1 to 6, which build up the tension, come the passes seven to nineteen which keep this tension constant or alter it to only a small extent, and which have c values of between 0.8 and 0.9. With the progressive pass numbers, the c values readily decrease as a result of the increase in size of the rollers.

From the above it can be gathered that beyond e.g., the first six passes which build up the tension, there is a jump in the c values from approximately 0.5 to approximately 0.9. This signifies that even at those speeds a jump into the high speed range is effected, i.e., a greater transmission ratio is produced between two adjacent passes in the region of the transition from those passes which build up the tension to those which maintain it. The transmission ratios can be calculated from the continuity equation

$$A \cdot V = A_1 \cdot V_1 \qquad \text{(Formula III)}$$

In the above equation the cross sectional areas of the tube after a pass are denoted by A and A_1 and the speeds of energence of the tube from the pass by V and V_1, for two adjacent passes respectively. If the formula for the peripheral speed

$$V = \frac{\pi \cdot n}{30} \cdot R \qquad \text{(Formula IV)}$$

is inserted into (Formula III), the following formula is obtained:

$$A \cdot n \cdot R = A_1 \cdot n_1 \cdot R_1 \qquad \text{(Formula V)}$$

This formula can also be expressed in the following manner:

$$\frac{n_1}{n} = \frac{A}{A_1} \cdot \frac{R_1}{R} = i \qquad \text{(Formula VI)}$$

which denotes the transmission ratio i.

If (Formula II) is inserted into (Formula VI) the following formula is obtained:

$$i = \frac{A_K \cdot (WD_K - c_K D_K)}{A_{K+1}\,(WD_{K+1} - c_{K+1} \cdot D_{K+1})} \qquad \text{(Formula VII)}$$

In this formula, K indicates the pass number. It can be seen from (Formula VII) that when the c values alter in large steps, then the transmission ratios also alter in large steps, because the values for A and D alter in a basically uniform manner.

The transmission ratios of the known rolling mills are calculated in accordance with the above-described method, that is with the pre-requisite of the so-called steady state, i.e., with the tube located in all of the passes of the rolling mill and with the leading and trailing end portions of the tube beyond or in front of the rolling mill. However, these ratios are no longer correct when each of the end portions of the tube passes through the rolling mill. When, for example, the leading portion of tube passes through the rolling mill, those passes which roll the leading longitudinal portions of the tube always serve to reduce the tension. The c values of these passes would always have to be 1 or more for the maximum possible tension to be applied. If the leading portion of the tube in question is elongated to a lesser degree than the middle portion of the tube, for the initially mentioned reasons, then a point in the region of the leading portion of the tube passes a specific point on the rolling mill at a lower speed than a point in the region of the middle portion of the tube. Therefore, as compared with the prescribed speed of the rollers, a particular cross section of the leading portion of the tube passes through the passes more slowly than a particular cross section of the middle portion. Consequently, the rollers exert a stronger pull on the leading portion of the tube and the c value automatically adjusts to 1.0 and over. However, this only applies for example to the sixth pass, since not until then is the difference of the lesser extension of the leading portion of the tube as compared with that of the middle portion of the tube at one specific point of the rolling mill sufficiently great. This is not the case until, for example, the sixth pass because not until then is the maximum tension built up. Of course, further prerequisites for the automatic adjustment of the c value to 1 and over, consist in the dimensions and shaping of the passes and the speed (transmission) ratios from pass to pass being perfectly co-ordinated with respect to one another, and in the speeds being kept constant independent of whether the tube has entered the rolling mill or to what extent it has entered. Perfect maintaining of the speeds is achieved in the known rolling mills by means of the so-called group drive, in which fixed transmission ratios are imposed on each of two speed sequences.

A similar process takes place in the case of the trailing end portion of the tube, which is also subjected to a lesser elongation then the middle portion of the tube, so that when issuing out of the rolling mill, the trailing end portions follows the middle portion more rapidly. Therefore, at a specific point in the rolling mill, the trailing end portion of the tube has a greater speed than a cross section of the middle longitudinal section of the tube. The higher speed of the trailing end portion of the tube leads to the c value, in a rolling mill having three-roller passes, becoming equal to or smaller than 0.5, and the rollers thus exert maximum pull in the opposite direction to the direction of rolling. This is also the case with the known rolling mills — again, only under the same pre-conditions as with the leading portion of the tube, and the effect does not come into force until the trailing end portion of the tube has, for example, passed through the sixth pass.

Although the transmissions and speeds have thus been determined for the steady state, the leading and trailing end portions of the tube are, after a certain number of passes and under the above-mentioned prerequisites, rolled in the middle and rear part of the rolling mill in such a way that maximum tension effects can be applied by the rollers. These maximum tension effects which can arise automatically under the above-mentioned pre-requisites and, for example, beyond the sixth pass, are not present at all or not in their entirety in the region of the first to sixth passes in the known

rolling processes and rolling mills. This is because the elongation difference between the leading end portion of the tube and the middle portion of the tube is still too small in the first pass.

In order to keep the thickened end portions of the tube as short as possible, and thus to keep the proportion of scrap low, endeavours are made also to subject the tube to as great a tension as possible in the region of the front, e.g. the first to sixth passes. This cannot however be achieved with the known processes and rolling mills, or can be achieved only incompletely, since hitherto the roller speeds have always been selected in accordance with the steady state, the *c* value in the first pass of a three-roller stand rolling mill being selected at approximately 0.5 which then rises to approximately 1.0 in the second to sixth passes. These *c* values and the speeds, which result therefrom, for the first passes are not suitable for shortening the thickened end portions to any great extent. Depending on the measurements of the tube and also on the dimensions and other factors of the rolling mill, the thickened end portions are, for example, approximately 2.2 to 2.5m long. In the case of rolling mills having individually driven stands, attempts have in fact been made to adjust the roller speeds e.g., of the first six passes to different values, as the leading end portion of the tube is entering, and thus to increase the tension in the region of these first passes. However, this is only possible in the case of individually driven stands with which it is difficult to maintain the predetermined speeds during the steady state. Furthermore, the cost of individually driven stands, including the control and regulating devices, is very high and they are more susceptible to trouble than the above-mentioned group drive having fixed speed sequences, which drive is constantly able to maintain the predetermined speeds. Moreover, in the case of a rolling mill having individually driven stands, the speeds of the first stands during entry of the leading end portion of the tube must constantly be altered as the number of passes that are effecting rolling increases, in order to adapt to the actual ratios. This necessitates an expensive regulating device, which is susceptible to trouble and resulted in only a light shortening of the thickened end portion, e.g., from 2.2 to 2.5*m* down to 1.9 to 2.1*m*.

The object of the invention is to shorten the length of the thickened end portions even further and to lower the proportion of scrap during the reducing rolling of tubes correspondingly.

In accordance with the invention, in the region of those passes of the rolling mill which are at the front when viewed in the direction of rolling and which build up the tension, preferably in the region of the first to sixth passes, during the entry of the leading end portion of the tube into and the exit of the trailing end portion of the tube from this region, the tube is acted upon, at least in the respective penultimate pass which builds up the tension, by a maximum tractive force, which is limited only by the transmission capacity of the frictional forces between the rollers of the pass and the tube.

The mere guaranteed realization of maximum tractive force in only one of the front passes represents a substantial intensification of the tension in the tube in this part of the rolling mill and thus a shortening of the thickened end portions of the tube. However, in accordance with a preferred feature of the invention, maximum tractive force is also to be exerted on the tube in several or in all the other front passes which build up the tension. This is not the case with known processes, since in the case of *c* values, which are selected in such processes, of approximately 0.5 for the first pass to 1.0 for the last pass which builds up the tension, for example the sixth pass, and also in the case of the corresponding intermediate values for the intermediate passes, the speed jumps or increments, which can be calculated therefrom, from one pass to the next, are too small, so that it is impossible for the maximum tractive force, which is limited only by the transmission capacity of the frictional forces between the rollers and the tube to be achieved.

The invention includes a rolling mill for carrying out the method according to the invention, wherein the speeds of the rollers are predetermined and are kept substantially constant during rolling, and wherein in the region of those passes of the rolling mill which are at the front when viewed in the direction of rolling and which build up the tension, preferably in the region of the first to sixth passes, the roller speed of the first pass of the rolling mill is determined in accordance with a *c* value equal to or smaller than 0.35, which fixes the rolling radius of the rollers, and the roller speed of the pass following on the last pass of those passes which build up the tension, is determined in accordance with a *c* value of 1.0 or over.

In the case of those passes which follow the last of the passes which build up the tension, the c values can increase to approximately 1.1, and in case of the first pass of the rolling mill, can approach zero. Therefore, in the method of the invention, *c* values which hitherto would have been regarded as absurd, may for the first time be selected for the first passes of the rolling mill. A *c* value of less than 0.5 in the first pass of the rolling mill signifies, in the case of a three-roller pass, that the rolling radius is greater than the distance between the axis of rotation of the roller and that portion of working surface of the roller which is furthest away from said axis, and thus that a particularly high relative speed is selected between the tube and the roller. However, since in the case of a higher relative speed between the tube and the roller no higher tractive forces can be transmitted than in the case of the lowest relative speeds, the view has hitherto been taken that, in order to preclude increased wear of the rollers, the relative speed should be as low as possible and thus the *c* values, e.g., in the case of the first stand should not be smaller than 0.5. The invention opposes this prejudice, although the above assumption is, in principle, correct. However, it was recognized that the wear of the rollers in the front passes is relatively low, because the relative speed between the rollers and the tube is also low in respect of the amount. In spite of the selection in the method according to the invention of extremely low *c* values, the relative speed in the front passes is, in respect of the amount, still substantially lower than the speed which is produced anyway in the latter passes, e.g., in the twentieth to twenty-fourth stands. The increased wear in the region of the front stands is in fact so small, as compared with normal wear, that it can be neglected, so that nothing conflicts with the reduction in the method according to the invention of the c value in the first pass.

By means of the small *c* value in the first pass of the rolling mill there are obtained in advantageous manner very large speed differences between the individual adjacent passes in the front region of the rolling mill, so that whilst the leading and trailing end portions of each

tube are passing through, maximum tractive forces are transmitted from the rollers to the tube, which forces are limited only by the transmission capacity of the frictional forces. The speed differences in the known methods and rolling mills are not adequate for this purpose, since they are selected in accordance with the steady and not in accordance with the non-steady state on the basis of jumps in the c values and thus in the speeds which are too small.

The invention can be used in rolling mills having individual drives for the stands as well as in those having group drive. However, since the speeds, which are predetermined in accordance with the invention, are to be kept constant regardless of how far the tube has entered the rolling mill, an expensive individual drive, which is susceptible to trouble in respect of regulation, is superfluous and the group drive is to be recommended, since it is possible with this drive to maintain precisely the determined speeds. Thus the thickened end portions are shortened from 2.2 to 2.5*m* in conventional individually driven rolling mills to approximately 1.8 to 2*m* with a group driven rolling mill according to the invention.

The invention, which when selecting the roller speeds in the front passes, takes into account and commences from the non-steady state of the entry of the leading end portion of the tube into or the exit of the end portion of the tube from the rolling mill, can be varied in quite diverse ways. In a preferred embodiment of the invention the roller speed of the penultimate pass of those which build up the tension, is determined in accordance with a *c* value of approximately 0.5. It is also advisable to select the roller speeds of the individual front passes of the rolling mill in accordance with *c* values, which are always greater than c values of the respective preceding pass. It is advantageous to determine the roller speeds of the second pass up to the last pass of those which build up the tension, in accordance with *c* values which linearly increase from a value equal to or smaller then 0.35 and a value equal to or greater than 1. On the other hand, it is also possible to cause the *c* values to rise in a non-linear manner, by selecting them between the stated values in accordance with a regressive or progressive curve.

The invention, which is clarified above using the example of a stretch-reducing rolling mill with three rollers per pass, can also be used analogously with rolling mills having a different number of rollers per pass, although in this case different c values are produced.

While we have described certain preferred practices and embodiments of our invention in the foregoing specification, it will be obvious that the invention may be otherwise practiced within the scope of the following claims.

We claim:

1. A method of rolling tubes under tension in a multipass stretch-reducing rolling mill, in which, during the entry of the leading end portion of the tube into and the exit of the trailing end portion of the tube from the region of those passes of the rolling mill which are at the entry end when viewed in the direction of rolling and which build up the tension subjecting the tube, at least in the respective penultimate pass of those passes which build up the tension, to a maximum tractive force, which is limited only by the transmission capacity of the frictional forces between the rollers and the tube and is created by causing the relevant peripheral speed of the rollers in such passes at each point of contact surface between the rollers and the tube to be greater than the speed of the tube passing through said rollers.

2. A method as claimed in claim **1,** wherein the mill has more than six passes and in which the region in which the tube tension is built up is encompassed by the first six passes.

3. A rolling mill having multiple passes, each pass including three-rollers for rolling tubes under tension, which mill is so adapted that the speeds of the rollers are pre-determined and are substantially maintained during rolling, in which in the region of those passes which are at the front when viewed in the direction of rolling and which serve to build up the tension, the roller speed of the first pass of the rolling mill is determined in accordance with a *c* value equal to or smaller than 0.35, which fixes the rolling radius of the rollers, and the roller speed of the pass following the last of the passes which serve to build up the tension is determined in accordance with a c value of 1.0 or over, said *c* value being determined from the formula $R = \frac{1}{2} \cdot WD - C \cdot D$) where R represents rolling radius, *D* the outer diameter of the tube and WD the ideal roller diameter.

4. A rolling mill as claimed in claim **3,** in which the roller speed of the penultimate pass of those passes which serve to build up the tension is determined in accordance with a *c* value of approximately 0.5.

5. A rolling mill as claimed in claim **3,** in which the roller speeds of the individual passes in the entry region of the rolling mill are selected in accordance with *c* values, which in every case are greater than the *c* values of the respective preceding passes.

6. A rolling mill as claimed in claim **4,** in which the roller speeds of the individual passes in the entry region of the rolling mill are selected in accordance with c values, which in every case are greater than the *c* values of the respective preceding passes.

7. A rolling mill as claimed in claim **3,** in which the roller speeds of the second pass up to the last pass of those passes which serve to build up the tension, are determined in accordance with *c* values which linearly increase from a value equal to or smaller than 0.35 to a value equal to or greater than 1.

8. A rolling mill as claimed in claim **3,** in which the roller speeds of the second pass up to the last pass of those passes which serve to build up the tension, are determined in accordance with c values which linearly increase from a value in excess of 0.35 to a value equal to or greater than 1.

9. A rolling mill as claimed in claim **5,** in which the roller speeds of the second pass up to the last pass of those passes which serve to build up the tension, are determined in accordance with *c* values which linearly increase from a value in excess of 0.35 to a value equal to or greater than 1.

10. A rolling mill as claimed in claim **3,** in which the region of those passes which serve to build up the tension is encompassed by the first six passes.

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