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CAUSES OF "COIL BREAK" DEFECTS ON HOT STRIP SURFACE IN THE CONTINUOUS PICKLER

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ABSTRACT

"Coil break" is a strip surface defect in the form of rough light transverse strips resulting from sharp breaks in coiling or uncoiling rolled products due to local stresses exceeding the yield strength of metal. The conditions for this defect in the inlet of a continuous pickler are determined. A procedure for calculating these conditions is proposed.

Keywords: hot-rolled products, yield strength, stretcher leveler, yield surface, stress, continuous pickler.

INTRODUCTION

Hot-rolled strips are pickled to remove scale, after which they are often sent to the consumer bypassing the stage of cold rolling. The surface of such strips suffers from the "coil break" defect (Fig. 1) [1 - 2]. This defect affects the hot strip surface in eliminating coil curvature during uncoiling and shape defects during strip flattening in roller straightening machines in the continuous pickling line [3 - 8] and depends on the strip stress strain state [9 - 10].

The diagram of stretching hot-rolled strips from low-carbon steel is characterized by the presence of a clearly pronounced intermittent flow area, i.e. the upper ("yield drop") and the lower yield strength (Fig. 2).

When longitudinal stresses are applied to a strip from such steel, the values of which are close to yield strength, an intermittent character of yield in closely located areas is observed [11].

After the accelerated hot strip cooling on the run-out table, in low-carbon steel iron nitrides begin to precipitate from the solid solution. The yield drop and surface on the diagram of stretching steel samples are caused by the fact that dislocations fixed by the precipitated particles of iron nitrides break out of this fixation when tensile stresses reach yield strength ($\sigma_{Ò}^{drop}$). The yield surface is caused by the motion of free dislocations freed from fixation at a constant voltage. In this way the "coil break" defect appears.

MATHEMATICAL DESCRIPTION OF THE PROCESS OF UNBENDING HOT STRIP LAYERS

After installing the hot-rolled coil on the continuous pickler uncoiler, the strip begins to move in the line of the unit. Figs. 3 and 4 illustrate the process of unbending a hot strip layer when uncoiling a coil from the continuous pickler uncoiler: h - strip thickness; ℓ_0^t - length of the upper side of the layer before unbending; R_0, φ_0 - the layer's radius and central angle before unbending; ℓ_0^m - length of the layer's central (neutral) line before unbending; ℓ_1^t - length of the upper side of the layer after unbending; R_1, φ_1 - the layer's radius and central angle after unbending; ℓ_1^m - length of the layer's central (neutral) line after unbending.

The length of the upper side of the layer before unbending is $\ell_0^t = R_0\varphi_0$. The length of the neutral line of the layer before unbending is $\ell_0^m = \left(R_0 - \frac{h}{2}\right)\varphi_0$. The length of the upper side of the layer after unbending is $\ell_1^t = R_1\varphi_1$. The length of the neutral line of the layer after unbending is $\ell_1^m = \left(R_1 - \frac{h}{2}\right)\varphi_1$:.

Fig. 1. “Coil break” defect.

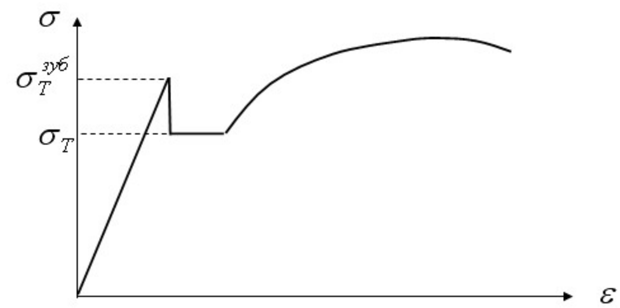

Fig. 2. Schematic diagram of stretching with “yield drop”.

As a result of elementary calculations, the value of the degree of relative deformation is obtained:

$$\varepsilon = \frac{\ell_0^t - \ell_1^t}{\ell_0^t} = \frac{R_0\varphi_0 - \dfrac{\left(R_0 - \dfrac{h}{2}\right)\varphi_0 R_1}{\left(R_1 - \dfrac{h}{2}\right)}}{R_0\varphi_0} = \qquad (1)$$

$$= 1 - \frac{\left(R_0 - \dfrac{h}{2}\right)R_1}{\left(R_1 - \dfrac{h}{2}\right)R_0} = \frac{h}{2}\left(\frac{1}{R_0} - \frac{1}{R_1}\right)$$

The stress distribution along the thickness of the strip layer is linear with respect to the current strip thickness:

$$\sigma = E\varepsilon = E\frac{h}{2}\left(\frac{1}{R_0} - \frac{1}{R_1}\right),$$

where E is the modulus of elasticity of the strip material. The condition of plastic flow $\sigma = \sigma_{\grave{O}}$:

$$E\frac{h}{2}\left(\frac{1}{R_0} - \frac{1}{R_1}\right) = \sigma_{\grave{O}}^{drop}. \qquad (2)$$

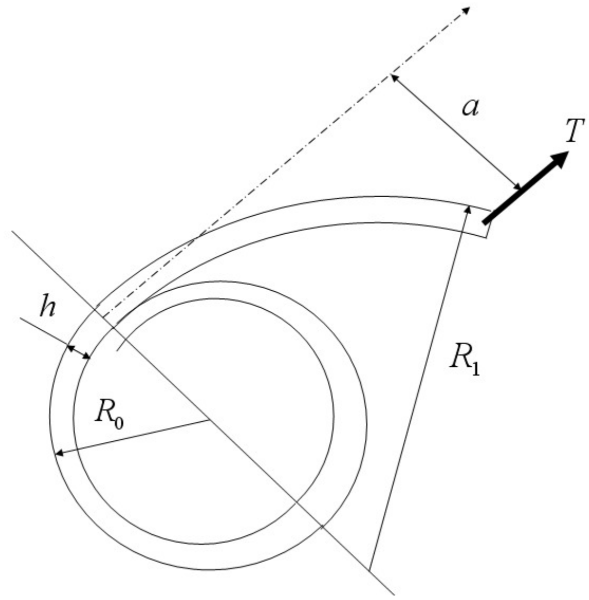

Fig. 3. Unbending the layer.

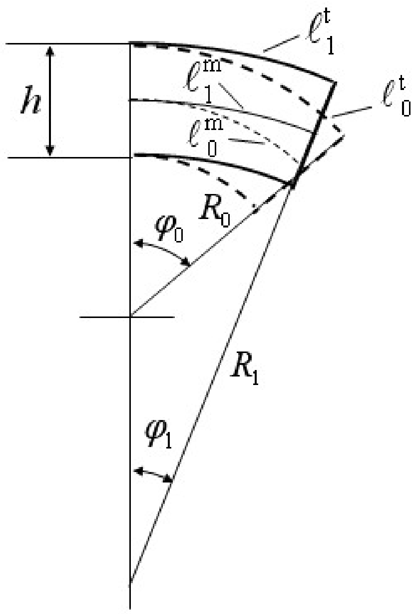

Fig. 4. Deformation of the layer.

RESULTS OF CALCULATIONS AND DISCUSSION OF CONDITIONS UNDER WHICH THE PLASTIC HINGE APPEARS

As an example, we calculate the curvature and the radius of the bend of the coil layer being unbent, whose radius R_0 is 1,000 mm, with thickness strip h = 3.0 mm, width B = 1,500 mm and the upper yield strength $\sigma_{\grave{O}}^{drop}$ = 270 MPa, at which a plastic hinge begins to form in the uncoiled strip. According to the formula (2),

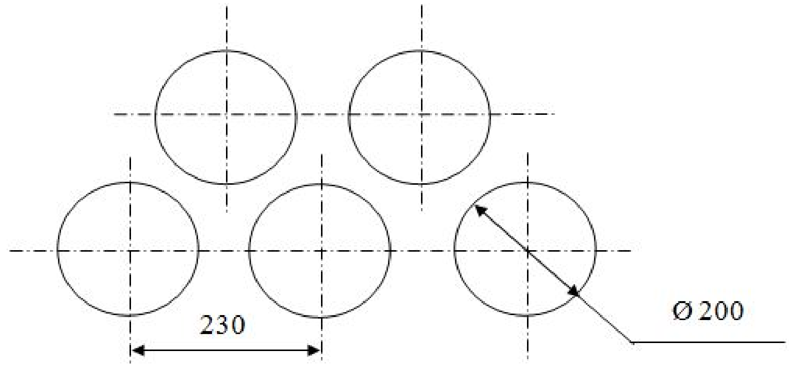

Fig. 5. Schematic diagram of a five-roller straightening machine.

the radius of the unbent layer is:

$$\frac{1}{R_1}=\frac{1}{R_0}-\frac{2\sigma_{\grave{O}}^{drop}}{E}=\frac{1}{10000}\ .$$

At the maximum coil radius R_0 = 1,150 mm, the curvature radius of the layer is $R_1=-32760$ mm, i.e. the layer must be bent in the opposite direction. In this case, with complete unbending of the layer, conditions for the formation of the “coil break” defect are not created.

At the minimum coil radius R_0 = 425 mm, the curvature radius of the layer is $R_1=688$ mm.

When the layer’s curvature radius becomes equal to 10,000 mm at its unbending during uncoiling, a plastic hinge will begin to form in the layer. Moreover, because of the “drop” in the diagram of stretching, the stresses in the strip decrease in an abrupt way, which leads to a sharp plastic strip fracture. The height of the drop, the value of the yield strength $\sigma_{\grave{O}}$ corresponding to the yield surface, and the radius of the coil on the uncoiler determine the conditions for the “coil break” defect.

MATHEMATICAL DESCRIPTION OF STRIP LEVELLING IN A FIVE-ROLLER STRAIGHTENING MACHINE

The hot rolled strip is straigntened in a five-roller straightening machine as part of a straightening and withdrawal unit of the continuous pickler (Fig. 5). If we assume that the strip is bent circularly between the rollers, then a five-roller straightening machine provides a minimum bend radius of 200 mm. The maximum depth of the upper rollers before their contact with the lower rollers (Fig. 6) is 2d = 36.4 mm. The distance between the contact points of the rollers is $2a^*$ = 115 mm.

Let us determine the dependence of the strip curvature radius R on the upper roller depth g (Fig. 7).

Assuming that the strip curvature radius is much longer than the strip thickness and the roller radius, R, g^* and a will be equal to $R+r$, g and a^*, respectively. Then:

$$R=\frac{g^2+2a^2}{2g} \tag{3}$$

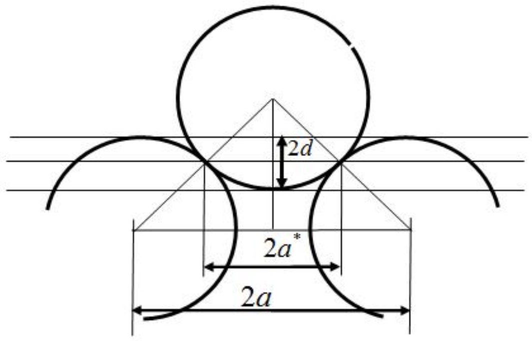

Fig. 6. Maximum roller depth.

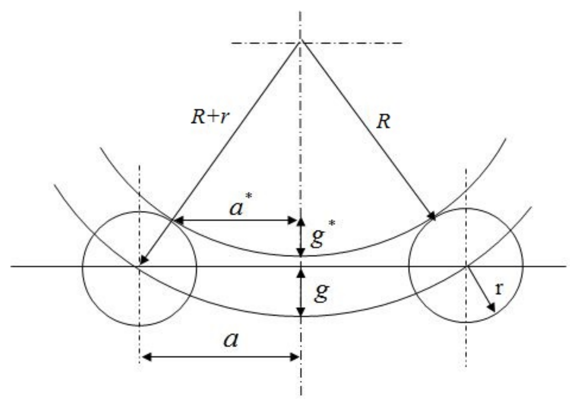

Fig. 7. Dependence of R on g^*.

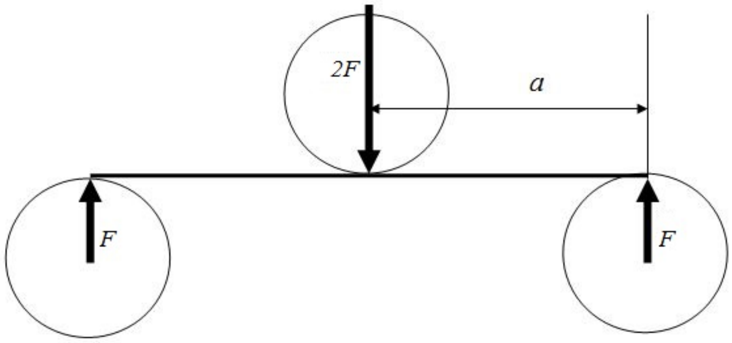

Fig. 8. Diagram for calculating the moment.

When the strip passes through the straightening machine, it experiences pressure from the upper and lower rollers (Fig. 8). The moment experienced by the strip in the roller straightening machine at the section a

$$M = F \cdot x \quad (4)$$

In solving the elastic line equation

$EJ\dfrac{d^2y}{dx^2} = M(x)$ the deflection line equation is obtained: $y = \dfrac{F}{EJ}\left(\dfrac{'x^3}{6} - \dfrac{a^2}{2}x\right)$.

At $x = a$, the arrow of the deflection of the strip section is equal to:

$$s = \frac{F}{EJ}\frac{a^3}{3} \quad (5)$$

Hence:

$$F = 3\frac{sEJ}{a^3}\ ,\ J = \frac{Bh^3}{12} \quad (6)$$

The force F is equal to:

$$F = \frac{1}{4}\frac{sbh^3E}{a^3} \quad (7)$$

Stresses experienced by the strip during unbending:

$$\sigma = E\frac{h}{2}\left(\frac{1}{R_0} - \frac{1}{R}\right) = E\frac{h}{2}\frac{1}{R_{ef}} \quad (8)$$

where:

R_0 is the radius of the initial curvature of the layer of the uncoiled coil,

R is the curvature radius according to the formula (3),

R_{ef} is the curvature radius ensuring the bend of a flat strip with the same stress level.

The maximum voltage experienced by the strip is determined as follows:

$$\sigma = \frac{M(x)}{W}, \quad (9)$$

where $W = \dfrac{Bh^2}{6}$ is the static rectangular moment.

Assuming that during the coil break $\sigma = \sigma_{\hat{O}}^{drop}$, the distance between the coil break lines is calculated as follows:

$$M(x) = Fx = \sigma_T^{drop}W \Rightarrow x = \frac{\sigma_T^{drop}W}{F} \quad (10)$$

RESULTS OF CALCULATIONS AND DISCUSSION OF CONDITIONS UNDER WHICH THE PLASTIC HINGE APPEARS IN A FIVE-ROLLER STRAIGHTENING MACHINE

Let us estimate the distance between the coil break lines obtained in a five-roller straightening machine. The yield strength, strip thickness and width are the same as in the previous example.

Assuming that the upper roller depth g = 1 mm, then, in accordance with (3), the curvature radius of the layer R is 13,225 mm.

The voltage experienced by the strip 3 mm thick before the first upper roller at the minimum diameter of the coil in accordance with (8) $\sigma = 728$ MPa, while R_{ef} = 412 mm.

The transformed formula (3) takes the form $g_{ef}^2 - 2R_{ef}g_{ef} + 2a^2 = 0$.

The effective upper roller depth value g_{ef} = 8.1 mm; it is calculated with the help of the formula (3) at which R_{ef} = 412 mm.

The deflection arrow s from the formula (5) is equal to g_{ef}. Then the force F (6) is equal to

$$F = \frac{1}{4}\frac{sbh^3E}{a^3} = 86280 \quad N.$$

In the described case, at the time when the "coil break" defect appears, $\sigma = \sigma_{\hat{O}}^{drop}$ while the bending moment is (9) $M = 608$ Nm.

In accordance with the formula (4), the distance between the coil break lines x = 7.5 mm.

This means that, under the accepted conditions, the "coil break" defect will be formed before the first upper roller of the straightening machine with a period of around 7.5 mm.

CONCLUSIONS

Conditions under which the "coil break" defect appears on hot strip steel surfaces are determined, and a technique for calculating the radius of a hot-rolled steel coil is developed; when the radius is reached during uncoiling, conditions are created on the uncoiled strip for the "coil break" defect.

REFERENCES

1. H. McKenzie, P.E. Evans, P. Prickett, An Investigation of Coil Break Behaviour in Hot Rolled Steel Strip, AISE Annual Convention and Exposition, PR-991-082, 2001.
2. L. Jun, Control Technique of Break Marks in Hot Strip Mill, Iron and Steel – Beijing, 44, 2009, 68-71.
3. V.N. Shinkin, Calculation of steel sheet's curvature for its flattening in the eight-roller straightening machine, Chernye Metally, 2, 2017, 46-50, (in Russian).
4. V.N. Shinkin, Calculation of bending moments of steel sheet and support reactions under flattening on the eight-roller straightening machine, Chernye Metally, 4, 2017, 49-53, (in Russian).
5. V.N. Shinkin, Calculation of technological parameters of O-forming press for manufacture of large-diameter steel pipes, CIS Iron and Steel Review, 13, 2017, 33-37.
6. V.N. Shinkin, Mathematical model of technological parameters' calculation of flanging press and the formation criterion of corrugation defect of steel sheet's edge, CIS Iron and Steel Review, 13, 2017, 44-47.
7. V.N. Shinkin, Asymmetric three-roller sheet-bending systems in steel-pipe production, Steel in Translation, 47, 4, 2017, 235-240.
8. V.N. Shinkin, Failure of large-diameter steel pipe with rolling scabs, Steel in Translation, 47, 6, 2017, 363-368.
9. S.M. Belskiy, Yu.A. Muhin, S.V.Chebotareva, The characteristic features of the "coil break" defect on the surface of the hot-rolled strip of aging steel, Rolling, 11, 2011, 2-5.
10. I.I. Shopin, S.M. Bel'skii, Influence of band's roughness on stress-stain state of a coil, Rolling, 10, 2016, 3-7.
11. S.M. Belskiy, Yu.A. Muhin, S.V.Chebotareva, The characteristic features of the defect «coil breaks» on the surface of the hot-rolled strip of aging steel, Rolling, 11, 2011, 2-5.