Energy-saving method of cutting a pre-bent bar on the shear machine

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Abstract. For transverse cutting of rolled products on mills, a shear machine with parallel knives is used. The permissible cross-sectional dimensions of rolled products, cut on this type of shear machine, are determined by the maximum force needed for cutting the bar in the cold state. It is obvious, that the lower the cutting force required, the lower the energy consumption.

In order to reduce energy consumption during the rolled metal cutting at Siberian State Industrial University a cutting device for cutting a pre-bent bar has been developed in which the bar in the cutting zone under the action of gravity is bent due to the fact that the level of the outgoing roller table is located below the level of the approach roller table. A technique is proposed for calculating the force of cutting a pre-bent bar on the shear machine. The conditions are determined (the ratio of the length of the bar overhang and the difference in the levels of the approach and outgoing roller tables) for obtaining a qualitative cut when cutting the pre-bent bar. It is established that when cutting a pre-bent bar, the maximum cutting force is less than when cutting a straight bar.

1. Introduction

For transverse cutting of the rolled products on mills, shear machine with parallel knives are used. The permissible cross-sectional dimensions of the bar cut on such shear machine of this type are determined by the cutting force of the bar in the cold state $P$, which can be determined [1] from the dependence

$$P = \tau \cdot F,$$  

(1)

where: $\tau$ – tangential stresses arising during the cutting of a straight bar; $F$ – the cross-sectional area of the bar. The cutting force reaches its maximum value at $\tau = \tau_u$, where $\tau_u$ – the ultimate strength of the cut material.

It is obvious that the value of cutting force $P$ determines the energy consumption of the cutting process, and therefore it can be adopted as a criterion for the optimality of the process being studied.

2. Results and discussion

In order to reduce energy consumption during cutting of rolled metal at Siberian State Industrial University a cutting device for a pre-bent bar has been developed [2] with the level of the outgoing roller table (figure 1) located below the level of the approach roller table, which leads to spontaneous

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2. Results and discussion

In order to reduce energy consumption during cutting of rolled metal at Siberian State Industrial University a cutting device for a pre-bent bar has been developed [2] with the level of the outgoing roller table (figure 1) located below the level of the approach roller table, which leads to spontaneous
bending of the bar under its gravity and appearance of normal stresses in it before the beginning of the cutting process.

![Figure 1](image_url)

**Figure 1.** Scheme of cutting the pre-bent bar of rolled metal: 1 – upper knife; 2 – lower knife; 3 – bar; 4 – approach roller table; 5 – outgoing roller table; 6 - clamp.

The cutting process is as follows. Before the beginning of cutting, the bars of knives are diluted and the bar passes between them along the roller table; the upper knife is above the level of the upper surface of the bar and does not interfere with the movement of the bar. Then, by using the stop, the bar stops at a predetermined position along the length. Under the action of gravity the descending part of the bar, lying on the approach roller table, bends, and the part of the bar located on the feeding roller table is rigidly fixed with the help of a clamp.

In this case, normal stresses $\sigma$ appear in the bent part of the bar even before the cutting process begins, which reach their maximum value in the marginal fibers along the height of the workpiece in the cutting zone. When the upper knife is lowered, the cutting process takes place, during which the shearing stresses arise in the cutting plane due to the force of the moving knife. Thus, in the cutting zone of the bar there is a complex stressed state, in which the magnitude of the stresses arising in the section is determined from the third strength hypothesis [3]:

$$\sigma_{eq} = \sqrt{\sigma^2 + 4\tau^2} \leq \sigma_u \approx 2\tau_u, \quad (2)$$

where $\sigma_u$ - the ultimate strength of the bar material under the action of normal stresses. Expressing the action of tangential stresses from (1) and substituting in (2) we obtain

$$\sqrt{\sigma^2 + 4\frac{P^2}{F^2}} \approx 2\tau_u, \quad (3)$$

where the cutting force $P$ is defined as

$$P \approx \sqrt{\frac{4\tau^2 - \sigma^2}{4}.F^2} \approx \sqrt{\tau^2 - \frac{\sigma^2}{4}} \cdot F. \quad (4)$$

Analysis of dependencies (1) and (4) shows that the required cutting force of the pre-bent bar is less than that required force for cutting a straight bar.
The straightness of the workpiece is a prerequisite for obtaining a quality product in the form of a measured product (cut billet), therefore, the deformation of the bending of the bar before the cut must not exceed the elastic deformations, that is, the normal stresses in the bar during its bent, should be less than the yield strength of the bar material:

$$\sigma = \frac{M_{\text{bent}}}{W} \leq \sigma_y, \quad (5)$$

where $M_{\text{bent}}$ – the internal bending moment arising in the bar under the action of gravity not supported by the rollers of the outgoing roller table; $W$ – resistance moment of the section of the bar. The magnitude of the bending moment of the bar is determined by [3]

$$M_{\text{bent}} = \frac{ql^2}{2}, \quad (6)$$

where $q = F\gamma g$ – distributed load acting on the bent part of the bar under the action of gravity; $\gamma$ – specific mass of the bar material; $g$ – acceleration of gravity; $l$ – length of the bar at which the normal stresses remain elastic in the part of the bar that does not rest on the rollers of the approach roller table.

The maximum allowable length of the bar, with allowance for (5), will be determined by the dependence

$$l_{\text{ad}} = \sqrt{\frac{2W}{q} \cdot \frac{\sigma_y}{\gamma g}}. \quad (7)$$

If the length of the cut bar is less than $l_{\text{ad}}$, then the bar will be deformed elastically without additional support in the form of the upper surface of the roller of the outgoing roller table. If the length of the cut bar is greater than $l_{\text{ad}}$, then the residual deformations will appear in the bar without additional support, which is not permissible.

The distance from the top surface of the roller of the approach roller table to the upper surface of the roller of the outgoing roller table is determined from the condition that with the maximum allowable deflection, the normal stresses arising in the bar will be less than the yield strength of the bar material. The maximum allowable deflection given by the difference in the upper levels of the approach and outgoing roller tables is determined from the allowable length of the bar, under elastic deformation of the bar [4]:

$$h_{\text{max}} = \frac{ql_{\text{ad}}^4}{8EJ} = \frac{W^2\sigma_y^2}{2F\gamma gEJ},$$

where $E$ is the modulus of elasticity of the first kind of bar material; $J$ – the moment of inertia of the bar section.

Obviously, the larger the deflection, the larger the normal stresses appearing in the bent bar and the lesser force must be applied to perform the cutting operation. However, because of the dispersion of the mechanical characteristics of the material at the maximum calculated value of the deflection, a residual plastic deformation of the bar is possible [5], therefore the maximum permissible deflection should be taken less than the calculated deflection, that is, $h = 0.8 h_{\text{max}}$.

To verify the correctness of the analytical comparison of the cutting forces of the straight bar and the pre-bent one, a cutting force of 40 x 40 mm square was made from steel 40, for which the tensile-compression strength $\sigma_u = 568$ MPa, the shear strength $\tau_u = 340$ MPa, and the yield stress at tension-compression $\sigma_y = 333$ MPa.

According to formula (1), the cutting force of the straight bar is 544 kN, and the cutting force of the bar material pre-bent to the yield strength by formula (4) is 472 kN. As it follows from the calculation, the cutting force of the pre-bent bar is 14% less than the cutting force of the straight bar.

3. Conclusion

Conditions are determined (the ratio of the length of the bar overhang and the difference in the levels of the approach and outgoing roller tables) for obtaining a qualitative cut when cutting a pre-bent bar.
It is established that when cutting a pre-bent bar, the cutting force is less compared to cutting a straight bar, which makes the proposed cutting process more energy efficient.

References

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