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# Simulation of slitting of coiled steel at multi-disk shears of coil slitting lines

**Abstract**

*At present time, multi-disk shears mounted in the coil slitting lines (CSL) are used for slitting of coiled steel in manufacture of electric welded tubes of small and medium diameter from tube strip billet. In the conditions of wide strip dimension and steel grade range production, transition from one tube strip size to another with varying of steel grades and its mechanical properties is connected with additional adjusting of technological process parameters for providing the required quality. It is possible to manage the process on the base of the developed generalized model that is built on the results of statistical processing of the passive production experiment and allows to adjust parameters of equipment.*

***Key words:*** *rolling, coil slitting, multi-disk shears, tube strip billet, mechanical properties, electric-welded tubes, tube steels.*

## *Introduction*

It was revealed on the base of analysis of previous publications [1, 2] and start-up operations at coil slitting lines that quality of separation surfaces is primarily defined by mechanical properties of rolled products and technological parameters of shears adjusting.

Coil slitting lines for strips with large thickness that are used in metallurgical industry have the drive of shear shaft similar to the drive of rolling stand rolls [6]. In the case of driving cut, shear shafts of disk shears are driving during the total slitting period. Driven character of cut stipulates some deviation of the plane of cut edge (cutting angle) from the normal to a strip surface, what is expressed in trapezium-shape cross-section of tube strip.

Based on analysis of technical literature and conducted investigations, it is possible to mark the measures for minimization of trapezium and cutting angle.

## *Methods and materials*

Physical simulation of coil steel slitting at multi-disk shears in order to improve slitting quality has been conducted in the form of industrial experiment with consequent data processing in the "Statistika" program [3-5]. This experiment covered data about slitting of 310 coils with thickness 3-16 mm of steels St3sp (Ст3сп), 09G2S (09Г2С) and 10KhSND (10ХСНД). Such combination of physical experiment and mathematical simulation as development of theoretical methods allows to develop generalized process models.

The following shape geometrical deviations have been measured as investigated objects – quality parameters of slitting (picture 1): $H_{pl}$ – ductile belt, mm; $H_{otr}$ – tearing-off surface, mm; $H_{razr}$ – destruction surface, mm; $H_{zaus}$ – burr amount, mm; $B_{tr}$ – trapezium amount, mm (it doesn't displayed on the figure 1).

Trapezium amount ($B_{tr}$, mm) has been calculated as the half of difference between the maximal and minimal tube strip thickness measured from each of its surfaces (figure 2):

$$B_{tr} = (B_b - B_m)/2 \quad (1),$$

where $B_b$ is maximal width of tube strip, mm, $B_m$ is minimal width of tube strip, mm.

Cutting angle (trapezium angle) is calculated via the following formula [4]:

$$\alpha = \mathrm{arctg}((B_{tr}/2)/(h-H_{pl})) \quad (2),$$

where $\alpha$ is edge cutting angle, $^o$,
$B_{tr}$ is amount of cut trapezium, mm,
$h$ is thickness of tube strip, mm,
$H_{pl}$ is height of a ductile belt, mm.

Average value of $B_{tr}$ for all strips that were formed after coil slitting was used in calculations. The following technological variables were investigated: $s$ – distance between shears, mm; $n$ – overlapping of shears, mm; $\sigma_T$, $\sigma_{0.2}$ – yield strength and tensile strength of strip respectively, MPa; $\delta$ – specific elongation, %; $V$ – strip speed, m/min; $p$ – specific tension at uncoiler, MPa.

The relative correlation matrix for al cutting parameters has been built at the first stage of experimental studies. The parameters characterizing strip cut quality have been revealed: $H_{pl}/h$, $H_{otr}/h$, $H_{razr}/h$, $H_{zaus}/h$; it is shown that they are dependent one from other. It means that varying some parameters we force other to vary respectively. E.g., decrease of $H_{otr}/h$ is occurred owing to increase of $H_{razr}/h$. Additionally,

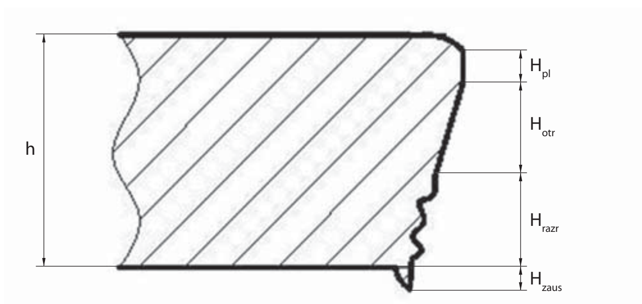


**Fig. 1. Scheme of measuring cutting parameters of a tube strip billet**

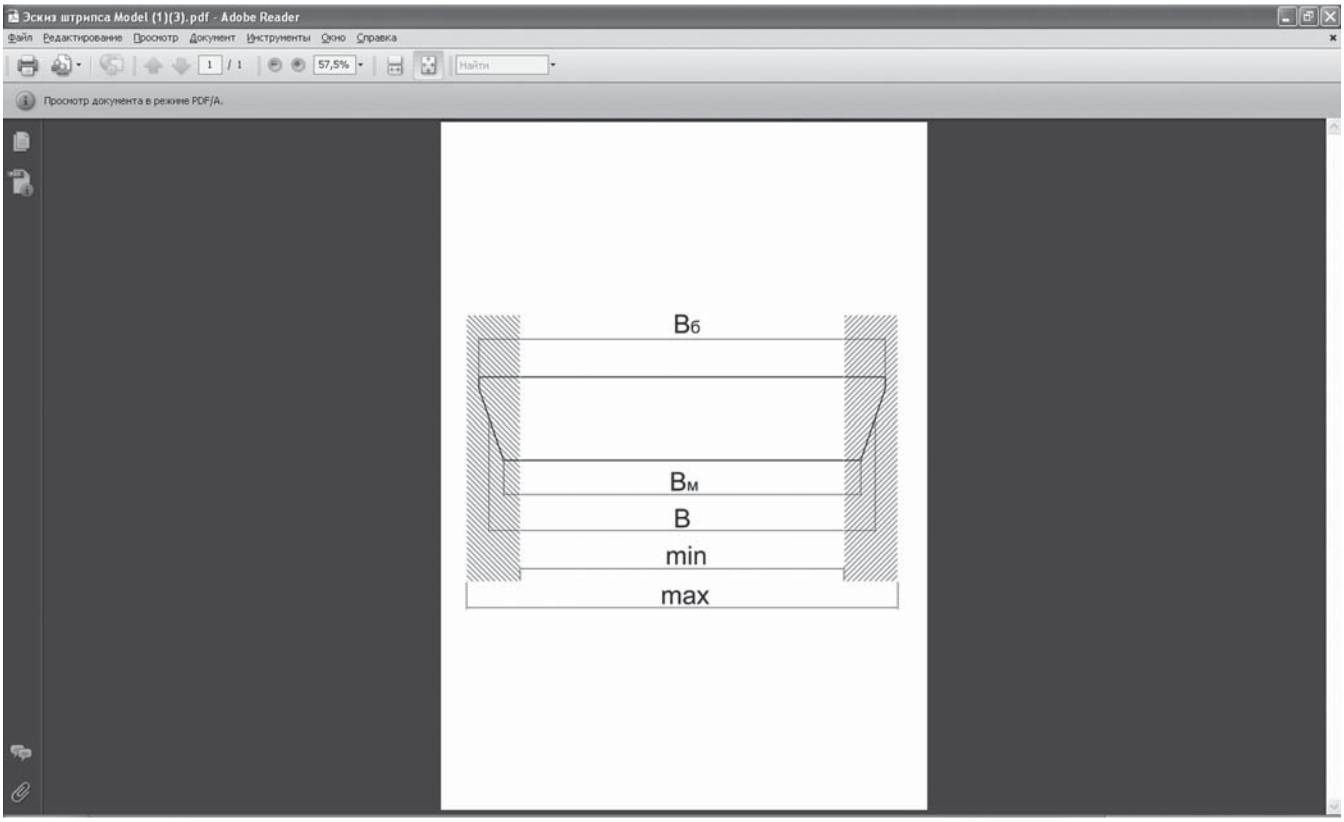


**Fig. 2. Cross section of a tube strip: $B_б$ ($B_b$) – width of the larger side of tube strip; $B_м$ ($B_m$) – with of the smaller side of tube strip; *B* – width of tube strip; *min* – minimal width of tube strip according to the standard for finished products (tube strip); *max* – maximal width of tube strip according to the standard for finished products (tube strip).**

$H_{zaus}/h$ depends on parameters of cut material and wear of cutting edge of disk shears (in the framework of measuring inaccuracy. In this case, it is sufficiently to examine the most important parameter from those that are characterizing cut quality across the strip thickness – for example *Hotr/h*, that should be maximized. The remained parameter *Btr/h* that characterize cut quality across the strip width is not dependent from other parameters and should be minimized.

Some of the examined technological parameters ($\sigma_T$, $\delta$ and *V*) can't be controlled, while *s/h*, *n/h* and p can be managed and using them we can optimize cut parameters ($B_{tr}/h$ and $H_{otr}/h$). Speed *V* was preset as large as 100 m/min and 50 m/min for the strip thickness h not more than 8.0 mm and more than 8.0 mm correspondingly (according to the technical data of the coil slitting lines.

In order to rise accuracy of optimization of $B_{tr}/h$, the collection of initial data with $B_{tr}/h \le 0.2$ was used. Optimization of cut parameters $B_{tr}/h$ and $H_{otr}/h$ has been conducted for the next areas of determination of controlled technological parameters: *s/h* = [0.1; 0.25], *n/h* = [-0/014; 0.375] and *p* = [1; 8.65], MPa. In this case the values of observed cut parameters have been varied in the ranges: $B_{tr}/h$ = [0.025; 0.2] and $H_{otr}/h$ = [0.6125; 0.945].

Based on processing of experimental data, the statistical models of the process of coiled steel slitting are obtained as regression equations that allow to calculate controlled technological characteristics for optimization of cut parameters for different steel grades with different mechanical properties.

In the process of slitting of hot-rolled coils, it is necessary to take into account deviation of tube strip width; in this case both narrow and wide sides of tube strip should meet the requirements of the standard for delivery of ready products (tube strip) (figure 2). Trapezium-shape cross-section of tube strip is characterized by cut trapezium and cutting angle.

After processing of experimental data, the regression relationships between cut trapezium value ($B_{tr}$) — from one side, and relative overlapping of shears (*n/h*) and specific tension at uncoiler (*p*) – from other side, were obtained. The relationship between trapezium value and relative gap between shears (*s/h*) is equivalent to the relationship between trapezium and relative overlapping of shears.

Analysis of these relationships testifies that minimal trapezium values are achieved via decrease of overlapping of shears and gap between shears, as well as via increase of specific tension at uncoiler. According to the [8], the concrete optimal value of gap between shears in rolled coil slitting exists for each steel grade. This optimal gap provides high cut quality practically without chips and it can be realized in the case when cracks of brittle destruction, initiated under the effect of the opposite shears, are moving towards each other and forming one plane. If the gap is larger than optimal, misalignment of destruction surfaces from the opposite shears leads to forming of chips and bending of edges. In the case of strip slitting with the gap less than optimal, the areas of brittle and tough destruction arising at the opposite disk shears not only increase substantially torque of shears drive, but also accelerate their nose and wear (figure 3) [8].

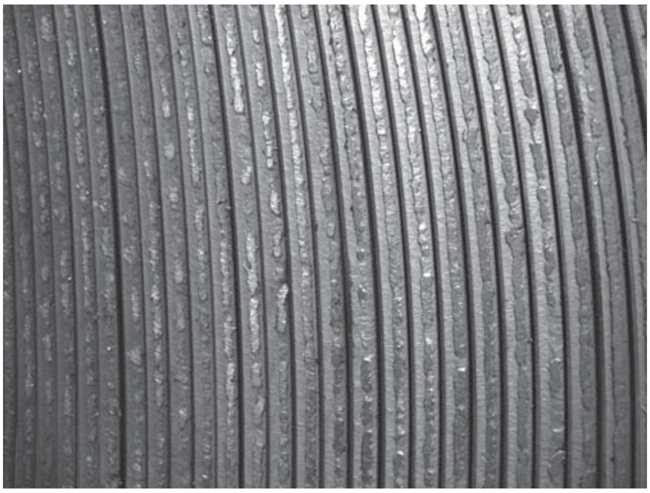

**Fig. 3. View of coiled steel after slitting at the coil slitting line with non-optimal parameters and areas of tough and ductile fracture**

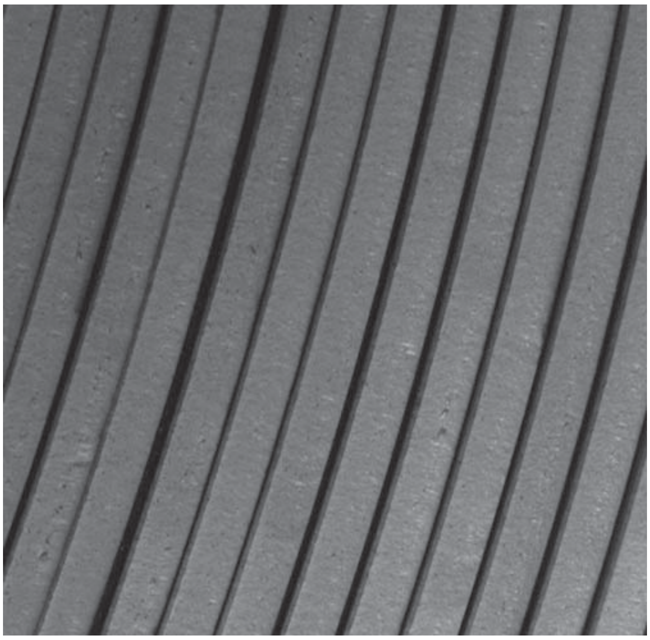

**Fig. 4. View of coiled steel after slitting with optimal parameters obtained as a results of usage of generalized process model**

The developed generalized model of the process of slitting of coiled steel at multi-disk shears of coil slitting lines was used in fabrication of tube strip billets of 10ХСНД (10KhSND) steel for Tikhvinsky freight car building plant and displayed its high efficiency (figure 4).

The positive responses about quality of cutting edge and geometrical parameters of tube strip have been received on the base of the results of tube strip processing at the customer.

***Results and conclusions***

1. Mathematical models of the process of slitting of coiled strip at the coil slitting lines using "Statistika" program have been built based on the results of processing of experimental data as regression equations for the following controlled parameters: gap between shears, overlapping of shears, strip speed, specific tension at uncoiler; it allows to improve line adjusting for fabrication of billets with other dimensions.

2. Recommendations for minimizing of trapezium value and cutting angle are given; they can be used in slitting of coiled strip at the coil slitting lines.

3. These recommendations have been tested in slitting of coiled steel to tube strip billets of 10ХСНД (10KhSND) steel for Tikhvinsky freight car building plant and can be used as generalized model of the process of slitting of coiled steel at multi-disk shears during different production and adjusting stages at coil slitting lines.

**REFERENCES**


1. *Mashiny i agregaty metallurgicheskikh zavodov* (Machines and units of metallurgical works) in 3 volumes. Vol. 3. Tselikov A. I., Polukhin P. I., Grebenik V. M. et al. *Mashiny i agregaty dlya proizvodstva i otdelki prokata* (Machines and units for manufacturing and finishing of rolled products). Manual for high schools. Moscow. Metallurgiya. 1981. 576 p.
2. Babkin A. G., Lozovoy V. N., Zagumennov O. V. *Osobennosti prodol'noy rezki rulonnogo prokata bz stali 08ps pri proizvodstve shtripsa dlya svarnykh vodogazoprovodnykh trub* (Features of slitting of coiled rolled products of 08ps steel in tube strip manufacturing for welded water and gas pipeline tubes). *Metallurg – Metallurgist*. 2007. No. 9. P. 37-38.
3. Borovkov A. A. *Matematicheskaya statistika* (Mathematical statistics). Novosibirsk. 1997. 772 p.
4. Pugachev V. S. *Teoriya veroyatnostey i matematicheskaya statistika* (Theory of probabilities and mathematical statistics). Moscow. Nauka. 1979. 496 p.
5. Borovikov V. P., Borovikov I. P. STATISTICA. *Statisticheskiy analiz i obrabotka dannykh v srede Windows* (Statistical analysis and data processing in Windows medium). Moscow. "Filin" Information and publishing house. 1997. 608 p.
6. Raskatov E. Yu. *Issledovanie protsessa i razrabotka sposoba rezki tonkikh polos iz transformatornykh staley* (Study of the process and development of the method of slitting for thin strips of transformer steels). The thesis of Dr. Eng. Ekaterinburg. 2002. P. 29.
7. Shestakov V. V., Kolobov A. V., Seleznev M. S. et al. *Razrabotka statistichesloy modeli razrezki rulonnoy stali na APR v usloviyakh OOO "Severstal TPZ – Sheksna"* (Development of statistical model for slitting of coiled steel at the coil slitting line of "Severstal TPZ – Sheksna". Izvestiya VUZov. Chernaya Metallurgiya – News Bulletin of High Schools. Ferrous Metallurgy. 2011. No. 9. P. 39-41.
8. Kolobov A. V., Fedotov E. S., Lisunets N. L. et al. *Puti minimizatsiii trapetsiii i ugla reza pri razrezke rulonnoy stali na APR v usloviyakh OOO "Severstal TPZ – Sheksna"* (Ways of minimization of cutting trapezium and cutting angle in slitting of coiled steel at the coil slitting line of "Severstal TPZ – Sheksna". *Izvestiya VUZov. Chernaya Metallurgiya – News Bulletin of High Schools. Ferrous Metallurgy*. 2012. No. 1. P. 17-19.