Development of innovative production technology of automotive high quality in the conditions of cold rolling mill

S A Kondrashov, E M Golubchik and Yu N Kondrashova
Nosov Magnitogorsk State Technical University, 38 Lenina street, Magnitogorsk, 455000, Russia
E-mail: Soulsnack@mail.ru

Abstract. The main tendency of ferrous metallurgy development is improvement of automotive sheet quality and production of the new steel grades which meet the requirements of the international standards. The studied subject is continuous cold strip mill 2500. Analysis of the defects for emulsion spots and spotted carburization showed that their distribution is irregular across the strip width. In the world practice, there are various ways to remove the lubricating and cooling liquid from the rolled strip during the production of automotive sheet by a cold rolling mill. Special modern systems are developed by both foreign and domestic firms are used to remove cooling lubricant from the strip. But significant disadvantage of such solutions is high cost. So, the rational solution of this problem is the development of an innovative technology for removing the cutting compound based on the principle of blowing with minimum amount of compressed air. The article describes an innovative system for cleaning the strip from the residues of the lubricating-cooling liquid in the production of an automotive sheet on the four-stand cold rolling mill 2500 and calculation of parameters. The implementation of improved automotive sheet production technology will reduce the compressed airflow more than 2.5 times, compared with the current system and significantly to expand the range of products.

1. Introduction
At the present time one of the main tendency of metallurgy development is improvement of metal product quality by the implementation of innovative methods of the metal production, and production of the modern steel grades. The problem of quality improving of cold-rolled sheets is a special meaning at achievement of high efficiency of its use in a market economy [1].

2. Main part
The studied subject is the continuous 2500 cold strip mill, which is a major power consumer of the industrial enterprise of ferrous metallurgy [3,4,5,6,7,8].

The analysis of defects was carried out and circle charts were constructed for emulsion spots, oil, electrolyte and spotted carburization (figure 1a, 1b). These diagrams show that the distribution of these defects is irregularly across the width of a cold-rolled strip.
There are various ways to remove coolant remains from the strip in a cold rolling mill. One way is to use felt or calico cleaners which are in gripping unit and the strip are rolled through it. Weakness of this method is that the part of draft force of coiling device is lost in the process of friction. Felt or textile fiber quickly absorb the erasable liquid, at the same time gradually lose absorbing properties, and thus the quality of erasure decreases with time. Besides, these materials gradually lose their fibers, which are remained on the sheet and cause surface defects of the rolled sheet during further processing. One else problem is that facings which are stuck in a felt or calico cleanser can cause further scratches on the sheet [2].

Removal of the coolant remains is possible by using of a wiping roll. However, final result of erasure depends on the surface of the work rollers and on the erasing rollers. But this method isn’t effective, because of contaminants pick up to the rollers and subsequently to the rolled strip and in which case the quality of removal of contaminants from the surface depends on the flatness of the sheet, its thickness and rolling speed.

Special modern systems for blowing of a strip are also used for cleaning of a strip, which are developed by both foreign, and domestic-owned firms, including Siemens, SMS Demag, Spraying System Co. and etc. As an example we will consider using of the perspective VacuRoll device by Spraying System Co and the principle of its work. The system consists of two horizontally arranged rollers (figure 2).

![Figure 1. Distribution of defects in width a) emulsion spots, b) spotted carburization.](image)

The principle of the system is that the system creates a uniform vacuum along the entire length of the roller, including its edges. As the coolant is removed from the strip, it passes through the roller shell. Thus, the emulsion and oils are drawn into the surface of the roller shell, and solid inclusions are gripped by the discs and remain between them to prevent scratches on the strip. The emulsion passes through the hollow center of the roller housing and then enters into the emulsion system for reuse. But a significant disadvantage of this solution is the overprice, the equipment reconstruction and the location choice for this strip cleaning system in the output part of the cold rolling mill [3,4].

Based on the above methods of cleaning the strip from the emulsion, a rational solution is the development of innovative production technology, parameter determination and the introduction of a new strip cleaning system based on the principle of blowing with compressed air. This method has a significant disadvantage in increased compressed air flow, so this system is designed in such a way as to take into account all the features of the cold rolled strip production with a minimum compressed air.
flow. At introduction this system will reduce the air flow more than by 2.5 times in comparison with the current system [2,5].

The strip cleaning system based on the compressed air supply principle consists of two parts:

1. Development and installation of a new plow for the compressed air supply, in order to clean the strip behind the IV stand from cutting compound remains. It is necessary to place 2 independent compressed air supply zones on this plow for effective metal cleaning of different widths from cutting compound (figure 3).

2. Production and installation of a new sticker box construction behind the IV stand (figure 4).

**Figure 3.** Scheme of a new plow for supplying compressed air.

This version of the plow will not only effectively remove cutting compound remains from the strip, but also save the compressed air consumption.

**Figure 4.** Advanced sticker a) box design b) installation scheme.

This version of the sticker box will allow to flow of emulsion with no hassle into the crankcase of the IV stand, then into the emulsion system, and also it will eliminate possibility of emulsion accumulation on the sticker box. The structural feature of this version of the sticker box will prevent
the emulsion from getting into the coiler crankcase by installing a bump under the sticker box (figure 4).

The system for the strip cleaning from the cutting compound behind the IV stand will work according to figure 5 as a result of such implementation.

The emulsion falling on the sticker box by another methods does not accumulate on it and it gets with no hassle from the table on the bump into the crankcase of the IV stand, then into the emulsion system. Consequently, the cutting compound does not fall on the rolled strip during the blowing, with the formation of swirling air currents [2].

![Diagram](image)

**Figure 5.** The scheme of the improved a) system for cleaning the strip behind the IV stand from the cutting compound b) the scheme for connecting the plow to the air line.

At installation of a new plow design (fig. 5) it is planned to eliminate the risks of the arising swirling air currents during the blowing for cleaning the rolled strip from the cutting compound. Such plow design is achieved due to its calculated length of 2360 mm and a blow-out area of 2400 mm, which is less than the width of the aperture between the base box, which is 2500 mm. It is important to divide the plow into 2 zones for saving of compressed air and reducing the risk of getting cutting compound to the rolled strip. The first zone (center) is designed for blowing with a width of the rolled strip in the range from 1000-1560 mm, the second zone (edges) is jointed for rolling a strip with a width of more than 1561 mm. For the on-line activation and de-activation of the compressed air supply are provided a remote opening and closing of the valve of the 1st and 2nd blow zones, the control unit of which is installed in the main post of the 4-stand mill (figure 5).

### 3. Calculation

Holes of rectangular cross-section are made on the plow proceeding from conditions and features at which the blowing will work.

Slot jets when flowing out of elongated rectangular holes with a ratio of sides $a_0/b_0>5$. The jet of compressed air formed at the outflow from the elongated rectangular hole is calculated as flat at a distance $x<6a_0$, where $a_0$ is the size of the larger side of the rectangular hole, and $x$ is the distance from the nozzle to the strip [1,2].

The plow parameters are calculated.

For zone I:

$a_0 = 95$ mm, $b_0 = 3$ mm, $x = 400$ mm.

$$x<6a_0,$$  

(1)
where \( a_0 \) is the size of the larger side of the rectangular hole; \( x \) is the distance from the nozzle to the strip.

Based on the formula the area of the compressed air coating of one nozzle is 570 mm (6*95). In order to prevent the emulsion from entering on the strip between the nozzle cover zones it is necessary to place the nozzles in Zone I 520 mm apart to provide a 25 mm overlap zone on each side. Based on the formula \( x < 6a_0 \) (400<570) the distance from a plow nozzle to the rolled strip was accepted 400 mm for ensuring necessary parameters.

Based on the formula (1) \( 400 < 420 \) the distance from a plow nozzle to the rolled strip was accepted 400 mm for ensuring necessary parameters.

Based on the formula (1) \( x < 6a_0 \) (400<570) the distance from a plow nozzle to the rolled strip was accepted 400 mm for ensuring necessary parameters.

Calculation of compressed air flow is given below.

The main parameters for the calculation of compressed air flow are adopted:

Pressure is 5 atmospheres (0.51 MPa) and temperature.

The available hours of mill.

For zone I:

\( a_0 = 95 \text{ mm}, \ b_0 = 3 \text{ mm}, \ x = 400 \text{ mm}. \)

95/5>5, 400<6*95.

The flow capacity of the nozzle is calculated by the formula:

\[
G = 3.16B_3\alpha_1F\sqrt{(P_1 + 0.1)\rho},
\]

where \( G \) is flow capacity, kg/h;

\( B_3 \) is coefficient that takes into account the physical and chemical properties of gases and vapors at operating parameters (for compressed air 0.770);
\( \alpha_1 \) is the flow coefficient corresponding to the area \( F \) for atmosphere (0.66); 
\( F \) is nozzle cross-sectional area, \( \text{mm}^2 \); 
\( P_1 \) is pressure before the nozzle, MPa; 
\( \rho \) is density of compressed air, \( \text{kg/m}^3 \).

\[
\rho = \frac{(P_1 + 0.1) \times 10^6}{B_4 R T_1},
\]

(3)

where \( B_4 \) is compressibility factor of real gas (for air 1); 
\( R \) is gas constant (for air 287); 
\( T_1 \) is temperature of the working medium before the nozzle, K.

\[
\rho = \frac{(0.51 + 0.1) \times 10^6}{1 \times 287 \times 283} = 7.51 \frac{kg}{m^3},
\]

\[
G = 3.16 \times 0.77 \times 0.66 \times (95 \times 3) \sqrt{(0.51 + 0.1) \times 7.51} = 979.65 \frac{kg}{h}
\]

Calculated by the formula the mass air flow is converted into a volumetric:

\[
V = 979.63 \div 1.2 = 816.36 \frac{m^3}{h}
\]

(When the temperature of the compressed air in the main line decreases the density increases and the flow rate increases. At 0º C the flow in zone I is 831 \( \text{m}^3/h \)).

The volume of air passing through one nozzle for 5996 operating hours of the mill is calculated by the formula:

\[
V^I = 816.36 \times 5996 = 4894886.77 \text{ m}^3 = 4894.89 \text{ thousand m}^3
\]

Volume of air passing at full functional of zone I (3 nozzles in operation) for 5996 hours is calculated by the formula:

\[
V_{f.f.} = 4894.89 \times 3 = 14684.66 \text{ thousand m}^3
\]

For zone II:
\( a_0 = 70 \text{ mm}, b_0 = 3 \text{ mm} \).

The width of the coating for blowing one nozzle is 420 mm (6\( a_0 \)). For a covering of width over 1561 mm, two nozzles must be distributed on the plow at a distance of 460 mm from the edge nozzle of zone I. To avoid the formation of a thin jet of coolant on the strip the zone of overlapping air flows will be 10 mm (figure 7).

\[
G = 3.16 \times 0.77 \times 0.66 \times (70 \times 3) \sqrt{(0.51 + 0.1) \times 7.51} = 721.83 \frac{kg}{h}
\]

\[
V = 721.83 \div 1.2 = 601.53 \text{ m}^3
\]

Hour age for the production of metal with a width of more than 1561 mm in 2015 is calculated based on the ratio of the total number of tons for the average hot hour for this range of width:
\[ t = 50826.96 \div 288.37 = 176.3 \text{ hours} \]

During the work of 2 nozzles the air consumption on production of wide metal will be:

\[ G_{II} = 3601.53 \times 2 \times 176.3 = 212098.6 \text{ m}^3 = 212.1 \text{ thousand m}^3 \]

The air consumption for the constant operation of II zones during 5996 hours will be:

\[ G_{total} = 14684.66 + 212.1 = 14896.76 \text{ thousand m}^3 \]

The air consumption for the constant operation of II zones during 5996 hours will be:

\[ G'_{total} = 14684.66 + \left( \frac{601.53}{1000} \right) \times 2 \times 5996 = 14684.66 + 7213.52 = 21898.18 \text{ thousand m}^3 \]

According to economists the air flow at the current system was 38235 thousand m³ in 2015. Consequently for the production of wide metal (when zone II is connected) the savings in compressed air will be:

\[ G_{sav} = 38235 - 14896.76 = 23338.24 \text{ thousand m}^3 \]

According to the economist the cost of 1 thousand m³ is 359.8 rubles. Saving during the work of zone I for 5996 hours and connection of zone II for 176.3 hours in rubles will be:

\[ E = 23338.24 \times 359.8 = 8397099.15 \text{ rub} = 8.4 \text{ million rubles} \]

Reduction of compressed air consumption will be:

\[ G_{reduction} = \frac{38235}{14896.76} = 2.57 \]

During the continuous work of zone I and zone II for 5996 hours of the mill operation:

\[ G'_e = 38235 - 21898.18 = 16336.83 \text{ thousand m}^3 \]

Reduction of compressed air consumption during operation of zone I and zone II during 5996 hours:
\[ G^I = \frac{38235}{21898.18} = 1.75 \]

Saving during the continuous work of zone I and zone II for 5996 hours in rubles will be:

\[ E'_{c.a.} = 16336.82 \times 359.8 = 5877988.67 \text{ rubles} = 5.9 \text{ million rubles} \]

4. Conclusion
In the conclusion, the implementation of innovative production technology of an automotive sheet of an improved quality of a 4-stand cold-rolling mill will make it possible to reduce the consumption of compressed air by more than 2.5 times compared with the current system and significantly expand the range of products.

References
[1] Kondrashov S A, Golubchik E M and Martynova T Y 2017 Proc. Int. Conf. Metallurgy Technologies Innovations Quality vol 1 (Novokuznetsk: Siberian State Industrial University) p 144
[2] Kondrashov S A and Mamaev I N 2017 The Proceedings Of The Distributors vol 1, ed Spirin S A and Chuvikova L K (Magnitogorsk) p 116
[3] Polyakova M A and Golubchik E M 2015 Conference On Structural Mechanical And Material Engineering vol 19 p 17
[4] Polyakova M A, Gulin A E and Golubchik E M 2014 Applied Mechanics and Materials 656 497
[5] Golubchik E M 2014 Nosov Magnitogorsk State Technical University Bulletin 1 63–9
[6] Malapheev A V, Zaslavets B I, Igumenshev V A, Bulanova O V and Rotanova Yu N 2008 South Ural State University Bulletin, Power Engineering Series 9 3–8
[7] Bulanova O V, Zaslavets B I, Igumenshev V A, Malapheev A V and Rotanova Yu N 2009 Higher School Bulletin, Electro mechanics 1 60–5
[8] Karandaev A S, Rotanova Yu N, Kornilov G P, Karandaeva O I, Rovneyko V V and Galyamov R R 2009 South Ural State University Bulletin, Power Engineering Series 12 16