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IMPROVING THE METHODS OF ROLL USE ON ROLLING MILLS AT THE ARSELORMITTAL TEMIRTAU

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This article examines ways of reducing the consumption of rolling-mill rolls, extending their service life, improving the use of existing rolls, and introducing new rolls. Among the methods that can improve roll use are moving rolls to different stands of hot-and cold-rolling mills and implementing a system to assemble sets of rolls for the mills. The patterns of movement of the rolls need to be taken into account as part of the roll-use strategy. With allowance for these patterns, the company ArselorMittal Temirtau calculated the roll-changing schedule that is optimum for its continuous 1700 wide-strip mill from the standpoint of minimizing the total wear of the work rolls in the finishing stands during service. A model containing a criterion for moving rolls among different stands was used to evaluate the operating conditions of the rolls on the cold-rolling mills in sheet shop No. 3. Values were recommended for the allowable reductions in the rolls' diameter in each stand of these mills.

Keywords: *cold-rolling-mill rolls, hot-rolling-mill rolls, roll use, roll wear.*

One proven method of reducing the consumption of rolling-mill rolls and making them last longer is to develop new and improve existing methods of using these rolls. This also applies to sets of rolls and the schedules used to move rolls to different stands in hot- and cold-rolling mills [1]. Rolls must be used with allowance for their patterns of movement, beginning with the creation of a reserve stock of rolls in the shop and ending with the recycling of used rolls (by re-quenching, reboring to other dimensions, or consignment to scrap) [2].

There is a considerable range of conditions under which rolls are used in the stands of continuous wide-strip hot-rolling mills (CWSMs). These variations are due mainly to differences in the temperature of the steel that is being rolled and the amount by which the semifinished product is reduced. Thus, rolls should be supplied to such mills based on the main criterion used to evaluate the rolls' service properties under the operating conditions characteristic of these mills [3, 4].

Until 2001, the finishing stands of the 1700 CWSM hot-rolling mill at ArselorMittal Temirtau were supplied with alloyed two-layer cast iron rolls having a chilled working layer from 10 to 30–32 mm thick, a transitional layer of mottled cast iron, and a core of gray iron. Finishing stands Nos. 6–8 had so-called old-generation LPKhNd-62 and LPKhNd-63 rolls, while

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TABLE 1. Performance Indices and Service Properties of the New and Old Rolls on a Continuous 1700 Wide-Strip Mill

Rolls	Wear criterion K_w	Wear resistance, 10^3 tons/mm	Strength criterion K_s	Frequency of roll breakage in stands 6–8, %	Thermal-resistance criterion K_c	Frequency of roll-cracking, %
Old roll models						
LPKhNd-62	0.34	10.3	0.18	23.6	0.18	8.5
LPKhNd-n-62	0.34	10.4	0.22	11.6	0.18	8.2
LPKhNd-70	0.30	12.2	0.22	12.5	0.10	14.8
LPKhNd-72	0.28	13.1	0.27	11.9	0.10	12.9
LPKhNd-76	0.26	3.4	0.28	11.2	0.10	12.4
New roll models						
Hi-Cr	0.62	5.82	1.23	3.33	0.28	10.21
ICDP	0.86	3.83	1.47	1.27	0.09	8.83

finishing stands Nos. 9–12 had LPKhNd-70, LPKhNd-71, LPKhNd-72, LPKhNd-74, and LPKhNd-76 rolls. For the last 8–10 years, the finishing stands of the 1700 CWSM have been operated with new-generation rolls – Hi-Cr and ICDP rolls [5].

The differentiated approach that was proposed in [3, 4] and is now being used at ArselorMittal Temirtau for the finishing train of the 1700 CWSM has allowed the company to analyze the quality of the materials of the old- and new-generation rolls and their service properties with allowance for their resistance to heat and wear in the leader stand and finishing stand [6]. Table 1 shows the performance and service characteristics of the old- and new-generation rolls.

The authors of [6] established that the highest strength and best wear resistance were shown by old-generation rolls LPKhNd-76 in the finishing stands and old-generation rolls LPKhNd-n-62 in the initial stands of the finishing train. As regards the new-generation rolls in the finishing stands, the ICDP rolls demonstrated the best strength and wear resistance compared to the old-generation rolls. In the initial stands of the finishing train, the best indices for wear resistance, thermal resistance, and strength were obtained for the new-generation Hi-Cr rolls. This significantly improves the durability of the rolls and makes it possible to predict the roll-changing times with satisfactory accuracy.

On the 1700 CWSM at ArselorMittal Temirtau, the rolls are moved in the direction opposite the rolling direction in accordance with a rolling schedule drawn up by the shop. The rolls are moved as their active layer undergoes wear and the quality of the surface of the roll body changes. A certain range of values for work-roll diameter is specified for each stand of the mill in accordance with the schedule established for moving the rolls to different stands when they are reground.

An analysis of the reasons for the wear of the active layer of the work rolls showed that in addition to causes of a technological nature, more than 50% of the active layer is ground off the rolls that are removed from the stands when planned roll changes are made, i.e., that much of the layer is lost as a result of normal wear. An average of 0.2–0.4 mm of metal is removed from a roll during one regrinding operation. This amount is 2–5 times greater than the thickness of the normative layer (0.05–0.10 mm) [6].

One reason for excessive consumption of the active layer of the rolls is that when rolls are being prepared for installation in the stands they are paired with one another during the grinding operation. To ensure that the difference between the diameters of the bodies of the rolls is within the prescribed range, an excess amount of the "healthy" layer is ground from the roll that is larger in diameter.

ICDP work rolls were installed in stands Nos. 9–12 of the 1700 CWSM for the hot rolling of starting strip for tinplate production, while Hi-Cr rolls (high-chromium rolls with a chromium content >16%) were installed in stands Nos. 6–8. Since a sufficient quantity of rolls made of the high-chromium material were in stock, they were used in stands Nos. 6–8 to roll all the products normally rolled on the mill. Statistical data show that 10–15% of the active layer is consumed in adjust-

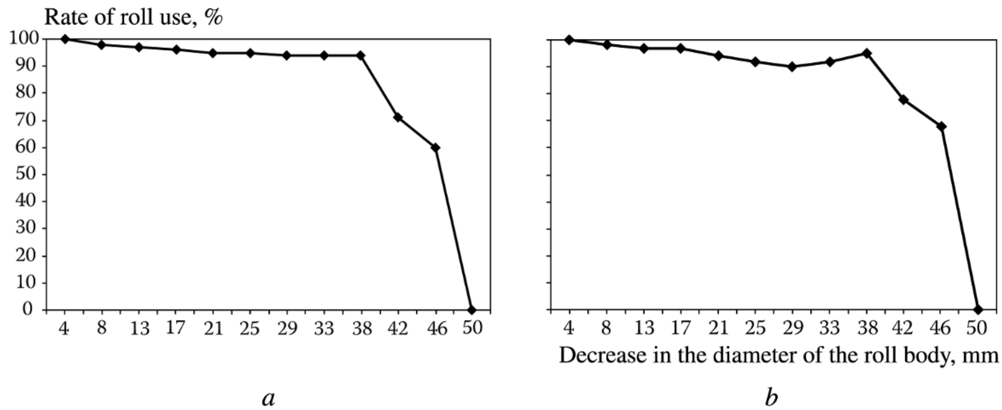

Fig. 1. Rate of use of rolls in relation to the decrease in their diameter: *a*) Hi-Cr rolls in finishing stands Nos. 6–8; *b*) ICDP rolls in finishing stands Nos. 9–12.

TABLE 2. Schedule for Moving Rolls between the Stands of a Continuous 1700 Mill for Hot-Rolling Wide Strip

Stand in which the roll is used	Range of roll-body diameters, mm (theoretical)	Diameter of rolls when moved from stand to stand in accordance with the TU specifications, mm
Hi-Cr		
8th stand	710.0–694.8	702–697
7th stand	694.8–678.7	697–694
6th stand	678.7–664.0	694–690
ICDP		
11th stand	710.0–700.7	710–708
12th stand	700.7–691.2	708–703
11th stand	691.2–681.7	703–699
10th stand	681.7–672.3	699–696
9th stand	672.3–664.0	696–692

ing the roll diameter. Such a method of roll preparation leads to an unjustifiable increase in unit roll consumption and a corresponding increase in production costs during the rolling conversion [5].

The authors of [7, 8] used the method in [9, 10] to determine the running values of roll-body diameter for which a roll can be moved to the next stand. The probability P_j of problem-free use of the roll was used as the criterion for deciding whether or not to transfer the roll to another stand. The length of time that rolls were used in each stand was determined based on the projected decrease in roll diameter ΔD.

Figure 1 shows graphs illustrating the rate of consumption of different types of work rolls on the 1700 CWSM during the period 2004–2005 as the diameter of the roll bodies decreased (the nominal diameter of a new roll was 710 mm and the final diameter was 664 mm). In other words, the figure shows the number of rolls that were left in service after reaching different diameters.

The data obtained were used to calculate the values of roll diameter at which a roll should be moved from one stand to another (Table 2).

The rolls' periodic (as the rolls undergo wear) movement among the different stands of the rolling mill is an essential element of the roll-use technology that the shop chooses to employ. Reducing the wear of rolls is one of the most important problems in rolled-product manufacturing, and the amount of wear that a roll undergoes depends directly on the roll-changing schedule that is instituted. It follows from this that there is a need to study and improve the technologies currently employed in the use of rolling-mill rolls.

One well-known method of using rolls on strip mills which contain a large number of stands entails the use of new rolls in the last (finishing) stand. Then these rolls are transferred to other stands after they have undergone a certain amount of wear. The stands to which the rolls are moved are successively located in the direction opposite the rolling direction. Here, the main criterion used to determine when rolls should be moved from one stand to another is their diameter [11].

The ratio of the actual diameter of the work rolls before being installed in the stand to their initial diameter can be used as a roll-changing criterion which characterizes the hardness of the roll body. We obtained a relation that expresses the dependence of the wear of the surface of the work-roll body $\Delta R_w = f(D_{fact}/D_{ini})$ on the ratio of the rolls' actual diameter D_{fact} to their initial diameter D_{ini}. To keep the flatness of the strip from being disturbed during the roll campaign, the degree of wear of the work rolls and the elongation factor must both smoothly decrease from the maximum values in the first stand of the finishing train to the minimum values in the last stand [11, 12].

A nomogram constructed for a 1700 CWSM was presented in [12]. The nomogram makes it possible to determine the number of the stand to which a roll should be moved based on the depth of the chilled layer (the number of regrindings). It is assumed that the wear of the rolls in the different stands changes linearly – from the maximum value in the first stand to the minimum value in the last stand. New rolls should be installed in the leader stand for one or two campaigns to eliminate the adverse effect of internal defects on the quality of the strip's surface.

Use of the roll-changing schedules developed for the finishing train of the 1700 CWSM based on the nomogram has made the irregular character of the distribution of wear of the rolls by stand more uniform, reduced roll consumption overall, and improved the quality of the metal.

The authors of [9] proposed a method of optimizing the roll-changing schedule for mills with a large number of stands while keeping the frequency of the planned roll changes constant. By varying (in accordance with certain technological considerations) the sequence in which rolls are moved to different stands, the quantity E_{ij} – the efficiency of use of the working layer of a roll – can be determined for each *j*th period (stage) of service and each *i*th stand. If we add the resulting values of E_{ij}, we obtain the conditional quantity ΣE_{ij}, which is proportional to projected service life (total accrued operating time) of rolls for a chosen roll-changing schedule. The schedule that among all of the possible (technologically workable) schedules yields the largest sum of E_{ij} (under the condition that no rolls are returned to a stand in which they have already been used) is considered to be the optimum schedule. This schedule makes it possible to roll the largest amount of metal with the use of a specified number of rolls.

On the 1700 CWSM at ArselorMittal Temirtau, the following schedules are used to move the rolls among the different finishing stands in the direction opposite the rolling direction as their active layer undergoes wear and the quality of the surface of the roll-bodies changes (the numbers in the schedules denote the numbers of the stands, while the arrows indicate the direction of a roll's movement from one stand to another stand):

work rolls: 11 → 12 → 10 → 9 → 8 → 7 → 6;
backup rolls: 12 → 11 → 10 → 9 → 8 → 7 → 6 → 5 → 4 → 3 → 2 → 1.

The roll-changing schedule provides for the installation of new rolls in stand No. 11, with these rolls subsequently being moved to stand No. 12 in order to find surface defects: crazing, delamination, erosion.

When the rolls contain deep defects, the sequence indicated above in the schedule is disrupted as the rolls are reground because the removal of the defects during the grinding operation reduces the thickness of the active layer over the roll's diameter to a value below the thickness specified for the given stand. In this case, after the defects have been removed the roll is installed in a stand which has been designated to operate with rolls of the same diameter as that roll.

The roll-changing schedule on the 1700 CWSM was optimized in accordance with the criterion of minimizing the total amount of wear of the working layer of the rolls [13–15]:

$$\sum_{1}^{n} u_{kj} \to \min, \tag{1}$$

where u_{kj} is the amount of wear of the working layer of a roll; $k = 1, 2, ..., K$ is the number of the stand; $j = 1, 2, ..., J$ is the stage of service.

The recommendations in [16] were followed in formulating the optimization problem.

The system of constraints that exists is due to the technical requirements on the use of rolls in rolling-mill stands [17–19]:

$$\Sigma u_{(1)}(0) < \Sigma u_{(2)}(0) < ... < \Sigma u_{(K)}(0); \tag{2}$$

$$K^{\mathrm{r}}_{(1)} > K^{\mathrm{r}}_{(2)} > ... > K^{\mathrm{r}}_{(K)}; \tag{3}$$

$$m \in M_{\mathrm{p}}, \tag{4}$$

where (1), (2), ..., (K) is a certain roll-changing schedule for stands 1, 2, ..., K; m is the optimum roll-changing schedule; and M_{p} is the set of permissible schedules.

Conditions (1)–(4) correspond to the problem of forming a set of permissible schedules for the work rolls in the different stands of the mill:

$$M_{\mathrm{p}} \subset M_{(k)} \subset M_k, \tag{5}$$

where $M_{(k)}$ is the set of all possible movements of the rolls among the stands; $M_k = M_{(1)} \cup M_{(2)} \cup ... \cup M_{(k)}$ is the number of variants of roll movement among the stands.

The set of all possible roll-movement variants in the Kth stands can be formed by the method of iteration

$$M_{(k)} = K! \tag{6}$$

The variation in the diameter of new rolls is negligible at the beginning of their service, so at this point it is best to rely on inequality (2) to determine the stands in which the rolls will be installed. Requirements (3) and (4) are taken into account later. In inequality (2), the (1) subscript denotes the stand in which the rolls with the smallest total amount of wear are used. The rolls that have undergone the most wear are used in stands with the number K. The sequence (1), (2), ..., (K) for which inequality (2) is satisfied indicates the roll-changing schedule that should be used.

Under actual production conditions, rolls are often used multiple times in one or several stands of a mill. If the average number of regrindings $K^{\mathrm{r}}_{(K)}$ of the work rolls during their period of service in each stand is determined, then the rolls should be moved to another stand and reground more often in order to ensure that the quality of the product is high. The last rolls in the finishing stands are usually responsible for ensuring that the required level of product quality is attained. In this case, the specific schedule for moving rolls among the different stands is determined by inequality (3), which reflects the overall pattern of movement of the mill's stock of rolls in accordance with the sequence (1), (2), ..., (K).

The authors of [13–15] used the above-described approach to create a computer program in the language Turbo Pascal for solving the problem of optimizing the schedule for changing the work rolls in the finishing stands of the 1700 CWSM at ArselorMittal Temirtau. The total number of variants of the roll-changing schedule under the given conditions is $M_k = 2160$, the number of possible (with allowance for the constraints) variants $M_k = 248$, and the number of conditionally optimum variants is 7.

The optimum roll-changing schedule was expertly chosen from among the conditionally optimum schedules with allowance for the specific service conditions of the rolls (Table 3).

TABLE 3. Shop Schedule and the Optimum Schedule for Moving the Work Rolls among the Finishing Stands of the Continuous 1700 Wide-Strip Mill

Roll-transfer schedule	Roll-transfer sequence	Total wear of the rolls during service, μm
Shop schedule	11 → 12 → 10 → 9 → 8 → 7 → 6	24129.40
Optimum schedule	12 → 10 → 11 → 7 → 6 → 8 → 9	23627.19

TABLE 4. Criteria for Moving Work Rolls from Stand to Stand in the Cold-Rolling Mills of Flat-Rolled Products Shop No. 3 during Service

Mills in shop No. 3	Range of roll-body diameters, mm	Reduction in roll diameter during the period planned for use of the rolls in a stand, mm	Percentage of rolls used up in the given stand before their transfer to the next stand $Y = f(X)$, %
Temper mill	607.20–606.13	1.07	89.04
Rolling-temper mill	606.13–604.93	1.20	79.21
1400, stand No. 6	604.93–603.57	1.36	68.98
1400, stand No. 5	603.57–601.99	1.58	58.25
1400, stand No. 4	601.99–600.07	1.92	46.85
1400, stand No. 3	600.07–597.59	2.48	34.50
1400, stand No. 2	597.59–593.88	3.71	20.54
1400, stand No. 1	593.88–579.76	14.12	0.02

The optimum roll-changing schedule is characterized by a smaller amount of roll wear compared to the schedule normally used in the shop. The calculated difference between the roll wear in the optimum schedule and the existing shop schedule is 3.2%, which is equivalent to a decrease in unit roll consumption by 0.031 kg/ton.

Based on an examination of the most well-known roll-changing schedules for rolling mills, *it was found that it is best to optimize roll-changing schedules based on the criterion of reducing roll wear to the minimum amount possible. The optimum schedule – the schedule that minimizes the total amount of roll wear during service – was calculated for the work rolls in the finishing stands of the 1700 CWSM at ArselorMittal Temirtau.*

Reducing the consumption of rolling-mill rolls is also a promising approach to take to the operation of cold-rolling mills. Thus, as before, it remains important to explore different approaches to the use of rolling-mill rolls: using sets of rolls that include rolls of different types and mathematical modeling of roll-changing schedules [10–12, 20–22].

The need to obtain a high-quality surface on cold-rolled strip and the creation of favorable conditions for the use of the mill's rolls are the main criteria which are used in developing and modeling efficient roll-changing schedules and assembling roll sets for cold-rolling mills. The use of an efficient roll-changing schedule reduces the number of roll changes that are necessary and lengthens the rolls' service life.

The authors of [23, 24] developed criteria for moving rolls from stand to stand in a cold-rolling mill in sheet shop No. 3 at ArselorMittal Temirtau. The rolls are moved to other stands as the diameter of their body decreases. The criteria were developed based on a statistical analysis of the performance of 92 work rolls installed in a 1400 continuous rolling mill, a DS-1400 temper mill, and a PDS-1400 rolling-temper mill. The roll materials were steel 60Kh2SMF and 8Kh2SGF. The factory currently obtains steel 60Kh2SMF rolls from the Novokramatorsk Machine Plant (NKMZ) and steel 8Kh2SGF rolls from the Ural Heavy Machinery Plant (UZTM). From December 2007 to March 2009, a total of 2,408,621 tons of different grades of steel were rolled on the mills in shop No. 3 with the use of the above-indicated rolls.

The movement of rolls from stand to stand as their diameter decreases was modeled by a method that accounts for all the rolls which have been used on a mill [9]. Thus, roll-changing schedules for the cold-rolling mills in shop No. 3 can be drawn up by using a criterion based on range of the reductions which take place in the diameter of the roll bodies (Table 4) when all of the mills are regularly supplied with identical sets of rolls. Roll use is made easier under such conditions.

A model constructed with this criterion was used to evaluate the service conditions of the rolls on cold-rolling mills and recommendations were developed on the permissible decreases in roll diameter for each stand of the cold-rolling mills in sheet shop No. 3 at ArselorMittal Temirtau.

Conclusion. An evaluation was made of the service conditions of rolls in hot- and cold-rolling mills. With allowance for the existing technological constraints on the use of the rolls, the roll-changing schedule on the 1700 CWSM in flat-rolled products shop No. at ArselorMittal Temirtau was optimized so as to minimize the total wear of the work rolls in the finishing stands of the mill during service. A model with a specific roll-changing criterion was used to obtain values that can be recommended for the permissible reduction in roll diameter in each stand.

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