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Development of high-speed rolling modes of trim rails in the continuous reverse train

S V Smetanin[1], V N Peretyatko[2], V V Dorofeev[1], A G Nikitin[2] and E Ya Zhivago[2]

[1]EVRAZ Consolidated West Siberian Metallurgical Plant, 16 Kosmicheskoye shosse, 654043, Russia
[2]Siberian State Industrial University, 42 Kirova street, Novokuznetsk, 654007, Russia

E-mail: Sergey.Smetanin@evraz.com

Abstract. One of the main characteristics that makes it possible to use effectively a rolling mill is high-speed rolling mode. This paper presents the results of theoretical and practical investigations of tram rails rolling technology on the modern universal rail-and-structural steel mill of EVRAZ ZSMK. A new scheme for rolling tram rails in the finishing continuous reverse train was developed. The diagrams of the rolls revolution speed in the stand with the condition of the most effective use of technical characteristics of the main drives are developed. A new approach is offered for high-speed rolling modes at the stages of piece capture, steady-state process and rolled piece release during rolling in the continuous universal train including three stands. Based on the existing equipment of the rolling mill the recommendations are given concerning the frequency of rolls revolution separately for each pass and for each stand during continuous rolling in the finishing train. A rolling method is proposed in which the capture of the tolled metal in all passes is carried out at a constant speed of rolls revolution.

1. Introduction
Tramways around the world have a significant length, therefore both in Russia and abroad the tram rails need to meet rigid requirements. Currently in Russia construction projects of high-speed tram are at various stages of development and implementation, so tram rails of good quality are in high demand. In recent years, in the world practice of rolling production many metallurgical plants have undergone in-depth modernization and have constructed modern rail-and-structural steel mills. The fundamental difference between the modern rail-and-structural steel mill and the mill of the previous generation is that it is equipped with a high degree of mechanization and automation, while the modern rail-mill has a continuous finishing reversing train consisting of universal and two-roll stands. Modern rail-and-structural steel mills have significant advantages in comparison with the mills of the previous generation and make it possible to produce high-quality products.

2. Methods of research
The physical modeling was carried out on the existing rail-and-structural steel mill of "EVRAZ ZSMK" JSC, which is equipped with a powerful automation system and modern control and measuring system that allow different deformation-speed conditions for rolling to be set, and also a large amount of data to be recorded in real time.

One of the most important components of effective use of the rail-and-structural steel mill is the application of rational high-speed capabilities of the main drive.

The main goal of this work was to develop rational high-speed modes of rolling tram rails in the continuous reverse train based on the effective use of the technical characteristics of the modern rail-and-structural steel mill at “EVRAZ ZSMK” JSC.

In the literature there are methods for determining high-speed rolling modes in single-stand mills, as well as reverse stand with continuously connected stands [1, 2]. However, due to the fact that modern rail-and-structural steel mills have significantly better technical characteristics than the mills of previous generation, explanations on the choice of high-speed rolling modes are necessary [3-5].

The aim of the research is to study the features of rolling tram grooved rails at maximum speeds, provided by the main drive of the rolling mill, taking into account the emerging moments and rolling forces in the continuous reverse train in order to increase the productivity of the rolling mill.

The investigation of the speed modes was carried out during the rolling of tram grooved rails, which are one of the most complex profiles. The rail-and-structural steel mill has a continuous finishing reverse train consisting of two universal stands UR and UF, which have drive horizontal rolls and non-driven vertical rolls. Between the universal stands there is a drive stand duo ER. The sequence of the stands location is as follows: UR-ER-UF. The rolling scheme used on the rail-and-structural steel mill for the production of tram rails is as follows (figure 1): the first pass is made in two stands UR1 and ER1; the second pass after reverse also in two stands ER2-UR2 and the third finishing pass in three stands UR3-ER3-UF [6-8]. Thus, in three passes, the workpiece is processed in seven gauges. The characteristics of the rolling mill, the initial scheme for changing the rolls speed in the continuous reverse train and the features of the equipment and technological rolling modes are discussed in detail in [9-10]. In the technology under consideration, after each pass the gauges of the involved stands are tightened, and in the final third pass, in addition, the axial movement of the work stand ER to combine its finishing gauge and the rolling axis.

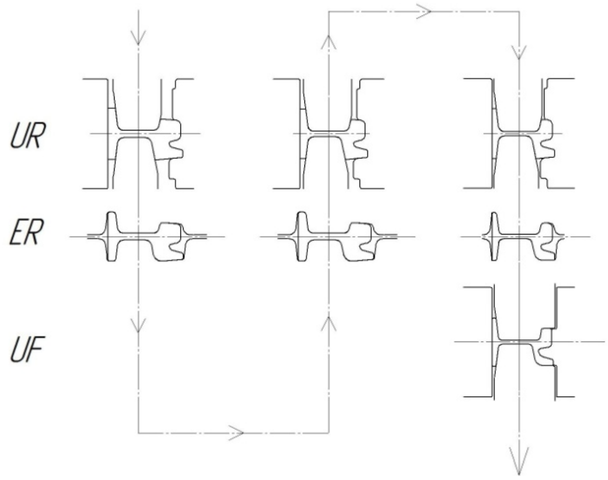

Figure 1. Scheme of tram rails rolling in the continuous train.

Let us consider high-speed rolling modes of tramway grooved rails, which were developed using the experimental-theoretical approach.

The first pass. In the first pass he rail metal is rolled in two working stands – a universal UR and a two-roll, only with horizontal rolls, Edger stand (ER). The speed diagram for the first pass is shown in figure 2. The UF universal stand rolls are parted for the free passage of the workpiece.

When the metal approaches the continuous train, the main engines of the universal stand UR and the auxiliary ER stand are automatically started. The acceleration of the rolls of the UR stand is from 0

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to 152 rpm with an acceleration of 74.15 rpm*s. The acceleration of ER rolls is from 0 to 175 rpm with an acceleration of 85.37 rpm*sec. After that the UR and ER stands are automatically converted to roll revolution with a constant speed. The metal capture is carried out at a constant roll speed for the UR stand at 152 rpm, for the ER stand at 175 rpm. The number of revolutions between the stands is different due to the fact that the rolls of stands are of different diameters and it is necessary in each subsequent stand for continuous rolling to take into account the draft from the breakdown in the previous gauge. After the metal is captured, in two stands the UR and ER the metal is rolled for a while at a constant speed. Then simultaneously in two stands there is an acceleration of the revolution of the rolls with the metal. The acceleration is continued to the maximum rolling speed of UR – 297.55 rpm and ER – 338.65 rpm. Next, the metal is rolled at the maximum speed simultaneously in two stands.

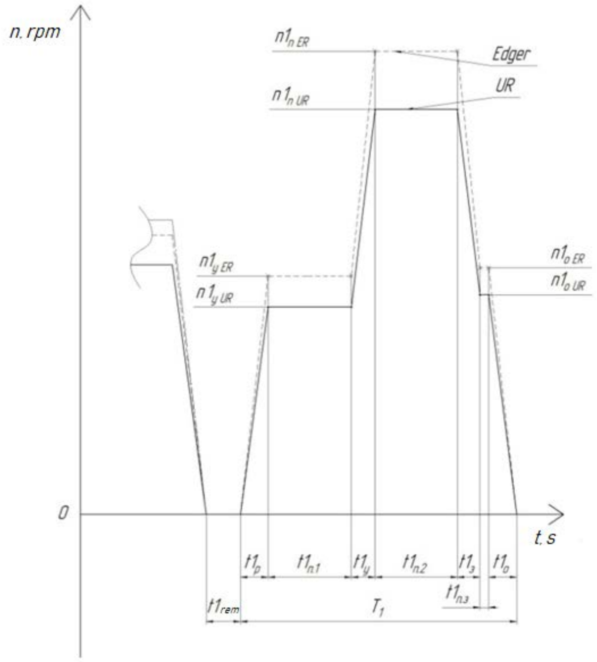

Figure 2. Diagram of speeds of the first pass, where: t_p – time of the stand acceleration without metal; t_{n1} – time of rolls revolution with constant speed; t_y – the acceleration time of the mill with the metal; t_{n2} – the time of metal rolling with a constant maximum speed; t_3 – time of the first stage of braking; t_{n3} – time of rolls revolution with constant speed; t_o – time of the second stage of braking. The number 1 after the letter t means the first passage of metal.

The rolled metal release from UR and ER stand takes place at the maximum speed and for a while the rolls rotate without metal. The braking of the rolls of UR and ER stands without metal is performed in two stages. For UR stand in the first stage of braking, the speed is reduced from 297.55 to 161.49 rpm after which the rolls rotate at a constant speed. At the second stage of braking, the revolution speed of the rolls decreases from 161.49 to 0 rpm. For ER stand in the first stage, braking is carried out and the speed of the rolls is reduced from 338.65 rpm to 181.52 rpm. After that, the rolls of ER stand rotate for a while at a constant speed. At the second stage of braking, the ER rolls revolution of decreases from 181.52 to 0 rpm (table 1).

Table 1. The work of the train “Tandem” in the first pass.

Operation	Stand UR, sec	Stand ER, sec
Acceleration time of rolls without a workpiece	2.05	2.05
Revolution speed of rolls at a constant speed	3.2	3.2
Time acceleration of rolls with a workpiece	1.75	1.75
Time of metal rolling at a constant maximum speed	4.85	4.85
Braking time at the first stage	1.65	1.65
Time of rolls revolution with a constant speed	0.65	0.65
Braking time of the second staged	2.05	2.05

The second pass. After the rolls are stopped and the gauges are tightened, the second pass starts in the reverse mode (figure 3). In the second pass the rolling is carried out in the continuous mode in two stands ER and UR. The rolls of the universal UF stand are parted for a free passage of the workpiece.

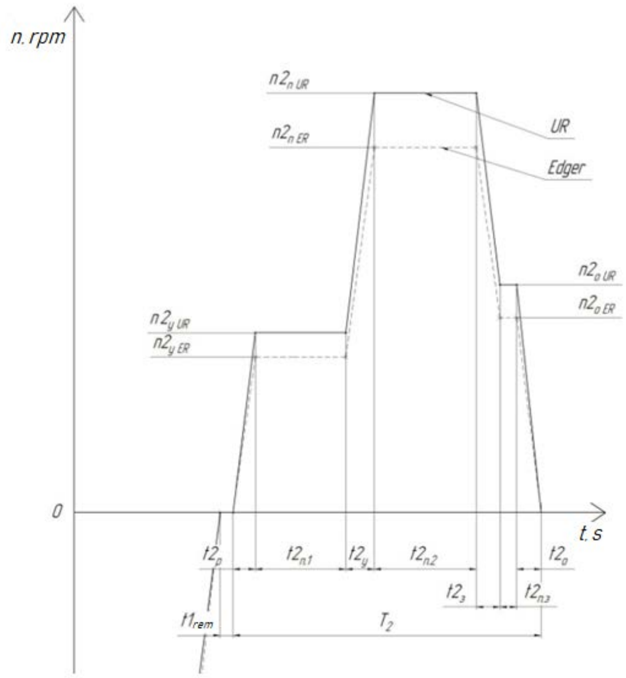

Figure 3. Speed diagram of the second pass.

The workpiece is first directed to the stand ER and then to the stand UR. Simultaneously, in automatic mode the two stands start to accelerate the rolls. In ER stand the rollers are accelerated from 0 to 114.97 rpm with an acceleration of 69.68 rpm*s. The acceleration of the rolls of UR stand is from 0 to 132.82 rpm with an acceleration of 80.5 rpm*s. After that ER and UR stands automatically transit roll revolution to a constant speed. The capture of metal is carried out at a constant revolution speed of the rolls, for ER stand at 114.28 rpm, for the UR stand at 132.82 rpm. After the metal capture in two stands ER and UR, the metal is rolled at a constant speed, after which the revolution of the rolls with the metal is simultaneously accelerated in two stands. Acceleration continues to the maximum rolling speed, which is in ER equal to 269.67 rpm, and in UR stand – 309.92 rpm. Then, for some time metal rolling occurs at the maximum speed simultaneously in two stands.

The rolled metal release from UR and ER stand takes place at the reduced speed. For ER stand after the start of braking of the rolls at 262.5 rpm the metal release from the stand takes place. Further, the rolls of ER stand rotate at a constant speed without metal. After the metal release from ER stand, braking continues at UR stand with metal and then the metal is released from it. Then the rolls of UR stand rotate without metal. The further braking of the rolling rolls in ER and UR stands is carried out in two stages. At the first stage of braking for ER stand, the speed is reduced from 269.67 rpm to 144.11 rpm, while for UR stand, the revolution speed is reduced from 309.92 rpm to 168.22 rpm. After that the rolls rotate for a while at a constant speed. Then the second stage of braking of the rolls takes place in ER stand from 144.11 rpm to 0 rpm and in UR stand from 168.22 rpm to 0 rpm (table 2).

Table 2. The work of the train “Tandem” in the second pass.

Operation	Stand UR, sec	Stand ER, sec
Acceleration time of rolls without a workpiece	1.65	1.65
Revolution speed of rolls at a constant speed	1.0	1.0
Time acceleration of rolls with a workpiece	2.1	2.1
Time of metal rolling at a constant maximum speed	7.55	7.55
Braking time at the first stage	1.75	1.75
Time of rolls revolution with a constant speed	1.25	1.25
Braking time of the second staged	1.8	1.8

The third pass. After the rolls are stopped, for the third pass ER stand moves axially for ER3 gauge setting in the rolling line of the finishing pass. The gauges dimensions of UR stands are set, and in UF the third finishing pass begins, which is the final one. In the third pass the rolling is carried out in a continuous mode in three stands UR-ER-UF (figure 4).

The rolls in all three stands are automatically accelerated by the main drives of the stands. In all stands acceleration starts simultaneously. In UR stand the acceleration of the rolls is from 0 to 183.44 rpm with acceleration of 73.38 rpm*sec. In ER stand acceleration of the rolls is from 0 to 205.35 rpm with acceleration of 82.14 rpm*sec. In UF stand acceleration of the rolls is from 0 to 216.77 rpm with acceleration 86.71 rpm*s. Then all three stands rotate at a constant speed.

The metal is captured at a constant speed of rolls revolution. In UR stand the workpiece is captured at a constant speed 183.44 rpm*s. In ER stand the workpiece is captured at a roll revolution speed 204.02 rpm and in UF stand at a roll revolution speed 216.77 rpm. Further the rolls of UR-ER-UF stands for a definite period of time roll the metal at a constant speed.

The rolled metal release takes place at a constant speed of rolls revolution in all stands – from UR stand at a constant roll speed 183.44 rpm, from ER at a roll speed 204.02 rpm and UF at a roll revolution speed 216.77 rpm. After release of the metal, the rolls of UR, ER and UF stands rotate for a while at a constant speed. Then, there is simultaneous braking of the rolls in all three stands from 183.44 rpm to 0 for UR; from 204.02 rpm to 0 for ER and from 216.77 rpm to 0 for UF (table 3).

After the rolls are stopped in all three stands, the gauge in UR1 stand is set, the ER stand is shifted to the initial position of ER1 gauge, and UF stand rolls are parted, after which the continuous reverse train is ready for rolling the next workpiece.

Table 3. The work of the train “Tandem” in the third pass.

Operation	Stand UR, sec	Stand ER, sec	Stand UF, sec
Acceleration time of rolls without a workpiece	2.5	2.5	2.5
Time before the metal is captured by rolls at a constant speed	1.6	3.3	4.95
Time of metal rolling at a constant maximum speed	18.44	18.44	18.44
Time of rolls revolution with a constant speed after workpiece release	5.95	4.25	2.6
Time of deceleration of the mill without a workpiece	2.5	2.5	2.5

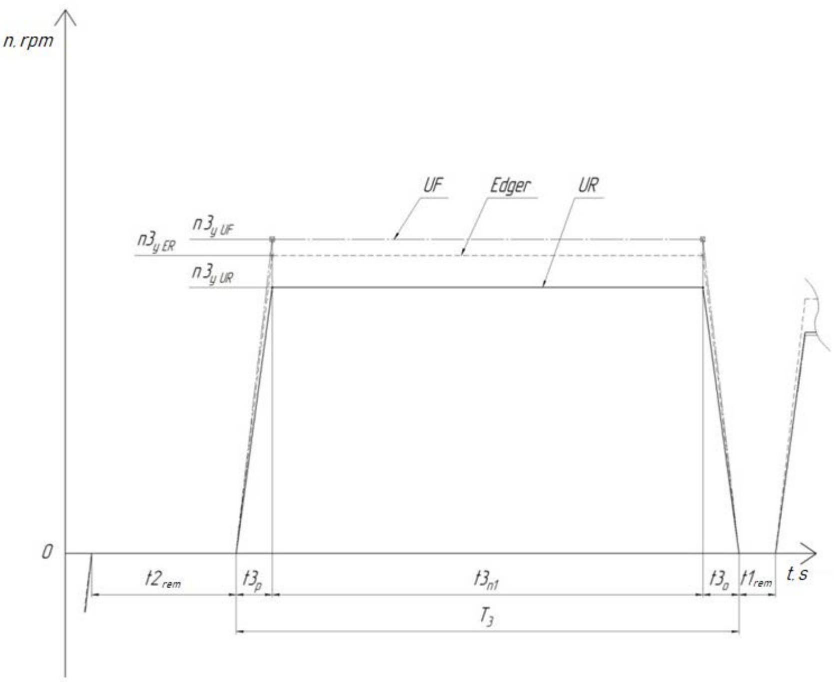

Figure 4. Speed diagram of the third pass.

3. Conclusions

1. In all passes and in all stands, the metal capture is carried out at a constant speed of rolls revolution.

2. When rolling the workpiece in the first and second passes, the speed diagrams have two stages with a constant speed of rolls revolution – reduced and maximum operating speed n_n. At a reduced constant speed (0.42-0.51) n_n, a steady metal capture by the rolls of the first stand occurs, then the workpiece passes interstand distance and the workpiece is captures by the rolls of the next stand. Then there is a simultaneous acceleration of rolls with metal in two stands to the maximum working speed n_n, and metal is rolled at the maximum working speed $n_n = n_{max}$.

3. Duting the third pass the metal capture, rolling and metal release are carried out at a constant working speed equal to n_n=(0.6-0.7)n_{max}, where n_{max} is the maximum number of revolutions of the mill main drive.

4. In connection with the specific features of equipment, the metal release in the first pass is carried out at the maximum constant speed, and the release in the second pass from ER2 gauge at a constant high speed and from UR2 gauge during the rolls braking.

5. The rolls braking in UR and ER stands after the first and second passes without metal is performed in two stages. In the first pass: for UR stand at the first stage of braking there is a reduction in speed from 297.55 to 161.49 rpm, at the second stage of braking the revolution speed of the rolls decreases from 161.49 to 0 rpm; for ER stand in the first stage of braking the number of rolls revolutions is reduced from 338.65 rpm to 181.52 rpm.

6. After that the rolls of ER stand rotate at a constant speed. At the second stage of braking, the rolls revolution in ER decreases from 181.52 to 0 rpm. In the second pass: at the first stage of braking for ER stand the speed is reduced from 269.67 rpm to 144.11 rpm, and for UR stand the revolution speed is reduced from 309.92 rpm to 168.22 rpm.

7. Then the rolls rotate at a constant speed. The second stage of braking of the rolls takes place in ER stand from 144.11 rpm to 0 rpm and in UR stand from 168.22 rpm to 0 rpm.

8. The introduction of these results allowed the productivity of the rolling mill to be increased by 10%.

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