Formation of the stress-strain state of rail bars during welding with preliminary vertical bending

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Abstract. The article defines the parameters and working conditions for the final restoration of the integrity of the rail beams of a continuous gauge rail by electrocontact welding, as well as when welding rails with each other when they are elongated in the field by the method of preliminary bending. This involves the process of welding rails at temperatures above the temperature of their fixation. In this connection, an appropriate calculation scheme has been considered in relation to which the necessary parameters have been determined to ensure the conditions for straightening the residual curvature and, as a consequence, the formations of the corresponding stress state. To ensure the self-straightening conditions, the resulting formula for determining the residual bending arrow, the elimination of which under the influence of its own weight leads to the appearance of compressive stresses in the weld zone. In addition, a formula has been derived for determining the compressive stresses in the weld zone arising in the rail after the elimination of residual curvature. This means that when performing welding operations without forced straightening of the rails, you can restore not only their integrity, or weld them together. Thereby form a corresponding temperature-stress state.

1 Introduction

One of the ways to increase the efficiency and reliability of the continuous welded rail track is to increase the length of rail bars [1]. With the advent of an efficient welding technology for short rail bars – electrical resistance welding – manufacture of block-long and section-long rail bars became possible [2].

1.1 Analysis of recent researches and publications

Scientific studies [3-8] on the integrity restoration and manufacture of long rail bars have shown that bar bending can be mechanized, and within certain limits the conditions for self-correction can be created with the provision of the appearance of a compressive force in welding area and, as a result, improving the quality of the welded joint. Obligatory

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conditions ensuring the quality of the welded joint are matching of the welded ends of the bars excluding both any angle between them, and bending moments in the support sections at the ends of the curved part of the bar.
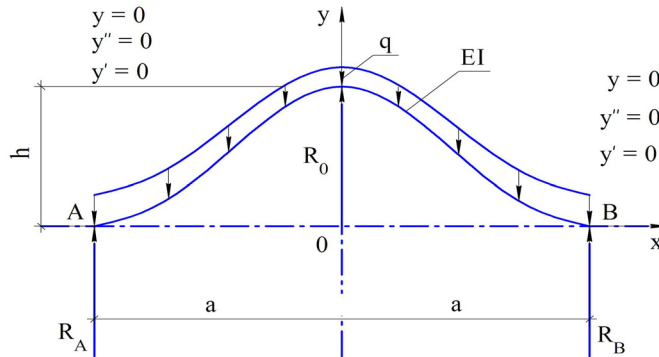

Fig.1. Computational model for determining the parameters of the stress-strain state of the bar during vertical bending

Based on these two conditions, the length of the curved part of the bar, or rather of the half-chord, is obtained

$$a = 4\sqrt{\frac{72hEI}{q}} \qquad \text{or} \qquad a = 2.914\sqrt{\frac{hEI}{q}}; \qquad (1)$$

elastic line equation:

$$y_x = -h\left[3\left(\frac{x}{a}\right)^4 - 8\left(\frac{x}{a}\right)^4 - 3\left(\frac{x}{a}\right)^2 - 1\right]; \qquad (2)$$

bending moment equation:

$$M_x = -\frac{12hEI}{a^2}\left[3\left(\frac{x}{a}\right)^2 - 4\frac{x}{a} + 1\right]; \qquad (3)$$

transverse force equation:

$$Q_x = -\frac{48hEI}{a^3}\left(\frac{3x}{2a}\right); \qquad (4)$$

reactions of the supports

$$R_A = R_B = \frac{24hEI}{a^3}, \qquad R_o = \frac{48hEI}{a^3}, \qquad (5)$$

where h – the lifting height (bending arrow) of the rail bar; a – the half-chord length; q – linear weight of the rails; EI – flexural stiffness of the rail bar in the vertical plane.

1.2 Determine the purpose and objectives of the study

One of the advantages of the method with the vertical pre-bending of a part of the bar is the use of the own weight of the rails to straighten the residual curvature. Self-straightening can

take place only with a residual bending arm of a certain value determined from the equilibrium conditions of all forces arising as a result of their redistribution after the middle part of the curved part of the rail bar is released from the support. Accordingly, the limiting value of the residual bending arm should be determined starting from which, under the influence of its own weight, the bar can be straightened, as well as other parameters of the stress-strain state during welding.

2 The basic part of the research

After the rail bar from is released form the support in the middle part of the curved part of the bar (Fig. 2), a longitudinal force (distance) appears on its ends, the value of which is determined from the equilibrium equation.
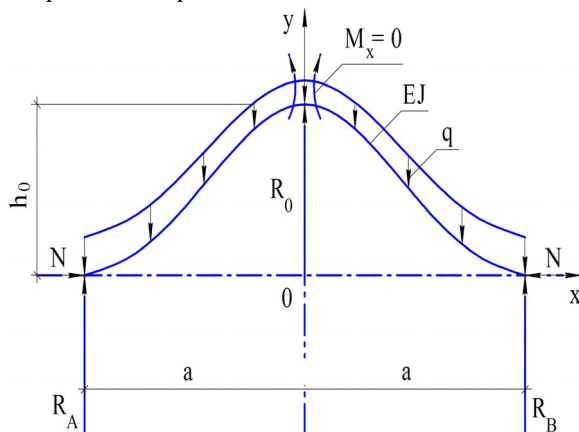

Fig. 2. Computational model for determining the maximum allowable bending arm at which self-straightening of residual curvature is provided

$$M_{x=0} + \frac{qa^2}{2} + Nh - qa^2 = 0, \tag{6}$$

or

$$\frac{12hEI}{2^2} - \frac{qa^2}{2} + Nh = 0, \tag{7}$$

then

$$N = \frac{qa^2}{2h} - \frac{12EI}{a^2} \tag{8}$$

After substituting the length of the half-chord a (1) into equation (8), an expression is obtained for determining the magnitude of the longitudinal force that arises in the bar when it is released from the support in the middle of the curved part.

$$N_h = 2\sqrt{\frac{2qEI}{h_o}}, \tag{9}$$

where h_0 – the value of the residual arm bending of the rail bar after it is released from the support in the middle of the curved part.

At the same time, to eliminate the residual bending arm, the longitudinal force N_o should be overcome, which according to Hooke's law is defined as

$$N_o = \frac{\Delta l}{2a} EF, \tag{10}$$

where Δl – difference between the length of the curved part of the bar; l – length of the chord $2a$; E – elastic modulus of rail steel ($E = 2.1 \cdot 10^6$ kg/cm^2); F – cross-sectional area of the rail.

The length of the curved part of the bar is determined by the formula

$$l = 2\int_o^a \sqrt{1 + \left(\frac{dy}{dx}\right)^2} \cdot dx, \tag{11}$$

or in relation to equation (2)

$$l = 2\int_o^a \sqrt{\left[\frac{12hx(x-a)^2}{a^4}\right]^2 + 1} \cdot dx, \tag{12}$$

The length of the curved part of the bar is determined by numerical integration using Simpson's rule [9] with respect to rails of the R65 type, for which $q = 0.65$ kg/cm, for h values of 10 cm to 100 cm in 10 cm pitch.

Table 1. Results of the calculation

h, cm	10	20	30	40	50	60	70	80	90	100
Δl, cm	0.081	0.272	0.553	0.915	1.352	1.861	2.436	3.078	3.782	4.547

The results of calculating the difference Δl between the length of the curved part of the bar and the corresponding chord, depending on the lifting height (bending arm), h are shown in Table 1, and in the form of a diagram (Fig. 3).
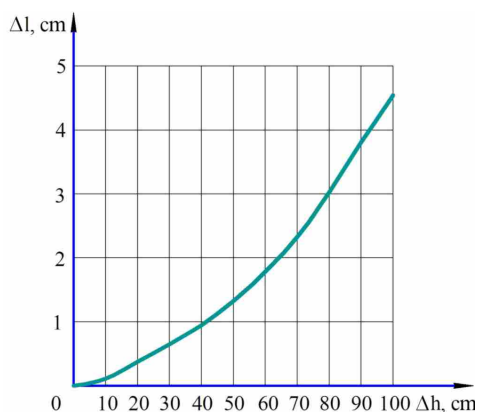

Fig. 3. Dependency diagram of the length of the curved part of the bar and the corresponding chord

The diagram has the form of the power function, which, after processing by the least square method [10], adopted a specific form for rails of type R65

$$\Delta l = 0.00144 h^{1.75} \qquad (13)$$

After further transformations in relation to all rail types, this formula took the form

$$\Delta l = 0.4706 \sqrt[4]{\frac{qh^7}{EI}}. \qquad (14)$$

After using equations (1) and (14) in equation (8), a formula was obtained for determining the force N_0, overcoming which leads to straightening the residual curvature

$$N_0 = 0.08075 \cdot F \sqrt{\frac{qh^3 E}{I}}. \qquad (15)$$

For self-straightening of the residual curvature, the condition should be met $N_h \geq N_0$. That is, using equations (9) and (15), inequality was made

$$\sqrt[2]{\frac{2qEI}{h}} \geq 0.08075 F \sqrt{\frac{qh^3 E}{I}}, \qquad (16)$$

from which

$$h_0 \leq 5.918 \sqrt{\frac{1}{F}}, \qquad (17)$$

where I and F – moment of inertia and the cross-sectional area of the corresponding rail type, respectively.

3 Conclusion

Thus, to ensure the conditions for self-straightening of the residual curvature, the residual arm should not exceed the value determined from formula (17).

Based on equation (15), a formula was obtained for determining the compressive stresses, arising in a rail after the elimination of residual curvature.

Table 2 shows the values of such a bar for different rail types.

Table 2. Maximum residual bending arm for different rail types

Rail type	Moment of inertia of the trail section I, cm	Cross-sectional areas of the rail F, cm^2	Residual arm h_o, cm
R50	2018	65.9	32
R65	3548	82.6	38
R75	4490	96.1	40

So, if the residual curvature is self-straightened, compressive stresses can be created, e.g. in rails P65, which are equal to 371 kg/cm^2 ($\approx$37 MPa), which, expressed in terms of temperature difference, will be about 15 °C. This means that when welding operations are performed without forced straightening of the rails, not only the integrity of the rail bars, but also their temperature mode within the limits of up to 15 °C can be restored.

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