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# Multi-factor regression analysis of the process of rails contact welding on K1000 machine

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**Abstract.** The article describes the technology of welding railroad rails with an electrocontact method by a pulsating reflow on a K1000 machine and production tests for a static three-point transverse bending. The analysis of the technology of welding rail rails on K1000 machine made it possible to determine the parameters of the welding mode and to reveal the essential (determining) characteristics of the technology for welding rails. The evaluation of the influence of the welding parameters on the value of the flexural force  $P_{\text{bend}}$  (kN) and the value of the deflection  $f_{\text{def}}$  (mm) was carried out by means of multiple regression analysis, which makes it possible to study the regularities of the change in the resultant index depending on the behavior of various factors. Based on the available data, a mathematical model of the process of contact welding of rails was created. The functional dependence of the influence of technological parameters on the force  $P_{\text{bend}}$ . Using the regression model, it is proposed to predict the quality of the welded seam and control the technological parameters of the process of contact welding of rails.

## 1. Introduction

Various methods of welding rails have been developed for the construction and repair of a seamless rail track. The most applicable technologies are: electrocontact and aluminothermic welding of rails. In the Russian Federation the most widely used electrocontact method of welding rails. Most of the rails are welded at stationary rail welding enterprises and a small part of joints by rail self-propelled machines [1]. In stationary conditions at the enterprise LLC “RSP-M” (RSP-29) welding is performed with the help of MCP 63.01, K1000, K1100 machines.

## 2. Research methods

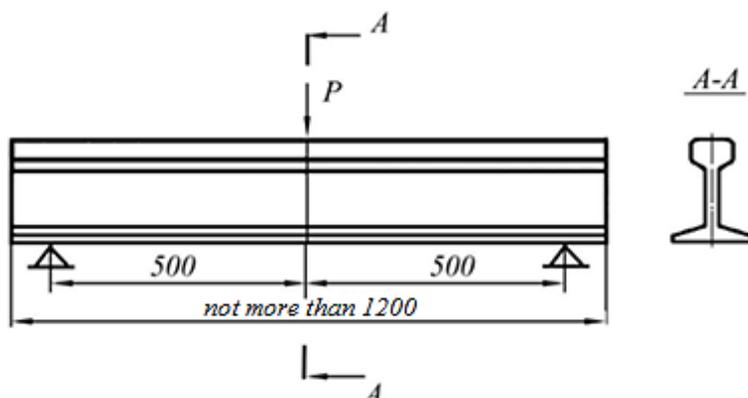
The process of welding of full-profile rails on the K1000 machine was monitored with the recording of the main parameters in the computer memory. These parameters were fixed during the welding process and stored in the database in a tabular form, and, if necessary, they can be represented graphically.

The technology of welding rails on RSP includes a mandatory welding of control samples at the beginning of the work shift. Two samples for each welding machine are welded, after which the non-heat-treatable joints are tested for three-point static bending according to the industry standard of RZD 1.08.002-2009 “Railway rails welded by the electrocontact method”. Static bending tests were carried out on a press of PMS-320 type.

Control samples are tested after welding and deburring in the welding machine without additional processing of the joints. In tests for static transverse bending, the test piece should have a length of at least 1200 mm with a welded joint in the middle. The load was applied in the middle of the span of the



control sample at the place of the welded joint with the distance between the supports of 1 m (figure 1).



**Figure 1.** Scheme of the test for static transverse bending.

### 3. Results and discussion

The process of welding rails by the electrocontact method on K1000 machine is divided into several stages: 1<sup>st</sup> stage of reflow, 2<sup>nd</sup> stage of reflow, forcing, upset, flash removal. Each stage is divided into several sections: the first stage of reflow consists of two sections (in table 1 they are numbered 1 and 2), the second stage of reflow consists of 4 sections (in table 1 they are numbered 3, 4, 5, 6), the forcing is divided into 2 sections (in table 1 they are numbered 7 and 8).

Each stage is characterized by welding modes: current strength  $I$ , A; voltage  $U$ , B; the amount of movement of the movable bed  $S$ , mm; pressure in the system  $P$ , atm; moving speed of the movable bed  $V$ , mm/s; duration of stage  $T$ , s [2].

**Table 1.** Defined parameters of the welding mode on K1000 machine.

Section No.	1	2	3	4	5	6	7	8
$U$ , B	$U_1$	$U_2$	$U_3$	$U_4$	$U_5$	$U_6$	$U_7$	$U_8$
$S$ , mm	$S_1$	$S_2$	$S_3$	$S_4$	$S_5$	$S_6$	$S_7$	$S_8$
$I_1$ , A	$I_{11}$	$I_{12}$	$I_{13}$	$I_{14}$	$I_{15}$	$I_{16}$	$I_{17}$	$I_{18}$
$I_2$ , A	$I_{21}$	$I_{22}$	$I_{23}$	$I_{24}$	$I_{25}$	$I_{26}$	$I_{27}$	$I_{28}$
$I_3$ , A	$I_{31}$	$I_{32}$	$I_{33}$	$I_{34}$	$I_{35}$	$I_{36}$	$I_{37}$	$I_{38}$
$V_m$ , B·10	$V_{m1}$	$V_{m2}$	$V_{m3}$	$V_{m4}$	$V_{m5}$	$V_{m6}$	$V_{m7}$	$V_{m8}$
$V_n$ , B·10	$V_{n1}$	$V_{n2}$	$V_{n3}$	$V_{n4}$	$V_{n5}$	$V_{n6}$	$V_{n7}$	$V_{n8}$
Upset under current, s				$O_1$				
Upset, mm·10				$O$				
Forging, s·10				$Pr$				

The test of one control sample is performed with the load applied to the head (elongation in the base), the second control sample is loaded on the base (elongation in the head). The results of the test are the values of force during bending  $P_{bend}$ , kN and the deflection force  $f_{def}$ , mm at which the control sample crashes, or the maximum values of these indicators if the sample does not fail during the tests. After the actual indicators are compared with the normative ones. If the sample has passed the regulatory requirements, welding of the rails into the line begins. If the sample does not withstand the regulatory requirements, then it is re-welded. If the repeated tests also have an unsatisfactory outcome, actions are undertaken to find the causes of low indicators and adjust the technological modes [3, 4].

The method of statistical modeling was used to describe the process of rails contact welding in this paper. To implement it, it is necessary to establish independent (input) variables, as well as to identify the dependent (output) parameters. To create a mathematical model of the process of contact welding

of rails, the existing database of parameters of welding modes and test results of welded joints was used.

As input variables were chosen: the average value of the current in each section  $I_{av}$ , A; the average value of the voltage in each section is  $U_{av}$  B; duration of setup under current  $O_1$ , s; amount of setup  $O$ , mm; duration of forging  $Pr$ , s; resistance of the joint  $R$ , Ohm. The results of tests for static transverse bending were selected As output parameters: the force arising from bending  $P_{bend}$ , kN and the values of the deflection  $f_{def}$ , mm.

For each section the corresponding path  $S$  (mm) is set, with which the welding machine sets the values  $U$ ,  $I_1$ ,  $I_2$ ,  $I_3$ ,  $V_m$ ,  $V_n$ . From the array of data the parameter values for each section were selected ( $U_{ji}, I_{ji}$ ) and the mean of these parameters was determined ( $\overline{U_j}, \overline{I_j}$ ):

$$\overline{U_j} = \frac{\sum U_{ji}}{p}, \quad (1)$$

where  $p$  – the number of values  $U_{ji}$  fixed by the sensor in this section;  $U_{ji}$  – value of voltage, fixed by the sensor at the moment of fusion on the  $j$ -th section;  $\overline{U_j}$  – the average value of the current in the  $j$ -th section.

$$\overline{I_j} = \frac{\sum I_{ji}}{p}, \quad (2)$$

where  $p$  – the number of values  $I_{ji}$  fixed by the sensor in this section;  $I_{ji}$  – value of voltage, fixed by the sensor at the moment of fusion on the  $j$ -th section;  $\overline{I_j}$  – the average value of the current in the  $j$ -th section.

After processing the production control data and parameters of the welding modes, data were obtained that reflect the main actual values of the welding modes on the machine of contact butt welding K1000 and the test results of weld joint consisting of 60 observations.

Based on the received production data they were statistically processed using the STATISTICA 10.0 package. The evaluation of the effect of the welding parameters on the amount of force  $P_{bend}$  (kN) and the deflection value  $f_{pr}$  (mm) was carried out by means of multiple regression analysis, which makes it possible to study the regularities of the change in the resultant index depending on the behavior of various factors [5-7].

The coefficients of the regression equations were calculated by the matrix method using the STATISTICA 10.0 package. The regression equation is presented in the following form:

$$Y = b_0 + b_1 \cdot X_1 + b_2 \cdot X_2 + \dots + b_n \cdot X_n, \quad (3)$$

where  $Y$  – the dependent (output) parameter;  
 $X_1, X_2, \dots, X_n$  – independent (input) variables;  
 $b_0, b_1, b_2, \dots, b_n$  – coefficients of regression.

The obtained model describing the process of rails welding R65 DT350 on K1000 machine No. 01 in the conditions of RSP-M (RSP-29) has the form:

$$P_{bend} = 18441.49 - 2.69 I_{1av} - 73.72 U_{1av} - 1.06 I_{2av} + 9.98 U_{2av} + 3.98 I_{3av} - 11.51 U_{3av} + 1.64 I_{4av} + 29.45 U_{4av} + 1.49 I_{5av} - 27.48 U_{5av} + 19.8 U_{6av} - 0.54 I_{7av} + 5.19 U_{7av} + 593.77 O_1 + 8.03 R; R^2 = 0.72.$$

The adequacy of these regression equations was verified by the average error of approximation:

$$\bar{\varepsilon} = \frac{1}{m} \sum_{i=1}^m \left| \frac{Y_i - \tilde{Y}_i}{Y_i} \right| \cdot 100, \quad (4)$$

where  $m$  – the number of observations;  $\tilde{Y}_i$  – the calculated value of the resulting indicator;

$Y_i$  – the actual value of the resulting indicator.

For  $P_{\text{bend}}$ , the average approximation error is equal to: 4.45%.

#### 4. Conclusion

On the basis of experimental data, a mathematical model of the process of contact welding of rails on the K1000 machine has been developed, which makes it possible to evaluate the the influence of the parameters of the process of rails contact welding on the quality of the welded seam.

It is proposed to predict the quality of the welded seam using the regression model and control the technological parameters of the process of rails contact welding.

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