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Method for strength calculating of structural elements of mobile machines for flash butt welding of rails

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Abstract. *Purpose. The subject of this study is the strength of the loaded units of mobile machines for flash butt welding by refining high-strength rails. The theme of the work is related to the development of a technique for strength calculating of the insulation of the central axis of these machines. The aim of the paper is to establish the mathematical dependence of the pressure on the insulation on the magnitude of deflections of the central axis under the action of the upset force.*
Design/methodology/approach. Using the Mohr's method, the displacements of the investigated sections of the central axis under the action of the upset force and the equivalent load distributed along the length of the insulation were calculated. The magnitude of the load distributed along the length of the insulation equivalent to the draft force was determined from the condition that the displacements of the same cross sections are equal under the action of this load and under the action of the upset force.
Results. An analytical expression for establishing the relationship between the pressure acting on the insulation and the magnitude of the upset force and the geometric dimensions of the structural elements of the machine was obtained. Based on the condition of the strength of the insulation for crushing, an analytical expression for establishing the relationship between the length of insulation and the size of the upset force, the geometric dimensions of the structural elements of the machine, and the physical and mechanical properties of the insulation material was obtained.
Originality/cost. The proposed methodology was tested in the calculation and design of the K1045 mobile rail welding machine, 4 of which is currently successfully used in the USA for welding rails in hard-to-reach places.

Keywords: flash butt welding of rails, rail welding machine, central axis insulation, upset force, strength calculation technique, bending, crushing

Introduction

When laying railroad tracks, as well as during their repair, contact butt welding is used in more than 90% of cases. This welding method ensures equal static and fatigue strength of welded joints with base metal, including the welding of railway frogs with rail ends [1, 2]. E.O. Paton Electric Welding Institute of NAS of Ukraine (PEWI) has many years of experience in the integrated development of equipment for flash butt welding of rails in stationary and field conditions [3]. Serial production of stationary and mobile rail welding machines based on the PEWI's inventions was set up by PJSC "Kakhovka Plant of Electric Welding Equipment" (KZESO). Among the mobile machines produced at KZESO company, the most widely used models are K255, K355A and K828 [4], and since the 2000s, taking into account the need to weld thermally strengthened rails, K76F type (manufactured by PAO «MK «Azovstal'») [5], new generation machines K920, K922 and K1000 are widely used [6, 7].

Today an actual problem for existing mobile welding machines is the welding of rails in hard-to-reach places, for example, in the subway or at the jointing of the main track rails with track switches [8].

Purpose

To solve this problem in the PEWI was developed the K1045 machine (Fig. 1) [9]. In the course of its design, it was necessary to take into account that the process of flash butt welding is associated with the application of a large upset force, as a result some certain design elements of the welding machine is affected by a high operational load. One of the loaded structural elements is the insulation of the central axis of the machine, seeing that this axis is bent and presses on the insulation during the welding. Therefore among other loaded elements of the machine it is necessary to ensure the strength of the insulation for crushing. The main input parameter for the calculation of structural elements for strength is the magnitude of the load acting on them. However, in the case under consideration, the relationship between the upset force and the load on the insulation is not obvious. Therefore, the purpose of this work is to establish the

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relationship between the pressure acting on the insulation and its length with the magnitude of the upset force, the geometric dimensions of the structural elements of the machine, and the physical and mechanical properties of the insulation material.

Fig. 1. K1045 mobile machine for flash butt welding of rails

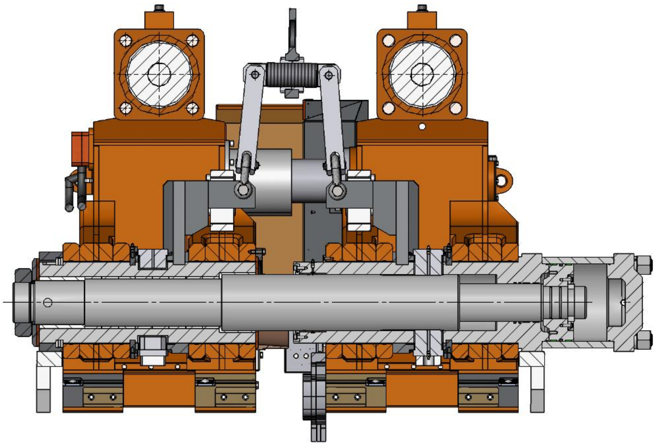

Fig. 2. Longitudinal cross-section of the K1045 mobile machine for flash butt welding of rails

Investigation

When the rails are welded, the machine transfers the force to them with the help of a hydraulic cylinder of upset 1, the central axis 2 which consists of two parts isolated from each other is flexing and pressing on insulation 3 (Fig. 2). Inasmuch as the pressure on the insulation is associated with the movements of the central axis during its bending, it is necessary to determine the vertical displacement of section *A* on the action of the upset force *P*. In order not to violate the symmetry, we determined the total displacement of the section *A* and section *B*, which are located symmetrically with respect to the joint of the welded rails (Fig. 3).

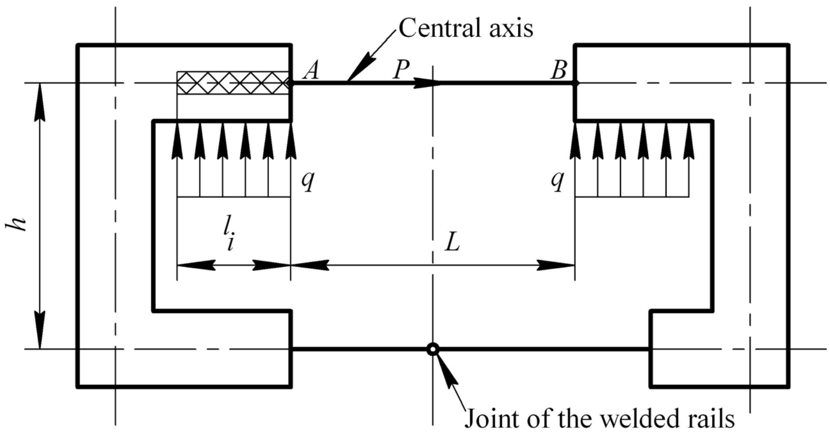

Fig. 3. The calculation scheme of machine loading during the welding

According to the Mohr's method, bending is determined by the formula [10]

$$f_i = \sum_j \int_S \frac{M_i \cdot M_{Pj} ds}{EJ}, \qquad (1)$$

where f_i is the desired displacement; M_i is the equation of the bending moment from the unit force which is applied in the direction of the desired displacement; M_{Pj} is the equation of the bending moment from the corresponding active or reactive external load; E is the modulus of elasticity of material; J is the moment of inertia of the cross section of the central axis.

To determine the necessary equations of bending moments, let us construct an equivalent system by conditionally cutting the contour along the cross-section of the central axis opposite the joint (Fig. 4).

According to the diagram (Fig. 4), the bending moment acting on the central axis due to the application of the upset force has a constant value

$$M_{PP}(x) = P \cdot h. \qquad (2)$$

Let us load the equivalent system by unit loads $F = 1$, applied in the direction of vertical displacement of sections *A* and *B* and plot the bending moment diagram from these forces (Fig. 5).

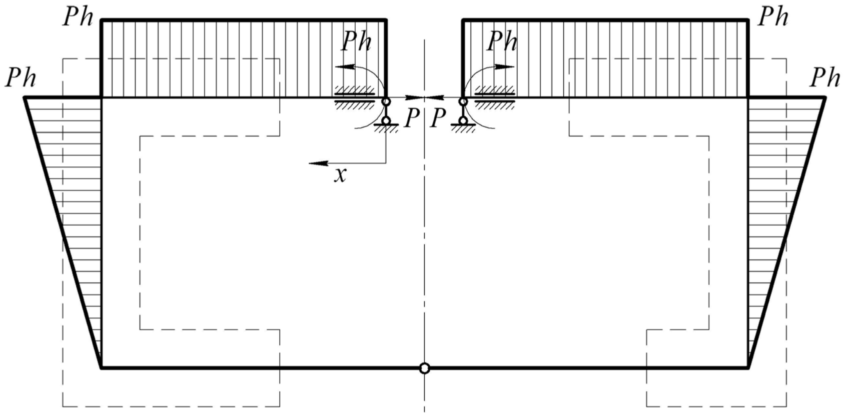

Fig. 4. The equivalent loading system and the bending moment diagram from the action of the upset force

According to the loading scheme (Fig. 5), the bending moment caused by the application of unit loads in the direction of vertical displacement of sections *A* and *B* is determined by the formula

$$M_v\left(x\right)=\frac{L}{2}-x\ . \tag{3}$$

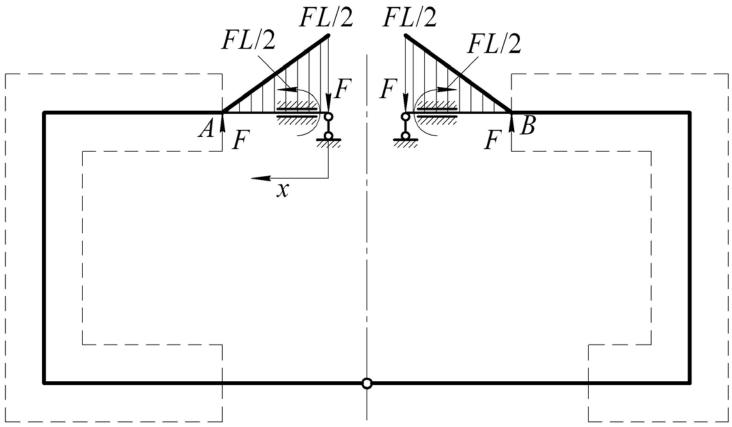

Fig. 5. Diagram of bending moments from the action of unit loads

Substituting (2) and (3) into (1) we determine the total displacement of sections *A* and *B*, from the action of the upset force

$$f_A+f_B=\frac{2}{EJ}\int_0^{L/2}P\cdot h\cdot\left(\frac{L}{2}-x\right)dx=\frac{2}{EJ}\cdot P\cdot h\cdot\frac{L^2}{8}\ . \tag{4}$$

To determine the pressure acting on the insulation, instead of the upset force, we apply to the equivalent system a linear force *q* uniformly distributed along the length of the insulation (see Fig. 3), and plot the diagram of the bending moments caused by this force (Fig. 6).

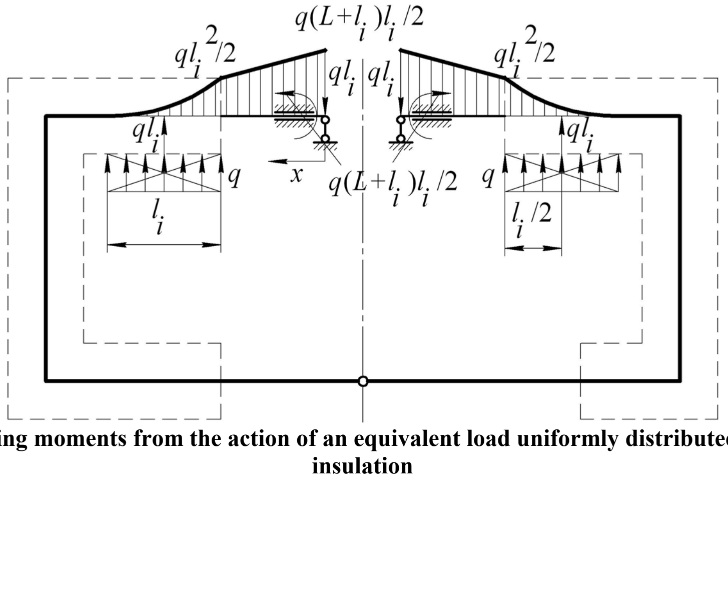

Fig. 6. Diagram of bending moments from the action of an equivalent load uniformly distributed along the length of the insulation

The equation of the bending moment from the equivalent load q on the areas of the central axis that are outside the body has the form

$$M_{Pq}(x) = q \cdot l_i \cdot \frac{L + l_i}{2} - q \cdot l_i \cdot x . \qquad (5)$$

To determine the total displacement of the cross sections A and B from the equivalent load q, substitute (5) and (3) into (1)

$$f_A + f_B = \frac{2}{EJ} \int_0^{L/2} q \cdot l_i \cdot \left(\frac{L + l_i}{2} - x \right) \cdot \left(\frac{L}{2} - x \right) dx = \frac{2}{EJ} \cdot \left[\frac{qL^2}{8} l_i \cdot \left(\frac{l_i}{2} + \frac{L}{3} \right) \right] . \qquad (6)$$

Equating the right-hand parts (4) and (6), we establish the relationship between the pressure acting per unit length of insulation, with the magnitude of the upset force

$$q = \frac{6 \cdot P \cdot h}{l_i \cdot (3l_i + 2L)} . \qquad (7)$$

According to [11], the strength of the insulation for crushing will be ensured if

$$\frac{q}{d} \le [\sigma]_{br} , \qquad (8)$$

where $[\sigma]_{br}$ is the allowable stress of insulation material for crushing; d is the diameter of the central axis, which can be determined by knowing the maximum value of the bending moment acting on the central axis (see Fig. 4), according to the known formula [11]

$$d \ge \sqrt[3]{\frac{32 \cdot P \cdot h}{\pi \cdot [\sigma]}} , \qquad (9)$$

where $[\sigma]$ is the allowable stress of the material of the central axis.

Substituting the expression for q from (7) into (8), we obtain

$$l_i \ge -\frac{L}{3} + \sqrt{\frac{L^2}{9} + \frac{2 \cdot P \cdot h}{d \cdot [\sigma]_{br}}} . \qquad (10)$$

Thus, the relationship between the length of insulation with the amount of upset force, the geometric dimensions of the structural elements of the machine, and the physical and mechanical properties of the insulation material was established.

Conclusions

1. A technique for calculating the strength of central axis insulation of mobile machines for flash butt welding of rails was developed. This technique consists in finding an analytical expression that establishes the relationship between the pressure acting per unit length of insulation, the amount of upset force and the geometric dimensions of the structural elements of the machine.
2. Based on the condition of the insulation strength for crushing, an analytical expression that establishes the relationship between the length of insulation and the size of the draft force, the geometric dimensions of the structural elements of the machine, and the physic al and mechanical properties of the insulation material is obtained.
3. The proposed methodology was tested in the calculation and design of the K1045 mobile rail welding machine, which is currently successfully used in the US for welding rails in hard-to-reach places.

Методика расчёта на прочность элементов конструкции мобильных машин для контактной сварки рельсов

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Аннотация. *Целью настоящей работы является разработка методики расчёта на прочность изоляции центральной оси мобильной машины для контактной стыковой сварки рельсов. Процесс контактной стыковой сварки связан с приложением большого осадочного усилия, в результате чего некоторые конструктивные элементы сварочной машины испытывают высокую нагрузку. Одним из нагруженных конструктивных элементов является изоляция центральной оси машины, так как в процессе сварки эта ось подвергается изгибу и давит на изоляцию. Основным входным параметром расчёта элементов конструкций на прочность является величина действующей на них нагрузки. Однако в рассматриваемом случае связь между усилием осадки и нагрузкой на изоляцию неочевидна. В основу разработанной методики положено предположение о том, что величина давления, действующего на изоляцию, связана с величиной прогибов центральной оси под действием усилия осадки. При помощи интегралов Мора были рассчитаны перемещения исследуемых сечений центральной оси под действием усилия осадки и эквивалентной нагрузки, распределённой по длине изоляции. Величина распределённой по длине изоляции нагрузки, эквивалентной усилию осадки, определялась из условия* *равенства перемещений одних и тех же сечений под действием этой нагрузки и под действием усилия осадки. Таким образом, было получено аналитическое выражение, которое устанавливает связь давления, действующего на изоляцию, с величиной усилия осадки и геометрическими размерами конструктивных элементов машины. На основании условия прочности изоляции на смятие получено аналитическое выражение, которое устанавливает связь длины изоляции с величиной усилия осадки, геометрическими размерами конструктивных элементов машины и физико-механическими свойствами материала изоляции. Предложенная методика была использована при расчёте и проектировании мобильной рельсосварочной машины К1045.*

Ключевые слова: *контактная стыковая сварка рельсов, рельсосварочная машина, изоляция центральной оси, усилие осадки, методика расчёта на прочность, изгиб, смятие*

Методика розрахунку на міцність елементів конструкції мобільних машин для контактного зварювання рейок

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Анотація. *Метою представленої роботи є розробка методики розрахунку на міцність ізоляції центральної осі мобільної машини для контактного стикового зварювання рейок. Процес контактного стикового зварювання пов'язаний з прикладанням великого зусилля осадки, в результаті чого деякі конструктивні елементи зварювальної машини знаходяться під дією високих навантажень. Одним з навантажених конструктивних елементів являється ізоляція центральної осі машини, так як в процесі зварювання ця вісь згинається і тисне на ізоляцію. Основним вхідним параметром розрахунку елементів конструкцій на міцність являється величина діючого на них навантаження. Але у випадку, що розглядається, зв'язок між зусиллям осадки та тиском на ізоляцію неочевидний. В основу розробленої методики покладено припущення про те, що величина тиску, що діє на ізоляцію, пов'язана з величиною прогинів центральної осі під дією зусилля осадки. За допомогою інтегралів Мора були розраховані переміщення досліджуваних перерізів центральної осі під дією зусилля осадки та еквівалентного навантаження, розподіленого по довжині ізоляції. Величина розподіленого по довжині ізоляції навантаження, еквівалентного зусиллю осадки, визначалась з умови рівності переміщень одних і тих самих перерізів під дією цього навантаження та під дією зусилля осадки. Таким чином, було отримано аналітичний вираз, який встановлює зв'язок тиску, що діє на ізоляцію, з величиною зусилля осадки і геометричними розмірами конструктивних елементів машини. Виходячи з умов міцності матеріалу ізоляції на зминання отримано аналітичний вираз, який встановлює зв'язок довжини ізоляції з величиною зусилля осадки, геометричними розмірами конструктивних елементів машини та фізико-механічними властивостями матеріалу ізоляції. Запропонована методика була використана при розрахунку і проектуванні мобільної рейкозварювальної машини К1045.*

Ключові слова: *контактне стикове зварювання рейок, рейкозварювальна машина, ізоляція центральної осі, зусилля осадки, методика розрахунку на міцність, згин, зминання*

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