DETERMINATION OF ADDITIONAL RESISTANCES TO SHEET PANEL DISPLACEMENT OVER DEAD ROLLER TABLE OF ASSEMBLY AND WELDING LINES

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The nature of force interaction of the front edge of sheet panels in displacement along the dead roller table of assembly and welding lines was investigated. The value of additional resistance to displacement of panels for a case of arrangement of rollers with a critical pitch, as well as relationship between its components, was determined. Load cyclograms, allowing for additional resistance to displacement, to be used in calculation of power of the transportation device drives, and recommendations for decrease of the additional resistance were developed.

Keywords: *arc welding, steel sheets, assembly and welding lines, roller table, displacement resistance, load cyclograms*

Assembly and welding of sheets into panels is one of the main technological operations in fabrication of railway tank-cars and other vessels. At displacement of sheet panels over the rollers of dead roller table in their assembly and welding lines, the transporting device drives overcome the resistance directly proportional to panel weight and dependent on roller parameters. This resistance is calculated from the known formulas, similar to calculation of the displacement resistance, for instance, for travel mechanisms of the traverser and hoisting cranes [1]. However, when the panel front edge moves over the rollers, unlike smooth movement of wheel over rail, a resistance jump occurs — an additional resistance appears, due to front edge sagging below the panel displacement plane and its running against the rollers. Additional resistances reach maximum values, when the rollers are mounted with a pitch equal to or close to the critical one, when the panel front edge runs against the roller barrel at such a distance below the transportation plane, increase of which, i.e. further sagging of the front edge, leads to a complete stop of the panel or its slipping under the roller (sagging of the panel front edge and its overhang are also critical at critical roller pitch) [2]. Power of the drives of devices transporting the panels is proportional to the resistance to panel displacement over the roller table (in the currently used structures of assembly and welding lines of large-sized panels from up to 16 mm sheets it is equal to about 10–15 kW). Increase of the total resistance to panel displacement at appearance of additional resistance requires a proportional increase of the forces to achieve this displacement, this automatically leading to overloading of the motors and other drive elements. In order to prevent the above situation, it is necessary to increase the power of transportation device drives adequately to the increased resistance, thus leading to an increase of their overall dimensions, power consumption and increased product cost. Such an additional load should be taken into account in selection of the optimum roller pitch and calculation of transporting device drive power, so that determination of additional resistances to sheet panel displacement over dead roller table is a highly important scientific and practical task.

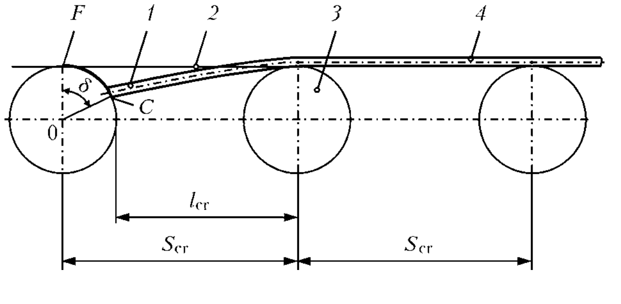

Figure 1. Schematic of panel front edge movement over the roller: *1* — panel front edge; *2* — panel transportation level; *3* — roller; *4* — panel; *C*, *F* — initial and final contact point of front edge with roller; l_{cr} — panel critical overhang; S_{cr} — critical roller pitch

In publications devoted to the problems of item transportation over roller tables and conveyers [2–6], attention was given to conditions of normal transportation of sheet panels and long cargoes and determination of their displacement resistance. Conditions for normal movement of sheet panel front edge onto the rollers are considered in detail in [2, 3]. Works [4, 6] analyze the methods of determination of additional resistance to displacement of extended cargoes over roller conveyors with drive rollers and beds installed between them. However, the above materials do not permit calculation of additional resistance to displacement of sheet panels along their assembly and welding lines, arising at panel front edge moving onto dead rollers of the roller table mounted without any intermediate beds (Figure 1).

The purpose of this work is determination of additional resistances to displacement of sheet panels along their assembly and welding lines, arising at panel front edge moving onto the rollers at displacement over the roller table with dead rollers mounted without intermediate beds.

To determine additional resistances, let us consider the schematic of force action at contact of panel front edge with the roller at its critical sagging on the roller table with critical roller pitch (Figure 2).

In the point of front edge contact, force Q of panel displacement, equal to its displacement resistance, is decomposed into two components, namely radial force Q_R, directed away from the point of contact to roller rotation axis, and circumferential force Q_c. In its turn, reaction from radial force $Q_R = Q_{R'}$ is decomposed into horizontal Q_h and vertical Q_v components. Additional resistance W_r to panel displacement is made up of two components: resistance W_{rol} from roller rotation at front edge moving onto them and resistance W_h to panel horizontal displacement at front edge contact with rollers:

$$W_r = W_{rol} + W_h. \quad (1)$$

Influence of the weight of overhanging front edge is not considered in this case, as the panel weight is fully allowed for in determination of the main resistance to panel displacement over the roller table.

Resistance W_{rol} due to roller rotation at front edge moving onto them is induced during roller rotation at the pressure of radial component on them similar to that induced in rollers at normal displacement of panels over them. It can be calculated by known formulas [1], for instance, by formula, converted from the formula of calculation of resistance to bridge crane trolley displacement in a steady-state operation mode:

$$W_{rol} = Q_R(f_{fr}d + 2\mu)/D_{rol}, \quad (2)$$

where f_{fr} is the coefficient of friction in roller journals; d is the roller journal diameter; μ is the coefficient of rolling friction; D_{rol} is the roller diameter in the rolling circle; $Q_R = Q \cos \alpha$; and from right triangle AOC at critical panel overhang and roller pitch (Figure 1) we obtain

$$\alpha = \arcsin (r/R_{rol}). \quad (3)$$

After transformations we obtain:

$$W_{rol} = Q \cos [\arcsin (r_{rol}/R_{rol})] \times (f_{fr}d + 2\mu)/D_{rol} = QK_{rol}; \quad (4)$$

$$K_{rol} = \cos [\arcsin (r_{rol}/R_{rol})] \times (f_{fr}d + 2\mu)/D_{rol}, \quad (5)$$

where K_{rol} is the coefficient of additional resistance to displacement due to roller rotation at panel front edge moving onto the roller table rollers; r_{rol} is the roller axis radius (bearing inner radius) equal to $d_{rol}/2$; R_{rol} is the roller radius in the rolling circle equal to $D_{rol}/2$.

From formulas (4) and (5) it is seen that additional resistance to roller rotation at contact with the front edge, does not depend on transported panel parameters, and only depends on roller parameters and their bearings.

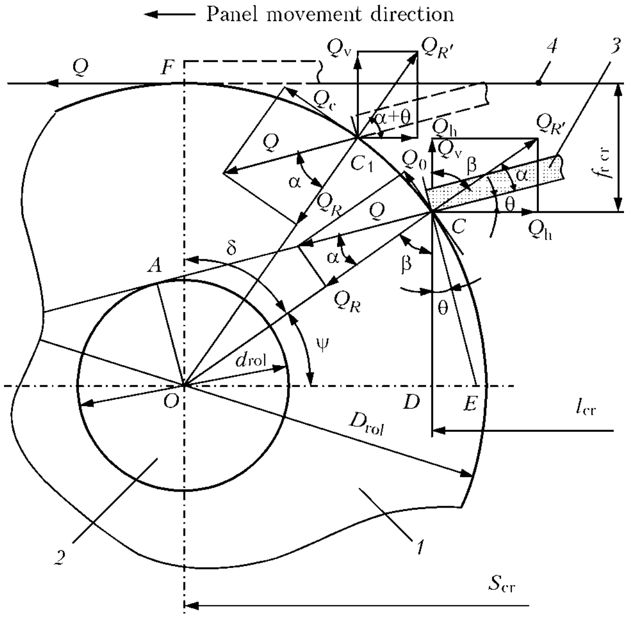

Figure 2. Schematic of force action at contact of panel front edge with the roller at panel critical sagging on a roller table with critical roller pitch: *1* — roller; *2* — journal; *3* — panel front edge; *4* — panel transportation level

Additional resistance to panel horizontal displacement at its front edge contact with rollers is the horizontal component of the reaction of radial force $Q_R = Q_{R'}$:

$$W_h = Q_R \sin \beta = Q \cos \alpha \cos (\alpha + \theta) = QK_h; \quad (6)$$

$$K_h = \cos \alpha \cos (\alpha + \theta), \quad (7)$$

where K_h is the coefficient of additional horizontal displacement resistance at contact of panel front edge with rollers; θ is the angle of rotation of front edge end plane at its critical sagging, equal to $K_\theta l_{cr}^3$ [2].

Expanding additional resistance formula (1) using formulas (4) and (6), we obtain:

$$W_r = Q(K_{rol} + K_h) = QK_r; \quad (8)$$

$$K_r = K_{rol} + K_h, \quad (9)$$

where K_r is the coefficient of additional resistance to displacement at panel front edge moving over the rollers.

At determination of K_r for different rollers, let us precise the value of calculated diameters for roller journals d. Journal calculated diameter is equal to average diameter of a roller bearing:

$$d = (d_{rol} + D_n)/2, \quad (10)$$

where d_{rol} ($d_{rol} = 2r_{rol}$) and D_n is the roller bearing inner and outer diameter, respectively.

As in terms of design the rollers can have rolling bearings with the same inner, but different outer diameters, the journal diameter for the same rollers and, accordingly, resistance to panel displacement over

Table 1. Values of coefficients K_{rol} of additional resistance to displacement due to rotation of rollers with different parameters

Parameter·10^3, m			Roller journal diameter $d \cdot 10^3$, m	$K_{rol} \cdot 100$ %	
Rollers d_{rol}/D_{rol}	Bearings			Limit	Average
	d_{rol}	D_{rol}			
25/100	25	37, 42, 47, 52, 62, 80	31.0–52.5	1.225–1.538	1.38
30/120	30	47, 55, 62, 72, 90	38.5–60.0	1.113–1.372	1.24
35/160	35	47, 55, 62, 72, 80, 100	41.0–67.5	0.863–1.106	0.99
40/200	40	62, 68, 80, 90, 110	51.0–75.0	0.767–0.944	0.86
45/250	45	68, 75, 85, 100, 120	56.5–82.5	0.648–0.802	0.73
50/280	50	80, 90, 110, 130	56.0–90.0	0.624–0.756	0.69
50/300				0.584–0.707	0.65
55/320	55	80, 90, 100, 120, 140	67.5–97.5	0.558–0.696	0.63
60/360	60	78, 85, 95, 110, 130, 150	69.0–105.0	0.503–0.651	0.58

Table 2. Values of coefficients K_r of additional resistance for sheet panels from 12Kh18N10T steel of different thickness at transportation over rollers of different diameters

$h \cdot 10^3$, m	$d_{rol}/D_{rol} \cdot 10^3$, m	Coefficients of resistance, %		
		$K_{rol.cr}$	K_h	K_r
4	25/100, 30/120, 35/160, 40/200, 45/250, 50/280, 55/320, 60/360	1.38, 1.24, 0.99, 0.86, 0.73, 0.69, 0.63, 0.58	92.49–94.40	93.87–94.98
6			92.72–94.79	94.10–95.37
8			92.86–95.31	94.24–95.89
10			92.96–95.53	94.34–96.11
12			93.03–95.70	94.41–96.28
16			93.13–95.92	94.51–96.50

such rollers, will be different at their same outer diameters.

Results of calculation of the coefficients of additional resistance to panel displacement for rollers of the most optimum outer diameters of 100, 120, 160, 200, 250, 280, 300, 320 and 360 mm, mounted on different bearings and having different journal diameters, are presented in Table 1 and in Figure 3. Parameters of the most common ball radial single-row rolling bearings [7], as well as f_{fr} = 0.015 and μ = = 0.04 cm were used [1].

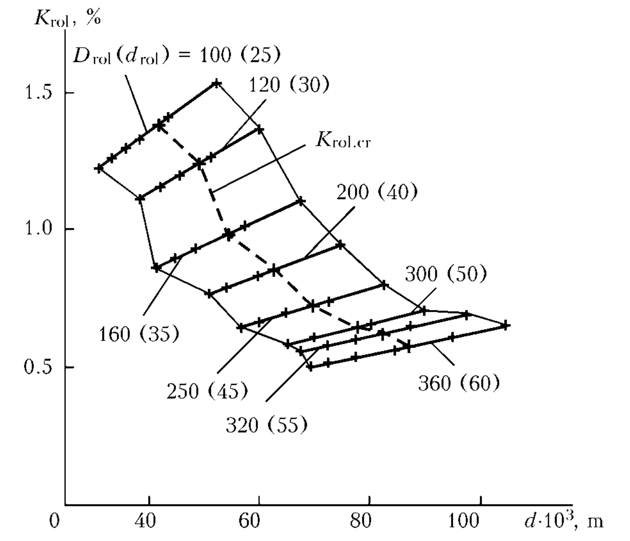

Figure 3. Coefficients K_{rol} of additional resistance to panel displacement due to roller rotation for rollers of different diameters with different journal diameters

Results of calculation of the coefficients of additional horizontal displacement resistance at panel front edge running against the rollers K_h and coefficients of full additional resistance in transportation of sheet panels K_r for sheet panels from 12Kh18N10T steel 4, 6, 8, 10, 12 and 16 mm thick over rollers of diameter D_{rol} = 100, 120, 160, 200, 250, 280, 320 and 360 mm, are given in Table 2. Values of panel critical overhang l_{cr} and angles of rotation of front edge end plane at its critical sagging θ (angles of section rotation at critical overhang values) were obtained from the respective graphs and formulas [2].

Analysis of the obtained results shows that the coefficient of additional resistance to displacement at panel front edge moving onto the rollers at critical panel overhang for sheets of different thickness, is equal to 93.87–96.50 % (almost 100 %), i.e. a unity. Coefficient of resistance to displacement due to roller rotation is up to 2 %, it decreases with increase of journal diameter and roller diameter and rises with increase of journal diameter at unchanged roller diameter. The main part of additional resistance is cre-

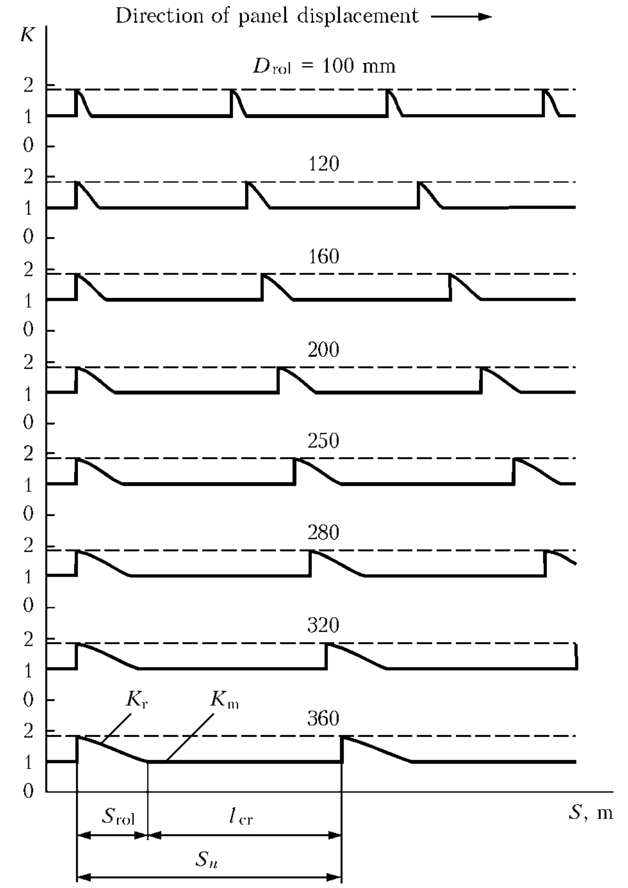

Figure 4. Cyclograms of the coefficients of resistance to displacement of 8 mm sheet panel from 12Kh18N10T steel over rollers of various diameters mounted with a critical pitch: K_m — coefficient of the main resistance equal to 1; K — total coefficient of resistance

ated by resistance to panel horizontal displacement at contact of its front edge with rollers, increasing slightly with increase of sheet thickness and roller diameter. Value of additional resistance decreases with decrease of roller pitch (and panel front edge overhang, respectively).

Duration of action of additional resistance at constant speed of panel displacement is directly proportional to path S_{rol} of front edge over the roller — length of arc CF (see Figures 1 and 2). Value of displacement of front edge from one roller to another

Table 3. Length of path of front edge of sheet panels from 8 mm 12Kh18N10T steel at transportation along the generatrix of rollers of different diameters

$d_{rol}/D_{rol}\cdot 10^3$, m	$l_{cr}\cdot 10^3$, m	K_r, %	$S_{rol}\cdot 10^3$, m	$\frac{S_{rol}}{S_{rol}+l_{cr}}$
25/100	1400	94.24	64.2	4.39
30/120	1460	94.10	76.8	5.00
35/160	1585	95.03	10.40	6.16
40/200	1680	95.53	13.10	7.23
45/250	1785	96.00	16.49	8.46
50/280	1830	95.87	18.41	9.14
55/320	1895	95.89	21.01	9.98
60/360	1945	95.89	23.60	10.82

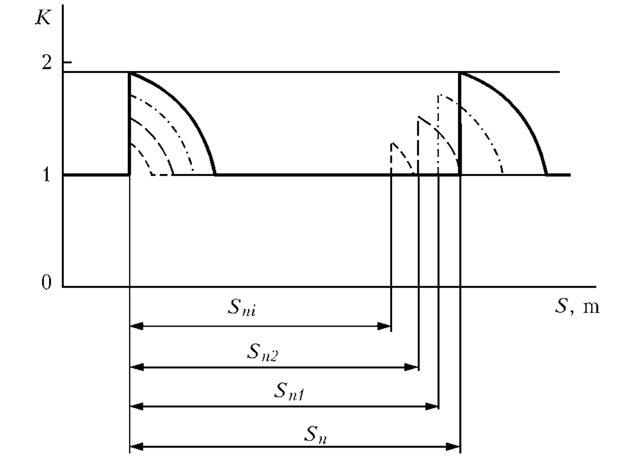

Figure 5. Nature of variation of coefficient of additional resistance at reduction of roller pitch: S_n–S_{ni} — front edge path at panel displacement by different (decreasing) roller pitch

(by roller pitch in plan view) at roller mounting with critical pitch will be

$$S_n = S_{rol} + l_{cr}. \quad (10)$$

The path of front edge over the roller (along the roller barrel arc CF) is

$$S_{rol} = \pi D_{rol}\delta/360, \quad (11)$$

where δ is the central angle of arc of roller of diameter D_{rol} (see Figures 1 and 2) equal to

$$\delta = 90° - \psi = 90° - (90° - \beta) = 90° - (\alpha + \theta). \quad (12)$$

Making the required transformations and calculations, we will get the values of the path, as well as value of the path relative to full displacement (in percent) of sheet panel front edge over the rollers. For sheet panels from 12Kh18N10T steel 8 mm thick at transportation over rollers of different diameters calculation results are given in Table 3, and cyclograms of the coefficients of the main and additional resistances to front edge displacements — in Figure 4.

The value, periodicity and duration of the action of additional resistance to panel displacement at its

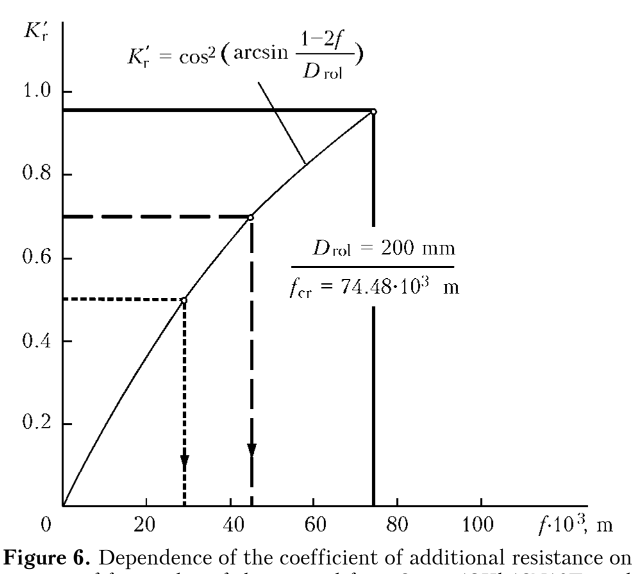

Figure 6. Dependence of the coefficient of additional resistance on sagging of front edge of sheet panel from 8 mm 12Kh18N10T steel

movement over the roller table with critical roller pitch are traceable by the cyclograms. One can see that with increase of roller diameter and critical overhang of panel front edge the length of front edge path over the roller and the duration of additional resistance action increase, respectively. At increase of roller pitch from the critical value, panel front edge overhang and sagging automatically decrease from the critical values, additional resistance to panel displacement and duration of its action decreasing, respectively (Figure 5). The given cyclograms actually are graphs of the transporting device drive loads, forming the basis for motor power calculation. At the known speed of panel displacement the time of covering certain sections of the path and influence of additional resistance on transporting device drive power are readily found.

Having analyzed the formulas of the coefficients of resistance (5), (7) and (9) and their calculated values in Table 2, we can see that additional resistance from the roller rotation (coefficient $K_{r.av}$) is equal to about 2 % of the total additional resistance. Value of angle θ in the formula of the coefficient of horizontal resistance K_h is also small. In addition, at decrease of front edge sagging from the critical value, angles α and ψ become larger, and angle θ decreases, value of angle α becoming close to value of angle ψ. Having transformed formulas (6) and (7), taking it into account, we obtain a simplified formula of the coefficient of additional resistance K'_r for calculation of its value at sagging of panel front edge below the critical values:

$$K'_r = \cos^2 \psi. \quad (13)$$

Considering that at minimum roller diameters of 100 mm and their journals of 25 mm maximum angle α (see Figure 2) is equal to 14.48°, and maximum angle (α + θ) is 17.21°, formula (13) can be used in the range of values ψ = 20–90°. Having expressed value ψ through sagging of front edge (see Figure 2), we obtain a formula of the coefficient of panel additional resistance at sagging below the critical values:

$$K'_r = \cos^2 \psi = \cos^2 [\arcsin (1 - 2f/D_{rol})], \quad (14)$$

where f is the sagging of panel front edge below the critical one.

The graph of this dependence for sheets from 12Kh18N10T steel 8 mm thick and rollers of 200 mm diameter, having critical sagging of 74.48 mm, is given in Figure 6. Taking the admissible for this case coefficient of additional resistance, we use the above graph to determine front edge sagging with this coefficient, and by sagging value we determine the required roller pitch from the known dependencies.

The direction of further research is development of criteria of selection of the optimum roller pitch for dead rollers of roller tables, allowing for the influence of additional resistance to panel displacement on transporting device drive power.

CONCLUSIONS

1. At panel front edge moving onto the rollers of dead roller table, the panel is exposed to additional resistance to displacement on each roller, which is practically equal to the main resistance at critical roller pitch.

2. It is confirmed that the main part of additional resistance to panel displacement over the roller table (at its maximum value) is made up by resistance to horizontal displacement at contact of front edge with the roller, and a small part — up to 2 % — is resistance to displacement due to roller rotation.

3. It is established that the value of additional resistance decreases with reduction of roller pitch, and at panel front edge displacement over the roller it decreases from its maximum value to zero.

4. The pitch of roller table rollers should be selected, allowing for the admissible value of additional resistance to panel displacement, and at calculation of transporting device drive power the load graphs should allow for the value and duration of the action of additional resistance.

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