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COMPARATIVE ESTIMATION OF PARAMETERS OF ROAD ROLLERS OF STATIC AND VIBRATING ACTION SUBJECT TO EFFECT OF COMPACTION WHEN CONSTRUCTING ROAD CARPETS OF NONRIGID TYPE

For each criterion dependences for parameters of different road rollers subject to effect of compaction are derived. The numerical value of the factor of effectiveness of a vibrating road roller against parameters of vibration and temperature modes of compaction of road base of hot road concrete mixes is obtained.

Keywords: road roller, factor of effectiveness of road roller, road concrete mix, effect of compaction.

Analysis of existing normative documents and recommendations, as well as technological schemes applied when compacting road bases of hot road concrete mixes shows that technological link may consist of different types of rollers. Road rollers provide required parameters of quality of construction such as durcapacity, coefficient of compaction and water resistance, these parameters are regulated by normative documents.

When selecting the types of road rollers it is necessary to take into account that material capacity to resist external load grows with an increase of material density.

Therefore, load from roller drum shall be increased when compaction. On these grounds mass of a road roller should be increased for subsequent compaction of the material on division [1, 3].

Necessity of road carpets compaction in specified temperature intervals leads to raising of the road rollers design parameters standards. To reduce a number of zones being compacted, rollers with wider drums are produced. Currently, there are models of rollers with a width of drum more than 2000 mm. It helps to reduce a number of zones being compacted and increase run time of a roller.

Analysis of rollers parameters shows that width of a drum may be different when rollers are equal in mass. It effects on force action of the roller on the material being compacted and obtained result of compaction.

Thus, as a linear pressure of a roller can be taken as criterion when comparing the parameters of rollers. It allows to take into account width of the rollers.

It is established that density of material being compacted depends on the magnitude of contact stresses after roller passage [2, 3]. Subject to contact stresses under roller drum the parameters of rollers with different methods of compaction are compared.

Intensity of drum impact on material being compacted is determined by residual deformation of the material after the passage of the roller. It is found that there is a direct relation between the residual deformation and the density of material [4]. The value of the residual deformation depends not only on the contact stress, but also on duration of loading. When using a vibrating road roller time of contact of the drum with the particle of material depends not only on the speed of compaction, but also on the nature of drum oscillations. It was found experimentally that vibrating rollers with relative disturbing force more than 1 work in vibroimpact mode when compaction road carpets with minor thickness of material layer being compacted. Therefore, effect of compaction will be different under equal contact stresses but different time of compaction. This fact should be taken into account when selecting the parameters of road rollers of vibratory and static action for their joint work in mechanized section.

Effectiveness of vibrating roller depends on its static and vibration parameters. It is believed that light vibratory roller can replace a heavier roller of static action. I is ound that the best result of compaction is achieved at the oscillation frequency of the driving forces 50—67 Hz. Increased frequency of oscillations (more than 50 Hz) slightly improves the quality of compaction. The nature of drum oscillations does not affect the quality of compaction. The best result is achieved with a relative driving force equal to 6 [5]. However, with the increase of the relative driving force roller with controlled vibrating drum becomes uncontrolled. If vibrating drum is leading slippage of a drum relative to the surface of the material being compacted occurs, and it affects the quality of compaction. Consequently, roller riding properties reduce as driving force increases. Because of this ratio between perturbing force and force of gravity of the vibrating parts in the self-propelled vibrating rollers is limited. The effectiveness of the roller depends on the speed of its movement in the process of compaction. It is found that increase in the operating speed of a roller causes decrease in the density of road concrete mix and requires increase in a number of passes on one track. Recommended operating speed of a roller is 1.2—1.5 km/h. Currently, there is no consensus regarding the factor of effectiveness of vibrating roller in relation to other types of rollers and its place in technological process of compaction of road concrete mixes. The results of research shows that compaction capcapacity of vibrating roller is the same as capacity of static one, load on drum of which is 6—10 times more than the load on a vibrating roller drum [5]. According to foreign studies, vibratory roller is 1.5—2 times more effective than static one. For comparison of different kinds of road rollers of static action efficiency coefficients, based on value of force impact of roller drum on unit of conventional area of contact were adopted [2, 6].

It was found experimentally that the nature of the stresses when compacted by static and vibrating rollers is different. The stresses in the contact zone change together with oscillation period from maximum to minimum because of oscillatory movement of the drum. As relative strength and frequency of oscillation increase, time of load on a particle of material being compacted changes. It affects the value of residual deformation of material and, consequently, the efficiency of the vibratory roller. Therefore, an the value of irreversible deformation under equal stressed state of material is objective indicator permitting to compare the parameters of the rollers on compaction effect in the process of compaction.

To compare the parameters of static and vibratory rollers experimental studies were carried out. The procedure of the experiment was simulated on the soils, and then measurements were performed on road concrete mixes. The thickness of the layer, time of loading, stresses on the contact surface of the curved punch, temperature of the mixture and residual deformation were controlled during experiments. It was found that as diameter increases, with a constant force impact of the drum, the residual deformation of the material decreases, regardless of the time of compression. The results are presented in Fig. 1. Data were obtained at a relative driving force equal to two and a line pressure equal to 18 kN / m. The data shows that the value of residual deformation, with equal value of contact stress, depends on the radius of the drum. Intensity of increase in deformation decreases in 0.4—0.6 sec, with the radius of the punch 800 mm, and deformation grows intensively during 1.6—2 sec, with a radius 300 mm.

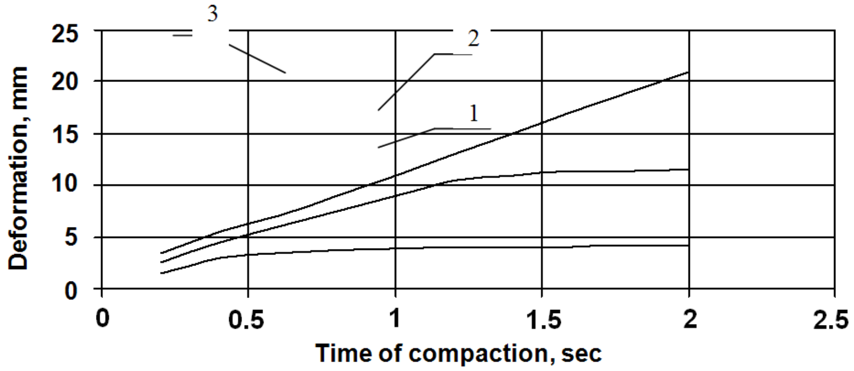

Fig. 1. Impact of the radius of the punch on residual deformation with the radius of the drum 1 — 800 mm; 2 — 600 mm; 3 — 300 mm

The reason is that area of contact of the drum decreases as the radius decreases. This leads to the increase in stresses and when they reach values exceeding the ultimate strength of material plastic deformations occur, the deformations reduces quality of the work. Consequently, the value of contact stresses and time of loading on material impact on development of residual deformation of the material. Similar regularity is true for static roller. From these facts it transpires that parameters of road rollers can be compared on residual deformation, with equal contact stresses and material properties.

Table 1 shows the results of measurements of residual deformation of the mix obtained when compacting the layer with thickness equal to 0.07 m by static load of 0.1—0.6 MPa, at the temperature of the mix 85—90 ºC and duration of loading 60 sec.

Table 1

Effect of contact sresses on residual deformation of the mix

Stresses, MPa	0.1	0.2	0.3	0.4	0.5	0.6
Deformation, mm	12	16.5	26	33	41.3	49.6

The residual deformation dependence of density was obtained:

$$\lambda = B + A\delta. \quad (1)$$

where λ is the deformation, mm; B and A are constant factors; δ is the density o material, kg/cm^3.

Deformation

$$\lambda = \lambda_{мак}(1 - e^{-\alpha t}). \quad (2)$$

where t is the time of loading, sec; α is the factor describing material properties, it is determined experimentally; $\lambda_{мак}$ is the greatest possible stress at given value of drum contact pressure, mm.

Therefore, if residual deformation of material under action of vibratory and static road rollers with equal contact stresses is known, it is possible to compare the parameters of the static and vibratory rollers on equal compaction capacity taking into account that properties of the mix and temperature modes are equal. Dependences of maximum deformation and factor α under static loading on material during 60 sec are obtained (Fig. 2).

To compare the parameters of road rollers when using different methods of compaction it is necessary to know the amount of strain depending on the parameters of vibration and temperature of the mixture. In general, the dependence of the deformation of the material from these factors has the form

$$\varepsilon_{общ} = f\,(P/Q;\ \omega;\ t_{см}) \qquad (3)$$

where P/Q is relative driving force; $t_{см}$ is the temperature of the mix, ºC; ω is the frequency of oscillations of driving force, Hz.

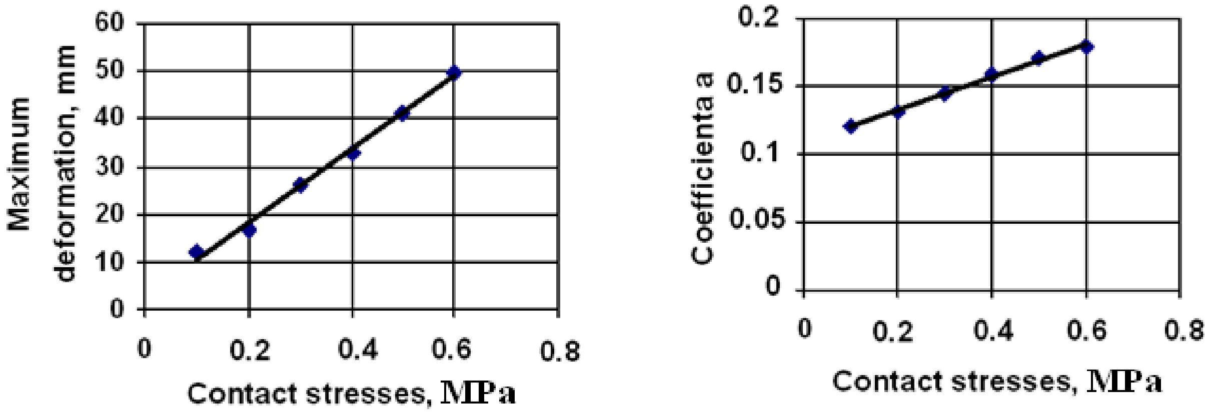

Fig. 2. Dependence of maximum deformation and factor α on contact stresses under long-term static load

Using the dependence (1), we can determine the residual deformation when a vibrating roller is operating, subject to relative driving force taking into account equality of driving forces and equal operating conditions of the rollers (see Table 2).

Table 2

Residual strain dependence of relative driving force (at different contact stresses)

at σ = 0.2 MPa						
P/Q	0	1	2	4	6	8
$t_к$	0.4	0.36	0.34	0.286	0.243	0.204
λ_1	0.96	0.87	0.77	0.69	0.59	0.50
λ_1/λ_o	1.0	0.9	0.8	0.72	0.61	0.52
at σ = 0.4 MPa						
P/Q	0	1	2	4	6	8
$t_к$	0.4	0.36	0.34	0.286	0.243	0.204
λ_1	2.08	1.88	1.68	1.50	1.29	1.08
λ_1/λ_o	1.0	0.9	0.8	0.72	0.61	0.52

The results show that there is a general dependence of residual deformation of material from relative driving force. It was found experimentally that the time of vibrating roller contact with material being compacted depends on the parameters of vibration and can be determined, taking into account relative driving force, at the oscillation frequency of 50 Hz, using the formula

$$t_к^в = t_к e^{-0.084(P/Q)}, \quad (4)$$

where $t_к^в$ is the time of contact of vibrating roller drum, sec; $t_к$ is the time of static roller drum, sec.

Dependence of relative deformation of the material on the relative driving force, at a constant temperature of the mixture and the oscillation frequency of the drum is shown in Fig. 3 and can be determined by the formula

$$\varepsilon_{отн} = 0.957e^{-0.0756(P/Q)}, \quad (5)$$

where $\varepsilon_{отн}$ is the relative deformation, depending on relative driving force, which is the ratio λ_1/λ_o, dimensionless quantity; λ_1 is the deformation o material under vibratory load; λ_o is the deformation under static load; *e* is the base of logarithm.

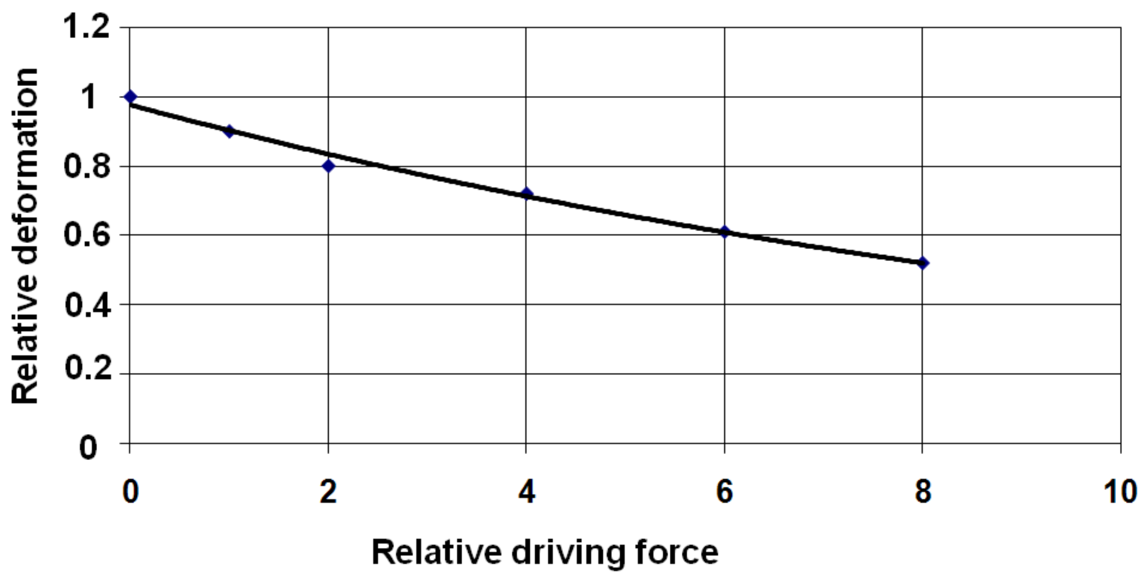

Fig. 3. The effect of relative driving force on relative deformation

It was found experimentally that the road roller performed at their best in resonant mode when the amplitude, vibration velocity and acceleration are maximum.

This was the basis for the building of various systems providing road rollers operation in resonant mode with soil compaction. At the same time, it was found that the frequency of drum oscillations does not affect the efficiency of road rollers under compression of road asphalt mixes [5].

In order to specify the impact of the oscillation frequency on the effectiveness of the vibratory roller experimental researches were carried out. The temperature of the mixture was equal to 80—85 ºC, the thickness of asphalt layer of the mixture of *D*-type was equal to 6.5—7.0 cm, the relative exciting force (*P*/*Q*) was equal to two.

The oscillation frequency varied from 25 to 75 Hz, the magnitude of contact stress 0.4 MPa. Mixture densified roller static effect for four passes. Measurements of residual strain were carried out after five passes of vibratory rollers with different oscillation frequency of the driving force. The results are presented in Table. 3.

Table 3

The effect of driving force oscillation frequency on mix relative deformation

Oscillation frequency, Hz	25	50	75
Time of contact for one pass, sec	0.32	0.34	0.36
Deformation, mm	5.8	6.2	6.6
Relative deformation	0.93	1.0	1.06

The data shows that the driving force oscillation frequency does not affect the residual deformation of compacted material. This is explained by the fact that amplitude of drum oscillations decreases with increase in drum oscillation frequency, which contributes to the reduction in the action of road rollers on the material. Analysis of parameters of vibrating rollers showed that when compacted asphalt mixtures road rollers with the frequency of 50 Hz are the most commonly encountered. The effectiveness of a road roller with the frequency of 50 Hz is taken to be equal to one. Then, the effectiveness road roller factor, depending on the frequency of drum oscillations is of the form

$$\varepsilon_\omega = 0.87e^{\,0.0026\omega}, \qquad (6)$$

where ε_ω is the relative deformation, depending on the frequency of drum oscillations, dimensionless quantity; ω is the frequency of oscillations of drum driving force, Hz.

It is known that the properties of hot asphalt mix depend on its temperature. Increase in the viscosity of bitumen contributes to strengthening of bonds between the particles of the material and formation of a monolithic layer having a greater distributive effect. This reduces the efficiency of all the machines.

Fig. 4 shows the results of calculations of residual deformation of the mixture at different temperatures after ten passes of static and vibratory rollers performed under the same contact pressures.

The data shows that efficiency of road rollers decreases with decrease in mix temperature regardless of the way of compression. It was found that when the rollers have the same contact pressure and operating conditions the residual deformation depends on the time of loading on the material, and this dependence is true for all temperature ranges of compaction.

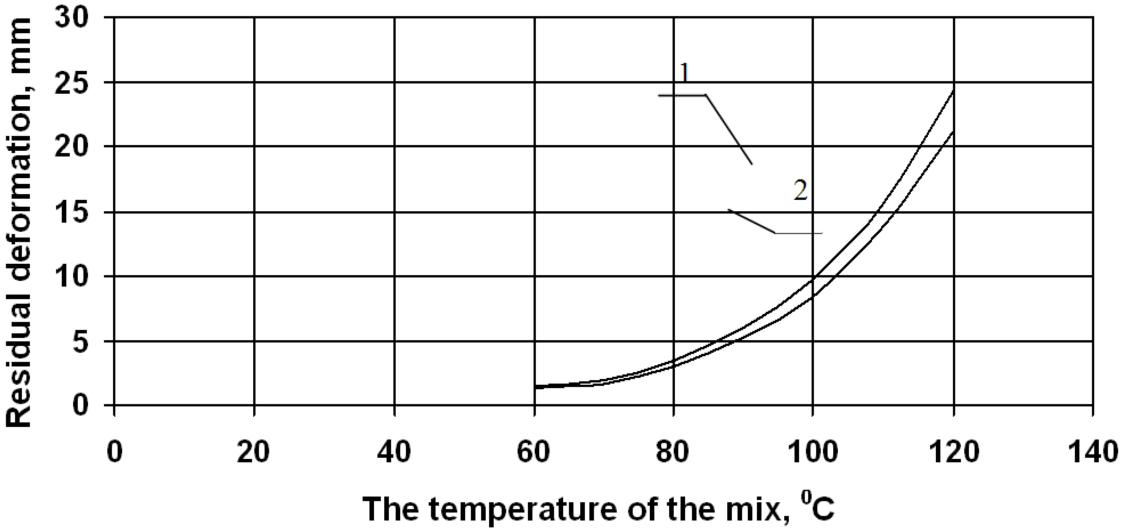

Fig. 4. The effect of the mix temperature on residual deformation of material:
1 — static road roller; 2 — vibrating road roller
(at relative driving force equal to 2 and frequency of drum oscillation equal to 50 Hz)

Fig. 5 shows the dependence of deformation (in the relative magnitude) on the temperature of the mixture when compacted with rollers of static and vibrating action. Figure 5 shows that the intensive growth of the material deformation occurs at the temperature of above 80 ºC, regardless of the way of compaction.

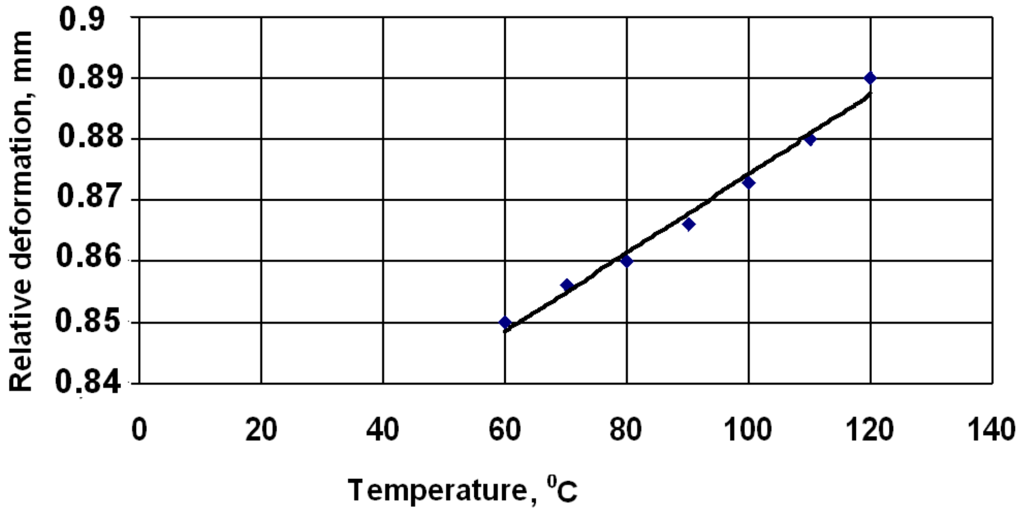

Fig. 5. The effect of the temperature on relative deformation of material

Dependence of mixture relative deformation on temperature is exponential, and relative deformation can be determined by the formula

$$\varepsilon_{отн} = 0.81\, e^{\,0.0007t}, \qquad (7)$$

where $\varepsilon_{отт}$ is the mix relative deformation, dimensionless quantity; t is the mix, ºC; e is the logarithm base. Correlation coefficient is 0.98.

Vibrating roller effectiveness factor when compacting hot mixes has the form

$$\varepsilon_{общ} = 0,67e^{\,0.0007t + 0.0026\omega - 0.0756(P/Q)}, \qquad (8)$$

where t is the mix temperature, ºC ; ω is the drum oscillation frequency, Hz; P/Q is the relative driving force.

The dependence of the relative deformation of the material on the parameters of vibration and temperature makes it possible, given the equal contact stress under the roller rinks of static and vibrating action, to determine the numerical ratio between the equivalent drums on the same compaction effect. Assuming that compaction capacity of the rollers at equal contact pressures is the same, the relation between their parameters has the form

$$\sqrt{q_1E_1/R_1} = \varepsilon_{отн} \cdot K_1 \cdot \sqrt{q_2E_2\,/R_2},\ \text{МПа}, \qquad (9)$$

where q_1 and q_2 are linear static pressure of static and vibratory rollers, kN/m; R_1 and R_2 are the radii of rollers, respectively, m; E_1 and E_2 are modulus of deformation of material being compacted, MPa; K_1 is the factor depending on the relative driving force, determined from expression

$$K_1 = 1.67 + 1.31\ln(P/Q). \qquad (10)$$

Presented dependence allows to determine the numerical relationship between the parameter of static and vibratory rollers actions under different conditions of the work. Assuming that the drums run on the same materials and the diameters of the rollers are equal, the numerical ratio has the form

$$q_1 = q_2K_{2.} \qquad (11)$$

where q_1 and q_2 are linear pressures of static and vibrating rollers; K_2 is the linear coefficient, depending on the vibration parameters, dimensionless quantity. Its numerical value is determined by the formula

$$K_2 = \varepsilon^2_{отн} \cdot (1.67+1.31\ \ln(P/Q))^2, \qquad (12)$$

where $\varepsilon_{отн}$ is the relative deformation of the mix after passes of the vibrating roller under equal contact pressures; P/Q is the relative driving force of the vibrating roller, dimensionless quantity.

Analysis of rollers parameters showed that the diameter of the drum depends on the width and ranges from 400 to 1400 mm.

Power characteristic affecting the contact pressure under the roller drum is the ratio of the drum linear pressure to the drum radius. In the case when linear pressures are equal and material modulus of deformation are equal, but roller radii are different, contact pressures will be different. The greater the radius, and, consequently, contact area, the less contact pressure.

The dependence for determination of the mass relationship of vibrating and static rollers takes the form

$$Q_1 = Q_2\, K_1^2\, \varepsilon^2_{отн}\, B_1R_1/B_2R_2. \qquad (13)$$

In the case when linear pressures of drum are different, the dependence has the form

$$q_1 = q_2\, K_1^2\, \varepsilon^2_{отн}\, R_1/R_2. \qquad (14)$$

The ratio of drum linear pressure to its radius is taken as power factor affecting the stresses under roller drum. In this case rollers can be compared using dependence

$$q_1/R_1 = q_2\, K_1^2\, \varepsilon^2_{отн}\, /R_2. \qquad (15)$$

where R_1 and R_2 are the radii of drums of static and vibrating rollers; q_1 and q_2 are linear pressures, respectively; K_1 is the factor, depending on vibration parameters; $\varepsilon_{отн}$ is the relative deformation.

As for static rollers, the ratio of linear pressure to drum radius ranges from 0.22 to 1.7. As for vibrating rollers, this ratio ranges from 0.29 to 0.65.

Fig. 6 presents the results of determination of a vibrating roller effectiveness factor against the relative driving force for different comparison test of vibrating and static rollers.

The data shows that the effectiveness of vibratory rollers compared to static rollers when compacting material with equal deformation capacity depends on the relative driving force. Intensive growth in stresses under vibrating drum occurs when the relative force raises up to three, then the growth rate decreases.

In the case when static parameters of the rollers (the radius and width of a drum) and deformation capacity are equal efficiency ratio increases rapidly to the relative force equal to 3, then it almost stabilizes at the value of factor equal to two.

When using rollers with different power parameters a vibrating roller effectiveness ratio increases to the relative force equal to four and then a decrease in effectiveness occurs because of reduction in time of drum and material contact.

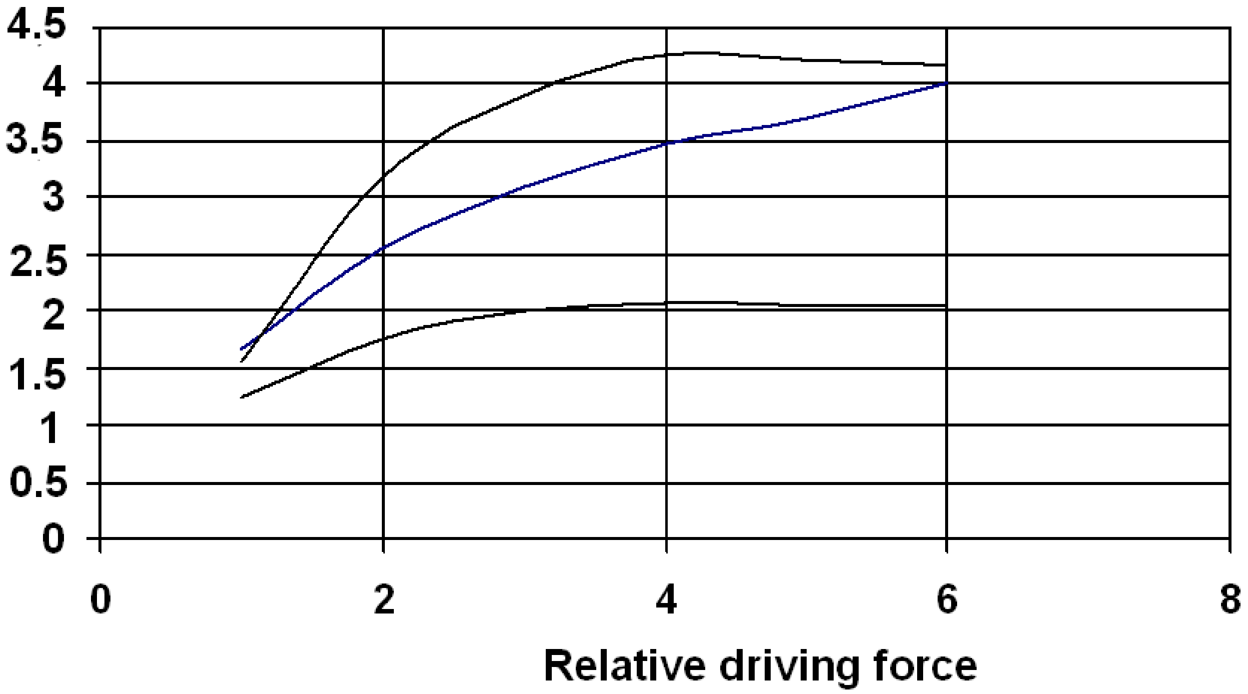

Fig. 6. The dependence of vibrating roller effectiveness factor on relative driving force:
1 — by contact stresses; 2 — subject to deformations at equal radii and drums width ($K_{1}\varepsilon_{отн}$);
3 — by compaction capacity of rollers, with width for width of zone being compacted ($K^{2}_{1}\varepsilon^{2}_{отн}$)

Thus, knowing the temperature modes and parameters of vibrating rollers, it is possible to determine the equivalent static roller using proposed dependences.

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