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EFFECT OF VIBRATION VELOCITY ON THE WEAR UNDER CONDITIONS OF ABRASIVE FRICTION

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Abstract: *The paper presents the development of both device and methodology for the study of the law of abrasion under conditions of abrasive friction due to vertical vibrations. Experimental results of the mass abrasion/wearing, the intensity of the abrasion and of the resistance on abrasion at one hand and their interdependence with the vibration speed of the normal oscillations, the material compositions and the variations in the load and the friction road, on the other hand, are reported.*

Keywords: *Tribology, abrasive friction, wear, vibration.*

1. INTRODUCTION

Reliability, life and operation ability of machines and equipment are mainly determined by the contact processes: friction, wear, lubrication and contact conductance. Multiple studies and a previous practical experience have shown that 80 – 90 % of equipment failure is not due to low structural strength of the elements but to intolerable wear in the contact joints [1,2].

Mechanical impact and the resulted vibrations lead to disturbance in the functional characteristics and failures in machines and equipment. Changes of vibration parameters influence the wear rate. Vibro-strength and vibro-wear-resistance of materials are most important factors for machine operation and exploitation resource. Vibration characteristics vary in wide interval at non-stationary operation regimes of tractor motors and gas turbines. These changes are significantly influenced by the grade of wear. The vibration frequency for technically damaged engines varies between 180 – 6500 Hz and the amplitude between 0.5 – 10 µm. High changes in the operation regime can cause resonance effects, which result in speed up of fatigue and wear mechanisms [3,4].

The main reason for leaving the normal operation regime of construction, agricultural and mining equipment is the abrasive wear, accompanied mostly by vibration impact [5].

A way for improvement of the exploitation resource of technical systems operating under conditions of abrasive and vibration impact is the improvement of the wear-resistance of surfaces by means of deposition of cladded coatings of special electrode materials [6].

The paper presents the results of a comparative study on wear and wear-resistance of cladded electric arc coatings for five types of electrode materials under conditions of dry abrasive friction and normal vibrations impact.

2. MATERIALS

The study is done by means of specimens of composite coatings deposited by electric arc cladding with electrode wire.

The selected electrode materials are designated for manual and automatic welding applying regimes of coating deposition in accordance with the recommendation of the technical certificate of the corresponding material for the used electrode thickness. The deposition is done at average values of the technological regime: welding speed 0.6 m/min (5 rev/min), current value I = 210 A and voltage 21.5 V in protective gas environment containing 83 % argon and 17 % CO_2 (Corgon) by means of the apparatus shown in Figure 1.

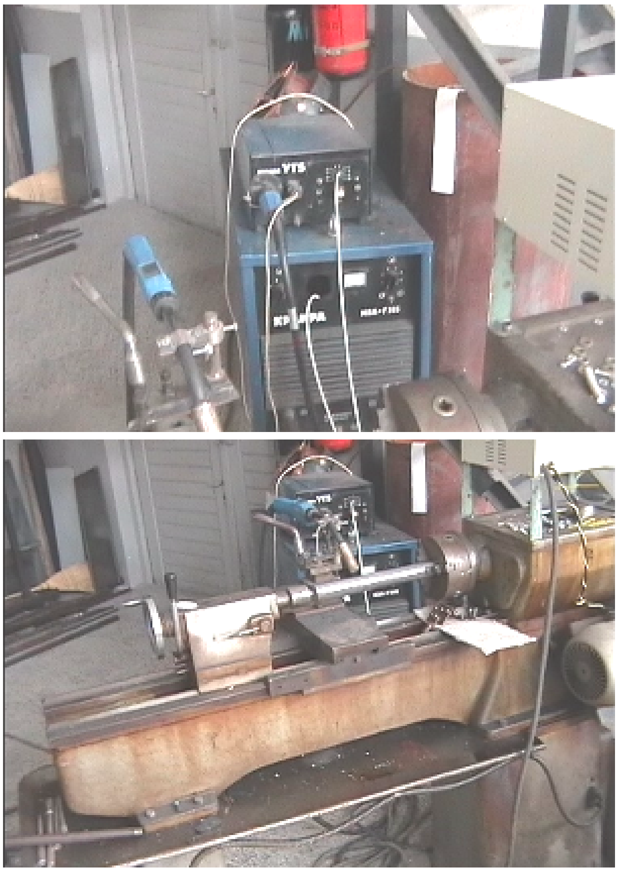

Figure 1. Device for cladded coatings arc deposition

The coatings are deposited on cylindrical specimens of diameter Ø 40 mm of C30 and 37Cr4 (Steel 40X). After the deposition, specimens of equal dimensions and roughness for all type of coatings are produced.

Data for the chemical composition of the studied coatings are given in Table 1.

Table 1. Chemical composition of the cladded coatings

Coating	Chemical composition of the cladded coatings [%]						
	C	Si	Mn	Cr	Mo	Nb	W
FOX DUR 350	0.2	1.2	1.4	1.8	-	-	-
EH 550	0.50	2.40	0.40	9.00	-	-	-
LNM 420	0.5	3	0.4	9	-	-	-
Fluxofil 58	0.45	0.60	1.60	5.50	0.60	-	-
Wearshield 70	4.2	2.7	-	18	8.5	9	7

The metallographic analysis is carried out on the cross-section of the specimens by means of metallographic microscopes Reichert MeF2 and PolyvarMet at magnification up to 1000 ×.

The microstructure of the cladded coatings is shown in Figures 2, 3, 4, 5 and 6, and the description and the micro-hardness are given in Table 2. The micro-hardness is measured by Micro Duromat 4000 micro-hardness meter at load 0.5 N and duration 10 s [6,7].

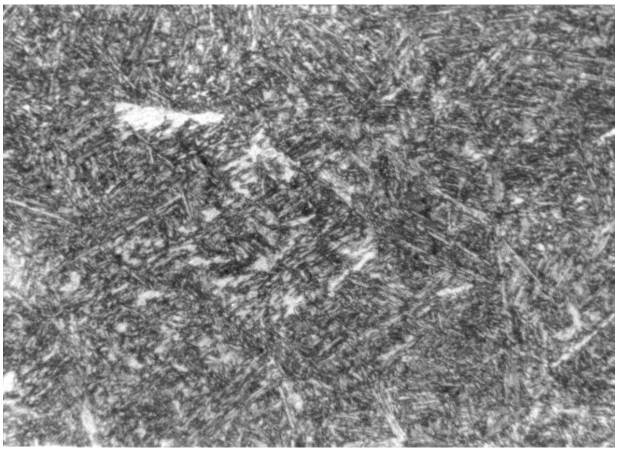

Figure 2. Microstructure of coating FOX DUR 350; 500 ×

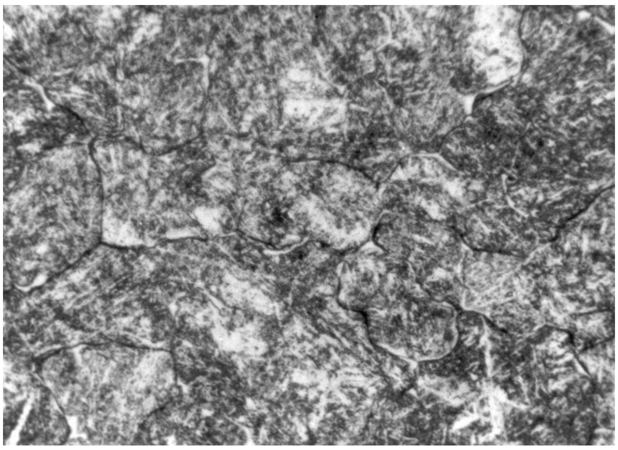

Figure 3. Microstructure of coating EH 550; 500 ×

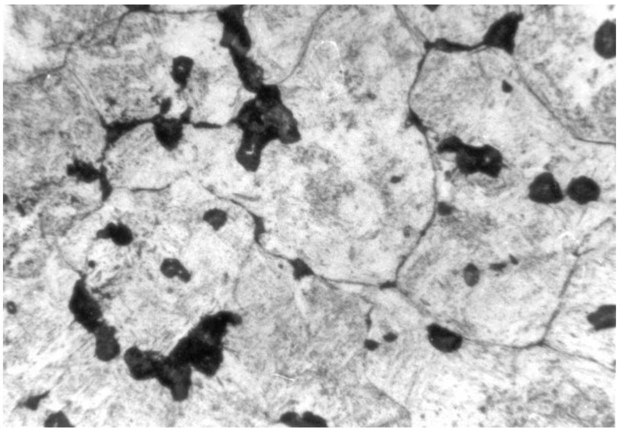

Figure 4. Microstructure of coating LNM 420; 500 ×

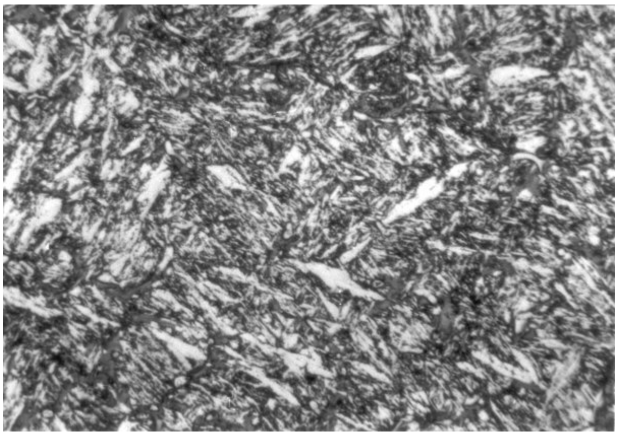

Figure 5. Microstructure of coating Fluxofil 58; 500 ×

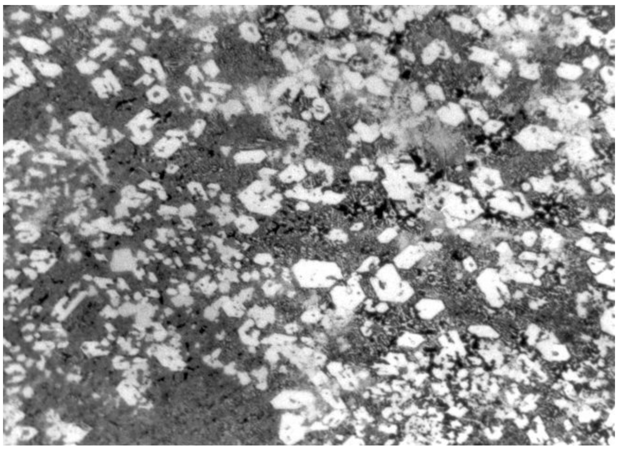

Figure 6. Microstructure of coating Wearshield 70; 500 ×

3. PROCEDURE AND DEVICE

Figure 7 shows the pin-on-cylinder device used for the study of abrasive wear under the periodically varying load.

The studied specimen 3 (the pin) is in contact through its front surface with the abrasive surface 5 of the counter-body – the horizontal cylinder 2. Specimen 3 has contact area diameter Ø 17 mm and is fixed in the holder of the loading block 4 though elastic connection allowing self-regulation of the specimen to the surface 5 providing possibility for rotation around its own vertical axis. This guaranties subsequent homogeneous wear of the whole apparent area of the specimen.

Table 2. Description of the microstructure and the microhardness

Coating	Microstructure	Microhardness [kg/mm^2]
FOX DUR 350	Bainite	393
EH 550	Martensite and Cr carbides	888
LNM 420	Martensite and Cr carbides in the compound of perlite shaped structure	660
Fluxofil 58	Martensite	658
Wearshield 70	Big primary complex carbides and eutecticum	Eutecticum: 745 Carbides: 1380

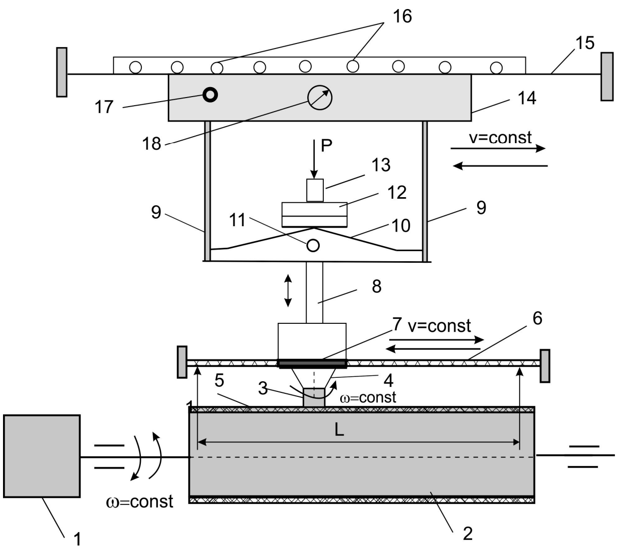

Figure 7. Functional scheme of the device for the study of abrasive wear under the vertical vibrations in the pin-on-cylinder device

The designations in Figure 7 are, as follows: 1 – motor; 2 – cylinder; 3 – coated specimen; 4 – loading block; 5 – abrasive surface; 6 – static rack bar; 7 – gear ring; 8 – specimen fastening mechanism; 9 – vibrating frame; 10,11 – fixing mechanism; 12,13 – loading weights and loading mechanism; 14 – vibrator; 15 –

vibrator supporting structure; 16 – vibrator driving mechanism; 17 – ON/OFF button of the vibrator; 18 – regulator of vibrations parameters.

The loading block 4 engages the static rack bar 6 through the horizontal gear ring 7. Being parallel to the cylinder 2, the rack provides relative translation of the specimen on the generant of the cylinder 2.

The specimen 3 is fastened through the appliance 8 to the vibration frame 9, which provides vibrations from the vibrator 14 along the axis of the specimen. The normal central load P along the axis of the specimen is given through selection of appropriate weights 12 in the loading mechanism 13.

The vibrator 14 is mounted on the carrying structure 15, executing translational movement simultaneously with the vibration frame 8, the loading block 4 and the specimen 3 on the generant of the cylinder 2.

The surface with the fixed abrasive is modelled with impregnated corundum with given hardness and grain size and is fastened on the surface of the cylinder 2.

The cylinder 2 rotates with constant angular speed around its horizontal axis. The motion of the specimen 3 is plane motion: the apparent contact area translates on the generant of the cylinder and at the same time rotates around the vertical axis passing through its center. In a given moment of time, the points of the contact zone have various in value and direction velocities; however, in the process of contact interaction they change position periodically against the abrasive surface of cylinder 2. This fact determines the homogeneous distribution of wear in all points of the contact area, which is the basic advantage of the device.

Another advantage of the device is the aspect that the specimen comes always in contact with fresh abrasive surface, where there is almost no wear debris. On one hand, this is the result of specimen's motion on helical line against the surface, and, on the other hand, the abrasive surface 5 is cleaned from the fine wear products by means of a vacuum pump. The stability of motion is provided by the constant ratio between the angular velocities of the drum and the specimen. The revolution direction of the cylinder, by switching on/off of the device is obtained by the control block. Switch-on of the vibrator 14 is given by the button 17, and the vertical vibration speed – by the regulator 18.

Vibration parameters: vibration displacement [mm], vibration speed [mm/s] and vibration acceleration [mm/s^2] are measured by the vibration meter PCR-VT 204 (Fig. 8a). The Table 3 shows the values of the speed in three axes: vertical vibration – w_z, vibration along the sliding way – w_y and the crosswise vibration – w_x along the x axis for every indication of the regulator 18 (Fig. 8b).

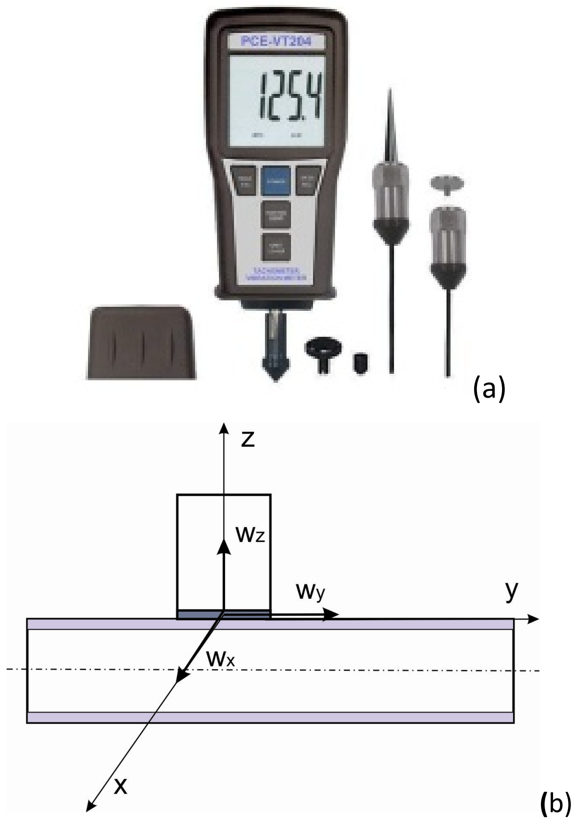

Figure 8. PCE-VT 204 vibration meter for the vibration parameters measurement

Table 3. Values of vibration speed components

Reference measures of the regulator	1	5	7	9	10
w_z [mm/s]	3	6	9	16	20
w_x [mm/s]	0.2	0.35	0.8	3.8	5
w_y [mm/s]	0.4	0.6	0.9	3.8	4.4
w [mm/s]	3	6.04	9.08	16.87	21.08

The vibration regulator 18 (Fig. 7) allows the setting of various values of the vibration speed in the interval 3 ≤ w_z ≤ 20 mm/s. The interval is selected in accordance with the requirements for assessment and classification of machines and equipment in ISO 2372 and VDI 2056. The machines and equipment are classified in 4 groups: К, M, G and T. The table shows data from the accepted normal and admissible limits of the values of the vibration speed.

The procedure of study consists in measurement of mass wear at different values of the vibration speed w_z given to the regulator 18 of the vibrator 14, for various constant values of the contact pressure, sliding velocity and type of abrasive surface.

The following characteristics are calculated based on the measured mass wear *m*:

- Wear rate:

$$\gamma = m / t \tag{1}$$

- Wear intensity:

$$i = m / A_a . \rho . L \tag{2}$$

- Wear-resistance:

$$I = \frac{1}{i} = \frac{A_a . \rho . L}{m} \tag{3}$$

where: *t* is the friction duration; A_a is the apparent contact area; *ρ* is the coating density; *L* is the friction path. The experimental study parameters are given in Table 4.

- The relative wear-resistance *δ* is the ratio between the coating wear-resistance in the presence of vibration I_w and the coating wear-resistance I_o without vibration under equal friction conditions.

$$\delta = I_w / I_o . \tag{4}$$

4. EXPERIMENTAL RESULTS

By means of the above described procedure and device, experimental results about the wear characteristics are obtained at various vibration values for the studied cladded coatings.

Table 4. Parameters of the experiment

Parameter	Value
Normal load	P = 3.92 N
Apparent area of contact	A_a = 2.27 · 10^{-4} m^2
Apparent contact pressure	p_a = 0.173 Pa
Friction path	L = 24.49 m
Sliding duration	t = 1.3 min
Sliding velocity	V = 0.31 m/min

Figure 9 shows graphically the relationship between mass wear and the value of the vertical vibration w_z, and Figure 10 shows the relationship between the vertical w_z, the horizontal w_y and the crosswise w_x vibration speed components.

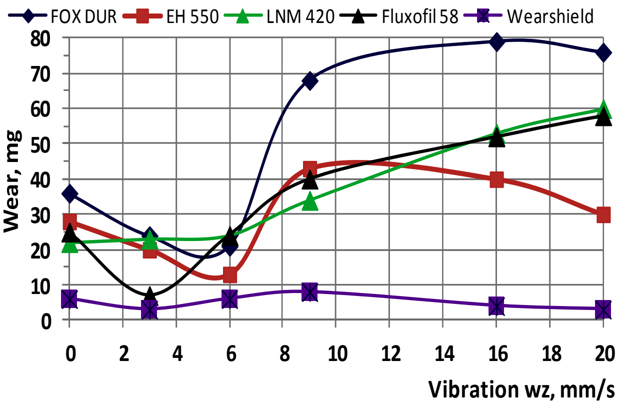

Figure 9. Wear vs. vertical vibration speed component w_z

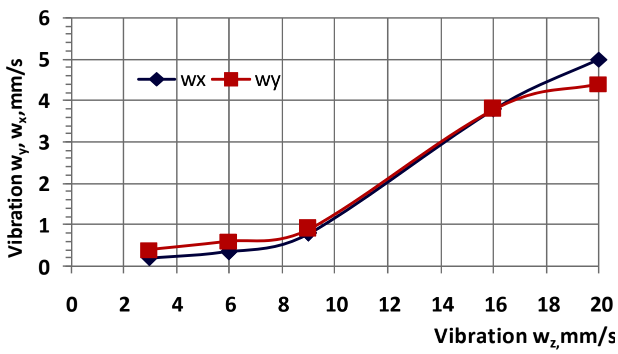

Figure 10. Relationship between vibration speed components w_z, w_x and w_y

5. DISCUSSION

The relationships between wear and vibration speed exhibit equivoque nonlinear character (Fig. 9). Three sections similar for all studied coatings are observed in the curves "wear-vibration speed".

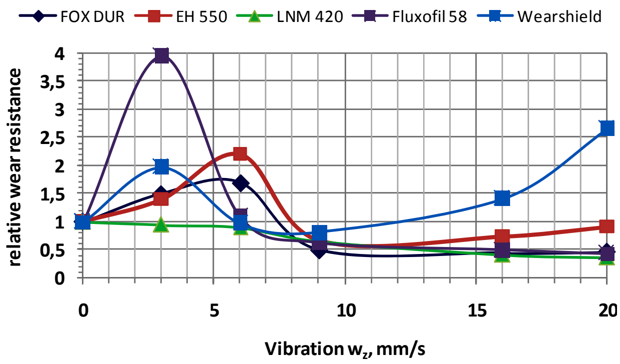

Figure 11. Relative wear-resistance vs. vertical vibration speed component w_z

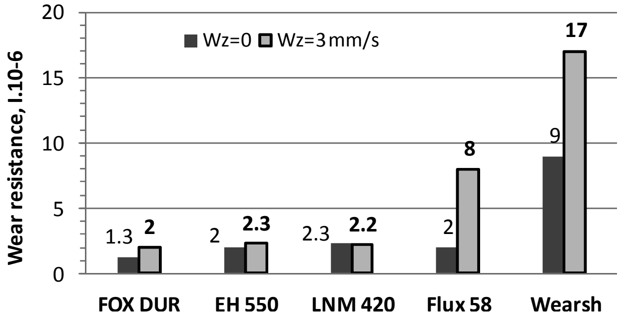

Figure 12. Diagram of coatings wear-resistance without and with vibration w_z = 3 mm/s

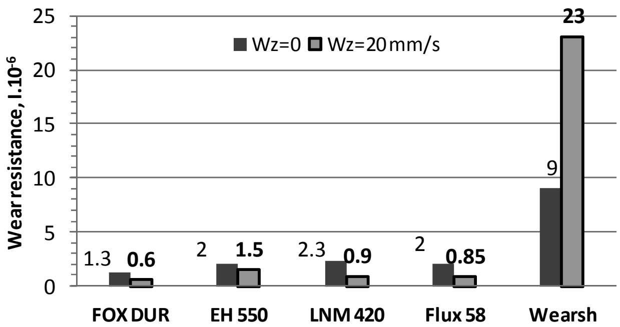

Figure 13. Diagram of coatings wear-resistance without and with vibration w_z = 20 mm/s

In the interval $0 < w_z \leq 6$ mm/s the wear decreases compared with that in the case of friction without vibration. The minimum values are attained at different vibration speed for the different coatings. For FOX DUR, EH 550 and LNM 420 coatings minimum of wear is observed at $w_z = 6$ mm/s, while for Fluxofil 58 and Wearshield 70 the minimum wear is at w_z = 3 mm/s.

In the interval $6 < w_z \leq 10$ mm/s the wear increase is almost exponential for all coatings and attains higher values than the wear in the case without vibrations. The wear rate is different for the different coatings, the highest value being for FOX DUR and EH 550 coatings.

In the interval $10 < w_z \leq 20$ mm/s the relationships show various characters: the wear increases gradually and almost linearly for FOX DUR, LNM 420 and Fluxofil 58 coatings, while for EH 550 it decreases at the higher values of the vibration speed.

The decease of wear at low vibration speeds, up to 6 mm/s, is due to decrease of the real contact area, respectively to increase of the real contact pressure and the corresponding strengthening of roughness tips causing increase in their micro-hardness and a corresponding increase of their resistance to wear.

The quick wear increase in the interval $6 < w_z \leq 10$ mm/s of vibration speeds results from the intensifying of fatigue destruction processes. The two other components w_x and w_y of the vibration speed also increase 1.5 – 2 times in this interval. Important influence in this case has the tangential component (direction along the sliding way) of the vibration speed (Fig. 10).

The gradual wear increase in the third section $10 < w_z \leq 20$ mm/s could be explained by a hypothesis of the domination of two possible factors: strengthening of the upper layer of the coating and/or demonstration of damping properties of some of the phases of the modified micro-structure during the process of contact interaction. Validation of this hypothesis requires additional studies of the micro-structure and micro-hardness of the coatings after wearing.

The variation of wear of the Wearshield 70 coating significantly differs from the other coatings. Similar wavy line of wear vs. vibration speed curves is observed, however with several times lower values. The wear-resistance in the presence of vibration speed 20 mm/s increases 2.7 times compared with the case without vibration, which is in correspondence with the higher micro-hardness of the carbide phases in its micro-structure (Fig. 13, Table 2).

6. CONCLUSION

The presented paper considers an original device for study of wear under the impact of normal vibrations under conditions of dry friction on surfaces with fixed abrasive particles.

Relationships are obtained for the dependence between mass wear and vibration speed for five type cladded arc coatings: FOX DUR, EH 550, LNM 420, Fluxofil 58 and Wearshield 70 under equal friction conditions. The relationships show nonlinear character with clear minimum of wear for all studied coatings.

Three sections in the curves of wear versus vibration speed are established for all studied coatings: section of wear decrease at vibration speed $0 < w_z \leq 6$ mm/s, section of exponential wear increase at $6 < w_z \leq 10$ mm/s and section of proportional wear increase at $10 < w_z \leq 20$ mm/s.

Maximal wear-resistance under conditions of vibration-abrasive wear shows Wearshield 70 coating. This maximum attains about 2.7 times higher value at vibration speed 20 mm/s compared with that in the case without vibration.

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