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EXPERIMENTAL STUDIES OF ELECTRODE COATING THICKNESS VARIATION AT PRESSING[*]

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Oscillographic and mathematical statistics methods were applied to study the regularities of formation of coating thickness variation in experimental electrodes UONI 13/55 with 4 mm rod diameter at their manufacture in angle hydraulic press under the conditions maximum close to production ones. It is found that coating thickness variation is a continuous, multistage, nonmonotonic (wavelike) and harmonic process, in which disturbances, arising at the starting stage, can be felt in subsequent stages of electrode pressing. Coating thickness variation is caused, primarily, by violation of elasticity and viscosity balance, on which the consistency of electrode coating masses depends. At the same time the probability of appearance of coating thickness variations is essentially influenced by the features of forming path of electrode coating press. 15 Ref., 7 Figures.

Keywords: *arc welding, coated electrodes, pressing, coating thickness variation, oscillography, mathematical statistics*

Viscoelasticity of electrode coating masses should be considered as the main cause for coating thickness variation. In terms of weld quality this is the most dangerous defect, arising, primarily, from quick discharge of elastic stresses, accumulated by coating mass during its application on the rods [1–5]. A lot of the suggested causes for coating thickness variation, the most often discussed in publications earlier, for instance [1, 6, 7], are not always the main ones. Nonetheless, many of them can, to a certain extent, facilitate appearance of coating thickness variation, caused by the above-mentioned elastic turbulence of coating masses.

Another important cause to be considered is the natural tendency of coating mass to find a coating shell cross-sectional configuration during interaction with the elastic rod in the press chamber, which would minimize energy consumption for flowing. It, apparently, proceeds by hydrodynamic, i.e. more complex mechanism, than does the traditional (as, for instance, in [1]), schematic of elastic deformation of the rod overhanging part under the impact of the coating mass, pumped into the press chamber. Otherwise, it would be difficult to explain why coating thickness variation arises in manufacture of electrodes in continuous-flow presses.

In the most unfavourable cases accumulation and discharge of elastic stresses proceed continuously, run very quickly and unpredictably. Coating thickness changes just as quickly. Application of its examination methods of equivalent speed should help understand this stochastic process. Such methods include oscillography, combined with mathematical statistics treatment of the recorded results.

Oscillographic studies of thickness variation were started at PWI long ago [8]. However, many of the obtained results could be analyzed and explained in terms of excess of elasticity over viscosity only now, when viscoelastic nature of coating masses can be regarded as quite well established by rheological studies [2–5].

Object and methods of investigation. Investigations were performed at manufacture of experimental electrodes UONI 13/55 with participation of personnel of PWI Experimental Production in commercial equipment with which it is fitted.

Material composition of electrode coating charge (wt.%) was as follows: marble — 51.5; fluorite concentrate — 19; quartz sand — 6; medium-carbon ferromanganese — 6.5; ferrosilicium FC-45 — 7; ferrotitanium — 7; mica-muscovite — 3; and purified Na-CMC —1 (above 100).

In preparation of equipment, and optimizing the electrode manufacturing process, procedure of thickness variation oscillography, oscillogram digitizing and statistical treatment of results, the following fractional composition of the mixture was used, ex-

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pressed as the total weight balance on 0315, 02, 016, 01 and 0063 grids to GOST 6613-86: 2, 10, 15, 25 and 35 wt.%, respectively. 65 % passed through 0063 mesh. Coating mass was prepared using NaK liquid glass with 3.05 module, 1.435 g.cm^{-3} density and 900 mPa·s viscosity, glass dose was 30 wt.%.

Dry mixture for the charge was prepared in cylindrical plough mixer of intensive type, and coating mass was prepared in single-roller mixer.

Electrodes were produced in hydraulic electrode coating press of Havelock Engineering Company with angular feed of coating mass (90°). Electrode rod diameter was 4 mm, coating thickness was 1.1–1.2 mm. Pressing speed was 420 electrodes per minute.

Wire and coating materials met the requirements of respective GOSTs, and allowances for deviations of forming tool dimensions complied with the requirements of acting normative documentation. Dies, rod guide tips and rod feeding rollers were not used for any other purpose, except for experiments performed in this work.

Coating mass flow, preliminarily turned along the rod guide, is reduced three times in Havelock Engineering press:

- in two-channel slot mass feeder, fixing the rod guide;
- in press chamber, located between the edge of rod guide tip and calibration sleeve cone;
- in calibration sleeve channel.

Turning of mass flow and each of its above-mentioned reductions are performed in transition flow regime, so that they are sources of hydrodynamic disturbances in it. Average gradient of shear rate, which determines the resistance, overcome by the mass during reduction, is proportional to jet reduction ratio and is dependent on the characteristic dimension of forming channel. For circular cylindrical channel, as in the calibration sleeve, this is the diameter, and for a flat or annular (slot) channel, as in mass feeder, this is its width. Moreover, acceleration of mass flow in two-channel mass feeder changes two more times, depending on whether the mass consistency allows passing through both parts of slotted channel at once, or just one of them. Standard gap between rod guide tip edge and calibration sleeve is 1.5 mm.

Continuous recording of coating thickness variation during electrode pressing was performed using specialized monitor with electromagnetic transducer block, supplied with Havelock Engineering Company press. Together with the calibration sleeve, the block is fastened on base seat, envisaged for this purpose in the press. Calibration sleeve position, also during travel, is adjusted by four bolts with the known thread pitch. Figure 1 gives the general view of the instrument in the working position [9].

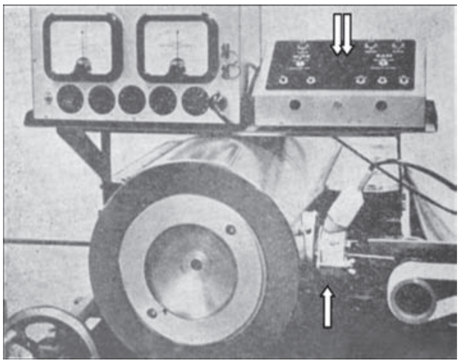

Figure 1. Head-sensor for measuring coating thickness variation in Havelock Engineering press (marked by an arrow)

Electromagnetic signals, proportional to horizontal and vertical coordinate components of electrode coating thickness variation vector (CC CTVV) formed in the monitor electronic block, are read from scales of two control pointer instruments in standard configuration. Actual state of thickness variation is determined by pointer deviation from zero. We used loop oscillograph 8SO-4 for continuous recording of these deviations. Recording was performed on aerial film, 120 mm wide, with sensitivity of 1200 units to GOST 100691–63. The film develops very quickly in the light. Recording speed was selected during preliminary experiments and was equal to 10 mm/s. Data recorded on the film were digitized during its subsequent processing, and coordinates of points separated from each other by a distance of 5–6 mm on the curves were determined.

Coating mass was prepared in the quantity of 50 or 100 kg (batch), briquetted and divided into three press charges, each of not more than two briquettes. During pressing out of the first charge, adjustment of coating mass and rod feeding to avoid the relative misalignment of the axes of calibration sleeve and the rods, and of loopback beam position was performed, as well as tuning of film recording. During pressing out of the second charge the main records of 50 to 360 s duration were made. The last charge was used as the reference one, and if required, the briquettes were soaked for up to one hour to check the «viability» of coating mixture. They were stored under the conditions, traditionally used in production to prevent moisture loss.

During pressing one electrode was selected every 7–10 s. They were instantly controlled in a portable concentrometer (shown in Figure 1 by a double arrow). Results were immediately recorded on film (casual inspection). At the end of the charge, single samples were taken in the quantity of not less than 10 electrodes, which were marked, and then controlled, and the results were statistically generalized in the laboratory (group control).

Results of casual and group control were used to correct the settings of the press and oscilloscope, in order to precise the position of zero lines (X_0, Y_0) on the film, designed for counting of CTVV horizontal (x_i) and vertical (y_i) components. Shifting of x_i up or down from zero meant thickening of coating shell right or left half. Similar shifting of y_i was indicative of thickening of its upper or lower parts.

Values of x_i and y_i were used to calculate individual values of coating thickness variation vector ($\mathbf{e}_i$) and angle of its orientation in the section, normal to electrode axis ($\mathrm{tg}\alpha_i = x_i/y_i$), then $\mathbf{e}_i$ map was plotted in comparison with the lines of mean ($\mathbf{e}_{im}$) and boundary values, specified by GOST 9466–75.

Values and angle of orientation of $\mathbf{e}_i$ are random quantities. The need for application of statistical methods for their assessment and presentation became clear already during preliminary experiments. With this purpose, individual $\mathbf{e}_i$ values found from 100 measurements, were grouped into conditional samples, each of five $\mathbf{e}_i$ values. Sample number was 20 pcs. Sample average ($\mathbf{e}_{av}$), standard deviations (s_r) and ranges (R), as well as their general average of 20 samples (E_{av}, S_r and R_{av}) were calculated. Presented graphically, these data more accurately reflect the variability of the processes and their tendencies, than do individual indexes [10].

Nature of CC CTVV oscillograms. Curves of CCTV horizontal and vertical components, similar to extrusion curves of coating masses, obtained in capillary plastometer OB 1435 [3], reflect the starting, structural, steady-state and final stages of pressing.

In the majority of experiments, recording was begun not right after starting the rod-feeder machine. Therefore, in short oscillograms, which reflect the pressing process during 15–35 s, the starting stage is not recorded, as a rule. Sometimes, the film captured only the final part of its structural (downward) branch, going into, so to speak, steady-state branch. As follows from Figure 2, in coating mass, used by us for procedure optimization, the starting portion of CC CTVV oscillograms has a clearly pronounced oscillating form. Here, for vertical component this is an almost ideal sinusoid with mild extremality of center line, gradually attenuating and eventually taking the shape of irregular oscillations, while the horizontal one is like that from the very start. The disturbances recorded on vertical component oscillogram, as beam shifting upwards or downwards from the loop, are almost synchronously reflected on the oscillogram of horizontal deflections as the respective beam shifting to the right-left (marked by arrows in Figure 2). This is attributable to relatively elastic consistency of the studied coating mass, and configuration of the forming zone of the used press, in particular, vertical location of two mass-feeding slots, which enables the viscoelastic coating mass periodically changing the flow path, jumping from the upper window into the lower one, and vice versa. Horizontal component further reflects the consequences of hydrodynamic disturbances, arising even before the coating mass has passed through mass-feeder slots, which are caused by flow turning by 90°. Cycles, associated with alternative passing of coating mass through the above-mentioned two slot channels of mass-feeder, are superimposed on them.

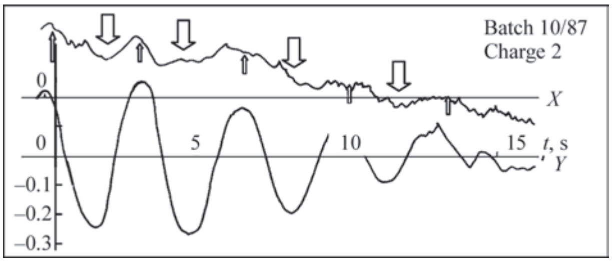

Figure 2. CC CTVV oscillograms obtained during pressing of UONI 13/55 electrodes (X — horizontal, Y — vertical components; arrows show responses of vertical component to a change of horizontal component)

The extent of sinusoidal portion of vertical oscillogram depends on the change of coating mass consistency, caused by briquette soaking before use. This stage could not be recorded for the first, freshest charge, because of prolonged setting-up of the press (just a stationary portion of 45 s duration was obtained). Duration of sinusoidal portion in the second charge was equal to 15 s, and that of the third one, which had been soaked longer than the other ones before application, was two times longer.

Results of calculation of attenuation in sinusoidal amplitudes, recorded at pressing electrodes from the second and third charges of coating mass, are given in Figure 3. It is seen that despite the relatively short soaking of coating mass in the briquette state, its relaxation period increased 3 times. Coating mass consistency changed, because of structure formation processes, which had occurred in it during this time.

We established the following general regularities of changing of the shape of CC CTVV curves, depending on consistency of coating masses for low-hydrogen electrodes during their manufacture in Havelock Engineering press. For highly elastic masses, both the oscillograms $x_i = f(t)$ and $y_i = f(t)$ at the starting stage of pressing have the form of sinusoids, although not always as ideal in shape, as in Figure 2. Further on they gradually degrade into oscillating curves of an irregular shape, and for $x_i = f(t)$ oscillograms this often occurs earlier than for $y_i = f(t)$.

For coating masses close in their consistency to the one presented in this work, only $y_i = f(t)$ oscillogram is sinusoidal, and that only at the start of pressing. For even softer coating masses $y_i = f(t)$ almost merges with zero line, while $x_i = f(t)$ curve preserves its irreg-

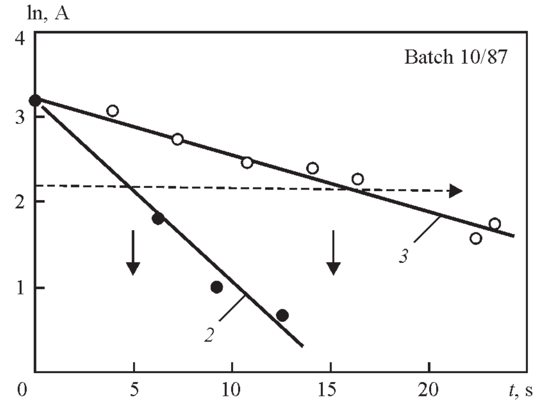

Figure 3. Comparison of oscillation amplitudes of vertical component of coating thickness variation vector during starting stage of pressing electrodes from second (*2*) and third (*3*) charge of coating mass

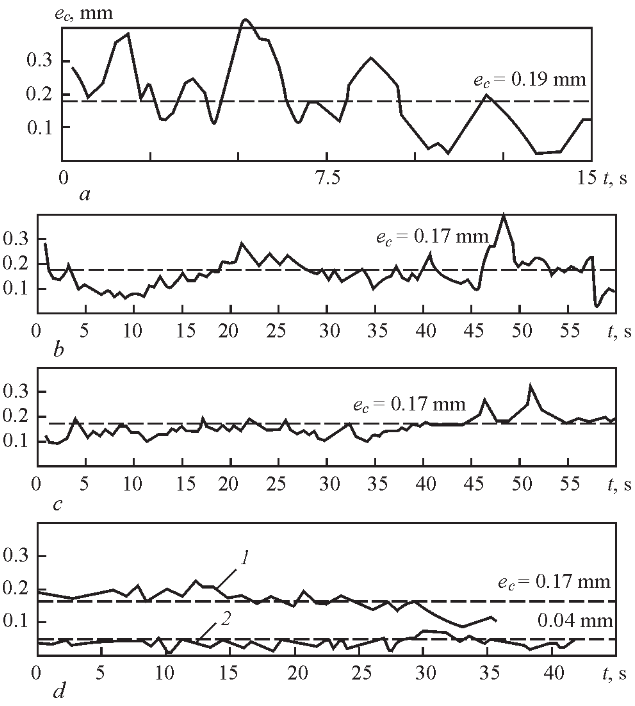

Figure 4. Evolution of CTVV of electrodes made during pressing of coating mass second charge: starting (*a*), stationary (*b*, *c*) and final (*d*) stage from first (*1*) and second (*2*) coating mass charge; e_i, $e_{i\,av}$ — individual and sample average values of coating thickness variation

ular shape longer. For fluid-like masses both the oscillograms have the shape of low-amplitude sinusoids from the very start.

Curves of evolution of coating thickness variation vector. Evolution of individual values of the vector of coating thickness variation is given in Figure 4. At the starting stage, it looks like not as perfect a sinusoid, as CTVV vertical component. Alongside that, one or two weak amplitudes are wedged between high amplitudes in some places. Both gradually attenuate (similar to CC CTVV sinusoids) that is indicative of relaxation nature of the process they reflect. Then they evolve into a kind of harmonic functional dependence with more than two variables. So far four harmonics could be singled out with oscillation frequency from 1 up to 0.04 s^{-1}.

CTVV changes in the pulsed mode not only by value, but also by its orientation in space. This can be judged by observing the changes of CTVV «trace», as $\mathbf{e}_i$ projection on a plane, normal to electrodes coming out of the press head. Figure 5 shows the form of this kind of phase trajectories obtained during the starting stage of electrode pressing. Initial point of each sample is marked with a cross, the final one — with an arrow. The first two samples consist of 20, and the third one — of 10 electrodes.

As we can see, pulsing amplitude by y_i (particularly, its positive part) decreases simultaneously with less noticeable decrease of x_i. This results in overall compression of x_i and y_i and, therefore, its gradual shifting to zero area takes places simultaneously with decrease of $\mathbf{e}_i$ value.

Further variations of $\mathbf{e}_i$ value and orientation were assessed by the following ten samples of electrodes,

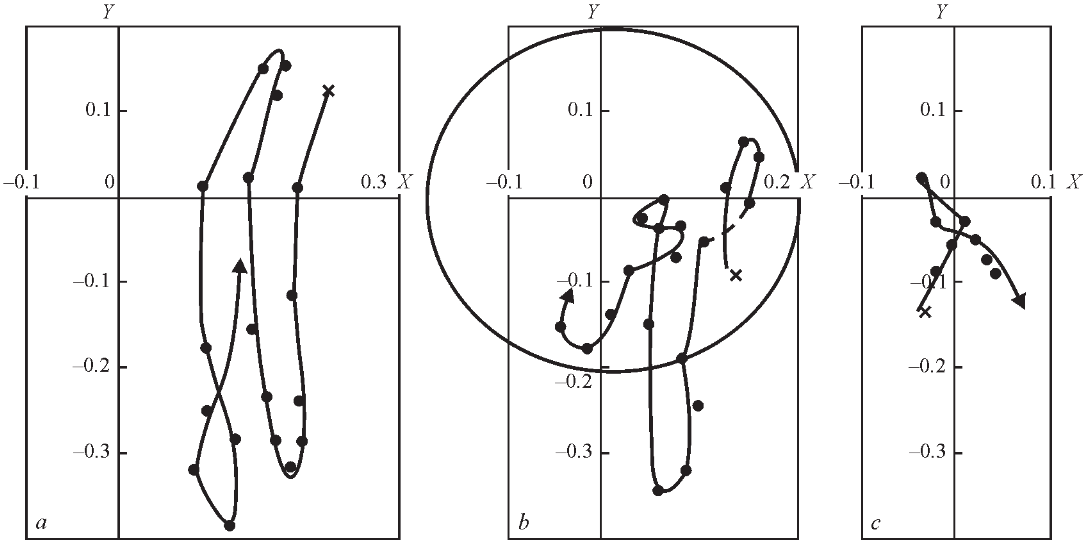

Figure 5. Appearance of phase trajectories of coating thickness variation vector during starting stage of electrode pressing. Numbers of coating thickness measurements, included into samples: *a* —1–20; *b* —21–40; *c* —41–50

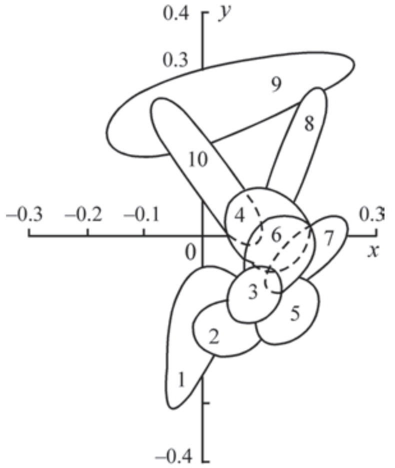

Figure 6. Nature of change of characteristics of coating thickness variation in electrodes pressed from coating mass of charge 2. Figures mark number of the sample, each of 10 electrodes selected from the stationary stage. They are shown in Figure 6 in the form of lobes, including 10 individual x_i and y_i values from each sample.

Together with Figure 4, it shows that in terms of CTVV evolution, this stage can only be called stationary with great reserve. Vector of coating thickness variation for electrodes pressed during this stage, first decreases, and then abruptly increases, while dislocation changes by pulsing spiral, in the form of successive rotational transitions from III to IV, I, II and then again to IV quadrant. It occurs nonmonotonically within each sample, as well as at transition from sample to sample, with different rate within just 60 seconds. Considering that 420 electrodes came out of the press head every minute, the rate of these changes is indeed huge, and it cannot be explained in terms of just variation of coating mass viscosity, as many have attempted to do up to now. For this purpose it is necessary to take into account in a timely manner the variation of relevant coating mass elasticity characteristic.

Evolution of statistical selective CTVV characteristics. Figure 7 reflects variations of sample averages and ranges of coating thickness variation during the «stationary» stage, compared to average sample values for each group, namely initial, middle and final. They more clearly reflect the general evolution of coating thickness variation, than does $\mathbf{e}_i$. Consequences of the process starting stage are quite evident in electrodes of initial group (*a*). Decrease of $\mathbf{e}_i$, occurring at the end of the starting stage, was followed by two spikes, separated by a short period of stabilization. On the whole, average sample values of thickness variation rise, and this increase is continued in the new series of samples (*b*), also in a wakelike, even though somewhat quieter manner. Signs of this characteristic decreasing appeared only at the final (*c*) stage, but, probably, only as the next descending branch of the wave. Constancy of general average value E_{av} on the level of 0.17 mm is an indirect confirmation of it.

Nonetheless, the process gradually calms down that is indicated by the reflected in Figure 7 decrease of oscillations and general sample average values of ranges (R_{av} = 0.090 mm in the initial and 0.025 mm in the final series of samples).

We do not give sample standard deviations of $\mathbf{e}_i$, although we also calculated them alongside the ranges, and took them into account in analysis of obtained results. The nature of their variation is similar to that of the ranges. Absolute values, however, are 2 to 3 times lower. If there is the need to assess the share of hidden rejects by $\mathbf{e}_i$, s_r value must be taken into account [10].

Constancy of E_{av} in the above analyzed samples of electrodes from charge 2 should not be regarded as an indication of the possibility of their value decreasing further. Results obtained when studying the electrodes of the first charge, given in Figure 4, *d* for comparison show that in this case, E_{av} eventually dropped to values of 0.04 mm (in charge 2), compared to 0.17 mm. The difference can also be to some extent linked to the change of coating thickness consistency during its soaking in briquettes.

Discussion of results. Presented investigation results show that unstable flow of coating mass is the main cause for coating thickness variation. Instabilities in the pressure flow usually arise when elasticity accumulated during coating mass deformation exceeds the level, which can be damped by its viscosity before it comes into contact with the rod in the press chamber. Coating thickness variation is exactly one of undesirable kinds of rapid discharge of excess elasticity during formation of coating shell on the rod. The other kind is discussed below.

Accumulation and relaxation of elastic stresses in the pressure flow of coating mass, from which electrode coating is formed in the press head, should be regarded as a continuous process, which starts at the moment, when coating mass flow begins, and which can go on until mass charge has been used completely. Results of conducted studies show that this is:

- on the whole, a relaxation process, in which statistical average value and scattering indices of thickness variation gradually decrease, i.e. overall balance of viscosity and elasticity improves, primarily, due to elastic stress relaxation;
- multistage process, characterized by elasticity and viscosity levels and ratios, which are different at different stages;
- «hereditary» process, in which disturbances, arising in its previous stages, are felt at its subsequent stages, including both the starting and final stages in the most unfavourable case;
- nonmonotonic and, most probably, wavelike process, during which the thickness variation, decreasing

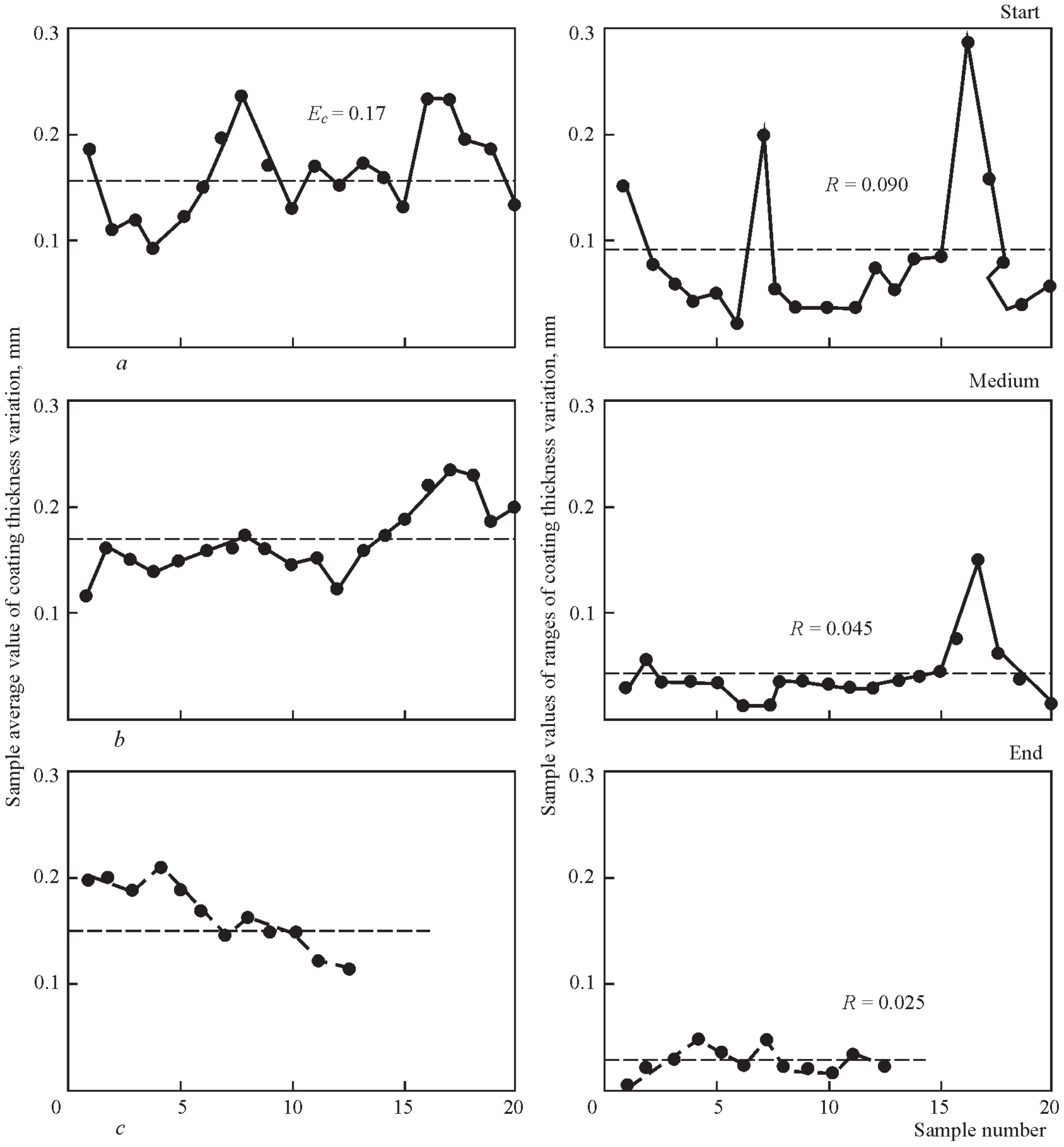

Figure 7. Measurement of CTVV statistical characteristics during electrode pressing from coating mass in charge 2 (for *a*–*c* see the text)

with time, increases again, having reached the next minimum, up to the previous or somewhat lower level;

- harmonic process, as short cycles with lower pulsing amplitudes run within the long cycle.

The main sources of elasticity are the starting deformation of coating mass, which is caused by its volumetric compression, on the one hand, and turning of coating mass flow through 90 degrees, on the other hand, significantly accelerating the layers in its outer contour. The action of the first source starts, when the piston is brought from the travel to working speed. Relaxing, they continue acting after switching on the rod-feeding machine and stop after complete relaxation of starting elasticity. The second source is, probably, active during the entire pressing cycle.

Elastic stresses, arising during this period, relax in different ways and with different speed in mass feeder channels, press chamber and calibration sleeve. Being superposed on each other, they are manifested as harmonics on the curve of evolution of thickness variation characteristic. Owing to reduction of coating mass flow, additional elastic energy is generated in each of them. Its relaxation occurs at subsequent stages of flow formation.

In this complicated pattern of origin and relaxation of elastic stresses, provoking thickness variation, the actual causes of nonmonotonic evolution of its values during electrode pressing need to be clarified. For this purpose, the known postulates of hydrodynamics of a Newtonian fluid flowing through an annular channel formed by two stationary non-concentric tubes should be précised, allowing for viscoelastic nature of electrode coating masses. Alongside that, instead of a stationary inner tube, an elastic rod should be considered, which is also prone to reversible deformations, is moving in synchronism with the shell, and which has a certain degree of freedom of the transverse displacements, while being inside the shell.

In keeping with hydrodynamic theory of fluid flow, volumetric rate of fluid flow through a circular tube with inner core of a round cross-section depends on axial displacement of the core relative to the outer tube.

In the case of their concentric position, the fluid in the annular gap flows, while enveloping the core by a layer with symmetric velocity profile. The more is the core shifted from the concentric position, the higher the volumetric rate (flow rate) of the fluid over the wide section of the gap, despite the fact that the size of overall cross-section, through which the fluid flows, remains unchanged [11, 12].

This conclusion is valid for pressure flows of Newtonian simple and complex fluids, as well as for viscoplastic materials, such as Bingham body. It, in principle, is independent on whether the coating and rod non-axiality is caused by careless pre-setting of press chamber elements, or whether it arises as a natural shifting of elastic rod due to coating mass elasticity. In either case increase of the degree of non-axiality leads to increase of the statistical scatter index of thickness variation. Thus, the tendency of coating mass circular flow to disturb the coaxial position of calibration sleeve with the rod should be regarded as a quite natural phenomenon. This conclusion does not lose its significance also for electrode coating masses, which are not fluids by their rheological properties and which move in synchronism with the rod, and not as an axially stationary core, as was considered above.

Our studies of rheological properties of electrode coating masses show that there are a number of reasons, why the «coating mass-rod» system, brought out of the concentric state, usually does not preserve its maximum thickness variation, at which the most favourable energy conditions for its pressure flow are achieved. The system comes out of this state with a certain periodicity, gradually approaching the stationary state. First of all, it should be taken into account that increase of volumetric rate of coating mass flow, caused by violation of sleeve and rod coaxiality, is accompanied by increase of the shear rate gradient $\dot{\gamma}$ in the mode of $\dot{\gamma}$ = const, in which its greatest dissipative heating occurs [13].

Both factors decrease shear viscosity of coating mass η, and, to a much greater extent, ξ — first difference coefficient of normal stresses. It characterizes the rate of coating mass elasticity decrease under the impact of increasing shear rate gradient [5]. Thus, with $\dot{\gamma}$ increase, caused by increase in thickness variation, the coating mass ability to dampen its elastic characteristics should be also enhanced, i.e. the probability of further increase of coating thickness variation decreases with time. As a result, every time the period of $\mathbf{e}_i$ increase is followed by its decrease, «rod-coating» system is discharged from elastic stresses, and gradually reaches the next minimum of thickness variation.

This is followed by beginning of its new cycle, as $\dot{\gamma}$ and T reached here will promote accumulation of elastic stresses.

It should not be overlooked that elastic stresses in pressure flow can relax not only in transverse (x_i and y_i) directions, but also along the moving electrode (z_i direction) with consequences which are not recorded by oscillographic method, accepted by us. They can be assessed indirectly. Imagine an electrode in the form of a two-layer stratified flow, in which the steel rod is replaced by coating mass, which differs from coating mass in the outer layer by elasticity and viscosity ratio. For example, let us choose marble powder as coating mass filler for the inner layer, and let coating charge be the coating mass filler for the outer layer, and vice versa. Consistency of the compared coating masses is different: plastic strength and extrusion pressure for the first, softer coating mass are P_m = = 0.35 MPa, and P_{extr} = 6.0 MPa, and for the second, tougher one, they are 1.95 and 23.5 MPa, respectively. Let us first imagine that the softer coating mass is inside the two-layer briquette, and the elastic one is outside, axially relative to it. Experiment shows that in the extrusion produced from such a billet the inner layer is torn into cylindrical pieces, brought apart to almost equal distances from each other along the axis by outer layer material. Now, if the softer component is placed outside the two-layer briquette with the elastic one inside it, the extrusion interface remains continuous, but acquires a wavelike shape. In the actual electrode the interface cannot deform like that. However, periodical longitudinal discharge of elastic stresses accumulated during deformation of coating mass, enveloping the steel rod, can be realized as jet restoration [14] by coating shell slipping along the rod surface. This results in violation of adhesion of coating shell with the rod.

The finer the coating mass filler, the higher the strength of baked sample of extrusion from it, but the lower the strength of coating shell from it in baked electrodes [15], particularly, when the coating mass is prepared using high-modulus liquid glass of low viscosity.

Thus, there are grounds to believe that elasticity of coating mass, accumulated in it at electrode pressing, not only causes thickness variation, but may also promote lowering of final coating strength in baked electrode, through weakening of coating adhesion to the rod as a result of elasticity relaxation.

Conclusions

1. Oscillographic and mathematical statistics methods were applied to study the regularities of formation of

coating thickness variation in experimental electrodes UONI 13/55 with 4 mm rod diameter at their manufacture in angle hydraulic press under conditions maximum close to production environment. Values of vertical and horizontal components of thickness variation vector were recorded on aerial film, moving with 10 mm·s^{-1} speed, at pressing speed of 420 electrodes per minute. Duration of observation in the experiment was varied from 30 to 240 s.

2. Results of conducted experiments suggest that coating thickness variation is caused by disbalance of elasticity and viscosity characteristics of coating masses, arising during coating mass application onto rods by extrusion. Elasticity should be regarded as a characteristic provoking appearance of coating thickness variation as a result of instant relaxation of accumulated elastic stresses, and viscosity — as a damping factor, weakening or suppressing the role of elasticity unfavourable from this point of view.

3. Accumulation and relaxation of elastic stresses in pressure flow of coating mass, from which electrode coating is formed in the press head, is a continuous multistage, nonmonotonic (wavelike) and harmonic process. In it, the disturbances, responsible for appearance of thickness variation, which arose in the previous stages, are felt at subsequent pressing stages, including, in the most unfavourable case, even the final stage.

4. Probability of formation of coating thickness variation is determined by coating mass consistency, and depends on design features of forming path of electrode coating press. Proneness to non-symmetrical configuration of the shell from coating mass on the rod is the result of its tendency to provide the most favourable energy conditions for the flow. Degree of rod deviation from the position coaxial relative to the shell depends on the nature of the change of elasticity and viscosity ratio as a result of such a deviation. Under real non-isothermal conditions, the influence of viscous heating of coating mass is superimposed on evolution of this ratio, alongside speed, resulting in evolution becoming more cyclic. Harmonics within each cycle reflect the influence of elasticity generation centers on it, which cause disturbance of stable flow of coating masses (for instance, acceleration, turning, reduction, separation and stratification of the flow). Number and kind of these centers depend on design features of forming head of electrode coating press.

5. Coating thickness variation, on the one hand, subtly responds to changes of coating mass consistency and forming path configuration, and, on the other hand, its value markedly and unpredictably changes by extent and orientation. As a result, process monitoring by this characteristic to improve product quality, can be highly problematic. In terms of coating mass rheology, lowering of coating masses tendency to elasticity accumulation in pressure flow state should become the main direction of their improvement in order to reduce coating thickness variation.

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