Principles of control automation of soil compacting machine operating mechanism

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Abstract. The relevance of the qualitative compaction of soil bases in the erection of embankment and foundations in building and structure construction is given.The quality of the compactible gravel and sandy soils provides the bearing capability and, accordingly, the strength and durability of constructed buildings.It has been established that the compaction quality depends on many external actions, such as surface roughness and soil moisture; granulometry, chemical composition and degree of elasticity of originalfilled soil for compaction.The analysis of technological processes of soil bases compaction of foreign and domestic information sources showed that the solution of such important problem as a continuous monitoring of soil compaction actual degree in the process of machine operation carry out only with the use of modern means of automation. An effective vibrodynamic method of gravel and sand material sealing for the building structure foundations for various applications was justified and suggested.The method of continuous monitoring the soil compaction by measurement of the amplitudes and frequencies of harmonic oscillations on the compactible surface was determined, which allowed to determine the basic elements of facilities of soil compacting machine monitoring system of operating, etc. mechanisms: an accelerometer, a bandpass filter, a vibro-harmonics, an on-board microcontroller. Adjustable parameters have been established to improve the soil compaction degree and the soil compacting machine performance, and the adjustable parameter dependences on the overall indexhave been experimentally determined, which is the soil compaction degree.A structural scheme of automatic control of the soil compacting machine control mechanism and theoperation algorithm has been developed.

1. Introduction
In modern construction, the filled soil compaction is an important part of engineering construction technology: building and structure foundation bases for various applications; hydraulic dams and dikesembankment; roads and railways; main pipeline trenches, etc.

This task is particularly relevant in the context of the rapid development of oil and gas production and transportation in recent years, as the pipeline rupture due to subsidence through the filled soil poor compaction can lead to an environmental disaster [1].

The bearing capability, strength and durability of constructed building structures depend on the quality of compactable gravel and sand base. It is established that up to 60% of damage occurs due to poor compaction of bulk construction materials [2].

Hence, there are prerequisites for control automation of filled soil compaction technological process to compensate for FB with maximum possible continuous output to the engineman's control panel of the objective assessments of the compaction degree quality [3].

The lack of domestic and foreign automatic control and control of the soil compaction degree systems is that they are information (light display) and have no ability to control the working

mechanism (WM) of the soil compacting machine depending on the optimum degree of soil compaction and taking into account external disturbing actionsFB [4, 5].

To solve the problem on implementation of the automatic control system (ACS) of soil compacting machine WM, it is necessary to determinethe compaction method and facilities of objective assessment of the compaction and to develop an algorithm for automatic optimization of the compaction technological process, which provides the signal transformation of the vibroacoustic sensors in the automatic equipment with application of modern computer engineering micro processing means [2].

2. Technique

Studies have shown that the basic and effective way is compaction with vibrodynamic effect of machine WM on the compactible sand and gravelbase surface, as the dynamic methods of soil compaction using vibration machines make up 80% of the total number of the compactible means [3].

A dynamic method of compaction is provided by a combination of static pressure and vibration effect on the soil [6].

When soil compaction, the displacementand convergenceof sand and gravel rigid particles occurs, as well as destruction, deformation and adhesion of brickle and cloggy components, which increases the density and strength of the soil foundation, the displacement of softening and weakening liquids and gases. According to experimental data, the bearing capability of soils due to compaction increases by 40% [1].

In the process of soil compaction under the influence of vibrodynamic loads from (WM),the harmonic oscillations of the soil base surface with a certain amplitude and frequency depending on the compaction degree are formed [7, 8].

Depending on the adjustable parameters, the WM changes in magnitude of soil ultimate deformation R_o, which leads to different values of the harmonic amplitudes A_1 and A_2 and, respectively, of the frequencies S_1 and S_2.

Experimentally obtained oscillograms of harmonic oscillations shows that the harmonics A_0 and A_1practically does not change depending on the machine passnumber, but they are much subject to change theharmonic of amplitude A_2, associated with the soil compaction degree. If to determine the amplitude level ofharmonics A_1 and A_2, then with high confidence we can get the main indicator, which is the current value of the soil compaction degree–ρ_ϕ.

Uncompactable soil has the smallest deformation modulus, which characterizes the soil elasticity degree and therefore the harmonics of vibrational oscillations have a very weak signal. With increase the compaction degree, soil becomes more "hard" and the harmonic of oscillations A_1 and A_2 appears.

Automatic analyzer selects the actual frequency from the input signal that has a harmonic frequency spectrum– the first harmonic and the second harmonic of the same frequency.After detection of these signals, the ratio of second harmonic to the first harmonic is calculated; this characterizes the compaction degree depending on the machine pass number.

Sinusoidal input signal is determined using the following formula:

$$A(K) = \frac{1}{N}\sum_{n=0}^{N-1} A(n)(\text{Cos}\frac{2\pi}{N}mK - J_m \text{Sin}\frac{2\pi}{N}mK) \qquad (1),$$

where A – sinusoidal input signal amplitude; K= 1, 2 – harmonicnumber; N– number of reports during the experiment; m–number of intermediate current report; J_m – imaginary part of complex plane.

From the formula (1) will receive the frequency of the 1st harmonic:

$$S_1(\kappa) = \sqrt{[R_e A_1(K)]^2 - [J_m A_1(K)]^2} \qquad (2)$$

where R_e– real part of complex plane.

The frequency of the 2nd harmonic is determined by a similar expression:

$$S_2(\kappa) = \sqrt{[R_e A_2(K)]^2 - [J_m A_2(K)]^2} \qquad (3)$$

The result of the actual soil compaction degree is determined using the following formula:

$$\rho_\phi = \frac{S_2(\kappa)}{S_1(\kappa)} < 1, \left[\frac{\text{г}}{\text{см}^3}\right] \qquad (4)$$

The solution to the problem on the optimization of the actual compaction degree is possible only on the basis of the WM automated control system with the use of modern computer technology.

In addition to operational information on the engineman's control panel on the soil compaction degree, an important technological aspect is the automatic control of the vibrating machine WM on the sensor signals, providing the optimum compaction degree.

Adjustable oscillation frequency of the WM eccentric creates perturbing force: $F_\omega = m_{o*Vm} * \omega^2$ (figure 1, characteristics of F_ω), where m_o– eccentric vibrating mass, $_{Vm}$– machine traverse speed, $\omega = 2*\Pi*f$– eccentric rotation speed, $f = 15$-50 Hz – eccentric oscillation frequency.

Operating vibrating machine WM forms the other adjustable parameters: F_y – compaction device impact force of the soil surface (figure 1, characteristics of F_y), τ_y – impact number on a single bay (timer) (figure 1, characteristics of τ_y).
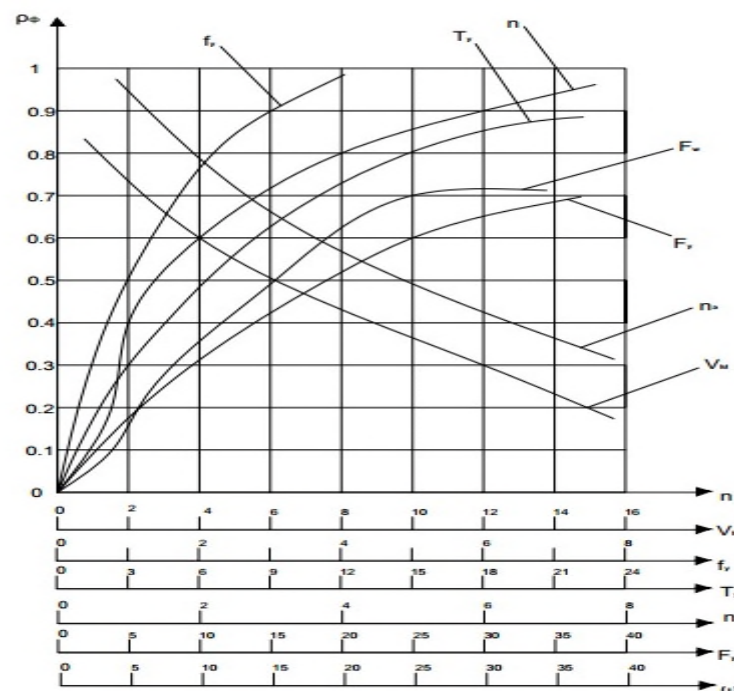
Figure 1. Characteristic of degree of soil compaction depending on the controlled parameters.

The criterion for soil quality determination on the vibrodynamic method of control is universal, because it does not measure absolute values of harmonic oscillation amplitudes, but their averaged values within the compactable area of a given size, defined by the machine pass number.

Since, apart from S_1 and S_2, there are other harmonics that are characterized by their amplitudes $S_i = f(A_i)$, then during the pulse width modulation, low harmonics, which does not reflect the compaction degree, are smoothed and we get the sine waves of the required frequencies S_1 and S_2, which with increasing of ρ_ϕ transferred to nonlinear characteristics (sections 1-2 and 3-4), as the value of the S_1 significantly decreases, but S_2 increases with ρ_ϕ growth.

3. Discussion

Adjustable (compensating) impacts $F\rho$ during the automated control in the continuous process of soil compaction include: n–number of machine passes with one bay, V_M– machine speed, τ_y- time (impact number) of compaction on a local area, F_y– compactable impact force, f_y– operating device impact frequency, F_ω–perturbing force from the eccentric rotation rate. The determination of values and time

of action of the regulatory parameters, which are included in the Fρ group and impact assessment on ρ_ϕ of the unregulated external actions F_B, has allowed obtaining reliable information about the increase degree of the actual soil density ρ_ϕ.

The issues for determination of the adjustable parameters actions Fρ and uncontrolled impacts F_B in such a dynamic system that can automate the compaction process, is possible only with the development and implementation of a microprocessor control system with flexible software, for implementation of which on the basis of active experiment the values of the adjustable parameters affecting the main parameter of ρ_ϕ were obtained (figure 2).

Operating performance and high compaction degree largely determine the technical and economic indicators when performing construction works. Criteria for optimal operation of the compacting machine are maximum productivity with minimum number of passes and increasing of machine movement speed by ensuring optimal soil density.

Operating performance is determined by the following formula:

$$\Pi_\ni = \frac{1000(B-b)V_m * Fw * fy * \tau y}{n} * K_{B,} \left[\frac{\text{м}^3}{\text{ч}}\right] \qquad (5)$$

where B – compaction b and width, [m]; b=0,1 m – related b and overlap width; V_m – machine movement speed during compaction, [m/hour]; n – number of machine passes on one bay; K_B=0,8…0,85 – machine utilization (fuelling, maintenance).

In the formula (5) the coefficients B, b, K_B, H_0 does not depend on the operation mode of the machine, but the coefficients n and V_m are functionally associated with the compaction degreeρ_ϕ (figure 1).

Therefore, $\Pi_\ni$ should be determined depending on the main indicator of ρ_ϕ, because there is no technological need for the maximum provision of $\Pi_\ni$ in case of poor compaction ρ_ϕ.

Increasing the value of "n" leads to decreasing of $\Pi_\ni$, but increasing ρ_ϕ, and the speed increasing V_m improving $\Pi_\ni$, but dramatically reduces ρ_ϕ (5). If you do not adjust the F_P parameter, for reaching a given value of ρ_ϕ, it is necessary to significantly reduce the performance of $\Pi_\ni$ (5), by reducing the machine speed and increasing the number of its passages, which leads to a decrease of techno-economic indicators. The ACS allows resolving this contradiction by adjusting the parameters of F_y, F_w, f_y, τ_y, the changes of which allow increasing the value of ρ_ϕ (5), without reducing the operational performance of the machine.

The formation of the control signals from the harmonic oscillation amplitudes, arising from the effects of the adjustable parameters F_y, F_w, f_y, τ_y is as follows (figure 2). During the filled soil compactionwith a vibrating operating device 1 at the output of the accelerometer 2 a harmonic-type signal occurs, which is close tosinewave. This signal, passing the amplifier 3, is sent to a band-pass filter 4, containing information on the process of soil compaction 25. This signal is being tuning outfrom both high-frequency and low-frequency noise.

With the output of the band-pass filter 4, a valid signal through the amplifier 6 is sent to the frequency converter in the analog signal 6 and the algebraic adder 7, on the input of which the signal from the adjustment 8 of the vibration amplitudes is sent, which determine the specified compaction degree. With the output of the adjustment 8, this signal comes on the analyzer 14.

The fixed signal from the adjustment 8, the algebraic adder 7 and the frequency converter in the analog signal 6 is sent to an analog-to-digital converter 9, which at its output generates a code and sends it to the memory block 13 and from its output to the input of the comparator 10, with "Output 1" of which the encoded signal is fixed at "Input 2" of the analyzer 14.On the "Output 2" of the comparator 10 the indicator 5 is connected. The signal from band-pass filter 4 in the form of pulses is sent to the complementing flip-flop 11, and from it is sent tothe pulse shaper 12, which converts the commands so that on the comparator output rectangular pulses occur, arising from various harmonics of the compactable soil 25.

In a controlled technological process several signals from the harmonic frequencies are formed, which arise from various adjustable parameters and are functionally associated with the actual soil compaction degree: ρ_ϕ = f(V_M, n. F_y, F_w, f_y, τ_y). The choice of optimal parameter values from the F_p group produces the controller software 22.

At the input of the comparator 10, the steady-state value of a monitored signal is fixed, for example harmonics amplitude signal, related to F_y that is sent to the "Input 1"of comparison analyzer 14, and at the "Input 2" the signal comes from the adjustment 8, where the actual value of the soil compaction degree is being compared specified: ρ_ϕ with ρ_0.

In case of $\rho_\phi \neq \rho_0$ unbalanced signal generates $\Delta\rho$, which is sent at the "Input 2" of the microprocessor controller 22, and with the "Output" a control signal generates through the normalizer 23 to change the operation mode of regulating actuating mechanic 24. Simultaneously, the multichannel normalizer 21 for connecting multiple converters generates a signal, corresponding to the impact 17, and in the case of the unbalance signal of the microprocessor controller 22 occurs, the following and the most effective optimal operation mode of regulating actuating mechanism 24 is installed on the adaptive program, for example, by changing the F_w parameter. Thus the monitoring signals, received from transmitters 15-20 with the use of multi-channel normalizer 21 happens. When the equality is achieved $\rho_\phi = \rho_0$ ($\Delta\rho=0$), the automatic control system switches to the steady-state mode, showing that the compaction is completed in a given area.
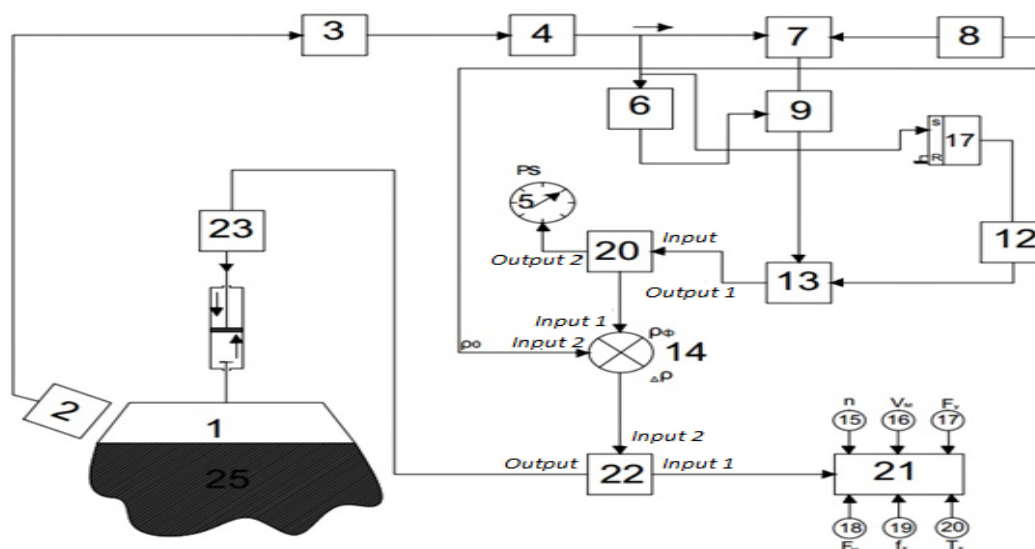
Figure 2. Structural arrangement of hardware components of automatic control system with the control mechanism of the soil compacting machine.

4. Conclusions

Preliminary analysis shows that the automation of the control process will increase the performance of work on soils compaction by at least 25% only due to the reduction in the number of passes on one grip and the increaseof the speed of the machine movementunderinsignificant environmental impacts owing to the created vibrational load.

In addition, the automatic control system allows improving the quality of soil compacting operations, reducing the consumption of combustibles and lubricants, and in some cases completely abandoning the traditional approaches to the control of the degree of compaction by taking soil samples and relieving the workers performing these operations.

References
[1]   Vaskovsky A M, Vorobiev A A 1998 *Automation of compaction of soil by vibration rollers* Moscow, Izvestiya VUZ - Institute of Higher Education, 36.
[2]   Kascheev A A 2005 *Technological substantiations of automation of the process of compaction of bulk soils by vibrodynamic method* Sat scientific Proceedings of "Interstroymech-2005", Moscow.

[3]   Shilkov V A 1992 *Automation of vibro impact impact machines for soil compaction and piling* Moscow, Stroiizdat.

[4]   Anashkin Z T, Balkireyeva V Ya 1994 *A method for continuously monitoring the density of the material to be laid when the vibrating roller is operating* Moscow, Construction and road machines, **6** 95.

[5]   Barkan D D, Shekhter O Ya 2002 *Theory of surface compaction of soil* Moscow, Gosstroizdat, **51** 89.

[6]   Akishkin A I, Voloshchin A P 1996 *The influence of the impact velocity on the compaction of a bound soil with impulses is less than optimal* Moscow Soyuzdornii, **26** 42.

[7]   Vladimirov V N 1996 *Investigation of the propagation of stresses and deformations in densified soil under the action of a vibrator* Moscow, Soyuzdornii, **24** 41.

[8]   Vladimirov V N 1998 *Studies of the propagation of vibrations, stresses and deformations in a compacted soil under the influence of a vibrator* Moscow, Stroyizdat.