Information System For Obtaining Parameters High-frequency Vibrations Of Road-Construction Machines

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***Abstract*—The abstract reveals the modern methods of developing an automated control system for special equipment. A mathematical description of the processes was carried out and an algorithm for the operation of the automated system was developed. The topic covered in this article is the most relevant, as it allows to optimize time costs. One of the most rational ways to intensify the processes of loosening are high-frequency oscillations of the ripper working body in the sonic range using resonant magnetostrictive vibrators. A new approach to the synthesis of a loosening process control system is needed, which covers a range of issues related to development of new principles and methods of automation. Only in this way it will be possible to significantly improve the technical and economic indicators of loosening machines, to avoid influence on them of significant fluctuations in quantitative and qualitative characteristics of soil.**

I. Introduction

Loosening machines occupy a special place for mechanization of earth-moving. Despite rapid development of new methods for soils excavation and specialized machines, the mechanical method of their destruction by rippers in the near future will remain the most effective in most operating conditions. This is explained by relative simplicity of rippers design, wide scope and versatility of its applications, high productivity and low cost per unit of work performed. Rippers play a special role while excavating rocky and frozen soils, and in the latter case, the issue of loosening is particularly relevant, since the area occupied by permafrost is 58% of our country, and together with seasonally frozen soils it covers almost 90% of its territory.

Technological processes of ground development are accompanied by vibrations of the road construction machine, which negatively affect the driver's condition, his fatigue, the ability to coordinate the operations of the workflow, reducing, ultimately, the productivity and quality of the technological operations carried out. The struggle against negative influence of vibrations should be based on information about quantitative and qualitative characteristics of vibration nature. Use of this information should help developers optimize the process of choosing a operator place and constructive execution of the operator's workplace, minimizing the negative effects of vibrations on the performance of control functions.

Problem statement

The mechanism of softening heavy soil when applying vibrations to the working body of loosening machine is the following: when energy is radiated into the mass, an elastic wave of displacements propagates in it, exposing it to compression-tension and shear deformations. The stresses arising in the soil can cause its destruction or significant softening, while it is not a separate impact which prevails in the soil mass, but it is a continuous oscillatory (wave) process, and the destruction effect depends on the intensity of the elastic wave and degree of its transmission to the mass.

Problem solution

Thus, it is necessary to develop a set of measures aimed at establishing and maintaining the resonant mode of oscillatory system, by means of introduction of automated control of modes of vibration impact on the soil.

If high-speed loads (high-frequency oscillations) are applied to the working body of the loosening machine, then the soil mainly experiences elastic deformations, which reduces energy consumption for plastic deformations, and the soil collapses like a brittle body

At the same time, the problem of influencing the parameters of road-building machines on the occurrence of a resonant mode of vibration, which is particularly strongly reflected not only on the condition of the operator, but also on the reliability of the technical components of road-building machines, can be solved.

An information microprocessor automatic system for obtaining parameters of high-frequency vibrations of road-building machines was developed.

The automatic device consists of two independent circuits: the circuit of automatic fixation of the constant amplitude of the oscillation of the elements and the circuit of automatic search of the resonant frequency on the basis of the received information about vibrations. The circuit of automatic maintenance of vibration amplitude constant consists of the following blocks:

- piezoelectric transducer;
- frequency-compensated amplifier;

- rectifier made in the form of an AC voltage module driver;
- voltage-frequency converter;
- cymometer;
- reference value register;
- operational counter;
- comparison devices;
- analog comparator;
- integrator;
- generator of controlled voltage;
- digital thyristor amplitude controller.

The contour of the automatic search for the resonant frequency consists of the following blocks:

- thyristor controlled generator;
- passive generator;
- analog-to-digital converter;
- cymometer;
- operational counter;
- memory register;
- digital comparator;
- control device;
- reversible counter;
- programmable divider.

The developed information system is universal and can be used to collect and process information about high-frequency vibrations on any types of road-building machines.

The system of automatic control of the process of digging ground is a closed system, including:

- managed object – «bulldozer – ground»;
- automatic control device.

II. Mathematical model

The mathematical model of the controlled object in this case can be represented by the equations of motion of the machine aggregate (for example, a bulldozer) and the forces of resistance to digging of the ground by earth-moving and transport machines..

The equation of motion of the bulldozer, taking into account the fact that the rigidity of the elements of the structure of the bulldozer is at least four orders of magnitude higher than the similar characteristics of the ground [1], has the form:

$$P_т - W = m\,(dv_д/dt), \tag{1}$$

$$J_i(d\omega_i/dt) = M_{дi} - P_{тi}\, r_i, \tag{2}$$

where $P_т$ – total driving force of the bulldozer unit;

W – full resistance when digging;

t – time;

m – bulldozer unit weight;

$v_д$ – actual speed of the bulldozer;

J_i, ω_i, $M_{дi}$, $P_{тi}$, r_i – moment of inertia, angular velocity, torque, driving force and rolling radius of the i-th propulsion.

The total driving force of the bulldozer is equal to:

$$P_т = \sum_i P_{тi} \tag{3}$$

The driving force of the i-th propulsion:

$$P_{mi} = \varphi(\delta_i), \tag{4}$$

where: δi – slip factor of the i-th thruster.

slip factor of the i-th thruster:

$$\delta_i = (v_{тi} - v_д)/v_{тi}, \tag{5}$$

where: $v_{тi}$ – theoretical speed of the movement of bulldozer.

Theoretical speed of the movement of bulldozer given that the rolling radius of the track is constant, can be considered a linear function of the engine speed:

$$v_т = (\pi r_{кi} n)/30 i_n, \tag{6}$$

where: n – number of revolutions of the engine shaft;

i_n – total transmission ratio for this gear;

$r_{кi}$ – rolling radius of the i-th thruster.

$$\omega_i = v_т/r_{кi}. \tag{7}$$

The total torque of the thrusters according to [1] can be considered a linear function of the engine torque

$$M_д = M_{дв} i_n \eta, \tag{8}$$

where: $M_{дв}$ – engine torque;

η - total efficiency of all gears between engine and propulsion.

The impedance to the movement of the dozer unit according to [2] can be determined by the formula

$$W = KBh + V_{пр}\gamma f_{пр} + V_{пр}\gamma f_{гм} cos^2\beta + Gf, \tag{9}$$

where: K – ground resistivity to frontal cutting;

B – the width of the bulldozer blade;

h – cutting depth in the process of moving of the prism of ground;

$V_{пр}$ – the actual volume of the prism drawing in the dense body;

γ - volumetric weight of ground in a dense body;

$f_{пр}$ – the coefficient of resistance to movement;

β - cutting angle;

$f_{гм}$ – the coefficient of friction of ground on metal;

G – total weight of bulldozer unit;

f - coefficient of resistance to the movement of the bulldozer unit.

The volume of the prism drawing through time t can be calculated by the formula

$$V_{\text{пр}} = B\int_0^t hv_{\text{д}}dt \quad (10)$$

The joint solution of equations (9) and (10) allows to obtain full resistance to the movement of the dozer when digging in the following form:

$$W = KBh + Gf + AB\int_0^t hv_{\text{д}}dt \quad (11)$$

where: A – constant.

The system of equations (1) - (8) and (11) allows us to describe quite accurately the process of digging the ground with a bulldozer. After appropriate transformations and the introduction of simplifying assumptions, necessary theoretical studies can be performed using modern computer technology.

Using the above equations it is possible, for example, to determine the theoretical plot of excavation during digging, which can serve as a criterion for optimality in further research.

Transforming equation (1) into account the expression (11), we obtain the basic equation of motion of the bulldozer when digging ground:

$$P_{\text{т}} = KBh - Gf - AB\int_0^t hv_{\text{д}}dt = m\frac{dv_{\text{д}}}{dt}. \quad (12)$$

Equation (12) must be solved separately for the area of deepening and recessing of the ladle of the bulldozer.

As the depth of recess increases, the total driving force P_m, developed by the propellers increases and reaches the value P_m max corresponding to the optimal mode of operation of the mover [2]. This moment should be considered the end of the recess. The depth of cut $h=h_{max}$.

After h_{max} is reached, it is necessary to recess excavation in such a way as to maintain a constant total driving force $P_{\text{т}\,max}$.

After differentiation of equation (12), taking into account the fact that during recessing of ladle, the actual speed of the bulldozer will be constant, we get:

$$dh/dt + (A/K)h = 0. \quad (13)$$

The solution of this equation is

$$h = h_{max}e^{-\frac{t}{\tau}} \quad ,(14)$$

where: $\tau = K/A$ – time constant of the place of recessing.

The maximum cutting depth is determined from the expression (12) with t=0 and $P_{\text{т}} = P_{\text{т}\,max}$:

$$h_{max} = (P_{\text{т}\,max} - Gf)/KB. \quad (15)$$

When transporting the ground, a part of the prism of the dragging goes into the side rollers, therefore, to compensate for these losses, it is necessary to finish the digging process at a depth of equal to [2]:

$$h_1 = (K_1 V_{\text{пр}})/B, \quad (16)$$

where: K_1 – ground dependent coefficient.

Thus, the obtained mathematical model makes it possible to carry out research on the process of digging with a bulldozer, determine the theoretical plot of excavation and be the main element of the system of automatic control of ground development modes by earth-moving and transport machines [3].

III. AUTOMATED SYSTEM

Exploring the work on the automation of road-building machines, in particular, bulldozers, we can conclude that most of the known developments provide automation only for the profiling process, excluding the digging process [4]. Thus, the well-known «Avtoplan-1» system with the aim of improving the planning properties of the bulldozer stabilizes the angular position of its push bar, and the «Avtoplan-2» system in addition protects the engine from overload. The «Combiplan-10» and system can operate in two modes: autonomous as the «Avtoplan» system and copier, in which the position of the blade of the bulldozer in height and misalignment is maintained along a directional laser beam.

In the process of digging the ground, the automatic control system of the bulldozer should solve other problems, namely, to ensure the realization of free maximum diesel power with a limit on the maximum allowable stable thrust force [5, 7]. For the implementation of such an automated system, a dual-circuit ACS can serve as a bulldozer working body. One circuit must maintain a given free diesel power when digging by automatically controlling the working body penetration as a function of the angular velocity of the diesel shaft of the bulldozer [8]. When skidding the bulldozer thrusters above the optimum value, another circuit must forcibly dig the working body as a function of the skidding coefficient regardless of the angular velocity of the diesel shaft.

Control algorithm fig.1, implementing this method of control, has been debugged in a system built on the basis of the microcomputer. In the program memory of the microcontroller are written binary codes proportional to the period of measurement of Ti, zones of insensitivity of the angular velocity misalignment of the diesel shaft $\Delta\omega_o$, slipping of the engine $\Delta\delta_o$, the value of the optimal coefficient of slipping (δ_o = 10% for tracked engines), duty cycle of the control signal in the function of the misalignment signals $\Delta\omega$ and $\Delta\delta$ according to the selected control law.

The value of the set value of the diesel angular speed is set by the operator during the test runs and is entered into the data memory from the control panel. In addition, the operator enters the digging time value, which provides automatic end of the digging process.

When the system is executed, the value of the digging process time and the set value of the diesel angular velocity ω_o (block 2) are entered.

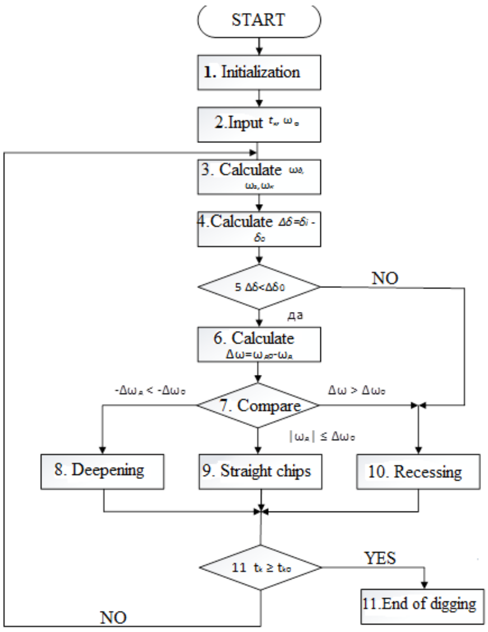

Fig. 1. Control algorithm

The algorithm is based on the sequential measurement of the current angular velocities of the diesel shaft ω_d, asterisk $\omega_з$ and the free-rolling wheel $\omega_к$, repeated measurement cycles, which significantly increases the measurement accuracy (block 3). In this case, the duration of the control signal is adjusted in each cycle.

Blocks 4, 5 calculate the slip factors of propulsion δ_i, the error signal for skidding $\Delta\delta = \delta i - \delta_o$ with the insensitive skidding zone $\Delta\delta_o$ and with the help of block 10 provide priority recessing of the bulldozer blade when the thrusters are slipping above the optimal d value regardless of the angular velocity of the diesel shaft.

Blocks 6, 7, 8, 9, 10 provide control of the blade of the bulldozer as a function of the angular velocity of the shaft of the diesel engine, provided that the thrust of the propellers is not more than optimal value.

Block 11 compares the set parameter of the end of digging $t_{ко}$ with its current value tk. When the condition is $t_к \geq t_{ко}$, block 12 ends the automatic process of digging and transfers control to the operator.

Thus, the automatic control system of the bulldozer blade when digging should be dual-circuit. The first circuit supports the specified driving force of the bulldozer in the process of digging by automatically controlling the depth of the blade as a function of the angular velocity of the diesel shaft. With excessive engine skidding, the second circuit of the automatic control system forcibly deepens the blade as a function of the engine skidding coefficient.

The following detailed description of the invention will describe one application of the preferred embodiment of the preferred use on an earth working machine, such as a bulldozer. Shown in fig. 2 is a side elevational view of a bulldozer 100 having an elongated blade 105 and a ripper 145.

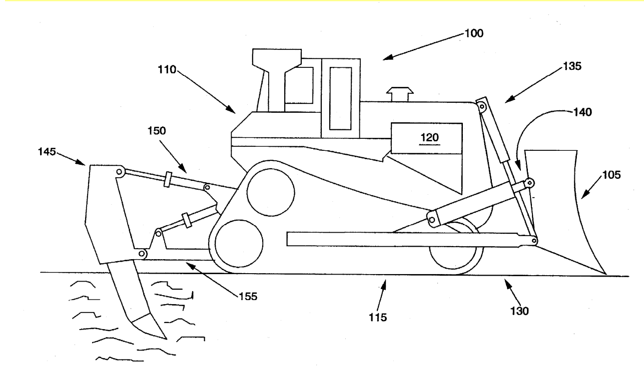

Fig. 2. Elevational view of a bulldozer

The machine 100 has a frame 110, an undercarriage 115 connected to the frame 110, and a prime mover 120 such as an internal combustion engine. The prime mover 125 is drivingly connected to an endless track 130 of the undercarriage 115, in any conventional well known manner. The prime mover rotates the track 130 and propels the machine 100 over the underlying terrain.

The blade 105 is controlled through the movement and positioning of blade lift cylinders 135 and blade tilt cylinders 140. Although not shown, the machine preferably includes two blade lift cylinders 135 and two blade tilt cylinders 140, one on each side of the blade 105. The ripper 145 is controlled through movement and positioning of a ripper tilt cylinder 150 and a ripper lift cylinder 155.

Referring to fig. 3, a block diagram of the ripper control system 200 associated with the present invention is shown. The control system 200 provides for both automatic and manual control of the ripper 145. Preferably, the ripper control system includes a microprocessor based controller 205. The controller 205 is adapted to sense a plurality of inputs and responsively produce output signals which are delivered to various hydraulic actuators or cylinders of the control system.

A joystick 245 is pivotally movable to a plurality of different positions and provides for manual control of the ripper.

An auto-return button 210 is provided for the operator to select an automatic ripper return function. Under the automatic ripper return function, the control system automatically raises the ripper to an upright or fully raised position.

Position sensing means 215 produces position signals in response to the position of the ripper 145. In one embodiment, the position sensing means 215 includes a pressure sensor 225 that senses the hydraulic pressure within a respective ripper cylinder 150,155 and produces a position signal in response to sensing a hydraulic pressure spike. The hydraulic pressure spike is indicative of the ripper being at the fully raised position. Note that, a pressure switch is a suitable replacement for the pressure sensor. In another embodiment, the position sensing means 225 includes a timer 235 that counts down (or up) from a first predetermined time value to a second predetermined time value and responsively produces a position signal. For example, the timer 235 initiates a count down sequence in response to the operator depressing the auto-return button 210. Once the timer 235 reaches a second predetermined time value, such as zero, then the ripper is said to at the fully raised position. In yet another embodiment, the position sensing means 215 may include displacement sensors 220,225 that sense the amount of cylinder extension in the ripper tilt and lift cylinders 150, 155 and responsively produce position signals indicative of the amount of cylinder extension in the respective cylinders. For example, the displacement sensors 220,225 may include a linear variable differential transformer (LVDT). It should be noted that other well known devices, for example, a magnetostrictive sensor, yo-yo type encoder, potentiometer, or resolver, and an RF signal generator are suitable replacements for the LVDT and within the scope of the invention.

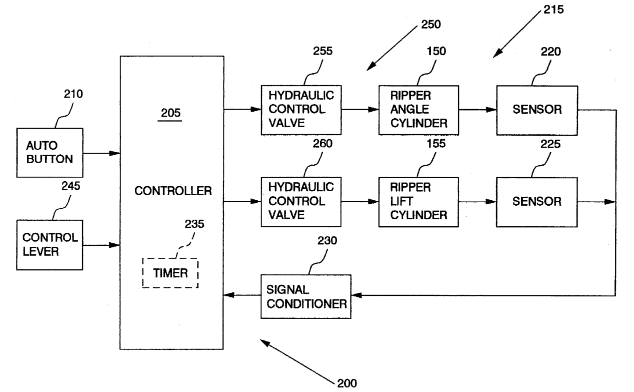

Fig. 3. Block diagram

The position signals are delivered to the controller 205 via a signal conditioner circuit 230 which converts the position signals into digital signals for the purpose of further processing. Such signal conditioner circuits are well known in the art. Note that, the signal conditioner circuit 230 may be part of the controller 205 and implemented in software.

When the auto-return button 210 is depressed, an auto-return signal is delivered to the controller 205 which directs a ripper control signal to a fluid operated ripper control system 250. The fluid operated control system 250 includes hydraulic control valves 255,260 which control the flow of hydraulic fluid to the respective hydraulic cylinders 150,155. The ripper control signal commands a driver circuit of any suitable commercially available type to effect actuation of the hydraulic control valves 255,260 to raise the ripper to the upright position. The controller 205 receives the cylinder position signals and determines when each cylinder moves to a predetermined position that is representative of the ripper being at the upright position. Once a cylinder is determined to be at the predetermined position, then the controller 205 stops delivering the ripper control signal to the associated hydraulic control valve. Thus, the controller 205 may actuate one or both of the hydraulic cylinders 150,155 in order to move the ripper to the upright position,

Thus, while the present invention has been particularly shown and described with reference to the preferred embodiment above, it will be understood by those skilled in the art that various additional embodiments may be contemplated without departing from the spirit and scope of the present invention.

IV. Conclusion

The conducted analysis of processes of heavy soils loosening, allowed us to draw the following conclusions:

The parameters of wave passing into the soil reach a maximum value when resistance of the oscillating system of the working body becomes equal to that of the attached soil. This condition becomes possible only by maintaining the resonant mode of oscillation of the working body, i.e. matching them with load through the use of an automatic optimization system.

We developed the self-adjusting system of extreme regulation, which allows providing efficient loosening at the resonant frequency of the magnetostrictive working body with minimum energy consumption. The contour of the automatic optimization system with extreme regulator connects the power N applied to the magnetostrictive working body and the frequency of the control signal. Thus, the technical and economic effect of using sound methods of loosening the soil, expressed in increasing the efficiency of the loosening machine by an average of 20% and increasing the energy efficiency of these processes, reducing the energy consumption for excavation of frozen soils by 15-20%..

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