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OPERATING OF MOBILE MACHINE UNITS SYSTEM USING THE MODEL OF MULTICOMPONENT COMPLEX MOVEMENT

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Abstract. *To solve the problems of mobile machine units system operating it is proposed using of complex multi-component (composite) movement physical models. Implementation of the proposed method is possible by creating of automatic operating systems of fuel supply to the engines using linear accelerometers.*
Key words*: mobile machine unit, operating, multi-component complex motion.*

УПРАВЛЕНИЕ СИСТЕМОЙ МОБИЛЬНЫХ МАШИННЫХ АГРЕГАТОВ С ИСПОЛЬЗОВАНИЕМ МОДЕЛИ МНОГОКОМПОНЕНТНОГО СЛОЖНОГО ДВИЖЕНИЯ

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Аннотация. *Для решения задач управления системой мобильных машинных агрегатов предложено использовать физические модели многокомпонентного сложного (составного) движения. Реализация предложенного метода возможна созданием систем автоматического управления подачей топлива в двигатели с использованием линейных акселерометров.*
Ключевые слова*: мобильный машинный агрегат, управление, многокомпонентное сложное движение.*

УПРАВЛІННЯ СИСТЕМОЮ МОБІЛЬНИХ МАШИННИХ АГРЕГАТІВ З ВИКОРИСТАННЯМ МОДЕЛІ БАГАТОКОМПОНЕНТНОГО СКЛАДНОГО РУХУ

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Анотація. *Для вирішення завдань управління системою мобільних машинних агрегатів запропоновано використовувати фізичні моделі багатокомпонентного складного (складеного) руху. Реалізація запропонованого методу можлива створенням систем автоматичного управління подачею палива в двигуни з використанням лінійних акселерометрів.*
Ключові слова*: мобільний машинний агрегат, управління, багатокомпонентний складний рух.*

Introduction

Under the system of mobile machine units it’s means a series of machines which don’t have rigid mechanical link between them, but committing a consistent relative motion. In particular cases it may be consistent movement of several machines by one or by the equidistant paths, as well as - in the opposite direction. There are problems of system components movement synchronizing and of their mutual location change operating.

Analysis of publications

Motion is called complex when a point or a solid motion is considered simultaneously with respect to two reference systems, one of which is considered to be provisionally fixed and the other moves in a certain way with respect to the first. Movement committed with the point (or body), called a composite or complex [1].

The movement of the moving coordinate system relative to the stationary was called translational motion, the trajectory and parameters of this movement called the trajectory and parameters of translational motion. The parameters of translational motion are displacement, velocity and acceleration of moving coordinate system control points relative to the fixed [1]. The relative motion of a point or a solid body is a movement considered the moving coordinate system. Regarding moving coordinate system there are reviewed trajectory displacement, velocity and acceleration of a point or a solid relative movement. The parameters of relative motion are called relative displacement, velocity and acceleration [1].

Traffic flow movement in a busy urban cycle, a motorcade movement on long-distance route, as well as various options for joint movement of tractors, tractors and combines, automobiles and harvesters during the performance of agricultural work can be considered as the mobile machine units movement. The difference of the observing system from the traditional mechanical system is no rigid mechanical connection between its elements (links). In such system the kinematic pairs, which together form a kinematic chain are conditional because the connection between the units are absent. In this regard there are no restrictions on units relative movement that is not in line with the classical theory of mechanisms and machines [2].

Nominal kinematic pairs have visual, information or telemechanical communications limiting system links relative movement. When analyzing these communications, to a first approximation, we can assume as non-homonymic. Mobile machine units system can be regarded as a point masses system with imposed restrictions on the maximum relative movement of units (mass). In this case, for operating of system elements movement we can use laws based on the physical model of multicomponent complex (composite) movement.

Objective and Problem Statement

The research objective is to develop a method of mobile machine units system operating using a physical model of a multi-component complex motion. As examples to illustrate the proposed method, it is necessary to consider the following special cases of mobile machine units motion:
- synchronization of forage harvester and tractor train movement;
- synchronization of automobiles in organized column movement;
- ensuring of safe overtaking of automobile moving into the oncoming traffic.

Synchronization of forage harvester and tractor train movement

Synchronization of variable mass tractor train and roots-removing combine movement considered earlier in [3]. The focus of the work [3] has been paid to the definition of the relationship between the change in tractor engine power and the rate of cargo weight increase in a tractor trailer as technical operations. However, the problem can be solved in another manner.

Combine movement [3] can be presented as a complex movement, and translational movement is a uniform machine movement at a predetermined process speed. In steady motion combine relative speed will fluctuate around zero in a big way (amplitude) and a period determined by fluctuations in the traction force and the motion resistance forces. Thus, the linear velocity and acceleration of the combine can be written as

$$\vec{V} = \vec{V}_e + \vec{V}_r = \vec{V}_{tech} + \Delta\vec{V}(t); \qquad (1)$$

$$\dot{\vec{V}} = \dot{\vec{V}}_r = \frac{d}{dt}\left[\Delta\vec{V}(t)\right], \qquad (2)$$

where $\vec{V}_e$ – combine translational speed equal to a given constant technological speed $\vec{V}_{tech}$; $\vec{V}_r$ – combine relative speed, resulting from random fluctuations of traction resistance movements forces,

$$\vec{V}_r = \Delta\vec{V}(t); \qquad (3)$$

$\dot{\vec{V}}_r$ – combine relative tangential acceleration; t – time.

For a single combine we should speak about stabilization process in its technological speed. In this case, the target operating function will be as follows

$$\left.\begin{aligned} U &= \Delta V(t) = 0 \\ \dot{U} &= \Delta\dot{V}(t) = 0 \end{aligned}\right\}. \qquad (4)$$

Implementation of operating law (4) is possible by using linear accelerometers [3, 4], that are recommended by variety standards [5, 6] to estimate the vehicle movement stability. Implementation of the law (4) is increasing of combine stability. [7] So, the expression (4) can be written as

$$U = \int_0^{\Delta t} \dot{V}_r(t)dt = 0\,, \qquad (5)$$

where Δt – combine stabilization system reaction time when a relative (in this case, absolute) linear acceleration appears.

Tractor train movement we also present in the form of a complex movement. In this case, in order to stabilize the relative position of two machine units it's need to ensure the equality of their linear velocities. At the same time the absolute speed and acceleration of the tractor train will be determined from the following equations

$$\vec{V}_1 = \vec{V}_{1e} + \vec{V}_{1r} = \vec{V} + \vec{V}_{1r} = \vec{V}_{tech} + \Delta\vec{V}(t) + \vec{V}_{1r}\,; \qquad (6)$$

$$\dot{\vec{V}}_1 = \dot{\vec{V}}_{1e} + \dot{\vec{V}}_{1r} = \dot{\vec{V}}_r + \dot{\vec{V}}_{1r} = \frac{d}{dt}\left[\Delta\vec{V}(t)\right] + \dot{\vec{V}}_{1r}\,, \qquad (7)$$

where $\vec{V}_{1e}$, $\dot{\vec{V}}_{1e}$ – translational linear speed and acceleration of tractor train; $\vec{V}_{1r}$, $\dot{\vec{V}}_{1r}$ – linear relative speed and acceleration of the tractor train.

When you load a root vegetable from the combine hopper on the trailer load platform [3] you should take into account negative acceleration due to increasing of the train weight. This acceleration is called in work [3] correction can be determined by the formula

$$\dot{\vec{V}}_{corr} = -\frac{\vec{V}_1}{m}\cdot\frac{dm}{dt}\,, \qquad (8)$$

where m – tractor train mass during the considered time; dm/dt – the speed of the tractor train mass increasing (combine performance).

For the tractor train of variable mass

$$\dot{\vec{V}}_1 = \frac{d}{dt}\left[\Delta\vec{V}(t)\right] + \dot{\vec{V}}_{1r} + \dot{\vec{V}}_{corr}\,. \qquad (9)$$

In the work [3], a block diagram of the automatic control system of simultaneous combine and tractor train movement is offered (Fig. 1).

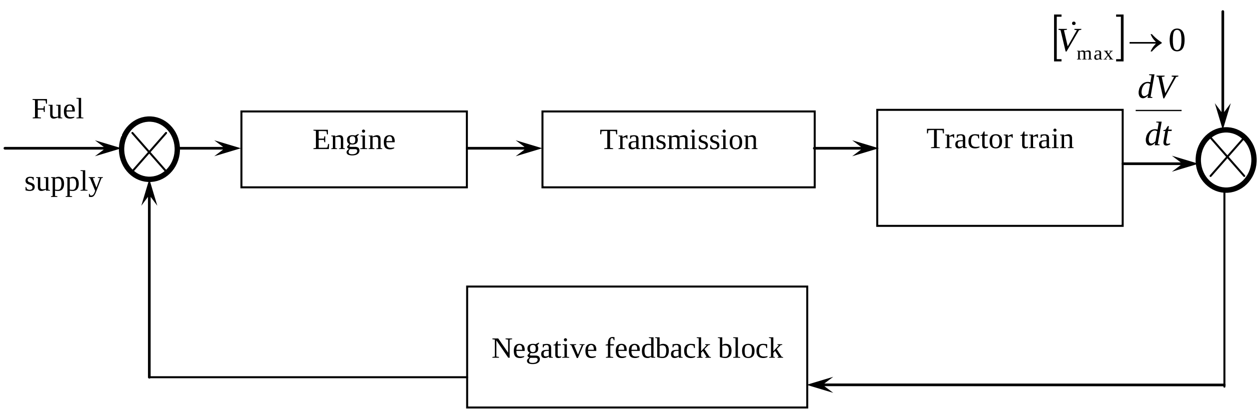

Fig. 1 – Block diagram of the automatic control system of simultaneous combine and tractor train movement [3]

Given the use of the automatic control system of simultaneous combine and tractor train movement, shown in Fig. 1, the linear tractor speed may be determined

$$\vec{V}_1 = \vec{V}_{tech} + \int_0^{\Delta t} \left\{ \frac{d}{dt}\left[\Delta \vec{V}(t)\right] + \dot{\vec{V}}_{1r} + \dot{\vec{V}}_{corr} \right\} dt = \qquad (10)$$
$$= \vec{V}_{tech} + \Delta \vec{V}(t) + \int_0^{\Delta t} \dot{\vec{V}}_{1r} \cdot dt + \frac{1}{m} \int_m^{m+\Delta m} \vec{V}_1 dm,$$

where Δm – tractor train mass changing during time Δt.

The condition of combine and tractor train synchronization in this case (when $V_1 = V_{tech}$) will be

$$U = \left[\Delta V(t)\right]^2 + \left[\int_0^{\Delta t} \dot{\vec{V}}_{1r} dt + \frac{1}{m} \int_m^{m+\Delta m} \vec{V}_{tech} dm \right]^2 = 0 . \qquad (11)$$

In fact, the equation (11) expresses the condition of equivalent to zero of the squares sum of the relative acceleration of the multicomponent complex motion of machine units - combine and tractor train (analogue of movement speed deviation dispersion). In an ideal regulating it gives an opportunity to provide a equivalent to zero of the sum of the relative movement speed.

Synchronization of automobiles in organized column movement

A similar problem occurs when you synchronize the movement of vehicles belonging to an organized column. In this case, automotive column trajectory and motion parameters are determined by the column head vehicle, dubbed the «automobile-leader». [8] Therefore, motion parameters of automobile following the automobile-leader may be represented as

$$\vec{V}_2 = \vec{V}_1 + \vec{V}_{2/1} = \vec{V}_{1e} + \vec{V}_{1r} + \vec{V}_{2/1}; \qquad (12)$$
$$\dot{\vec{V}}_2 = \dot{\vec{V}}_1 + \dot{\vec{V}}_{2/1} = \dot{\vec{V}}_{1e} + \dot{\vec{V}}_{1r} + \dot{\vec{V}}_{2/1}, \qquad (13)$$

where $\vec{V}_1$, $\dot{\vec{V}}_1$ – linear speed and acceleration of an automotive in the column head; $\vec{V}_{2/1}$, $\dot{\vec{V}}_{2/1}$ – relative linear speed and acceleration of the second automotive in column with respect to the head; $\vec{V}_{1e}$ – translational linear velocity of the head automobile, which is equal to a constant column speed, $\vec{V}_{1e} = \vec{V}_{pred}$; $\dot{\vec{V}}_{1e}$ – translational linear acceleration of the head automobile; at a constant predetermined speed $\vec{V}_{pred} = const$ it's equal to zero; $\vec{V}_{1r}$, $\dot{\vec{V}}_{1r}$ – linear relative speed and acceleration of the head automobile caused by random changes in traction and motion resistance forces.

Equations (12) and (13) with the accepted conditions take the form

$$\vec{V}_2 = \vec{V}_{pred} + \vec{V}_{1r} + \vec{V}_{2/1}; \qquad (14)$$
$$\dot{\vec{V}}_2 = \dot{\vec{V}}_{1r} + \dot{\vec{V}}_{2/1}. \qquad (15)$$

The condition for motion synchronization of the head and followed automobile in the column is the following

$$U = \left[V_{1r}\right]^2 + \left[V_{2/1}\right]^2 = 0; \qquad (16)$$
$$\frac{dU}{dt} = 2 \cdot \left[V_{1r} \cdot \dot{V}_{1r} + V_{2/1} \cdot \dot{V}_{2/1}\right] = 0. \qquad (17)$$

For an automobile traveling in the column at the third position, the equations (14) and (15) take the form

$$\vec{V}_3 = \vec{V}_{pred} + \vec{V}_{1r} + \vec{V}_{2/1} + \vec{V}_{3/2} = \vec{V}_{pred} + \vec{V}_{1r} + \vec{V}_{3/1}; \qquad (18)$$
$$\dot{\vec{V}}_3 = \dot{\vec{V}}_{1r} + \dot{\vec{V}}_{2/1} + \dot{\vec{V}}_{3/2} = \dot{\vec{V}}_{1r} + \dot{\vec{V}}_{3/1}, \qquad (19)$$

where $\vec{V}_{3/2}$, $\dot{\vec{V}}_{3/2}$ – relative linear speed and acceleration of the third automobile relative to the second; $\vec{V}_{3/1}$, $\dot{\vec{V}}_{3/1}$ – relative linear speed, and acceleration of the third automobile with respect to the head (automobile-leader).

Terms of movement synchronization will be

$$U = \left[V_{1r}\right]^2 + \left[V_{2/1}\right]^2 + \left[V_{3/2}\right]^2 = 0; \qquad (20)$$
$$\frac{dU}{dt} = 2\left[\vec{V}_{1r}\dot{V}_{1r} + \vec{V}_{2/1}\dot{V}_{2/1} + \vec{V}_{3/2}\dot{V}_{3/2}\right] = 0. \qquad (21)$$

For the n-th automobile in the column synchronization conditions are as follows:

$$U = [V_{1r}]^2 + \sum_{i=2}^{n} [V_{i+1/i}]^2 = 0; \quad (22)$$

$$\frac{dU}{dt} = 2\left[\dot{V}_{1r} \cdot V_{1r} + \sum_{i=2}^{n} \left(\dot{V}_{i+1/i} \cdot V_{i+1/i}\right)\right] = 0. \quad (23)$$

Ensuring of safe overtaking of automobile moving into the oncoming traffic

Fig. 2 is a schematic diagram of the ahead automobile overtaking with using of oncoming traffic. At the analysis we will conditionally assume that transition curves are absent and overtaking automobile in the initial and final overtaking phases simply moves in a lateral direction (Fig. 2).

In this case, the linear speed of the overtaking automobile can be represented as

$$\vec{V}_3 = \vec{V}_1 + \vec{V}_{3/1} = \vec{V}_e + \vec{V}_r; \quad (24)$$

where $\vec{V}_1 = \vec{V}_e$ – translational speed motion; $\vec{V}_{3/1} = \vec{V}_r$ – automobile «3» speed relative to automobile «1»,

$$\vec{V}_{3/1} = \vec{V}_r = \Delta\vec{V}_3, \quad (25)$$

$\Delta\vec{V}_3$ – automobile «3» speed increasing required for the overtaking.

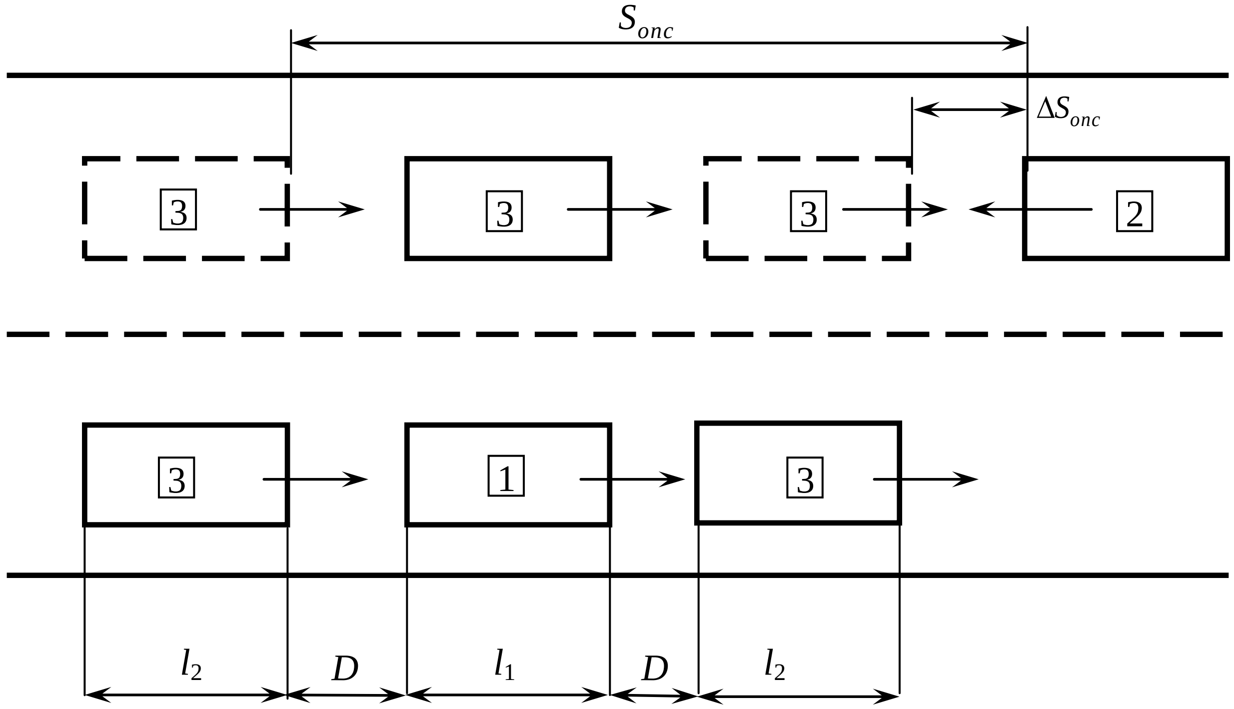

Fig. 2 – Schematic diagram of the ahead automobile overtaking with using of oncoming traffic: 1 – ahead automobile moving with a speed $\vec{V}_1$; 2 – oncoming automobile; 3 – overtaking automobile

When automobile «3» performs overtaking it have to pass a path in relative motion

$$S = 2D + l_1 + l_2, \quad (26)$$

where D – distance between the automobile «1» and «3»; l_1, l_2 – the overall length of the automobile «1» and «2».

The relative speed during overtaking is

$$\left|\vec{V}_r\right| = \left|\Delta\vec{V}_3\right| = \frac{S}{t_{ov}} = \frac{2D + l_1 + l_2}{t_{ov}}, \quad (27)$$

where t_{ov} – overtaking time.

Overtaking time can be determined after consideration of the automobile «3» complex motion, but with respect to the oncoming automobile «2».

$$\vec{V}_3 = \vec{V}_2 + \vec{V}_{3/2} = \vec{V}_2 + \vec{V}'_r, \quad (28)$$

where $\vec{V}_{3/2} = \vec{V}_r'$ – automobile «3» speed with respect to the oncoming automobile «2».

Since the speed vectors $\vec{V}_2$ and $\vec{V}_3$ oriented in opposite directions, $\vec{V}_{3/2}$ vector modulus is the sum of the vectors modules $\vec{V}_2$ and $\vec{V}_3$, i.e.

$$V_{3/2} = V_2 + V_3 . \quad (29)$$

Time of reducing the distance between the oncoming automobile «2» and «3» to zero

$$t_{2-3} = \frac{S_{onc}}{V_2 + V_3} , \quad (30)$$

where S_{onc} – the distance between oncoming automobiles «2» and «3» at the initial overtaking moment.

Obviously, overtaking time t_{ov} have to be less than time $t_{2\text{-}3}$. We write this condition in the form

$$t_{2-3} - t_{ov} = t_{res} , \quad (31)$$

where t_{res} – reserve time by security ensuring condition,

$$t_{res} = \frac{\Delta S_{onc}}{V_2 + V_3} , \quad (32)$$

ΔS_{onc} – the distance between oncoming automobiles «2» and «3» at the time of overtaking (reserve distance).

From equation (31), taking into account the relation (32), we can define the overtaking time

$$t_{ov} = t_{2-3} - t_{res} = \frac{S_{onc} - \Delta S_{onc}}{V_2 + V_3} . \quad (33)$$

The modulus of vector $\Delta\vec{V}_3$ of the overtaking automobile «3» speed relative increasing can be determined by substituting (33) into (27)

$$\Delta V_3 = \frac{2D + l_1 + l_2}{S_{onc} - \Delta S_{onc}} \cdot \left(V_2 + V_3\right) . \quad (34)$$

Findings

As a research result, it's proposed a method of mobile machines system movement operating using a physical model of a multi-component composite (composite) movement.

Implementation of the proposed method is possible by creating of automatic control systems of fuel supply to the engines using linear accelerometers.

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