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ABOUT THE MOTION OF THE WAGON ON THE MARSHALLING HUMP UNDER THE IMPACT OF AIR ENVIRONMENT AND TAILWIND

Saidvaliyev Shukhrat[1], Mekhmonboev Utkirbek[2]

[1]PhD, Soliyev Tokhirbek, [2]Student

[1,2]Tashkent State Transport University

Abstract: The article applies the concept on the addition of velocities in complex motion in vector form. Mathematical substantiated errors within the determination of the particular resistance to movement of the wagon from the air medium and wind, derived from the empirical relationships given the aerodynamic performance of the wagons. The results of the research can be utilized in the processing of the normative-technical document on the planning of hump devices on railways and making adjustments to the dynamics of rolling the wagon in textbooks for universities of railway transport.

Key words: railway, station, marshalling hump, wagon, air environment and wind, the results of calculations.

On the hump the automated shunting is dole out from the top with highest speed v_{iv}. Therefore, with the top of the hill will be linked stationary coordinate system $O_1x_1y_1z_1$ (Fig. 1). The trajectory of the point *M*, considered in relation to the system *Oxyz*, is the path relative (or local) motion, and in relation to $O_1x_1y_1z_1$ – *absolute (or full)* motion. *Motion of the movable system Oxyz* in relation to the fixed $O_1x_1y_1z_1$ is for a moving point *M portable movement*. The speed of a moving point *M* in relation to the system *Oxyz* called relative velocity $\overline{v}_r$, and relative to the system $O_1x_1y_1z_1$ – absolute speed $\overline{v}_a$. The speed of that invariably is associated with a moving frame of reference *Oxyz* in terms of space, in which the time *t* is a moving point *M*, called the transportation velocity $\overline{v}_e$. It may be noted that the carriage moving at a speed of $\overline{v}_{car} = \overline{v}$, can test the effect of the air environment and tailwind (as in Fig. 1). Therefore, from any point of the wagon (for example, point *O*) movable coordinate system *Oxyz* can be linked

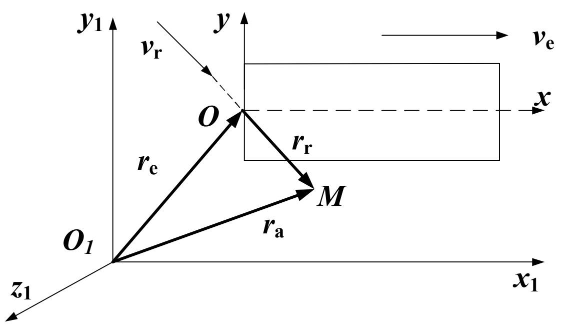

Fig. 1. The direction of the radius-vectors of the wagon and wind (air particles).

For better understanding of the complex motion of the point *M* in Fig. 1 is indicated: $\overline{r}_e$ – the vector-radius of the portable motion (motion of the wagon); $\overline{r}_r$ – the vector-radius of the relative motion of air particles *M*; $\overline{r}_a$ – vector-radius of the absolute motion of air particles *M* relative to the earth (absolute motion of air particles *M*) (Fig. 1); $\overline{v}_e$ – the direction of the velocity of movement of the wagon; $\overline{v}_r$ – the direction of the relative speed of air particles *M*.

When the complex movement of the radius-vector of the absolute motion of the particles of air *M* is equal to the geometric sum of the radius-vectors of the transportation and relative motion:

$$\overline{r}_a = \overline{r}_e + \overline{r}_r. \qquad (1)$$

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While the absolute motion of air particles *M* the radius-vector $\bar{r}_e$, $\bar{r}_r$ and $\bar{r}_a$ will over time *t* change in magnitude and direction according to different laws, each of these radius-vectors are variable vectors (vector-functions) that depend on the argument *t:*

$$\bar{r}_a(t) = \bar{r}_e(t) + \bar{r}_r(t). \quad (2)$$

Differentiating both parts of the vector equation (2) at time *t*, mathematical expression of the theorem of addition of velocities in complex motion in vector form is obtained:

$$\bar{v}_a = \bar{v}_e + \bar{v}_r, \quad (3)$$

where $\bar{v}_a$ – absolute velocity of air particles (Fig. 1); $\bar{v}_e$ – the transportation velocity (the speed of the wagon $\bar{v}_{car} = \bar{v}$); $\bar{v}_r$ – the relative speed of air particles.

Here, the direction of the velocity of the wagon $\bar{v}_{car} = \bar{v}$, as transportation speed $\bar{v}_e$, and wind $\bar{v}_w$, as absolute speed $\bar{v}_a$, and the relative speed of air particles, should have been provided, as shown in Fig. 2.

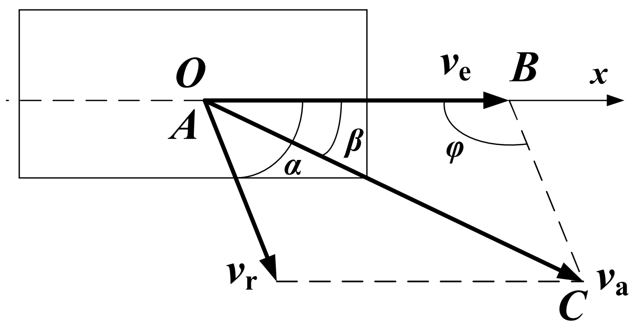

Fig. 2. The direction of the velocity vectors

In Fig. 2 are indicated: $\bar{v}_e = \bar{v}$ – the average velocity of the rolling of the single wagon in the area carrying the forward speed of wagon, m/s; $\bar{v}_a = \bar{v}_w$ – the wind speed relative to the ground (absolute speed of the particles is taken constant), m/s; *α* is the acute angle between the relative velocity of air particles $\bar{v}_r$ and the direction of sliding of the wagon (axis Ox) when exposed to tailwind (see Fig. 2), rad.; *α* is the obtuse angle between the direction of the relative velocity of air particles relative to the longitudinal axis of the car (axis *Ox*) and transportation wagon speed $\bar{v}_e$ when exposed to the oncoming wind (see Fig. 2,b), rad.; β – the angle between the wind direction and the axis of the section of the route (axis *Ox*), in which moves a single car at a speed of $\bar{v}_e$ when exposed to *passing* (see Fig. 2); $\bar{v}_r = \bar{v}_{\text{от}}$ – the relative speed of air; φ = π – α – the obtuse angle complementary to the direction of the relative speed of air particles $\bar{v}_r$ in relation to the transferring velocity of the car $\bar{v}_e$ when exposed to tailwind (see Fig. 2) to π rad.

The main error of works is that the relative speed of air particles $\bar{v}_r$ accepted as the absolute speed of the particles $\bar{v}_a = \bar{v}_w$.

If we discuss the eleventh counterexample in , where it was mentioned that regardless of physical sense based on the spherical law of cosines trigonometry incorrectly written formula, which found a relative velocity of the wagon $\bar{v}_r$ with respect to the direction of wind:

$$v_r^2 = v^2 + v_w^2 \pm 2vv_w \cos\beta, \quad (4)$$

where $v = v_e$ – the average velocity of the rolling of the single wagons in the area carrying the forward speed of the wagon, m/s;

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$v_w = v_a$ – wind speed (absolute speed is taken as constant), m/s;

β – the angle between the wind direction and the axis of the section of the route.

v_r – the relative speed of air particles.

We rewrite equality (4), given that it $v = v_e$ and $v_w = v_a$:

$$v_r^2 = v_e^2 + v_a^2 \pm 2v_e v_a \cos\beta ,$$

hence

$$v_{r1,2} = \sqrt{v_e^2 + v_a^2 \pm 2v_e v_a \cos\beta}. \quad (5)$$

The equation (5) under the root sign "plus" is recommended to accept with a headwind, and the "minus" sign – with a fair wind.

As can be seen, the relative speed of air particles v_r under the influence of tailwind and/or headwind find depending on the magnitude of the load speed of the car v_e, wind speed relative to the earth v_a, and the angle β (see Fig. 2,a), i.e. $v_r = f(v_e, v_a, \beta)$.

Thus, in the angle α between the relative velocity of the air particles v_r and the direction of sliding of the carriage (axis Ox) find depending on the magnitude of the load speed v_e of the wagon, the relative speed of air particles v_r and of the angle, i.e. $\alpha = f(v_e, v_r, \beta)$.

1. For the proof of correctness formula (8) will present the theorem of the cosines of trigonometry when the wind (see ΔABC Fig. 2):

$$a^2 = b^2 + c^2 - 2bc\cos A . \quad (6)$$

Taking into account that, according to ΔABC on Fig. 3, $a = v_a$, $b = v_e$, $c = v_r$ and $\cos A = \cos\varphi = \cos(\pi - \alpha) = -\cos\alpha$, we rewrite the formula (6) in the form:

$$v_r^2 + 2v_e \cos\alpha \cdot v_r + (v_e^2 - v_a^2) = 0. \quad (7)$$

Then,

$$v_{r1,2} = -v_e \cos\alpha \pm \sqrt{(v_e \cos\alpha)^2 - (v_e^2 - v_a^2)}. \quad (8)$$

As can be seen, the relative particle velocity v_r of air when exposed to a tailwind (see Fig. 2) find depending on the magnitude of the load speed v_e of the car and the wind speed relative to the earth (absolute particle velocity) v_a and the angle α, i.e. $v_r = f(v_e, v_a, \alpha)$, while, according to the formula (5) v_r is determined depending on the: $v_r = f(v_e, v_a, \beta)$.

2. For the proof of correctness and/or absurdity of the formula, where the angle α was found, depending on the speed v_e, v_r and angle β, i.e. $\alpha = f(v_e, v_r, \beta)$, when exposed to a tailwind (Fig. 3), according to ΔABC, use the theorem of sines trigonometry:

$$\frac{a}{\sin A} = \frac{b}{\sin B} = \frac{c}{\sin C}. \quad (9)$$

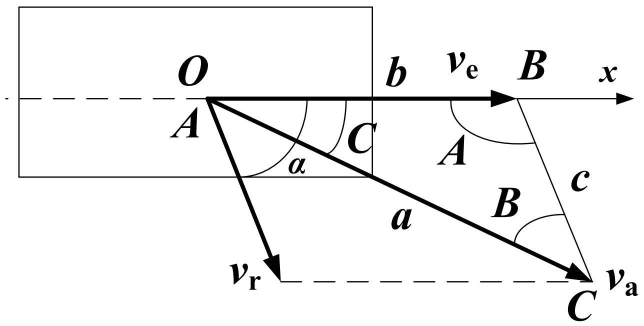

Fig. 3. On the sine theorem

In Fig. 3, according to Δ*ABC* marked: $a = v_a$, $b = v_e$, $c = v_r$ and sin*A* = sinφ or sinφ = sin(π – α) = sinα; sin*B* = sin[π – (φ + β] = sin{π – [(π – α) + β]} = sin(α – β); sin*C* = sinβ.

We rewrite the equality (9) in accordance with Fig. 3 signs:

$$\frac{v_a}{\sin\alpha} = \frac{v_e}{\sin(\alpha-\beta)} = \frac{v_r}{\sin\beta}. \qquad (10)$$

Then,
$$v_r \sin(\alpha-\beta) = v_e \sin\beta.$$

The last formula is given taking into account the formula function of the difference of angles α and β:

$$v_r(\sin\alpha\cos\beta - \cos\alpha\sin\beta) = v_e\sin\beta.$$

Dividing both parts of the last equality in sinβ, we obtain:

$$v_r\left(\sin\alpha\frac{\cos\beta}{\sin\beta} - \cos\alpha\right) = v_e.$$

We can get the form of irrational equations to find angle α:

$$\sin\alpha\cdot\mathrm{ctg}\beta - \frac{v_e}{v_r} = \sqrt{1-\sin^2\alpha}. \qquad (11)$$

Using functions of multiple angles (sin2β), after some elementary mathematical calculations we have the following quadratic equation:

$$\sin^2\alpha - 2\frac{v_e}{2v_r}\sin 2\beta\cdot\sin\alpha + \left[\left(\frac{v_e}{v_r}\right)^2 - 1\right]\sin^2\beta. \qquad (12)$$

Solving this quadratic equation, we obtain the formula to determine the angle α:

$$(\sin\alpha)_{1,2} = \frac{v_e}{2v_r}\sin 2\beta \pm \sqrt{\left(\frac{v_e}{2v_r}\sin 2\beta\right)^2 - \left[\left(\frac{v_e}{v_r}\right)^2 - 1\right]\sin^2\beta}. \qquad (13)$$

As can be seen, the obtained formula (9) of the wagon when exposed to tailwind (see Fig. 3) has a completely different but complicated form than the simple form of formula (3), which confirms the incorrectness of the formula.

Results of study can be used at processing of the standard and technical document on design of sorting devices on the railroads and corrections in the description of dynamics of rolling down of the wagon from marshalling hump.

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