MECHANICAL TEST OF THE STABILITY OF TRACTOR-SEMITRAILER SYSTEM

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One of the undesirable movements of road vehicles with trailer is "jack-knifing". It may occur with tractor-semitrailer systems, too and may cause serious accidents.

"Jack-knifing" can be tested by the dynamic models of the vehicle and the trailer on the basis of mechanical theorems. A characteristic structural part of the two-member vehicle model is the vertical, frictionless knuckle parallel with axis z, built between the vehicle and the trailer.

The tests refer to the case when "jack-knifing" occurs in horizontal plane xy.

"Jack-knifing" can be divided into four independent problems;

1. Development of the mechanical model of the combined vehicle.
2. Establishment of the differential equation system describing the phenomenon on the basis of the characteristic parameters of the model.
3. Solution of the differential equation system.
4. Comparison of the results given by the model and the data coming from experience, correction of the procedure and new calculations.

The aim of the lecture is to elaborate points 1 and 2.

"Jack-knifing" is a complicated movement, therefore simplifying conditions were introduced to facilitate the test. They are the following:

In the course of the movement of the combined vehicle

roll,
pitch,
yaw,
vibrations,
air resistance and
the gyroscopic effect of the wheels are not taken into account.

A further condition is that the steering angles of the vertical plane be identical.

According to the experiences of the accidents "jack-knifing" may occur after braking the tractor-semitrailer systems thus this case is tested in the following.

The simulation vehicle model O consists of two rigid bodies connected with a hinge (Figure 1). Local rectangular coordinate system $K_1(O_1x_1y_1z_1)$ is set to the centre of mass O_1 of vehicle, local coordinate system $K_2(O_2x_2y_2z_2)$ belongs to the centre of mass O_2 of trailer. The kinematic characteristics of the vehicle should be v_x, v_y, $\dot{v}_x$, $\dot{v}_y$, ω_1, $\dot{\omega}_1$, those of the trailer as a connected body, besides the previous ones ω_2, $\dot{\omega}_2$ as well.

Relative yaw angle was marked by γ according to Figure 1. The vehicle model has 4 degrees of freedom.

Equations of motions of the vehicle are the following (Figure 2):

$$m_g(\dot{v}_x - v_y\omega_1) = -(B_1 + B_2)\cos\delta - (s_1 + s_2)\sin\delta - B_3 - B_4 + F_x \quad (1)$$

$$m_g(\dot{v}_y + v_x\omega_1) = -(B_1 + B_2)\sin\delta + (S_1 + S_2)\cos\delta + S_3 + S_4 - F_y \quad (2)$$

$$I_g\dot{\omega}_1 = -(S_1 - S_2)t_1\sin\delta + (S_1 + S_2)t_4\cos\delta - (B_1 - B_2)t_1\cos\delta -$$

$$- (B_1 + B_2)t_4\sin\delta - (B_3 - B_4)t_2 - (S_3 + S_4)t_5 + F_yt_6 \quad (3)$$

and $\bar{\omega}_1 = \omega_1\bar{k}$

m_g is the mass of the vehicle
I_g is the moment of inertia of the vehicle to axis z_1
B_p, S_p components of force at the contact of the road and the tyres ($p = 1,2,3,4$)
t_q distance ($q = 1, 2, \ldots 6$)
F_x, F_y components of the fifth wheel constraint force steering angle.

The trailer is connected to the vehicle at saddle O, therefore acceleration of O and O_2 is necessary to equations of motion of the trailer. Calculation of the acceleration of saddle centre O is in the following way (Figure 1):

$$\bar{a}_0 = (\dot{v}_x - v_y\omega_1)\bar{i} + (\dot{v}_y + v_x\omega_1)\bar{j} + \dot{\omega}_1\bar{k}x(-t_6\bar{i}) + \omega_1\bar{k}x(\omega_1\bar{k}x - t_6\bar{i})$$

$$\bar{a}_0 = (\dot{v}_x - v_y\omega_1 + t_6\omega_1^2)\bar{i} + (\dot{v}_y + v_x\omega_1 - t_6\dot{\omega}_1)\bar{j}. \quad (4)$$

Acceleration of mass centre O_2 of the trailer compared to O (Figure 2):

$$\bar{a}_{O_2-O} = \dot{\omega}_2\bar{k}x(-t_7\cos\gamma\bar{i} + t_7\sin\gamma\bar{j}) + \omega_2\bar{k}x[\omega_2\bar{k}x(-t_7\cos\gamma i + t_7\sin\gamma\bar{j}]$$

$$\bar{a}_{O_2-O} = t_7[(\omega_2^2\cos\gamma - \dot{\omega}_2\sin\gamma)\bar{i} - (\omega_2^2\sin\gamma + \dot{\omega}_2\cos\gamma)\bar{j}] \quad (5)$$

$$\bar{\omega}_2 = \omega_2\bar{k}_2\,.$$

Acceleration of mass centre O_2 of the trailer is obtained by adding equations (4) and (5)

$$\bar{a}_{O_2} = (\dot{v}_x - v_y\omega_1 + t_6\omega_1^2 + t_7\omega_2^2\cos\gamma - t_7\dot{\omega}_2\sin\gamma)\bar{i}$$

$$(\dot{v}_y + v_x\omega_1 - t_6\dot{\omega}_1 - t_7\omega_2^2\sin\gamma - t_7\dot{\omega}_2\cos\gamma)\bar{j}\,. \quad (6)$$

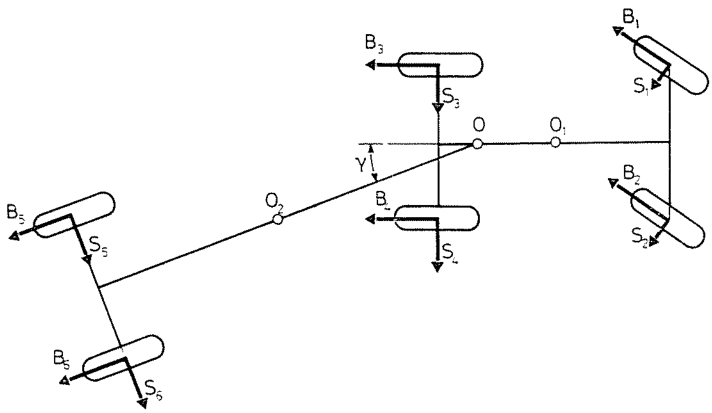

Fig. 1

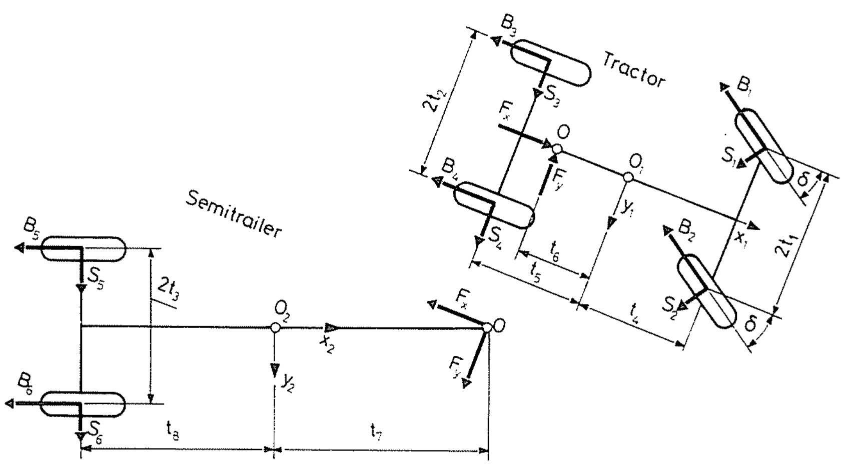

Fig. 2

In the knowledge of equation (6) the equations of motion of the trailer will be the following:

$$m_p(\dot{v}_x - v_y\omega_1 + t_6\omega_1^2 + t_7\omega_2^2 \cos \gamma - t_7\dot{\omega}_2 \sin \gamma) =$$
$$= - (B_5 + B_6) \cos \gamma + (S_5 + S_6) \sin \gamma - F_x \tag{7}$$
$$m_p(\dot{v}_y + v_x\omega_1 - t_6\dot{\omega}_1 - t_7\omega_2^2 \sin \gamma - t_7\dot{\omega}_2 \cos \gamma) =$$
$$= (B_5 + B_6 \sin \gamma + (S_5 + S_6) \cos \gamma + F_y \tag{8}$$
$$I_p\dot{\omega}_2 = (B_5 - B_6)t_3 + (S_5 + S_6)t_8 + F_xt_7 \sin \gamma - F_yt_7 \cos \gamma \tag{9}$$

m_p is the mass of the trailer
I_p is the moment of inertia of the trailer to axis z_2

B_r, S_r are the components of forces at the contact of the road and the tyres of the trailer ($r = 5, 6$)

t_s is distance ($s = 6, 7$).

Equations (1) (2) (3), (7) (8) (9) describe the dynamic behaviour of articulated road vehicle during braking as a function of the vehicle parameters. Because of the analysis of situations dangerous to traffic safety — such as the possibility of "jack-knifing" at tractor-semitrailer systems — relation and interaction of man — vehicle — road must be tested, too. Two methods are described in this connection.

One of them is a computer test where the stability of the articulated road vehicle is obtained in case of the change of the parameters [1]. The model introduced in this lecture is also suitable for this kind of test as the lateral stability of the combined vehicle can be described as a function of the parameters. The results obtained in this way can be used by the designers for the construction of new vehicles. The computer test is also suitable to simulate the situations dangerous to traffic safety to repeat and analyze them with the elimination of the danger.

The other method is the measurement of the constructed vehicle by instruments on test track on the basis of a previously prepared program [2]. The essence is that by changing the air pressure of the tyres of the trailer, by modifying vehicle load and by steering the characteristic parameters of vehicle movement can be measured. As it may cause accident-prone situations for the driver, the vehicle and the traffic, this test can be carried out only within certain limits. It is an expensive method. It follows from the foregoing that the "jack-knifing" of the tractor semi-trailer systems and the development of devices necessary for prevention can be studied by computer tests and on the test track.

The mechanical vehicle model suggested in the lecture also serves this double objective.

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