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Transfer of the Agricultural Tractor Center of Gravity during Emergency Braking

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Abstract: *Intensification of agriculture over the last decades has caused, among others, that the production of agricultural machinery has grown on a large scale. Farm tractors are made of high quality raw materials to further improve field work.*
The development of materials from which, for example, brake parts are produced in a tractor, is not an easy task, due to the combination of substance composition in the average friction lining. It is necessary to carry out laboratory, and often also complex simulation analyzes. For this you need detailed knowledge about the physical phenomenon being studied. This work aims to bring one of them closer. The paper presents a mathematical description of the forces acting on the vehicle during braking, and calculations of the axle load in various braking scenarios.
Key words: *braking, agriculture machinery, centre of mass*

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I. Introduction

In recent years, the industry is developing very dynamically. This also applies to agriculture and the machinery used in it [1]. Modern farm tractors are bigger, heavier, and their maximum speed is higher. In some machines, it reaches up to 60 km / h [2]. This fact affects of course the process of steering the tractor, and in particular the course of braking.

Brakes, because they have to cope with more energy, must be more efficient and more reliable than before. Manufacturers meet these requirements with new types of materials used for the production of friction linings. However, their development is not easy. In the average friction material you can find about 20 different substances combined in different proportions using a matrix [3]. The combination of the composition is virtually unlimited. This allows you to shape the properties of the final product depending on the consumer's needs.

Determining the properties of each material combination requires separate tests. Basic values such as coefficient of friction, heat capacity, thermal conductivity or density are determined at the laboratory stand. More complicated quantities, such as the temperature achieved during braking, are very often determined by simulation tests [4, 5]. Unfortunately, they require a lot of information. Only then can you sufficiently reflect the actual conditions and obtain good quality results. The purpose of this work is to check how much the front wheels are weighted when braking an agricultural tractor. This will allow you to determine what maximum braking torque that can be obtained on individual axes.

2. Object of research

As a research object, a popular tractor in Poland was chosen. Its most important data (according to the manufacturer's information), relevant from the point of view of this work is shown in Figure 1, and in Table 1.

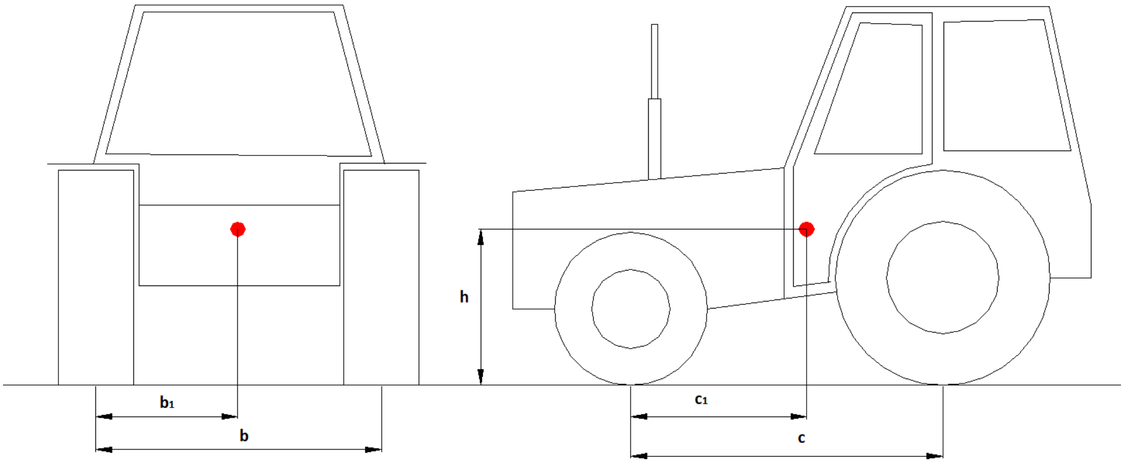

Fig. 1. Diagram of a selected agricultural tractor

Tab. 1. Selected technical data of an agricultural tractor

Description	Symbol	Value
Wheelbase	c	2925mm
Rear axle width	b	2602mm
Center of gravity distance from the front axle	c1	1345mm
Center of gravity distance from the rear center of the left tire	b1	1301mm
Height of the center of gravity	h	910mm
Total mass	m	16000kg
Maximum speed	V_{max}	50km/h
Maximum slope angle	ϕ	20^o

In addition to the above data, it was assumed that:
- The suspension does not deflect during braking,
- The braking is done without slipping,
- The coefficient of friction is constant both between the tires and the ground as well as between the drums and the jaws,
- braking is carried out on an even surface, with a constant delay, from the maximum speed to a complete stop.

3. Mathematic description

In the present study, two cases were considered: a) braking on a flat road, and b) at sliding down a hill with a slope of 20 ° (figure 2).

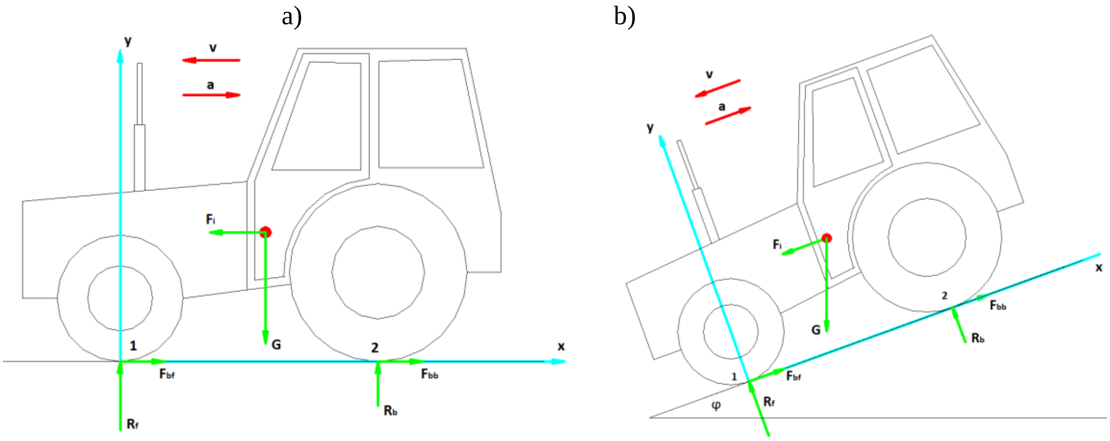

Fig. 2. Schematic of forces acting on the braking tractor: a- acceleration, v- velocity, G- gravitation force, F_i- intertia, F_b- braking force, R- reaction.

In the case of a), in order for the braking to take place while maintaining vehicle stability, the equations of forces and torques will take the form of:

$$\begin{cases} \sum F_x = F_{bf} + F_{bb} - F_i = 0 \\ \sum F_y = R_f + R_b - G = 0 \\ \sum T_1 = F_i \cdot h - G \cdot c1 + R_b \cdot c = 0 \end{cases} \quad (1)$$

It should be noted that according to Columb's theorem of friction, the braking force will depend on the value of the coefficient of friction and the normal force resulting from the axle load (equal reaction), so [6]:

$$F_{bf} = R_f \cdot \mu_f \quad (2)$$

$$F_{bb} = R_b \cdot \mu_b \quad (3)$$

where:: μ_f - coefficients of friction between the front tires and the surface, μ_b - coefficients of friction between the front tires and the surface. In further considerations, it was assumed that braking takes place on the road, which for all tires provides a coefficient of friction $\mu = 1$. With the above in mind it can be concluded that the maximum tractor delay will be the acceleration of the earth:

$$a_{max} = g = 9{,}81 \frac{m}{s^2} \quad (4)$$

The reaction of the front wheels was determined from the second equation of the system of equations (1):

$$R_f = G - R_b = g \cdot m - R_b \quad (5)$$

while using the third equation, the reaction of the rear wheels was determined:

$$R_b = \frac{G \cdot c1 - F_i \cdot h}{c} \quad (6)$$

After substituting, below was obtained:

$$R_f = g \cdot m - \frac{g \cdot m \cdot c1 - m \cdot a \cdot h}{c} \quad (7)$$

In the case of b), when the tractor brakes on a slope of the road, the fact that the gravity breaks down into two components should be taken into account. The system of equations will thus have the form:

$$\begin{cases} \sum F_x = F_{bf} + F_{bb} - F_i - G \cdot sin\varphi = 0 \\ \sum F_y = R_f + R_b - G \cdot cos\varphi = 0 \\ \sum T_1 = F_i \cdot h - G \cdot cos\varphi \cdot c1 + G \cdot sin\varphi \cdot h + R_b \cdot c = 0 \end{cases} \quad (8)$$

Taking into account the previous assumptions, reaction was determined on the rear and front wheels:

$$R_f = G \cdot cos\varphi - R_b = m \cdot g \cdot cos\varphi - R_b \quad (9)$$

$$R_b = \frac{G \cdot cos\varphi \cdot c1 - G \cdot sin\varphi \cdot h - F_i \cdot h}{c} \quad (10)$$

After substitution, it was obtained:

$$R_f = m \cdot g \cdot cos\varphi - \frac{m \cdot g \cdot cos\varphi \cdot c1 - m \cdot g \cdot sin\varphi \cdot h - m \cdot a \cdot h}{c} \quad (11)$$

II. Results and discussion

The mathematical analysis made it possible to calculate the normal force on the front axle of an agricultural tractor depending on deceleration. Two cases were considered: braking on a flat road, and when going down a hill. The results of the analyzes are shown in Figure 3.

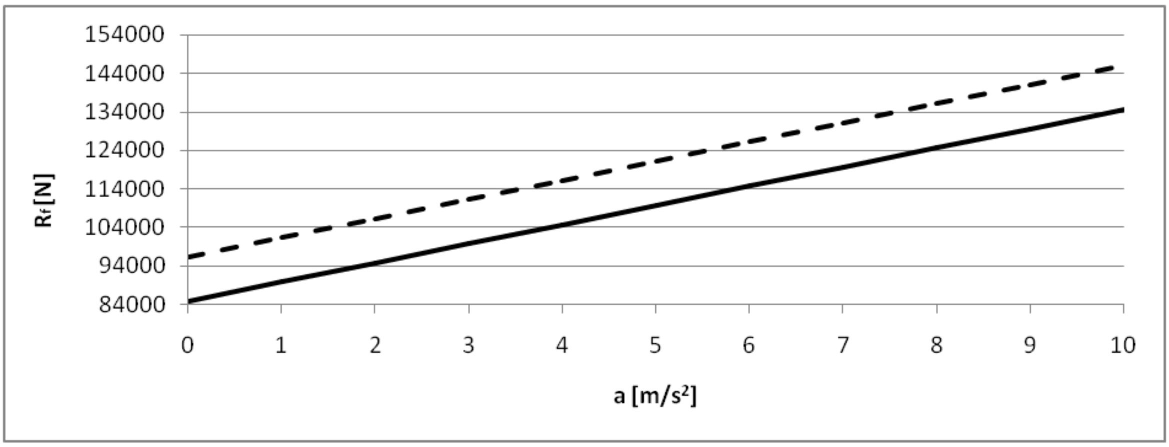

Fig. 3. Graphs of reaction value to the front axle of an agricultural tractor as a result of braking: — on a flat road, - - when descending from a hill

It can be noticed that the reaction of the front axle increases with the increase of the delay value. On a flat surface, under static conditions, the normal force on the front axle is just over 84kN. Emergency braking causes increase to over 134kN. The reaction value increase is therefore about 60%. A similar trend can be seen in the calculation of braking when driving down a hill. The force increase occurs from just over 96kN in static conditions, to over 146kN during braking with a delay equal to earth acceleration. The increase is therefore 52%.

III. Conclusion

This paper presents calculations concerning the displacement of the center of mass of an agricultural tractor during the braking process. This knowledge is necessary, for example, for correct simulation tests, because as shown in formulas (2) and (3) the braking force depends on the normal force. The greater the braking force, in turn, causes a greater frictional moment in the brake system. This will cause a more intensive heating up of the rubbing steam. The calculations showed that emergency braking causes the front axle load increase:
- By 60% in the case of driving on a flat surface;
- By 52% in the case of braking when going downhill after a slope of 20^o.

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