SIMULATING TRACTOR'S STATIC STABILITY IN RELATION TO ITS POSITION ON A SLOPE

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Abstract

Agricultural machinery, tractors in particular, is one of the main causes for fatal accidents in the agriculture. Despite a decrease in the number of fatal accidents during the last 15 years, it is still high, with the average of 34 fatalities per year. Most accidents happen when a tractor overturns. Safety systems to protect the tractor driver in case of an overturn have softened the consequences to a certain degree, however, they have not reduced the number of accidents. A detailed analysis of problems and causes, leading to a tractor overturn have revealed that by improving tractor's static stability we can positively influence the safety as early as during the concept phase. We designed a mathematical model and a numerical simulation for the static stability of a tractor with an oscillating front axle in relation to its position on a slope. It was followed by analysing the changes of individual parameters, such as the position of the centre of gravity, the wheelbase, the wheel track width and the height of the oscillating axle mounting point, and their impact on tractor's static stability in relation to its position on a slope. Results show that manipulating these parameters can significantly increase tractor's static stability. A better static stability is directly proportional to improved dynamic stability, resulting in a better safety in view of a tractor overturn, particularly while working on a sloping terrain.

Keywords: Static stability, tractor, analysis, mathematical model, simulation.

Presenting Author's Biography

Ivan Demšar was born in Kranj, Slovenia, on April 12, 1978. He received a BS in mechanical engineering design from the Faculty of Mechanical Engineering in Ljubljana in 2002. Since September 2002 he has been a research assistant at the Faculty of Mechanical Engineering's LECAD laboratory. His research work is mostly oriented towards image processing and model building. His interests also include agricultural machinery.

1 Introduction

A tractor is a vital and universal tool for the agriculture. Its use is on the rise, however, it goes hand in hand with an increase in the number of accidents. Statistics show [1,2,3] that most fatal accidents happen when a tractor overturns. There are several reasons for overturning. One of the most frequent ones is misjudgement of the terrain by the operator, resulting in sliding and then overturning. The next reason is overturning as a result of driving over an edge, followed by a wrong gear or excessive speed (Figure 1). What these causes have in common is the fact that a tractor overturns when its stability limit is exceeded.

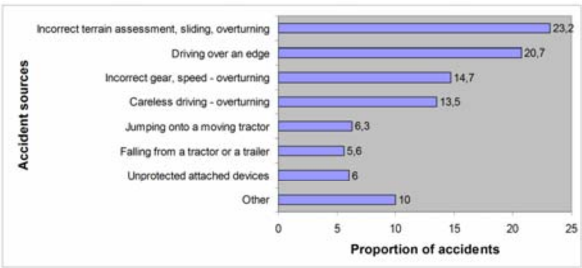

Fig. 1 Circumstances of fatal accidents.

Several safety systems have been developed to protect the driver and soften the consequences in case of a tractor overturn. Rollover protective structure [4, 5, 6] with its rollover bar and safety cab is the best known and widely used system. Later, it was followed by the safety belt and AutoROPS [8] system. After introducing these measures, the number of fatal accidents as a result of a tractor overturn has decreased [7]. However, the number of overturns themselves has stayed the same. It is vital to find a solution how to prevent the number of overturns rather than simply soften their consequences.

For these reasons, we decided to analyse the issue of tractor's stability [14, 15]. First, we extracted the key parameters and tried to improve the stability through a proper selection of the parameters. With tractor's stability we refer to the incline (steepness) where a tractor overturns. According to the literature [13], there are two types of stability. When a tractor is standing still it is a matter of static stability and when it is moving it is a matter of dynamic stability. Considering that accidents usually occur when a tractor is moving it is easy to conclude that dynamic stability is the issue. Besides the static stability, the key parameters, affecting dynamic stability are factors from the environment, such as a rough terrain, potholes, washboards, stones etc as well as subjective factors, particularly speed and driving style (Figure 2).

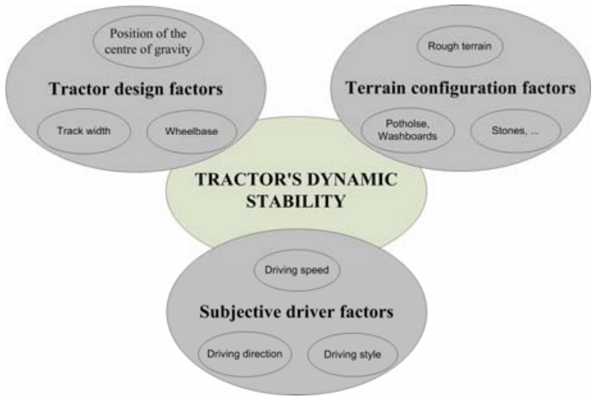

Fig. 2 Factors affecting tractor's dynamic stability.

A more detailed analysis of individual factors showed that during the concept phase of designing a new tractor we can hardly or not at all exert influence upon some groups of the aforementioned factors, affecting tractor's dynamic stability. The driver's subjective factors are the most difficult to affect. Each driver has his or her own style, which changes again with his or her state of mind and feelings. The other group is the diversity of terrain configuration. This is another group of factors which tractor designers cannot influence. It can be partly influenced by landowners or land managers. It has been concluded that designers of new tractors can exert influence only upon the design factors, falling into the category of tractor's static stability. It is clear that improving tractor's static stability also improves its dynamic stability, reducing the probability for a tractor overturn.

Analyses have revealed that changing individual parameters can significantly affect tractor's static stability. All key parameters - supports, the position of the centre of gravity, wheelbase, the wheel track width and the height of the oscillating front axle mounting point - have been analysed and are presented in the paper. We designed a numerical simulation for tractor's static stability in order to find out which parameters and to what extent affect tractor's static stability in relation to its position on a slope.

1.1 Tractor's Static Stability

The significant contribution of tractor's static stability towards the overall safety of a tractor in terms of overturning has been described in the introduction. A closer examination of tractor's static stability has revealed several parameters, affecting the static stability (Figure 3).

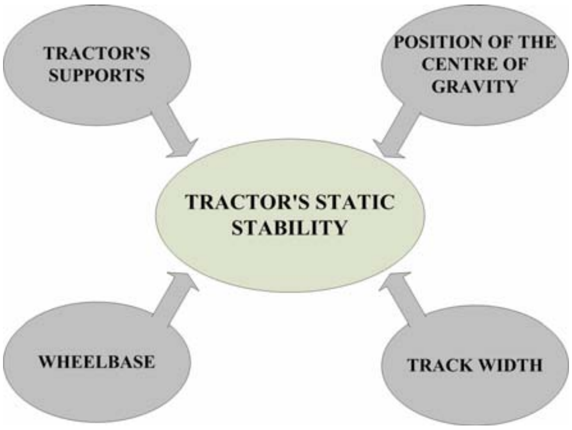

Fig. 3 Design parameters with the biggest impact on tractor's static stability

1.1.1 Tractor's Supports

Theory says that each stiff body is supported at three points. On this basis, several solutions have been developed with the aim of providing a constant contact of all four wheels with the ground. In the literature and in the existing models, produced by established manufacturers, we recognised several ways of tractor supports. Most standard tractors still feature oscillating mounting of the front axle. It means that the front axle is rotationally mounted to the tractor body. It allows the front axle to tilt by a certain degree (ψ) (Figure 4) in relation to the rear axle, providing s better grip with the ground. Recently and particularly on bigger transport tractors, sprung axles (mostly front, sometimes also rear) are usually used. For smaller tractors, the central articulation point is the most common solution. In this case, the entire front part of the tractor tilts together with the axle.

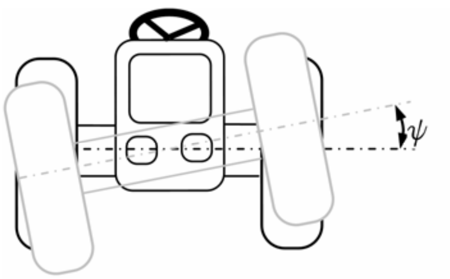

Fig. 4 Tractor with an oscillating front axle.

The subject of our analysis is support by means of an oscillating mounting of the front axle, shown in Figure 5. As already said, the rear axle is stiffly mounted to the main body and the front axle is rotationally mounted with a pin (point E) along the longitudinal axle. For this type of support, the contact between a tractor and the ground can be illustrated by a support plane ABC_1D_1, achieved by projecting the support triangle ABE onto the ground. Endpoints A and B represent the contact between the rear wheels and the ground while endpoint E is the joint between the tractor's body and the front axle. At the intersection between the projected triangle and segment $\overline{CD}$ we get points C_1 and D_1 (Figure 5).

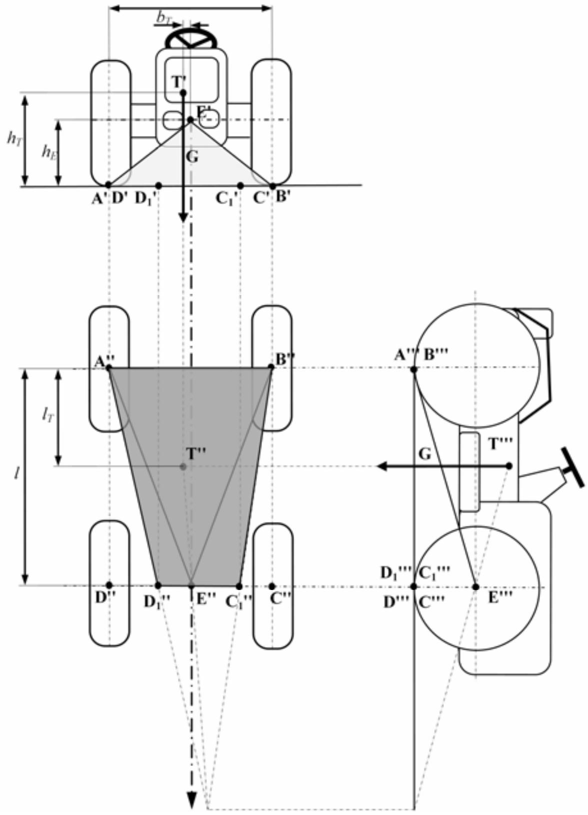

Fig. 5 Supports for a tractor with an oscillating front axle.

1.1.2 Position of the centre of gravity

The centre of gravity is the key element of determining tractor's static stability. The centre of gravity is marked with point (T) that involves the whole mass of a tractor. The position of the centre of gravity is given as the distance of the centre of gravity from the ground(h_T), its distance from the rear axle (l_T) and its shift from the tractor's axle to the right, in the direction of driving (b_T) (Figure 5).

The ISO 789-6 [9] standard stipulates the method for defining the centre of gravity for tractors. Manufacturers usually do not state exactly the position of the centre of gravity. Its distance from the rear axle (l_T) can be determined by looking into the ratio between both axles loads. According to the literature, a typical position of the centre of gravity is 25.4 centimetres above the ground and 0.6 metre before the rear axle and in the middle of the tractor's main body. These data refer to rear wheel driven tractors and weight distribution 30-70 between the front (30%) and the rear axle (70%) [11]. The author states that the centre of gravity in four wheel driven tractors is shifted a little forward. The exact position of the centre of gravity also depends on additional loads and trailed equipment.

1.1.3 Wheelbase

This is the distance between the front and the rear axle. The wheelbase (1) (Figure 6) depends entirely on the size (power) of a tractor and its purpose. A tractor with a longer wheelbase has better working characteristics but its agility remains a problem. The wheelbase mostly affects tractor's longitudinal static stability.

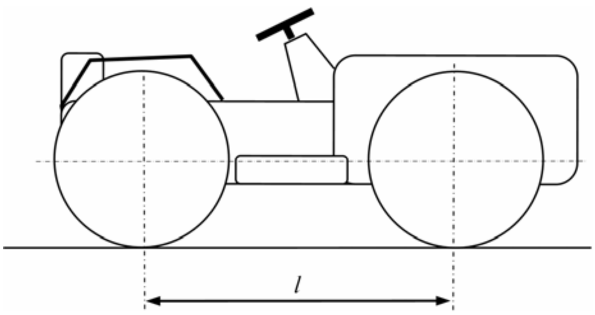

Fig. 6 Tractor's wheelbase

1.1.4 The wheel track width

The ISO 4004 [10] standard defines the wheel track width (b) as the distance between the symmetry planes of the wheels on the same axle (Figure 7). Similarly to the wheelbase, the track width depends on the size of a tractor. The ISO 4004 standard recommends the following wheel track widths: 1500 ± 25mm, 1800 ± 25 mm and 2000 ± 25 mm. Contrary to the wheelbase, the track width affects lateral stability only and has no influence upon the longitudinal stability.

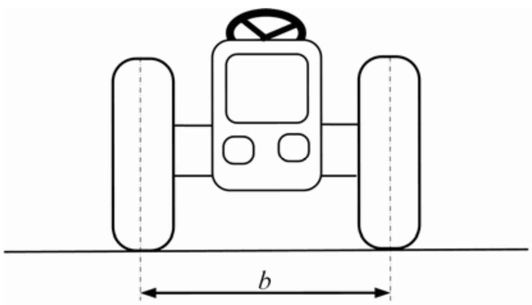

Fig. 7 Tractor's wheel track width.

1.1.5 The height of the oscillating axle mounting point

The height of the oscillating axle mounting point h_E (Figure 8) is the distance between the centre of the oscillating mounting of the front axle (point E) from the ground. It mostly depends on the size of a tractor and design solutions of the front axle. The height of the oscillating front axle mounting point is usually the same as the radius of the front wheels. The height of the oscillating mounting point affects tractor's lateral stability particularly when it is going down a slope.

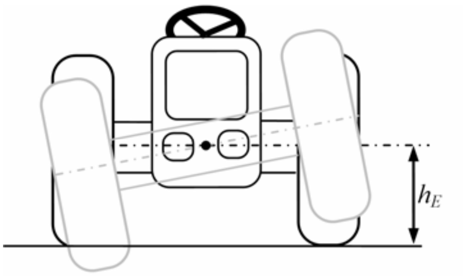

Fig. 8 The height of the oscillating axle mounting point

2 Mathematical model

Choosing a suitable mathematical model is an important step towards defining the numerical values for tractor's static stability. The model determines complexity of the subsequent procedures and agreement between the results and the measurements. Our mathematical model for determining the static stability has been designed for a tractor with an oscillating front axle (Figure 5). The position of the centre of gravity, the wheelbase, the track width and the height of the oscillating axle mounting point are the input data that can be manipulated. This procedure allows assessing the influence of individual parameters on static stability. Static instability, leading to a tractor overturn occurs when the line of force $\vec{G}$, passing through the centre of gravity T, passes over the support plane ABC_1D_1. In terms of the point where the line of force passes over the support plane, there are two examples of static stability:

1. Longitudinal static stability

   Longitudinal static stability becomes an issue when a tractor rolls over either the rear wheels (Figure 10a) or front wheels (Figure 10b)

2. Lateral static stability

   When a tractor rolls over its left (Figure 13a) or right wheels (Figure 13b) it is a matter of lateral static stability.

Angle β describes angular movements of a tractor in relation to the direction of a slope. In the selected coordinate system, angle $\beta = 0°$ shall mean that a tractor points up a slope, $\beta = \pm 90°$ represents a

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tractor perpendicular to a slope and $\beta = \pm 180°$ shall mean a tractor pointing down a slope (Figure 9).

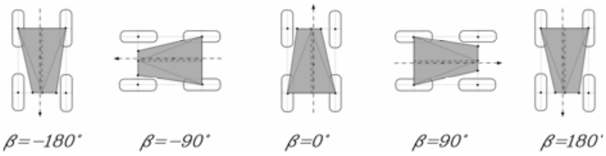

Fig. 9 Position of a tractor on a slope.

The line between longitudinal stability and lateral stability (rolling over points A, B, C_1 and D_1) is marked with corresponding angles β_k. They are determined with geometry means (equations 1.1, 1.2, 1.3, 1.4)

$$\beta_{kA} = \tan^{-1}\left(\frac{\frac{b}{2} - b_T}{l_T}\right) \quad (1.1)$$

$$\beta_{kB} = \tan^{-1}\left(\frac{\frac{b}{2} + b_T}{l_T}\right) \quad (1.2)$$

$$\beta_{kC_1} = \tan^{-1}\left(\frac{\frac{l_F\left(\frac{b}{2} + b_F\right)}{l + l_F} + b_F + b_T}{l - l_T}\right) \quad (1.3)$$

$$\beta_{kD_1} = \tan^{-1}\left(\frac{\frac{l_F\left(\frac{b}{2} - b_F\right)}{l + l_F} + b_F - b_T}{l - l_T}\right) \quad (1.4)$$

with:

$$l_F = \frac{h_E(l - l_T)}{h_T - h_E}$$ and

$$b_F = \frac{b_T \cdot h_E}{h_T - h_E}.$$

2.1.1 Longitudinal static stability

Longitudinal static stability becomes an issue when a tractor rolls over either the rear wheels (segment $\overline{AB}$) or front wheels (segment $\overline{C_1D_1}$) (Figure 5). What follows is an example where static stability depends solely on the distance of the centre of gravity from the rear axle and from the ground (equation 1.5).

$$\gamma_{\beta=0°} = \tan^{-1}\left(\frac{l_T}{h_T}\right) \quad (1.5)$$

With $\beta = \pm 180°$ (tractor pointing down a slope) (Figure 10b), its static stability depends on the height of the centre of gravity and its distance from the front axle (equation 1.6).

$$\gamma_{\beta=\pm180°} = \tan^{-1}\left(\frac{(l - l_T)}{h_T}\right) \quad (1.6)$$

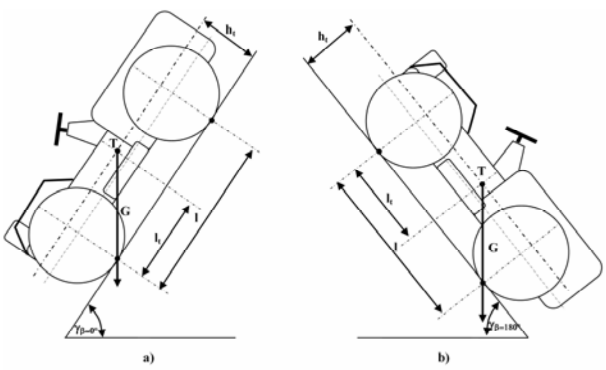

Fig. 10 Longitudinal static stability; a) rolling backwards ($\beta = 0°$), b) rolling forwards ($\beta = \pm 180°$).

Generally speaking, when tractor's position is between $-\beta_{kB}$ and β_{kA} (rolling over the rear wheels) in relation to the direction of a slope, tractor's static stability can be calculated using equation 1.7 (Figure 11a). When tractor's position is between $\pi - \beta_{kC_1}$ and $\pi + \beta_{kD_1}$ (rolling over the front wheels), static stability can be calculated using equation 1.8 (Figure 11b).

$$\gamma_{-\beta_B \le \beta \le \beta_{kA}} = \tan^{-1}\left(\frac{\frac{l_T}{\cos(\beta)}}{h_T}\right) \quad (1.7)$$

$$\gamma_{\pi-\beta_{C1} \le \beta \le \pi+\beta_{kD1}} = \tan^{-1}\left(\frac{\frac{l - l_T}{\cos(\beta)}}{h_T}\right) \quad (1.8)$$

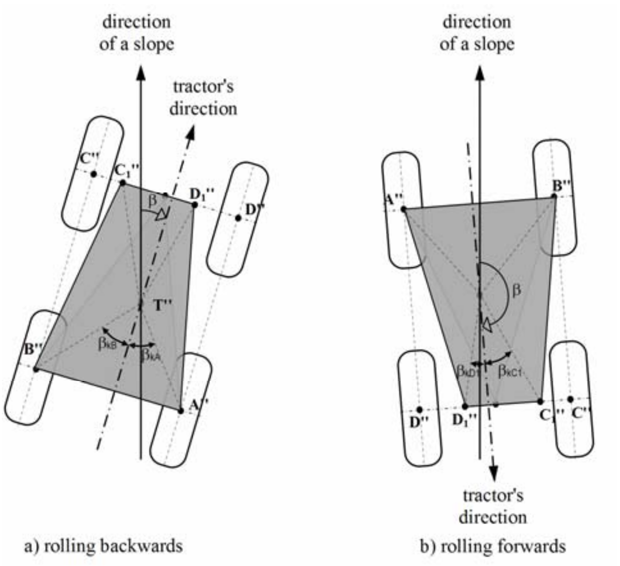

Fig. 11 Longitudinal static stability limit.

2.1.2 Lateral static stability

Lateral static stability is defined as the point where a tractor tips over to its side (segments $\overline{AD_1}$ and $\overline{BC_1}$ respectively) (Figure 3). Besides tractor's characteristics and similarly to longitudinal stability, lateral stability also depends on the angle of a tractor on a slope. With $\beta = \pm 90°$ (tractor perpendicular to a slope) (Figure 12), it is a matter of pure lateral static stability. When a tractor rolls over its right side it is a matter of right lateral stability, determined using the equation 1.9. When a tractor rolls over its right side the left, lateral stability is calculated using the equation 1.10.

$$\gamma_{\beta=90°} = \tan^{-1}\left(\frac{(l - l_T + l_F)\cdot\left(\frac{b}{2} - b_T\right)}{(l + l_F)\cdot h_T}\right) \qquad (1.9)$$

$$\gamma_{\beta=-90°} = \tan^{-1}\left(\frac{(l - l_T + l_F)\cdot\left(\frac{b}{2} + b_T\right)}{(l + l_F)\cdot h_T}\right) \qquad (1.10)$$

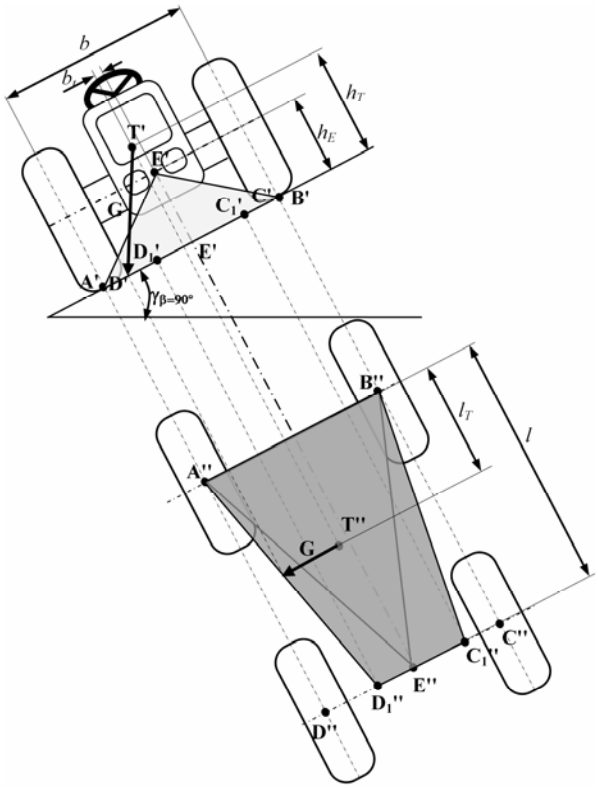

Fig. 12 Pure lateral static stability of a tractor ($\beta = 90°$).

When tractor's angle in relation to the direction of a slope is between β_{kA} and $\pi - \beta_{kD_1}$ (tipping over to its right side) (Figure 7b), tractor's static stability can be described by the equation 1.11. When tractor's angle is between $-\beta_{kB}$ and $-\pi + \beta_{kC_1}$ (tipping over to its left side) (Figure 7a), tractor's static stability is described by the equation 1.12.

$$\gamma_{\beta_{kA} \le \beta \le \pi - \beta_{kD1}} = \tan^{-1}\left(\frac{l_T \cdot \cos\left(\beta_{kA} + \tan\left(\frac{l + l_F}{\frac{b}{2} + b_F}\right)\right)}{\cos(\beta_{kA})\cdot\cos\left(\beta + \tan\left(\frac{l + l_F}{\frac{b}{2} + b_F}\right)\right) h_T}\right) \qquad (1.11)$$

$$\gamma_{-\pi + \beta_{kC1} \le \beta \le -\beta_{kB}} = \tan^{-1}\left(\frac{l_T \cdot \cos\left(\beta_{kB} - \tan^{-1}\left(\frac{l + l_F}{\frac{b}{2} - b_F}\right)\right)}{\cos(\beta_{kB})\cdot\cos\left(\beta - \tan\left(\frac{l + l_F}{\frac{b}{2} - b_F}\right)\right) h_T}\right) \qquad (1.12)$$

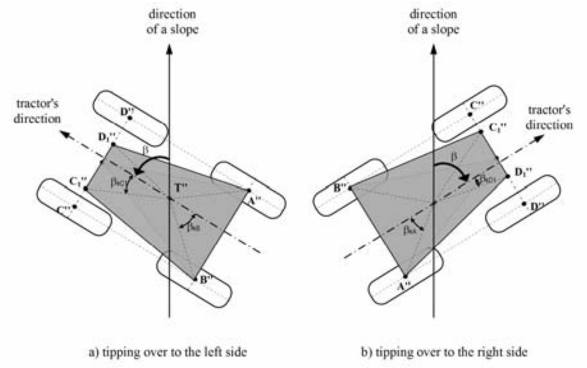

Fig. 13 Lateral static stability limit.

Tab. 1: Values for design parameters of a characteristic tractor

Wheelbase l	121 mm
Track width b	96 mm
Height of the oscillating front axle mounting point h_E	28 mm
Distance between the centre of gravity and the ground h_T	44,5 mm
Distance between the centre of gravity and the rear axle l_T	52,2 mm
Shift of the centre of gravity from the tractor's symmetry plane to the right b_T	0 mm

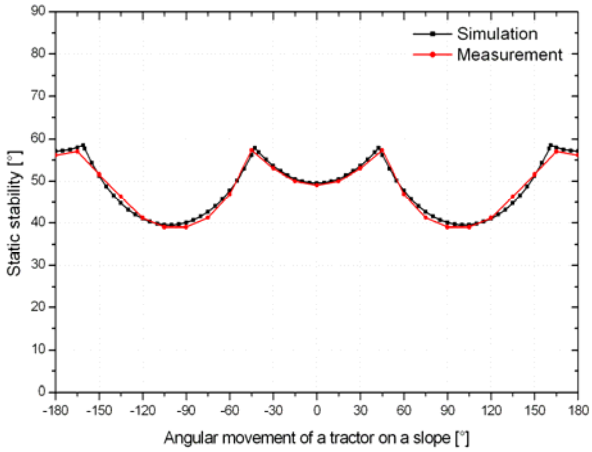

Fig. 15 Comparing static stability of the characteristic tractor model.

3 Results

3.1 Comparison between the measured and simulated tractor's static stability

We designed a characteristic model of a tractor design, featuring an oscillating front axle. Using a measuring apparatus, shown in Figure 14, we measured the actual static stability of a characteristic model of a tractor in relation to the angular movement on a slope.

Fig. 14 Measuring static stability of a characteristic model of a tractor in relation to its position on a slope

After that, we measured individual values of the design's parameters and determined the position of the centre of gravity for the characteristic model according to the ISO 789-6 standard. The results of the measurement are shown in Table 1. These data were used as the basis for a numerical simulation. A comparison between the collected results of the measurements and the simulation (Figure 15) confirmed that the selected process of numerically simulating static stability of a tractor with an oscillating front axle was suitable.

3.2 Analysis of the effects of changing design parameters on tractor's static stability

Simulating static stability of a tractor at different values of individual parameters, we analysed the effects of changing individual parameters of the tractor design on tractor's static stability. Figure 16 shows simulations of static stability for the Reform MOUNTY 65 mountain tractor. Its characteristic values are shown in Table 2.

Tab. 2: Values of design parameters for the Reform MOUNTY 65 mountain tractor [12].

Wheelbase l	2195 mm
Track width b	1580 mm
Height of the oscillating front axle mounting point h_E	352 mm
Distance between the centre of gravity and the ground h_T	680 mm
Distance between the centre of gravity and the rear axle l_T	960 mm
Shift of the centre of gravity from the tractor's symmetry plane to the right b_T	9 mm

Individual uninterrupted sections represent the limits of tractor's static stability in terms of the type of overturns - forwards, to the left, backwards, to the right and forwards again (Figures 11 and 13).

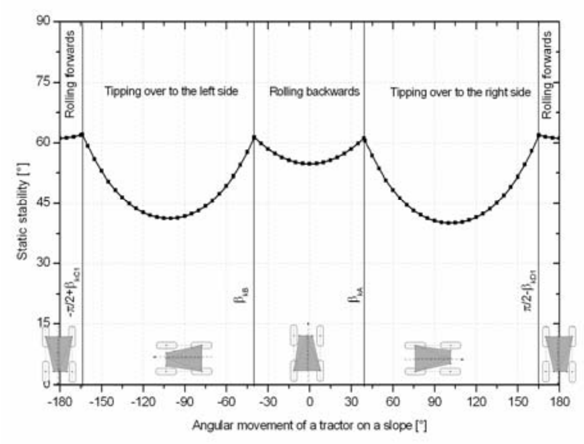

Fig. 16 Simulating static stability of the Reform MOUNTY 65 mountain tractor.

3.2.1 Tractor's static stability in relation to the changes of the wheelbase

The range of tractor's static stability is changing due to changes of its wheelbase. The wheelbase was changed in the range between 1500 and 3000 mm with a constant weight distribution between the rear (56,3%) and the front (43,7%) axle. In order to assess tractor's static stability, simulations for the wheelbases of 1500 mm, 1800 mm, 2500 mm and 3000 mm were carried out. The graph in Figure 17 shows that increasing the wheelbase at a constant load has the biggest influence on improvements in longitudinal static stability. At the same time, the range of longitudinal static stability (Figure 11) is being reduced together with a longer wheelbase. Changes of the wheelbase have a minimal effect on lateral static stability. Other parameters that are not changing are presented in Table 2.

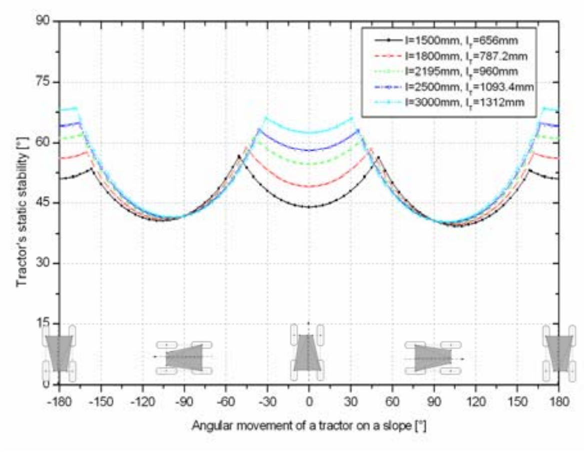

Fig. 17 Simulating tractor's static stability in relation to the changes of the wheelbase.

3.2.2 Tractor's static stability in relation to the changes of the track width

Increasing the track width is the best known way of improving tractor's stability. Turning wheel rims is the most widely used method of changing the track width. Figure 18 shows a graph representing simulations of tractor's static stability with track width symmetrically changing from 1200 mm to 2000 mm. Similarly to the changes of the wheelbase, this example showed that increasing the track width has the biggest effect on improvement of tractor's lateral stability and simultaneously on the range of lateral static stability (Figure 13). Other parameters that are not changing are taken from Table 2.

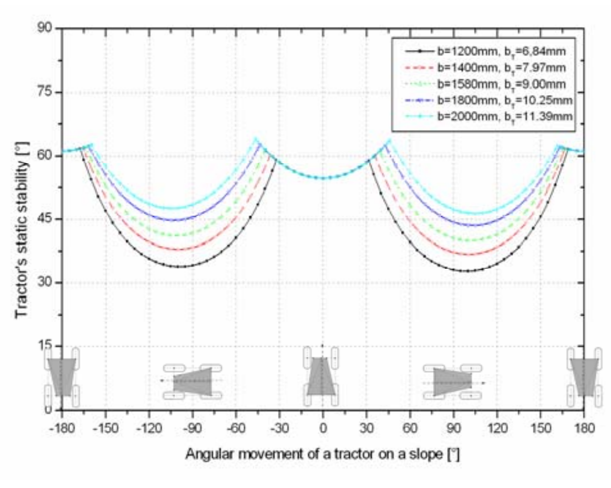

Fig. 18 Simulating tractor's static stability in relation to the changes of the track width.

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3.2.3 Tractor's static stability in relation to the changes of the height of the front axle mounting point

With existing design solutions on standard tractors, produced by established manufacturers, the height of the oscillating front axle mounting point is the same as the radius of the front wheels. Changing the size of wheels also means different mounting points of the oscillating front axle but at the same time, the height of the centre of gravity changes, too. Changing the height of the oscillating front axle mounting point without significantly changing the height of the centre of gravity would require designing a special front axle mounting. We carried out numerical simulations of static stability at different heights of the oscillating front axle mounting point at a constant height of the centre of gravity. Comparing the results (Figure 19) has revealed that a higher oscillating mounting point has the biggest effect on improvements in lateral stability when driving down a slope and it increases the range of longitudinal static stability (Figure 11b). When the height of the oscillating front axle mounting point is the same as the height of the centre of gravity points C_1 and D_1 become points C and D (Figure 5), and we get the effect of stiffly mounted wheels.

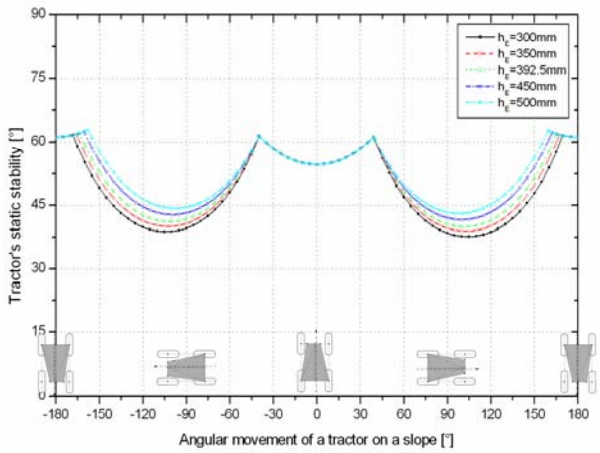

Fig. 19 Simulating tractor's static stability in relation to the changes of the height of the front axle mounting point

3.2.4 Tractor's static stability in relation to the changes of the distance between the centre of gravity and the rear axle

Distance between the centre of gravity and the rear axle, i.e. the position of the centre of gravity in the longitudinal direction, depends of the weight distribution between the front and the rear axle. For standard, four wheel driven tractors, the usual weight distribution is 60% to the rear and 40% to the front axle. With rear wheels driven tractors, the centre of gravity is pushed a little further back. On the other hand, the centre of gravity on transport and towing tractors is pushed a little further to the front axle (Bernik, 2004). We designed a simulation for static stability of a tractor with a wheelbase of 2195 mm and changing weight distribution between the rear and the front axle: 70% at the rear and 30 % at the front ($l_T = 658.5mm$), 60% at the rear and 40 % at the front ($l_T = 878mm$), 56.3% at the rear and 43.7 % at the front ($l_T = 960mm$), 50% at the rear and 50 % at the front ($l_T = 1097.5mm$) and 40% at the rear and 70 % at the front ($l_T = 1317mm$).

Comparing the results in Figure 20 has revealed that a shorter distance of the centre of gravity from tractor's rear axle means lower longitudinal stability in case of overturning backwards. Lateral static stability and longitudinal static stability in case of overturning forwards increase with a shorter distance between the centre of gravity and the rear axle. The range of longitudinal static stability in case of overturning backwards (Figure 11a) increases while in case of overturning forwards (Figure 11b) it decreases but at a considerably slower rate.

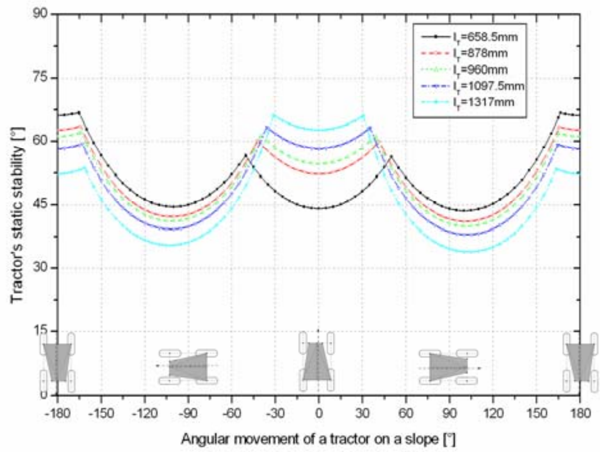

Fig. 20 Simulating tractor's static stability in relation to the changes of the distance between the centre of gravity and the rear axle

The effect of changes in the position of the centre of gravity in the longitudinal direction also appears when different symmetrical devices are attached to a tractor. Devices, attached to the rear of a tractor decrease the distance of the centre of gravity from the rear axle while devices, attached to the front of a tractor, increase the distance.

3.2.5 Tractor's static stability in relation to the changes of the distance between the centre of gravity and tractor's symmetric plane

Measuring the position of the centre of gravity in accordance with the ISO 789-6 standard showed that it is not necessary for the centre of gravity to be within tractor's symmetric plane. Compared to the track width, the effect of shifting the centre of gravity from the symmetric plane is negligible (0.6% for the Reform MOUNTY 65). Attaching devices to the side of a tractor can significantly contribute to decreasing lateral stability on the side where the device is attached. For this reason, we designed a numerical simulation for tractor's static stability, where the centre of gravity was shifted from the symmetric plane by 0 to 200 to the right, looking in the direction of a tractor. Results show that increasing the distance between the centre of gravity and the symmetric plane has the biggest effect upon the lateral static stability. Figure 21 shows simulations of static stability for the cases when the centre of gravity is shifted to the right, looking in the direction of driving. Shifting to the left ($b_T < 0$) yields a mirrored picture.

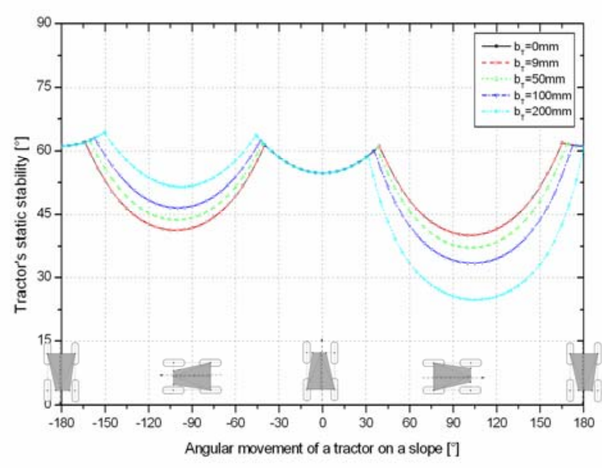

Fig. 21 Simulating tractor's static stability in relation to the changes of the distance between the centre of gravity and tractor's symmetric plane

3.2.6 Tractor's static stability in relation to the changes of the distance between the centre of gravity and the ground

Results in Figure 22 show that out of all the above-mentioned parameters, the distance between the centre of gravity from the ground has the biggest effect. We analysed the results of simulations where the centre of gravity's heights between 400 and 960 mm above the ground were monitored. It has been concluded that lowering the centre of gravity significantly contributes to improvements in static stability (lateral and longitudinal) over the entire range of tractor's angular movements on a slope.

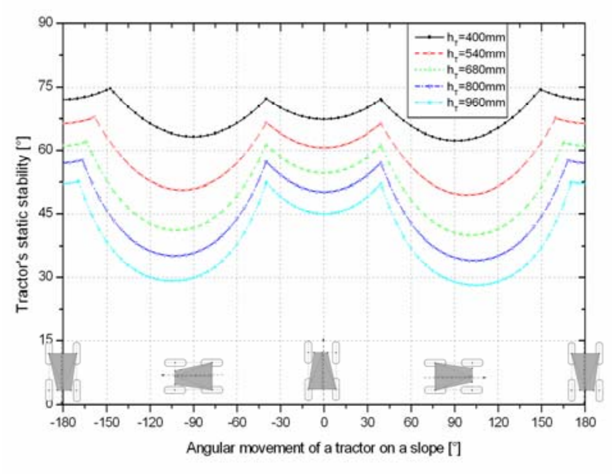

Fig. 22 Simulating tractor's static stability in relation to the changes of the distance between the centre of gravity and the ground

4 Conclusion

On the basis of a numerical simulation, we analysed influences of individual design parameters on tractor's static stability in relation to its position on a slope. It has been concluded that the distance between the centre of gravity from the ground has the biggest effect on static stability. By lowering the centre of gravity, longitudinal as well as lateral static stability improve. The limiting factor here is the clearance height under a tractor.

Longitudinal static stability can be improved by increasing the wheelbase. This parameter also has a limiting factor because a longer wheelbase means less agility - a bigger turning circle. This problem can be partly solved by improving the steering system (bigger angle of lock or four wheel steering). With a constant wheelbase and in terms of overturning backwards, a similar effect can be achieved by increasing the distance of the centre of gravity from the rear axle. However, it results in a lower lateral as well as longitudinal static stability in case of overturning forwards.

Numerical simulations have shown that the problem of longitudinal static stability and partially also that of lateral static stability can be solved by the height of the oscillating front axle mounting point, particularly when driving down a slope. Positive effects of such change can be observed up to the point when the height of the oscillating front axle mounting point is the same as the height of the centre of gravity.

Things are similar for lateral static stability. Increasing the track width increases lateral static stability, however, there is a problem of roadways width. A solution to this problem has been found in the form of a fast continuously variable track width during the operation. Besides, the system allows an easy and quick adjustment of track width, depending on working conditions, contributing to time efficiency and quality of work.

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