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TRACTOR DECELERATION DEPENDENCY BY THE KINEMATIC DISCREPENCY

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Abstract

Tractor 4×4 moving with enabled front axle drive, in many cases there are kinematic discrepancies between the front and rear wheels theoretical speeds. Once the tractor is unloaded from pull or push forces, kinematic discrepancies makes one wheel to slip, while the other skid. Therefore, during the braking process, the kinematic discrepancy changes the wheel's adhesion to the road.

In this research, we have proven that, kinematic discrepancy reduces the braking efficiency. By comparing the braking performance of the tractor while braking, we can clearly say it the tractor braking performance varies when the different kinematic factor. However, with a small tractor speed, the total braking time and averages of deceleration are almost equal, regardless of the kinematic discrepancy.

The article presents and analyses tractor with 4x2 and 4x4 driving wheels braking deceleration parameters, when the tractor is braking with engine with different kinematic discrepancy

*Keywords**:** deceleration, braking, tractor, tires.*

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Introduction

Tractors of these times are much faster and more efficient, so they have different uses. Tractors are working in transport, cargo, driving with implements and without them in the fields, etc. for most of the time. However, the specifics of agricultural machinery work are special - the driving conditions often change - hard soil - soft soil - road, etc. Therefore, it is not always optimal to use constant tractor parameters. The most used tractors are with 4x4 driving wheels, of which the effectiveness is highly dependent on kinematic discrepancy. Kinematic discrepancy between front and rear wheels can be because of disproportionately wheel rolling radius changes. It happens because of tires deformations, wheels that are not identical and coordinated. The ideal case of vehicles is when kinematic discrepancy is equal to 1, that means speed of front and rear wheels axles are identical. In agricultural tractors rear and front wheels are usually different sizes and front wheels theoretical driving speed are higher by 1-3 percent compared to rear [9,12].

In order to improve the tractor traction parameters and efficiency, in most cases ballasts are used, the tire air pressure is reduced or various traction control systems are used. But almost all of these cures change the tractor tire roll radiuses, it means that additional tire deformation occurs, and kinematic discrepancy occurs. Due to the kinematic discrepancy between the theoretical speeds of the front and rear wheels (even on a straight-line road), the front wheels start to slip. Then the steering wheel does not sufficiently engage with the base and does not produce the required power to turn the tractor on the tractor, worsening him steering [1,5,6].

If tires inflation pressure and tractor driving speed are changed, tires deformation and wheels radiuses heavily exchange. But if the drive-wheels radiuses are changing disproportionately, the tractor's with locked drive-axles, linear velocity of front and rear wheels doesn't match who gives large kinematic discrepancy, which increases power losses in transmission and reduces the total tractive efficiency and give it lowest braking performance when tractor braking. For this reason kinematic discrepancy influences significantly power distribution between the driving axles and wheels and as consequence fuel consumption, mobility, and stability [1,2,3]

So the important parameters, if we need to describe kinematic discrepancy are three tire parameters [4,5]:

- Inflation pressure;
- Tire size;
- Wear

However, the kinematic inconsistency factor not only reduces the efficiency of tractor engagement, but also reduce the tractor's driving speed [5,6].

Generally, it is the following actuating forces that reduce the tractor's speed:

- braking;
- rolling resistance;
- air resistance;
- friction bearings;
- etc.

Brake and steering systems in vehicles are the most effective gear, which directly affects the vehicle dynamics. In general, the brake system is running in the longitudinal vehicle dynamics and driving dynamics system running side.

All braking systems are divided into two categories: 1) emergency braking, corresponding to a maximum possible braking intensity 2) operational or partial braking [3,8]

The maximum braking force developed by vehicle wheel depends on the wheels' grip to the road and vertical road reaction affecting the wheel. Operational braking intensity is always less than the maximum possible braking efficiency. Emergency braking does not exceed 5 – 10% of all braking situations [6,7,8].

Engine braking occurs when the retarding forces within an engine are used to slow the vehicle down and not using additional external braking mechanisms, example like friction brakes.

The efficiency prescribed for a braking system should be determined based on the stopping distance s_z or the mean value of fully developed deceleration d_m [11]:

$$s_z = \frac{v}{3,6}\left(t_0 + \frac{1}{2}t_n\right) + \frac{1}{2}\frac{(v/3.6)^2}{d_m}, \ \text{m} \qquad (1)$$

where: v – initial speed [m s^{-1}]; t_0 – brake actuation time referred to as the braking system delay time ,s; t_n – braking deceleration increase time, s, d_m – fully developed braking deceleration, m/s^2.

When stopping with emergency brake with grouped the brake pedals, automatically turning on front wheel drive, because of the front and rear drive axles kinematic coupling all wheels are used. For this reason the tractor's 4×4 braking dynamics are inseparable from driving wheels' kinematic discrepancy.

So summing up, we can say that correct kinematic discrepancy can increase other tractor parameters, like better traction force, lower roiling resistance, better fuel economy but also making better braking performance [5-11].

Aim of the research

The aim of this research is to analyze kinematic discrepancy for the all-wheel drive tractor when braking by engine and show how the tractor's braking different from the kinematic discrepancy with different tires radius.

Materials and methods

By studying the processes of transport dynamics from the kinematic discrepancy, changing the tire pressure, it has been observed that changing the tire air pressure- changes the other parameters of the tire. Therefore, in order to avoid this, a uniform tire pressure was used, and a tire of different height (Fig. 1) was used for due to kinematic discrepancy. Main goal of this research is to find tractors engine braking parameter dependency by different tires radius and driving speed in the same road pavement.

The main technical data of the tractor Ford 8340 used in the experiments are shown in Table 1.

Table 1. Technical data of tractor

Technical data	**Ford 8340**
Rated engine power, kW	98
Rated engine speed, rpm	2100
Weight of the tractor, kg	3800
Wheelbase, mm	2610
Front tires (1,)	Trelleborg 440/65 R28, year: 2009, t.d. 77 %
Front tires (2)	Trelleborg 440/65 R24 year: 2009, t.d. 76 %
Rear tires	Trelleborg 540/65 R38 year: 2010, t.d. 73%
Weight of the front axle, kg	1500
Weight of the rear axle, kg	2300
Recommendations front tires pressure, kPa	170 - 200
Recommendations rear tires pressure, kPa	140 - 160

Figure. 1. Different tires type: 1 – Trelleborg 440/65 R28; 2 – Trelleborg 440/65 R24

The first tires are designed in standard equipment for the tractor. Tractor deceleration, braking distance, time and different engine speeds with different gear was measured. Driving speed and engine gear are shown in Table 2.

Table 2. Driving and engine speed from a different gear

Gear/rpm	1200	1600	2000
4	1,39 m s^{-1}	2,5 m s^{-1}	3,06 m s^{-1}
5	2,78 m s^{-1}	3,06 m s^{-1}	4,17 m s^{-1}
6	3,61 m s^{-1}	3,89 m s^{-1}	5 m s^{-1}
7	4,45 m s^{-1}	5 m s^{-1}	5,56 m s^{-1}

Investigations was carried out with the tractor reaching driving speed at a certain engine speed with identical, but different tire sizes on the gravel road.

Weather conditions was: temperature 18°C, wind speed 3,8 m s^{-1} and humidity 70 %.

Tractors braking parameter research dependency from tires size and driving speed was made with recommendations front 180 kPa and rear 150 kPa tire pressure. All research was made with front drive turned on and turned off, riding on the same segment, same direction with different driving speed. Test were made on the gravel road surface, on horizontal, straight road. For distance measuring we used Measi S3a measurement device with measurement error of ±1.5 mm. For deceleration measuring we used AccDriver 211 device (Fig. 2.) which is mounted in the tractor.

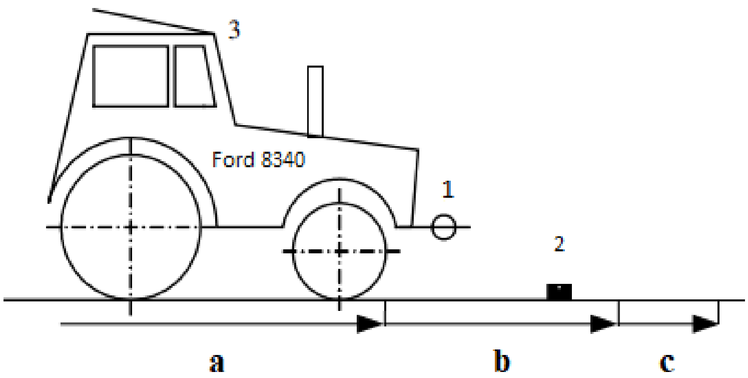

Figure. 2. Research scheme: 1 – distance indicator; 2 – the marked line; 3 – deceleration measurement device; a – tractor acceleration; b – constant speed zones; b – braking zones

The device was activated prior to the test. During the test, the tractor braking device automatically show an acceleration and deceleration of the tractor. When starting to stop, the device activation is not required. When the tractor has reached the steady driving speed, the device has been switched on and the braking process is starting. The device AccDriver 211 has a built-in memory and stores the test data automatically. All device result was check additionally with counting of distance travelled and braking time.

Technical parameters of AccDriver device are presented in Table 3.

Table 3. Acceleration measurement device AccDriver 211 technical specification.

Technical data	**AccDriver 211**
Size	105x65x20 mm
Screen	132x32 point
Acceleration measurement range	±2g (±20 m s^{-2})
Acceleration measurement accuracy (when 25 ^{0}C)	0,04 m s^{-2}
Weight	100 g

In order to have more accurate results, all tests were repeated 3 times.

Results

Tractor 4×4 moving with enabled front axle drive, in many cases there are kinematic discrepancies between the front and rear wheels theoretical speeds. If tires radius are changed, kinematic discrepancy will be changed. During the braking process, the kinematic discrepancy changes the wheel's adhesion to the road.

The tests are presented by comparing the results obtained with the tractor braking with R24 and R28 tyres. Tractor with different tire size have different kinematic discrepancy.

Fig 3 shows the tractor moving resistance force dependent tractor tires size, when front tires are changed, while the rear is steady.

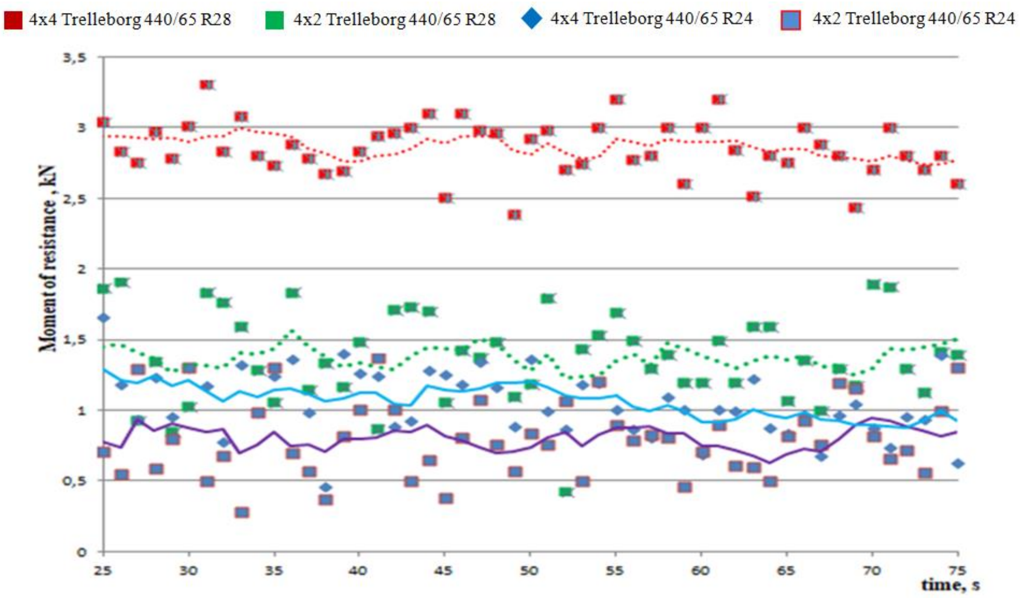

Figure. 3. Tractor moving resistance force dependency on different tire size on the front, while rear tires are steady, on gravel surface road

Tractor 4x4 with R24 tires in front, kinematic discrepancy was 1.02. It is almost perfect results, which recommends agricultural tractors, where wheels are different sizes. Moment of resistance was respectively equal to 0,88 kN and different 1,21 kN when turn off 4x2 and turn on 4x4 front axle. But when we changed the tires to R28, kinematic discrepancy grow till 1,08 and moment of resistance increased almost two times compared with R24, from 1,42 kN to 2,87 kN. It shows, that we lost traction power, when we have bigger kinematic discrepancy.

If we look at Fig 4, where are the tractor's 4x2 engine braking and comparing the moment resistance of the tractor according to tire height, we find that the increased efficiency of the kinematic discrepancy, the tractor's efficiency decreases because requires a higher engine power to overcome to the higher moment resistance. However, when the tractor engine is braked, the higher kinematic factor is the opposite.

In Fig 4 showed that the tractor's 4x4 deceleration is very similar. The deceleration averages for the tires R24 and R28, respectively are 0.7 and 0.8 m s^{-2}, and the maximum braking values are almost equal.

However, Fig 5 shows in the case of tractor 4x4 at the lower driving speed, the deceleration respectively raise from 0.7 to 0.8 m s^{-2} at R24 and 0.8 to 1 m s^{-2} when used R28 tires.

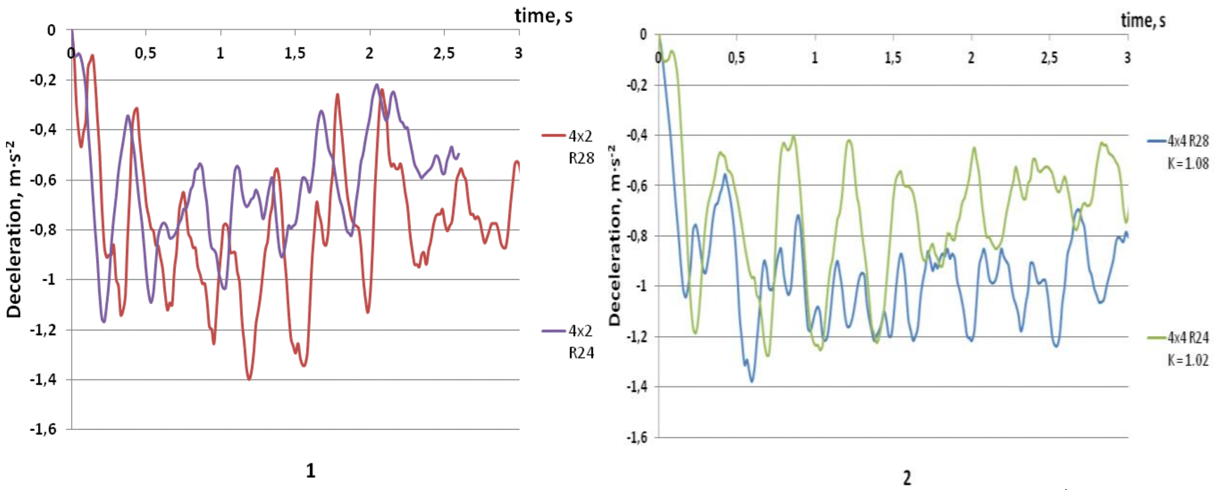

Fig. 4. Tractor 4x2 (**1**) and 4x4 (**2**) engine deceleration when driving speed 5,56 m s^{-1}

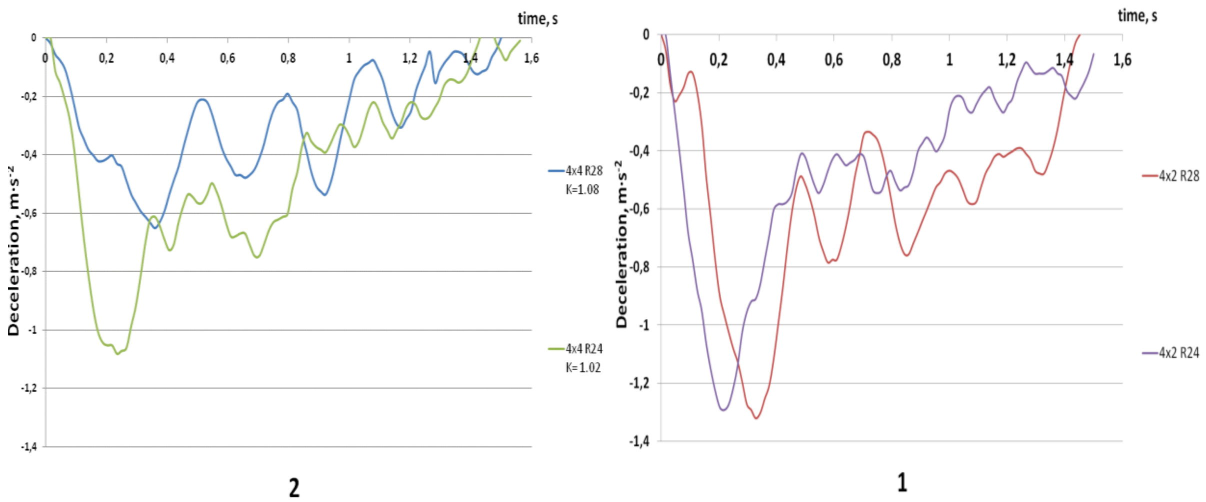

Fig. 5. Tractor 4x2 (**1**) and 4x4 (**2**) engine deceleration when driving speed 1,39 m s^{-1}

Comparing Fig 4 and Fig 5, it can be seen that the tractor deceleration is longer when driving at 5,56 m s^{-1} speed, if we comparing with 1,39 m s^{-1} driving speed.

To reach 5,56 m s^{-1} speed, the tractor needs to drive gear 7 at 2000 rpm ,when reach 1,39 m s^{-1} need gear 4 and 1200 rpm. As a result, the engine receives a different braking load during braking.

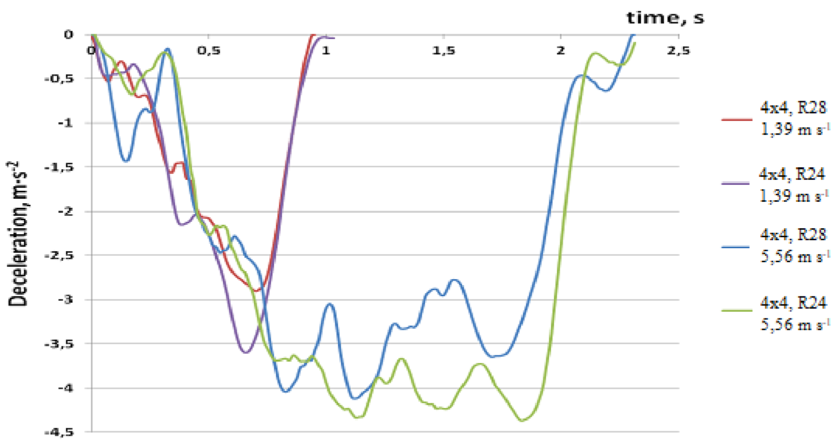

Fig. 6. Tractor 4x4 emergency braking deceleration

But, when returning to the kinematic discrepancy, comparing Fig 4 and Fig 5, the graphs show that the kinematic discrepancy of the tractor at a lower speed does not produce such high efficiency.

By comparing the braking performance of the tractor while braking the engine, we can clearly see in Fig. 6 in the event of emergency braking of tractors. i.e. maximum braking until complete stop, the tractor braking performance varies when the different tire sizes. However, with a small tractor speed, the total braking time and averages of deceleration are almost equal.

So summing up, we can say that kinematic factors have negative effect for tractor's performance parameters.

Conclusions

1. Tractor 4x4 with R24 size tires in front, kinematic discrepancy was 1.02. It is almost perfect results, which recommends agricultural tractors. But when front tires changed to R28 size, kinematic discrepancy grow till 1,08 and moment of resistance increased almost two times compared with R24, from 1,42 kN to 2,87 kN. Therefore, during the braking process, the kinematic discrepancy also changes the wheel's adhesion to the road, so it is negative effect for tractor's performance.

2. Comparing the moment resistance of the tractor according to kinematic, we find that the increased efficiency of the kinematic discrepancy, the tractor's efficiency decreases because requires a higher engine power to overcome to the higher moment resistance. However, when the tractor engine is braked, the higher kinematic factor is the opposite.
3. Front wheels were forced to skid/slip because of kinematic discrepancy, they create the opposite direction of torque transmitted to the rear wheels, for this reason generate lower rear wheel braking torque and the total braking power. So depending on the number of drive axles, the tractor stopping distance and time can be changing.
4. By comparing the braking performance of the tractor while braking, we can clearly say it the tractor braking performance varies when the different kinematic factor. The deceleration averages, when we have 1,08 kinematic factor for the tires R24 and R28, respectively are 0.7 and 0.8 m s^{-2}, and the maximum braking values are almost equal 1,4 m s^{-2}, when driving speed 1,39 m s^{-1}. But when we have it kinematic factor closer to 1, tractor deceleration respectively raise from 0.7 to 0.8 m s^{-2} at R24 and 0.8 to 1 m s^{-2} when used R28 tires.
5. Kinematic discrepancy of the tractor at a lower driving speed does not make such high braking performance efficiency comparing tractor with a higher driving speed.

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