KINEMATIC DISCREPANCY AND MOVING RESISTANCE DEPENDENCE ON TIRES AIR PRESSURE IN 4X4 TRACTORS

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Abstract. The article presents and analyzes the reasons of kinematic discrepancy in 4x4 tractors. The kinematic discrepancy between the driving wheels occurs in tractors and other self propelled machines. In field works, the slippage of the driving wheels is usually adjusted by changing the mass of ballasts and air pressure of tires, but, by adding weight and changing tire air pressure, the wheel rolling radius is changed, too. During transportation, tractors are equipped with trailers and semi trailers. Depending on the load weigh the vertical forces of the tractor and the wheel radius change in wide range. Kinematic discrepancy occurs, then the wheel rolling radius is changed disproportionately. Due to kinematic discrepancy, the front and rear wheels have to slip unequally, some of them can even slide. These factors have negative effect for the tractor performance parameters, the transmission is loaded heavily, power losses are increased, the tires wear faster, fuel consumption is increased. But it is hard to find scientific articles on the impact of kinematic discrepancy on tractor rolling resistance and braking performance. In this article kinematic discrepancy of 4x4 tractors depending on the tire air pressure is shown and analyzed.

Keywords: inflation pressure, kinematic discrepancy, moving resistance, tractor.

Introduction

Kinematic discrepancy is an integral part in all-wheel drive vehicles. It occurs because of theoretical speed difference between the front and rear axles of wheels. Kinematic discrepancy between the front and rear wheels can be because of disproportional wheel rolling radius changes. It happens because of tire deformations, wheels that are not identical and coordinated [1]. The ideal case of vehicles is when kinematic discrepancy is equal to 1, that means the speed of the front and rear wheel axles is identical. In agricultural tractors rear and front wheels are usually of different sizes and the front wheel theoretical driving speed is higher by 2-3 percent compared to the rear [2].

In order to improve the tractor traction parameters, 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. Because of that almost all drive wheels have to slip unequally or some of them start to skid [1, 2]. Skidding of the front wheels influences the power distribution and creates power circulation between the wheel drives and axes. Because of that the fuel consumption, mobility and rigidity of the vehicle are increased. It can be avoided by choosing correct tire pressure in the front and rear wheels by summing up vertical loads correctly [2-4].

Correctly chosen tire air pressure is a very important parameter for tire operation lifetime and tractor‘s attractive force. While riding on harder surfaces (stubble, dry gravel roads, concrete or asphalt surface), the tire air pressure should be higher- 1.5-1.8 bar [5-7]. There are opinions that correctly adjusted tire air pressure also leads not only to lower kinematic discrepancy, but also lets to minimize power losses, which occur due to the influence between the tire and the road. [2; 8; 9].

Correct tire pressure can help minimize kinematic discrepancy and increase other tractor parameters [3; 4; 11; 12]:

- better traction force;
- lower rolling resistance;
- better fuel economy.

The goal of this analysis is to establish the tire influence pressure for the wheel drive theoretical speed kinematic discrepancy, also to find the kinematic discrepancy influence on the all-wheel drive tractor moving resistance.

Materials and methods

By changing the air pressure of the tractor wheel drives, their deformities also change. Disproportionate deformations of the front and rear wheels change all wheel drive tractor‘s kinematic discrepancy size. The main goal of this research was to find the tractor‘s wheel ride kinematic discrepancy, generated by the tire air pressure regulating, variation limits. Also, to find the kinematic discrepancy effect from the tractor moving resistance. For these researches the Case IH Farmall U Pro 115 tractor was used and movement resistance was generated by using another tractor (Zetor 10540). The main technical data of the tractors used in the experiments are shown in Table 1.

Table 1

Technical data of tractors

Technical data	CASE IH Farmall U Pro 115	Zetor 10540
Rated engine power, kW	114	78,3
Rated engine speed, rpm	2200	2250
Weight of the tractor, kg	4900	4336
Wheelbase, mm	2420	2380
Front tires	Trelleborg 480/65 R24	Barum 19.9 – 14 R38
Rear tires	Trelleborg 540/65 R38	Barum 12.4 – 28TZ19
Weight of the front axle, kg	2004	1848
Weight of the rear axle, kg	2896	2488

For the movement resistance test, the tractor Case IH Farmall U Pro 115 was pulled by Zetor 10540 (Fig. 1). The tractors were joined with rigid connection, which had an integrated pulling force (examined tractors resistance force) measurement device, dynamometer, TCEMT 213 R3. Dynamometer measuring ranges 0-25 kN, measurement error ± 1%.

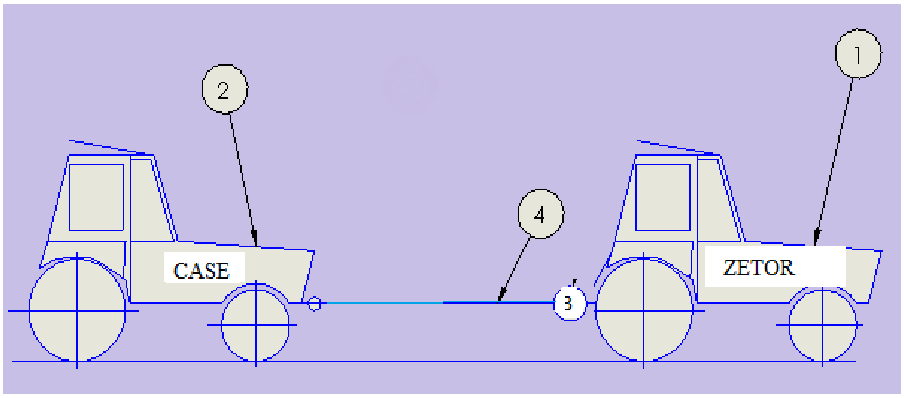

Fig. 1. **Research scheme:** 1 – tractor Case IH Farmall U Pro 115; 2 – tractor Zetor 10540; 3 – pulling force measurement device; 4 – rigid connection

Kinematic discrepancy was calculated by all-wheel drive tractors front and rear wheels slippage rates, the formula is shown below:

$$k_n = \frac{1-\delta_r}{1-\delta_f} \; , \tag{1}$$

where δ_r and δ_f – the slippage (or sliding – when the result was obtained with a minus sign) of the front and rear driving wheels;

Tractors front and rear wheels slippage factor was calculated by the given formula:

$$\delta = \frac{s_t - s_a}{s_t} \; , \tag{2}$$

where s_d and s_a – theoretical and actual wheel distances for 10 wheel rolls.

During the tests, the distances were measured, how far each of the front and rear wheels traveled during 10 rolls. Markers were attached to the front and rear wheels and marks were made on the road for the distances that both front and rear wheel traveled. The theoretical distance according to the

American Society of Agricultural Engineers (ASAE) standard S296.2 as the distance travelled per revolution of the wheel when operating at the specified zero condition. In this research specified zero condition has been given by pulling the tractor with front drive turned off.

Actual distance travelled of the front and rear wheels of the tractor was found by pulling with front drive turned on.

All wheel drive tractor kinematic discrepancy dependence from tire air pressure research was made by creating pressure (0.7; 1.1 ;1.5 ;1.9; 2.3 bar) combinations in tractors front and rear tires. All researches were made with front drive turned on and turned off, riding on the same segment, same direction. Tests were made on hard road surface, on horizontal, straight road. The length of the chosen segment is 80 meters. During all tests the distance, travelled during 10 rolls of both – the front and rear wheels, was measured. For distance measuring we used Measi S3a measurement device with measurement error of ±1.5 mm. In order to have more accurate results, all tests were repeated for 3 times.

Results and discussion

Fig. 2 shows the all-wheel drive tractor kinematic discrepancy between the front and rear tractor wheel dependence, when the tire air pressure in the front and rear tires was: : 2.3; 1.9; 1.5; 1.1 and 0.7 bar.

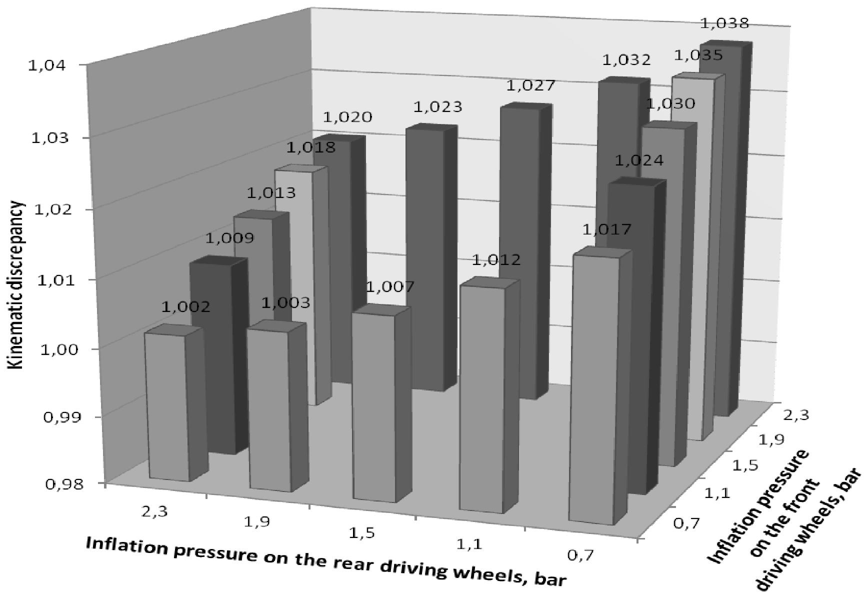

Fig. 2. **Kinematic discrepancy of the driving wheels of the tractor driving on different inflation pressure on the front and rear driving wheels**

In Fig. 2 it can be seen, that the kinematic discrepancy coefficient was higher than 1 during rides with all tire pressure combination (between 0.7-2.3 bar.) in the front/rear tires. The lowest kinematic discrepancy coefficient is equal to 1.002, when the front tire air pressure is 0.7 bar and the rear tire pressure – 2.3 bar. The highest kinematic discrepancy of 1.038 is calculated, when the rear tire inflation pressure is 0.7 bar and the front tire inflation pressure – 2.3. Kinematic discrepancy coefficient lowered from 1.038 to 1.02 when the inflation pressure in the rear tires increased from 0.7 to 2.3 bar, while the inflation pressure in the front tires was constant – 2.3 bar. By reducing pressure in the front tires from 2.3 to 0.7 bar, when pressure in the rear tires was constant 0.7 bar, kinematic discrepancy decreased from 1.02 to 1.002. It shows, that, in order to have lower kinematic discrepancy on asphalt surface, it is recommended to use higher inflation pressure in the rear tires and lower inflation pressure in the front tires.

Fig. 3 and Fig. 4 show the tractor moving resistance force dependent from inflation pressure in the front and rear tires, when the tractor front driving wheels turn off 4x2 (Fig. 3) and turn on 4x4 (Fig. 4) on hard surface road.

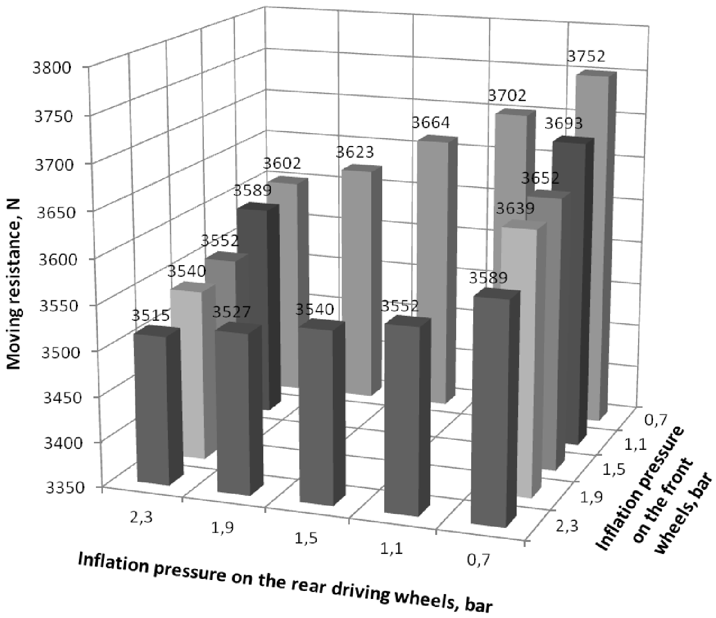

Fig. 3. **Tractor 4x2 moving resistance force dependences on different inflation pressure on the front and rear tires on hard surface road**

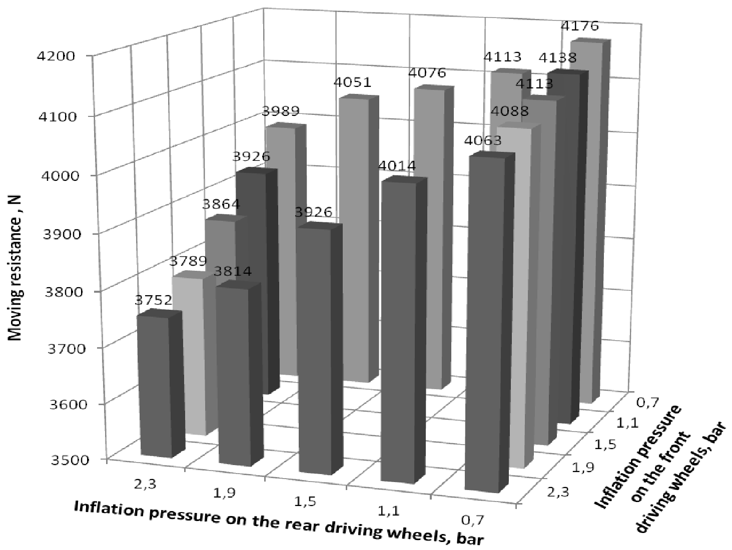

Fig. 4. **Tractor 4x4 moving resistance force dependences on different inflation pressure on the front and rear tires on hard surface road**

Also Figs. 3 and 4 show that for the tractor with 4x2 driving wheels the moving resistance force is lower. It is 474 N, the lowest moving resistance force compared with 4x4 driving wheels, when both the front and rear tire inflation pressure is 0.7 bars. The highest tractor 4x2 moving resistance force on hard surface road is 3752 N, with 4x4 – 4176 N. Equal tire inflation pressure reduced in the front and rear tires gives different effects on the wheel moving resistance. When the front tire inflation pressure is increased from 0.7 to 1.1 bar and rear tire inflation pressure 0.7 bar, the moving resistance on hard surface road decreases from 3752 to 3693 N with 4x2 and from 4176 to 4138 N with 4x4 driving wheels. When the inflation pressure in the rear tires is increased from 0.7 to 2.3 bar and the inflation pressure in the front tires is 2.3 bar, the moving resistance force decreases from 3589 N to 3515 N with 4x2 and from 4063 to 3572 N with 4x4 driving wheels.

The compared Fig. 3 and Fig. 4 show that the moving resistance force is higher, when the inflation pressure in tires is lower. When the tractor moving resistance force is compared with 4x2 and 4x4 driving wheels on hard surface road with different inflation pressure, kinematic discrepancy increases the moving resistance. At the highest kinematic discrepancy, moving resistance between 4x2 and 4x4 driving wheels is the largest – 462 N. The analysed dependencies in Figs. 2, 3 and 4 show that it is related with kinematic discrepancy between the front and rear wheel drive variation.

Conclusions

1. The tractor Case IH Farmall U Pro 115 lowest kinematic discrepancy coefficient between the front and rear-wheel drive is 1.002, when the front tire inflation pressure is 0.7 bar and the rear tire inflation pressure is 2.3 bar.
2. The highest tractor moving resistance force on hard surface road with 4x2 driving wheels is 3752 N, with 4x4 driving wheels – 4176 N.
3. Equal tire inflation pressure reduced in the front and rear tires gives different effects on the wheel moving resistance. This is related to kinematic discrepancy between the front and rear-wheel drive variation.
4. Kinematic discrepancy between the front and rear wheel drives increases the tractor moving resistance on hard surface road. When the highest kinematic discrepancy coefficient is 1.038, the tractor moving resistance is the highest and equal to 462 N, between rides with 4x2 and 4x4 drive wheels.

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