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Possibilities of improving the wheel tractor drive force transmission to soil

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Abstract

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The possibility of increasing maximal drawbar pull of tractor working on the soil was evaluated. The increase in drawbar pull occurred due to special wheels mounted on the drive axle. The special wheels were equipped with auto-extensible blades and designed at the Slovak University of Agriculture in Nitra. The main advantage of the special wheels is an automatic extension of steel blades to increase the drawbar pull during a wheel slip and automatic return to the base position to allow the transport of tractor by the route. The testing operation points at the decrease of wheel slip resulted in the increase of drawbar pull. The drawbar pull of tractor equipped with standard tyres and special wheels was compared in different soil moisture conditions. The higher increase in drawbar pull was measured during the tractor operation on the soil with higher moisture in comparison to the soil with lower moisture level.

Keywords: tractor drawbar pull test; soil moisture; adapter, auto-extensible blades wheel; tipping spikes

The testing of new tractors design used in agriculture keeps on rising since these machines influence directly the agricultural production results (Müllerová et al. 2012). The increase of tractor travelling speed resulting from the reduction of driving wheels slip and thus the reduction of wheel-to-soil impact time is one of the possibilities of negative effects suppression of soil pressing by tractor (Semetko et al. 2004).

Drawbar pull, travel reduction (slip), and rolling resistance are the main criteria to describe the traction behaviour of off-road vehicles. Besides the engine performance, drawbar pull is influenced by the traction conditions such as the soil and tyre parameters (Schreiber, Kutzbach 2008).

The drawbar pull of tractor is influenced by various factors. A very significant parameter influencing the drawbar pull is tyre pressure. Noréus and Trigell (2008) performed the measurement of drawbar pull at various tyre pressures. The test showed that drawbar pull is vastly improved at lower tyre pressure.

Söhne (1968) and Sonnen (1969) compared the two- and four-wheel drive for agricultural tractors. It was found that the tractor with the four-wheel drive achieves better drawbar performance in comparison with the tractor with the rear wheel drive. It is concluded that as tractor power increases and as the soil becomes weaker and less frictional, then the balance of advantage changes from the two-wheel to four-wheel drive. The type of tyres is the next important factor to increase the drawbar pull and influence the tractive performance, as well as soil stresses under a vehicle (Kielbasa, Korenko 2006).

The results of a theoretical analysis reveal that for a four-wheel-drive tractor to achieve the optimum tractive performance under a given operating con-

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Fig. 1. Half-track adapters testing using standard breaking test with breaking vehicle

dition, the thrust (or driving torque) distribution between the front and rear axles should be such that the slips of the front and rear tyres are equal. Field test data confirm the theoretical findings that when theoretical speed ratio is equal to 1, the efficiency of slip and tractive efficiency reach their respective peaks, fuel consumption per unit drawbar power reaches its minimum, and overall tractive performance is at its optimum (Wong et al. 1998).

Based on these principles, following solutions have been proposed for common tractors with the two- or four-wheel drive.

Regarding wheel tractor traction improvement, apart from under-inflation of driving wheels, the tractor drawbar pull enhancement can be summarized into the following four alternatives:

Alternative 1: **Half-track adapters (rear/front+rear)**

These possibilities allow reducing the field operations costs and improve the driving force transfer to a soft base (support). These solutions were tested in a standard drawbar pull test on asphalt paved road and soil surface four years ago (Fig. 1). Triangular rubber track adapters were designed to replace wheels of self-driven agricultural machines and particularly combine harvesters because they cause soil impaction at the highest rate. This solution is expensive and an installation has to be made by specialists.

Alternative 2: **Special wheels with auto-extensible blades**

Based on the analysis of max. driving forces of a small tractor (Sloboda et al. 2008), special wheels with auto-extensible blades were designed at the Department of Transport and Handling of the Faculty of Engineering, Slovak University of Agriculture in Nitra for the rear driving wheels of the tractor Mini 070. The main advantage of this solution is the wheel needs not to be removed when moving on roads as well as auto-extension when tractor driving wheels slip. An automatic return of blades to the basic position is achieved by the reverse motion of the tractor. The auto-extensible blade wheels compensate the weight increase need, so the tractor could not need any additional ballast. The extensible blade wheels are fitted on the wheel disc according to Fig. 2.

Alternative 3: **Anti-skidding paddy adapter/rim**

This equipment is known as a ploughing paddy wheel rim and it is manufactured mainly for two-wheels walking tractors. The tractor has to be lifted to mount it on, lifting being the main disadvantage. Proper mounting onto the tyre using two bolts requires proper tyre inflation to the minimal pressure 200 kPa. The rim is manufactured specially for particular tractor tyre type, Barum 6,15/155-R14-4PR in this case, with unloaded tyre perimeter 1,870 mm and for the tread width 130 mm, it cannot be used for all the R14 tyres generally. However, there is a certain tolerance of use in the perimeter range from 1,810 mm to 1,920 mm of the unloaded (not deformed) tyre. Sixteen pieces of grip blades are welded on the rim perimeter in regular distances.

Fig. 2. Mounting of extensible blade wheels on driving wheel disc

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Fig. 3. Paddy rims mounting on drive wheel perimeter

Alternative 4: **Tipping (dumping, draw-out) spikes**

The fourth proposed solution (Fig. 5) is in the phase of final design now, with manufacturing and fitting planned for this year, into tyres of the tractor Mini 070 type Barum 6,15/155-R14-4PR, obsolete one but suitable for draw spikes application. The spikes position will not be symmetrical to achieve the spikes drawing not in line, so not only two grooves will be created at slippage. Contiguous invasion (derogation) is considerable (heavy), but not weakening the tractor tyre body. Forthcoming real test will show the extent of self-cleaning ability of the tyre tread deterioration. The drawbar pull of the same tyre not fitted with tipping spikes will be tested and compared in following tests. Tipping spikes are removed from the tyre in a similar way as a non-skid chain. Spikes tipping into operational position will be automatic after locking bolt removal. The bolt will fix the control steel wire rope in the end position (Fig. 5a). The spikes will be ejected at tyre slippage on the whole tyre perimeter (Fig. 5b). The spikes return will be achieved by short reverse movement and then fixing of the control steel wire rope with two bolts at one side of the tyre, similarly as in the case of wheels with auto-extensible blades. We assume the tyre clogged by the soil will not block the spikes return into grooves in the tread because of the reverse motion of the tractor and its weight.

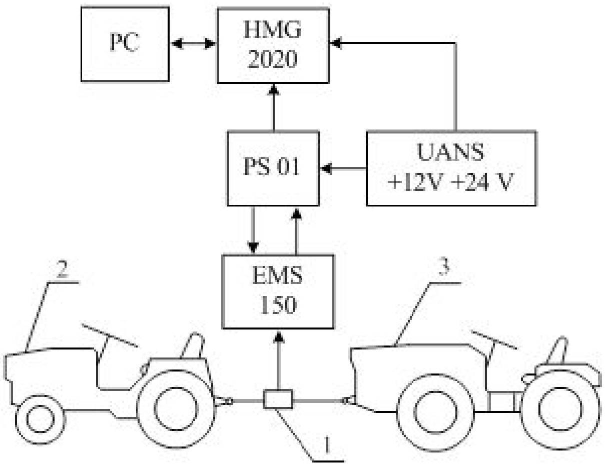

Fig. 4. System for measurement of tractor drawbar pulls

1 – force sensor EMS 150; 2 – tractor type Mini 070 equipped with different wheel types; 3 – loading tractor type T4K10; HMG 2020 – digital portable recording device; UANS – universal battery source; PC – personal computer; PS 01 – junction box

The spikes will have rectangular cross section on prototype to achieve better drawbar conditions. One bracket section will consist of an arm, transverse rod and two spikes and will be made from one material of adequate strength grade.

MATERIAL AND METHODS

To compare standard tyres and special wheels the measurements of drawbar pull were realized on the same field at different soil moisture in October 2012. The field was ready for autumn tillage. Tractor type Mini 070 (Agrozet, Prostějov, Czech Republic) was used to compare the standard tyres and special wheels equipped with auto-extension steel blades. The tractor was braking by the second tractor during the measurement of drawbar pull. The max. drawbar pull was reached at the 100% wheel slip.

Table 1. Specifications of the tractor type Mini 070

Year of manufacture	1989	
Construction weight	310 kg	
Driving speed at rated engine speed 3,600 rpm	1^{st} gear	1.53 km/h
	2^{nd} gear	2.72 km/h
	3^{rd} gear	4.96 km/h
	4^{th} gear	14.40 km/h
Clutch	dry, single plate, with direct mechanical shutoff	
Engine	petrol, four-stroke, air-cooled Briggs & Stratton	
	number of cylinders	1
	displacement	400 cm^3
	max. performance/rotation speed	8 kW/3,600 rpm

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Table 2. Specifications of the tractor type T4K10

Year of manufacture	1966	
Construction weight	820 kg	
Engine	two-stroke, air-cooled diesel	
	number of cylinders	1
	displacement	900 cm^3
	max. performance	10 kW

Measurement of drawbar pull. The drawbar pull measurement of the tractor type Mini 070 (Fig. 2) equipped with different wheels was performed by means of a tensometric force sensor marked as 150 EMS, as shown in Fig. 4. The force sensor is connected between the loading tractor T4K10 (Agrostroj, Prostějov, Czech Republic) and the tractor type Mini 070 through a chain. A portable recording unit HMG 2020 (Hydac GmbH, Sulzbach/Saar, Germany) was used to record electrical signals from the force sensor. The tractor type Mini was set at the first gear (gear I) during the measurement.

Technical parameters and specifications of tractor type Mini 070 equipped with different wheels types and the tractor type T4K10 used to brake the first one are listed in Tables 1 and 2.

Statistical proceedings of the measured values. The measurement of drawbar pull was realized during the time of 2.8 seconds. The sampling frequency 0.05 Hz was set on portable recording device to obtain the high precision results. Therefore the measured data-set consists of 56 values. The final mean value of drawbar pull was calculated from data file by using the 50 values. The first 6 values represent the increase in drawbar pull and therefore they were not used to calculate mean value.

The mean value A of drawbar pull was calculated by using the arithmetic mean:

$$A = \frac{1}{n}\sum_{i=1}^{n} a_i \tag{1}$$

where:
n – data-set extent

The coefficient of variation CV was used to express a measure of the dispersion of data points in a data series around the mean:

$$CV = \frac{\sigma}{A}\times 100 \tag{2}$$

where:
σ – standard deviation (N)
A – mean (N)

Bulk weight ρ_w of soil was determined by using gravimetric method according to the standard STN 72 1010: 1989:

$$\rho_w = \frac{m_1}{V} \tag{3}$$

where:
m_1 – weight of soil volume (g)
V – volume of soil (cm^3)

The soil moisture was calculated according to the standard STN 46 5321:1969 after drying at 105°C:

$$w = \frac{m_1}{m_2}\times 100 \tag{4}$$

where:
m_2 – weight of soil after drying (g)

The characteristics of field. The measurement of drawbar pull was realized on the field with the area of approximately 2,000 m^2. The measurements were carried out on Chernozem soil type. In the year 2010, there were soil moisture w = 22% and average soil bulk density ρ_w = 1.33 g/cm^3. In the year 2012 the measurements were realized at soil moisture w = 14 and average soil bulk density ρ_w = 1.51 g/cm^3.

RESULTS AND DISCUSSION

Results achieved with half-track adapters

Tests of the first alternative proposed were performed in June and July in year 2010 on asphalt paved road and in July and August 2010 at the field in the testing centre CNH Modena in Italy (Molari et al. 2012). The tests were carried out on a straight part of the experimental test track of asphalt paved road and on the soil straight passage of 150 m length. A loading vehicle was used in drawbar pull test on the paved road. Field tests ran

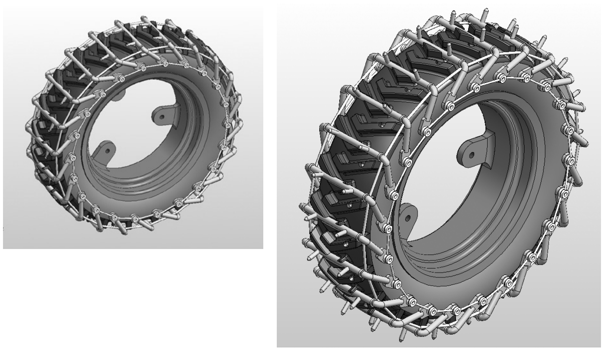

Fig. 5. Spikes in the tyre tread body: (a) in tilted position, (b) in operational position

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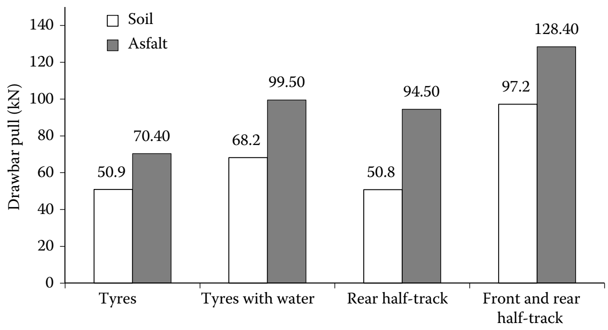

Fig. 6. Comparison of maximum drawbar pull of tractor New Holland T7060

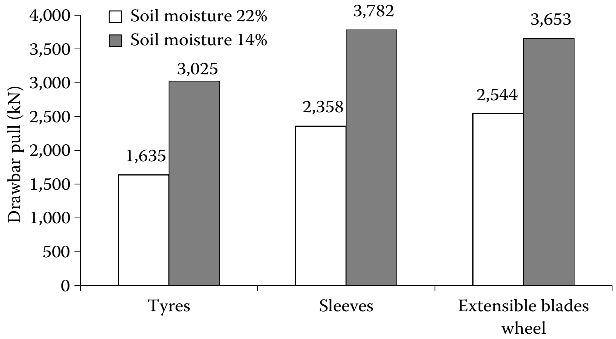

Fig. 7. Comparison of the highest drawbar pull of tractor Mini 070 on the soil at different soil moisture

similarly, soil tillage tool was attached to the braking vehicle to increase braking force and to achieve comparable conditions in both surfaces tests.

When evaluating the results achieved (Fig. 6), some information has to be added regarding changes in the weight of particular tractor versions. Air-inflated tyres tractor version has the weight of 8,180 kg, water-filled tyres version 11,320 kg, half-track version with rear half-track adapters 11,960 kg and tractor with front and rear half-track adapter 14,100 kg. The drawbar pull results achieved have to be evaluated taking the tractor weight into account as it is the factor with the highest effect on drawbar pull. On the other side, in spite of the considerable weight increase in case of the half-track adapter tractor versions, measured soil pressure values in the tractor track prefer clearly the half-track adapter versions.

Results achieved with other alternatives

Other alternatives tests, except the last one, were carried out in October 2010 and 2012. Favourable effect of extensible blades wheels and paddy rims with drawbar pull increase were achieved in all measurements on the soil, regardless of its moisture. October was chosen intentionally for testing, when the soil after crop harvest is ready for fall tillage characterised by the most energy-demanding agricultural operations. The soil is subjected to pressing effects by agricultural machinery in these operations.

It follows from the achieved results that the highest differences in average measured maximum drawbar pull (IInd speed gear) between compared driven wheels was found at higher soil moisture (Fig. 7). The average differences in the drawbar pull of both metal wheel alternatives compared to tyres are 15% greater at higher soil moisture than at lower soil moisture. This implies these mechanisms are used more effectively at the soil with higher moisture, causing lower soil resistance to tools. When comparing these two metal wheels alternatives application, drop in the drawbar pull of paddy rims at higher soil moisture has to be mentioned, caused likely by considerable clogging, already after a couple of meters motion on the moist soil. The interaction area of paddy rim blades is reduced and effectiveness falls. Extensible blades wheels do not have this limitation, since the blades swing slightly in free position and the stuck soil drops out even at 22% moisture. The slip loss of both metal wheel alternatives is approximately half compared to tyres, but at least 30% drawbar pull has to be generated to achieve that. The loss mentioned at lower drawbar pull is higher because the blades sinking into the soil consume certain amount of energy.

CONCLUSION

Drawbar pull measurements were performed using digital measuring and recording equipment in all cases according to similar methodology. Tractor Mini 070 braking was performed using the tractor T4-K10 up to the total slippage of drive wheels lasting approximately four seconds. The measuring track was traced to 50 meters, the measurements were repeated three times and then averaged. Tested auto-extensible blades can be applied to more heavy tractors as well, replacing to some extent wheel ballast, contributing to tractor weight increase. When evaluating all the alternatives mentioned in this paper, the soil protective functions of these systems have to be mentioned and the half-track adapter pointed out as the best alternative from this point of view. When consider-

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ing the initial purchasing costs, it is cheaper to improve the driving wheels traction applying one of the proposed alternatives from paddy rims, tipping spikes and auto-extensible blades.

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