Effect of Front Axle Suspension on Traction Parameters of Tractor with Mechanical Front Wheel Drive

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Abstract: The usage of active front axle suspension on tractors with mechanical front wheel drive started only one-two decades. The suspended front axle changes the shock parameters of the tractor and this also affects the traction parameters. During our research we wanted to find out how the major traction parameters (drawbar force, velocity, tractive performance, wheel slips) change due to the active front axle suspension. By using the results of field tests we verified that the active front axle suspension reduces the slip significantly, in other words it increases the value of the possible drawbar force at a given slip. It was also proved that on the chassis more moderate shock waves develop. Due to this, the range of the different traction parameters (statistical dispersion) will be more moderate. This results in more constant, less fluctuating drawbar force and the tractor will be able to deliver higher tractive performance.

Keywords: tractor, mechanical front wheel drive, tractive performance, front axle suspension

1. INTRODUCTION

From the 1980s the number of universal agricultural power machines with mechanical front wheel drive (MFWD) has increased continuously among the tractors used. These tractors nowadays, in most cases, have a linear characteristic suspended front axle. According to the manufacturers, by using the suspended front axle not only the comfort of the driving improves, but the drawbar force of the power machine increases as well, the slip reduces and on main roads the stability of the tractor increases. During research and investigations up until now the study of the tractive and energetic characteristics have not been emphasized.

The dragging ability of the tractor and the engine performance used as tractive performance can be described by the traction characteristics. The traction parameters typical of tractors are influenced by several parameters and these can be classed into three groups:

- soil mechanical parameters,
- the features of the tyre-soil relation, the features of the given tyre,
- the structural construction of the tractor, driving mode.

Based on the professional resources from the available data banks, little research work dealt with the effect of the front axle suspension on the traction features. The tests were done mainly on examining the relationships of the suspension and ‘shocking’; its analysis, possible modeling and simulation [1, 2, 3, 4, 5].

The research up until now defined the effect of vertical shocks of the wheels on the drawbar force and the tractive performance of the tire, based on mainly theoretical considerations and experience gained on single-wheel testing machines [6, 7].

By taking into consideration the fact that several scientists and publications deal with traction features of mechanical front wheel drive tractors without suspended front axle, it can be said that the investigation and comparative analyses of traction features of the active suspended front axle on tractors are far from being complete.

One of the aims of the research introduced in our paper was to examine how the active suspended front axle affects the major traction parameters (pulling force, velocity, tractive performance, wheel slips, etc.) of mechanical front wheel drive tractors and the relation of the slip – drawbar force.

2. MATHERIAL AND METHOD OF THE RESEARCH

2.1. Testing program

In order to achieve the targets we carried out field traction tests. The location of the investigations was the field of an Agricultural Ltd. from the centre of Hungary, 70 km far from Budapest on the South-East. The land was flat wasteland after harvesting. The definition of the soil characteristics was done by taking samples. From the 0-25 cm level of the soil, several random samples were taken. For defining the weight-bearing capacity and the compactness of the soil, the EIJKELKAMP 06.15.01 cone-shaped penetrometer was used. The penetrometer had a standard cone and arm [8].

The field traction test was done in two modes (rear wheel and all wheel drive). The total weight of the tractor was set to 7,860 kg with spare weights. During the examination we used three different static axle loads:

1) 33,08 % of the total weight (2,600 kg) on the front and 66,92 % (5,260 kg) on the rear axle;
2) 40,71 %-of the total weight (3,200 kg) on the front and 59,29 % (4,660 kg) on the rear axle;
3) 48,35 % of the total weight (3,800 kg) on the front and 51,65 % (4,060 kg) on the rear axle.

The measuring was done under three different gear conditions:

1) B1 gear: v=1,53 m/s (5,5 km/h);
2) B3 gear: v=2,19 m/s (7,9 km/h);
3) C2 gear: v=2,92 m/s (10,5 km/h).

Over and above that we used the front axle suspension in active and inactive mode. Altogether the number of examination settings was 36 (Figure 1).
The applied tire pressures were set in accordance with the static axle load settings as follows:
Setting 1. – 1.0 bar;
Setting 2. – 1.3 bar;
Setting 3. – 1.6 bar.

2.2. The object of investigation – vehicles

The test tractor was a JOHN DEERE 6920S power machine. The tractor’s front wheels are steered with mechanical front wheel drive. The main technical data of the power machine can be found in Table 1.

Table 1. Main technical data of the JOHN DEERE 6920S power machine

<table>
<thead>
<tr>
<th>Technical parameters</th>
<th>Unit</th>
<th>Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length</td>
<td>mm</td>
<td>5815</td>
</tr>
<tr>
<td>Axle distance</td>
<td>mm</td>
<td>2650</td>
</tr>
<tr>
<td>Gauge on the front/rear axle</td>
<td>mm</td>
<td>1412 – 2087/1319-2311</td>
</tr>
<tr>
<td>Own weight</td>
<td>kg</td>
<td>5600</td>
</tr>
<tr>
<td>Supplement weight front/rear</td>
<td>kg</td>
<td>2290/3420</td>
</tr>
<tr>
<td>Technically highest allowable max. total weight</td>
<td>kg</td>
<td>11.000</td>
</tr>
<tr>
<td>Technically highest allowable max. axle load</td>
<td>kg</td>
<td>front: 4600; rear: 7800</td>
</tr>
<tr>
<td>The height of the drag hog from the ground</td>
<td>mm</td>
<td>850</td>
</tr>
<tr>
<td>Nominal performance</td>
<td>kW</td>
<td>110 (2100 min⁻¹)</td>
</tr>
<tr>
<td>Mode of wheel suspension</td>
<td>Front/Rear</td>
<td>stable, suspended axle housing/stable, unsuspended axle housing</td>
</tr>
<tr>
<td>Tires</td>
<td>Front/Rear</td>
<td>TAUROS 14.9 R28/TAURUS 520/70 R38</td>
</tr>
</tbody>
</table>

The tractor had TLS system (Triple Link Suspension) active front axle suspension. The main feature of the TLS system is that the stable front axle housing is connected to the frame by two hydraulic slave cylinders. The slave cylinders are connected to three hydroaccumulators by an ECM, so they compose a closed system that ensures a continuous (active) suspension.

The loading was achieved by a specially built breaking vehicle. This vehicle was prepared by the Hungarian Institute Agricultural Engineering in Gödöllő from a MAZ 537 rocket and tank mover vehicle. The connection between the tractor and the vehicle was ensured by a coupling rod with dynamometer.

During the outdoor traction test the following data was recorded:
1) Velocity [m/s];
2) RPM of the front and rear wheel [min⁻¹];
3) RPM of the engine [min⁻¹];
4) Torque of the rear wheel [Nm];
5) Torque of the input shaft of the front axle housing [Nm];
6) Drawbar force [kN];
7) Vertical acceleration on the left and right side of the front axle and on the frame [m/s²];
8) Engine fuel consumption [l/h].

2.3. Method of data processing

A SPIDER Mobil measuring and data collecting system with 16 channels received the data from the different transmitters. The applied sampling density was 200 Hz. The data collected by the measuring system was recorded by a CATMAN software. During the data processing we set 14 measurement points at every setting, taking into consideration that (if it was possible) the sequentially load steps increased evenly.
We counted the average of the data collected during the 12 s every second. Then from these averaged values we counted the average value of the given measurement point, and we used these average values for further data processing and evaluation.

3. RESULTS AND DISCUSSION

3.1. Non-permanent performance balance of the tractor

Text During the operation of the tractor the load is not stable but varies acutely with time and is called an non-permanent load. This means that the performance balance of the tractor varies strongly with time and hence it has strong dynamics.

On Figure 2 one can see the fluctuation of the drawbar force under 30 kN with active and inactive front axle suspension.

![Fig. 1. Drawbar force fluctuation in case of active and inactive suspension under constant load](image)

From the diagram it can be clearly seen – though the load was stable during the measurement – there was a significant fluctuation in the values. This fluctuation – which means an non-permanent load for the tractor engine – is caused by the roughness of and the possible inhomogeneous soil. The visual analysis of Figure 2 shows that if the active front axle suspension is used, a smaller fluctuation of the drawbar force would be expected. Examining the further fluctuation of the drawbar force under different settings, but with the same load, we obtained similar results.

It is known that rolling resistance consists of tire and soil deformation and the energy loss caused by vertical shocks. The vertical shocks are caused by the combination of the roughness of the soil and the drawbar force. The shocks develop on the front wheels of the tractor and they are transmitted to the frame. We therefore examined the shock acceleration of the front tire and the frame during the exertion of the drawbar force. Figure 3 shows the frame-shock acceleration values connected to the fluctuation of the drawbar force represented on Figure 2. After visual evaluation, the difference between the frame shock acceleration in case of active and inactive suspension became obvious.

![Fig. 2. Frame shock accelerations in case of active and inactive front axle suspension with stable load](image)

But for the more objective analyses, we determined the RMS (Root Mean Square) values of the shock acceleration of the frame and the right and left front wheels by using the (1) relation

\[
RMS = \sqrt{\frac{x_1^2 + x_2^2 + \ldots + x_n^2}{n}}, \quad (1)
\]

where: \(x_{1,2,\ldots}\) - values of investigated parameter; \(n\) – number of data.

The values of the RMS calculation are summarized in Table 2. The counted RMS values undoubtedly support the previous assumption that the active front axle suspension reduces the frame shocks. For every setting – due to the active front axle – demonstrable milder fluctuation appeared on the frame. This more moderate shock acceleration amplitude means the amplitude of the fluctuation of the drawbar force will be more moderate as well. Another important result is that even in the case of permanent shock acceleration and scatter on the right or left front wheel (e.g. gear B3, 3200 kg load) with active suspension, the shock acceleration appearing on the frame is still more moderate.

For the more detailed and objective analyses we defined the statistical scatters of the drawbar force values and the main traction parameters (velocity, tractive performance, front and rear wheel slip) by using the known (2) formula:

\[
\sigma = \sqrt{\frac{\sum (x_i - \bar{x})^2}{n-1}}, \quad (2)
\]

where: \(x_i\) – the temporary value of the given parameter; \(\bar{x}\) - average value of the given parameter; \(n\) – number of data.
Table 2. RMS values of the shock accelerations of the frame and the right and left front wheel under the different experimental settings (F_v ≈ 30 kN)

<table>
<thead>
<tr>
<th>Gear</th>
<th>Static front axle load [kg]</th>
<th>RMS</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Left front wheel</td>
<td>Chassis</td>
<td>Right front wheel</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Active suspension</td>
<td>Inactive suspension</td>
<td>Active suspension</td>
<td>Inactive suspension</td>
<td>Active suspension</td>
<td>Inactive suspension</td>
</tr>
<tr>
<td>B1</td>
<td>2600</td>
<td>0.841</td>
<td>1.298</td>
<td>0.363</td>
<td>1.065</td>
<td>0.839</td>
<td>1.354</td>
</tr>
<tr>
<td></td>
<td>3200</td>
<td>0.922</td>
<td>1.165</td>
<td>0.566</td>
<td>0.787</td>
<td>1.152</td>
<td>0.978</td>
</tr>
<tr>
<td></td>
<td>3800</td>
<td>0.908</td>
<td>1.193</td>
<td>0.785</td>
<td>1.070</td>
<td>0.972</td>
<td>1.415</td>
</tr>
<tr>
<td>B3</td>
<td>2600</td>
<td>0.906</td>
<td>1.327</td>
<td>0.550</td>
<td>1.042</td>
<td>1.009</td>
<td>1.309</td>
</tr>
<tr>
<td></td>
<td>3200</td>
<td>1.073</td>
<td>0.788</td>
<td>0.461</td>
<td>1.109</td>
<td>1.352</td>
<td>1.089</td>
</tr>
<tr>
<td></td>
<td>3800</td>
<td>1.139</td>
<td>0.993</td>
<td>0.667</td>
<td>0.772</td>
<td>1.280</td>
<td>0.987</td>
</tr>
<tr>
<td>C2</td>
<td>2600</td>
<td>1.263</td>
<td>1.347</td>
<td>0.675</td>
<td>0.963</td>
<td>1.076</td>
<td>1.198</td>
</tr>
<tr>
<td></td>
<td>3200</td>
<td>1.295</td>
<td>1.859</td>
<td>0.771</td>
<td>1.154</td>
<td>1.637</td>
<td>1.686</td>
</tr>
<tr>
<td></td>
<td>3800</td>
<td>1.531</td>
<td>1.767</td>
<td>0.787</td>
<td>1.308</td>
<td>1.485</td>
<td>1.662</td>
</tr>
</tbody>
</table>

Table 3. The scatters of the traction parameters and shock acceleration values under 30 kN average drawbar force

<table>
<thead>
<tr>
<th>Gear: B1 (v=4,75 km/h);</th>
<th>Traction parameter</th>
<th>Active suspension</th>
<th>Inactive suspension</th>
<th>Active suspension</th>
<th>Inactive suspension</th>
<th>Active suspension</th>
<th>Inactive suspension</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Q_{front}=2600 kg</td>
<td>Q_{front}=3200 kg</td>
<td>Q_{front}=3800 kg</td>
<td>Q_{front}=3200 kg</td>
<td>Q_{front}=3800 kg</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Drawbar pull</td>
<td>1,480</td>
<td>1,959</td>
<td>1,660</td>
<td>1,809</td>
<td>1,898</td>
<td>2,776</td>
<td></td>
</tr>
<tr>
<td>Velocity</td>
<td>0,019</td>
<td>0,027</td>
<td>0,022</td>
<td>0,025</td>
<td>0,021</td>
<td>0,027</td>
<td></td>
</tr>
<tr>
<td>Traction power</td>
<td>2,100</td>
<td>2,690</td>
<td>2,399</td>
<td>2,537</td>
<td>2,729</td>
<td>3,886</td>
<td></td>
</tr>
<tr>
<td>Front wheel slip</td>
<td>1,368</td>
<td>1,761</td>
<td>1,539</td>
<td>1,686</td>
<td>1,661</td>
<td>1,849</td>
<td></td>
</tr>
<tr>
<td>Rear wheel slip</td>
<td>1,463</td>
<td>1,811</td>
<td>2,003</td>
<td>1,807</td>
<td>1,559</td>
<td>1,797</td>
<td></td>
</tr>
</tbody>
</table>

By using the scatter as a statistical feature, the divergence from the average value of a given parameter can be examined with active and inactive suspension. We defined the scatters of the examined parameters in all three gears and in all three static axle load distributions, with 30 kN average drawbar force. We did the calculations with the data collected during a 10-second recording period. This meant – by taking into consideration the 200 Hz sample taking frequency – 2000 pcs of data with all the parameters. In Table 3 the scatter values in gear B1 (v=4,75 km/h) can be seen.

After reviewing the results of the scatter examination the following conclusions can be drawn:
- with all three static axle loads the scatter of the drawbar force is lower in the case of active suspension than in inactive suspension. This means that the fluctuation of the drawbar force is smaller if the front axle of the tractor is suspended;
- increasing load implies increasing scatter of the drawbar force in the case of both active and inactive suspension, hence the fluctuation of traction parameters of the tractor increases with the load;
- the scatter values of the velocity do not show significant changes with either active or inactive suspension;

The results of the scatter examination definitely support the conclusion that the active front axle suspension results in smoother drawbar force performance. This is because the dynamic vertical load results in an adhesion force which is also smoother, because of the suspension.

3.2. Examing the drawbar force-slip relation

We defined the drawbar force-slip relation of the whole load cycle from the data collected during the different settings of the field traction test. After that we presented the curves of the active and inactive suspension with the same settings on a common diagram. Figure 3 is an example of this, that represents the changes of the drawbar force-slip at the first static axle load distribution (33/67 %) setting with B1 gear with active and inactive front axle suspension.

![Figure 3. Changing of the wheel slips plotted against the drawbar force](image)

From the curve it can be seen that the drawbar force-slip relation during the whole load cycle is similar, even with active and inactive suspension. The positive effect of the active front axle suspension can be observed with higher drawbar force exertion. In the case of the examined setting, it could be seen that above the 30 kN drawbar force value the slip of the rear and front wheels were smaller with active suspension. It is also clearly visible that by increasing the drawbar force the differences also increase. This trend is true for the other experimental settings. Generally speaking it means that the usage of the active front axle suspension reduces the scale of the wheel slip, during a given drawbar force exertion. In other words during a drawbar exertion for a given slip value, a higher drawbar force is obtained in the case of active front axle suspension.

4. CONCLUSION

The elaborated measurement method is suitable for defining the performance balance of mechanical front wheel drive tractors and comparing the active and inactive front axle suspension. During the field tests, with the help of the 100 and 200 Hz digital sample taking, the changes of the tractor in static performance balance can be tracked well and the changes of the vertical shock acceleration during the operation can be analyzed in detail.

There is a significant difference, for the benefit of active suspension, in the scatter values of drawbar force, tractive performance and the shock acceleration of the frame.

After analyzing the measurements of the field traction tests it can be said that in the case of all wheel drive, the suspension of the front axle results in a smoother dragging force of the tractor. With active front axle suspension and given slip, the tractor is able to exert a greater dragging force.

The reason might be that in the case of suspension with static front axle load – as an average value – smaller plus-minus changes can be observed. This proves that the measured drawbar force values show smaller fluctuation. Statistically it means more moderate scatter values.

REFERENCES


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