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Tyre deflection versus wheel load

Regarding soil protective machine management modern tyres offer great potential which, however, is rarely used consistently. Operation at the limit region with an optimal low inflation pressure for maximum soil protection bears the risk of damage by overload and is hardly to handle. The limits given by the manufacturer specifications can only be utilized if the dynamic stress occurring during operation is known. It will be explained, that the online measured tyre deflection is a reliable indicator and gives a more precise image of the actual stress situation than the exclusive consideration of static wheel loads.

Keywords
Soil protection, wheel load, tyres, tyre deflection, inflation pressure, Soil Load Monitor

Abstract
Landtechnik 66 (2011), no. 3, pp. 194–197, 5 figures, 4 references

Regarding soil protective machine management modern tyres offer great potential which, however, is rarely used consistently. Operation at the limit region with an optimal low inflation pressure for maximum soil protection bears the risk of damage by overload and is hardly to handle. The limits given by the manufacturer specifications can only be utilized if the dynamic stress occurring during operation is known. It will be explained, that the online measured tyre deflection is a reliable indicator and gives a more precise image of the actual stress situation than the exclusive consideration of static wheel loads.

It has long been known that not just the efficiency of power transmission but also soil protection is important in farm machinery travel over the soil surface. Particularly the mechanical load on the soil due to high wheel loads is criticized. That is why decision-guidelines for soil conserving machinery use have been developed (VDI Guideline 6101). The adjustment of inflation pressure (subsequently: tyre pressure) to the wheel load plays a special role here. The number of vehicles that are equipped with tyre pressure controllers or at least with a socket for quick changes of the tyre pressure is increasing steadily, but the decision which pressure is correct continues to remain with the operator. He mostly controls the pressure on the basis of statically calculated wheel loads or on the basis of experience. The on-line measurement of wheel loads with common techniques like load cells or strain gauges has proven to be problematic due to the chassis constructions. This is one of the reasons that, also in yield mapping, mostly other methods of weight monitoring are used. Related to the setting of the tyre pressure, it has been shown that the measurement of tyre deflection is a successful alternative for determining the wheel load.

Against this background a technique was developed (**figure 1**), with which the deflection and inflation pressure of tyres can be measured on agricultural vehicles and harvest machinery during use and radio transmitted to the driver in the cabin. Similar, but technically much more complicated measurement equipment has been used in agricultural research since the mid 1990s. [1] The new technology is suitable for practical use and, thanks to the radio communication, simple to install.

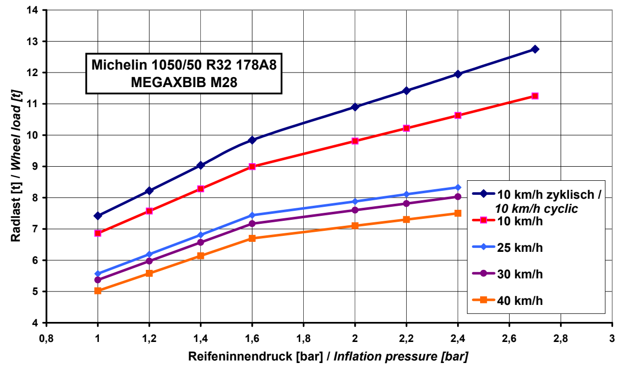
Fig. 1

Measuring device for tyre deflection and inflation pressure, installed on the rear wheel of a tractor

Tyres under Pressure

The flattening of a tyre while a vehicle is stationery is called deflection. When the tyre pressure is known, deflection is a good indicator for the weight load that impacts the wheel; this is commonly known as wheel load. The acceptable weight load of a tyre for safe use without risk of damage is not only dependent on tyre pressure, but also on driving speed. Among other things, due to the dynamic pressure peaks increasing with driving speeds, the acceptable static wheel load is reduced (**figure 2**)

Fig. 2

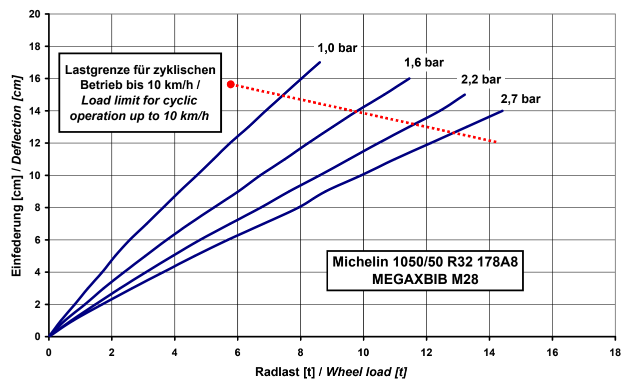


Maximum wheel loads as a function of inflation pressure and travelling speed [2]

The relationship between deflection and wheel load for different tyre pressures is presented in Figure 3. If one uses the limits recommended by the manufacturer as a basis, the result for the cyclical use on the field up to 10 km/h is a maximal tyre deflection of about 130–150 mm.

The qualitative run of the curve in **figure 3** can be seen as representative for a broad cross-section of the tyres studied. This proves that for each tyre pressure, a near to linear relationship exists between the deflection and wheel load.

Fig. 3



Tyre deflection as a function of wheel load measured at inflation pressure rates between 1.0 and 2.7 bar

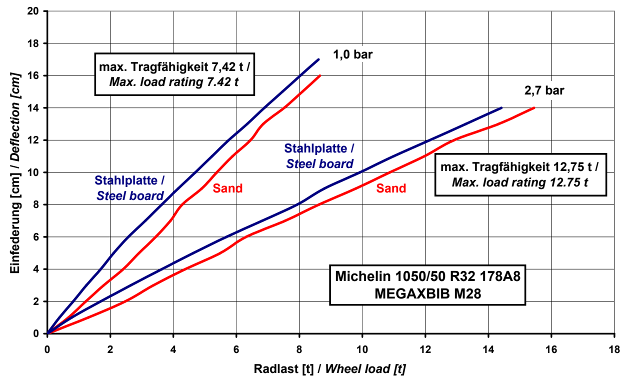
Tyre deflection and ground

The deflection of a tyre is, however, not only dependent on the inner pressure and the wheel load, but also on the effective contact area upon which the weight can be distributed. The presented measurements (**figure 3**) were recorded on a tyre test rig on a plain, hard surface (steel plate) which only had contact with the tread lugs of the tyres. This is essentially the equivalent to the situation during road travel. On the field, the tyre more or less sinks into the soil. Through the sinkage, the length of the contact area and its width increase depending on the bulges in the flanks of the tyre. Also the tread voids of the tyres can convey more load since they are directly in contact with the surface. The sum of these effects increases the effective contact areas, whereby the deflection of the tyre reduces with constant load. The influence of the surface on the tyre contact area was studied by Diserens [3] in detail.

If one assumes that not the given maximal load of the tyre table but the deformation of a tyre is the limiting factor for safe use, then a tyre can be more strongly loaded on a flexible surface. Alternatively the air pressure can be reduced with the same load in the interest of soil conserving passage. Thus, should the relationship between wheel load and tyre deflection be examined, the characteristics of the surface must be taken into account. Studies on this topic can be found in the literature [4] too.

Figure 4 represents the various reactions of tyres on hard surfaces and on sand with minimal and maximal values of the tyre pressure. With the measurements in an about 15 cm deep sandbox, the relationship on flexible soil should be simulated. All measurements were carried out at the tyre test rig.

Fig. 4



Comparison of tyre deflections on solid ground (steel plate) and on "untravelled" sandbed (sand box), inflation pressure rates: 1.0 and 2.7 bar

In sand, a clearly delineated negative of the tyre tread remained since the flexible surface was pressed into all of the voids. From the diagram it can be seen that the tyre in the sand box can carry an average of about 0.7 tons more load to achieve the same deflection as on the steel plate. The curves for the plate/sand are, with an almost similar ascending slope, only shifted in parallel. The parallel shift can be found at even small loads. This could be explained by the fact that the flexible sand box forms to the tyres optimally even at small loads. It can be assumed that the tyres on arable soil tend to react similarly. In the study the difference between street and field appears at first glance to be marginal. With 1.0 bar tyre pressure, the 0.7 tons related to the maximal load ability would shift to 7.42 tons but nonetheless featuring a gain of almost ten percent. With the same load, alternatively, the tyre pressure could be reduced by about 0.2 bar to conserve the soil. The results by Diserens [3] seem to indicate that in practice, particularly on soft, moist soils, even clearer differences can be expected.

Tyre Deflection and Total Weight

Even if wheel loads could be determined on the basis of tyre deflection and tyre pressure, the determination of total weights from the sum of the wheel loads for the purpose of yield mapping with the technology presented in **figure 2** is only possible under certain circumstances. Since the deflection is measured at one point on the circumference of a tyre, the equipment provides only one result per wheel rotation, which is sampled when the sensor is in a vertical downward position. Since the wheels of a vehicle never run synchronously, a simultaneous measurement of all tyres is not possible. In the least favourable case, a vehicle with a wheel diameter of 2 m covers a distance of ca 6 m before all values are measured. The sum of the four values only gives a representative result if the weight distribution on the wheels does not change over the distance covered. During field work this condition is generally difficult to maintain.

Although these theoretical considerations show that use of the tyre deflection is still problematic for the mapping of yield, the results of practical studies show that further research and development work could be of value here. **Figure 5**, which is representative for a whole series of studies, illustrates the dependence of the sum values of tyre deflection from the bunker filling of a beet harvester during harvesting with constant working speed.. The almost linear sloping curve is surprisingly in agreement with the theoretical expectations. The differences can be attributed to driving dynamics.

Conclusions

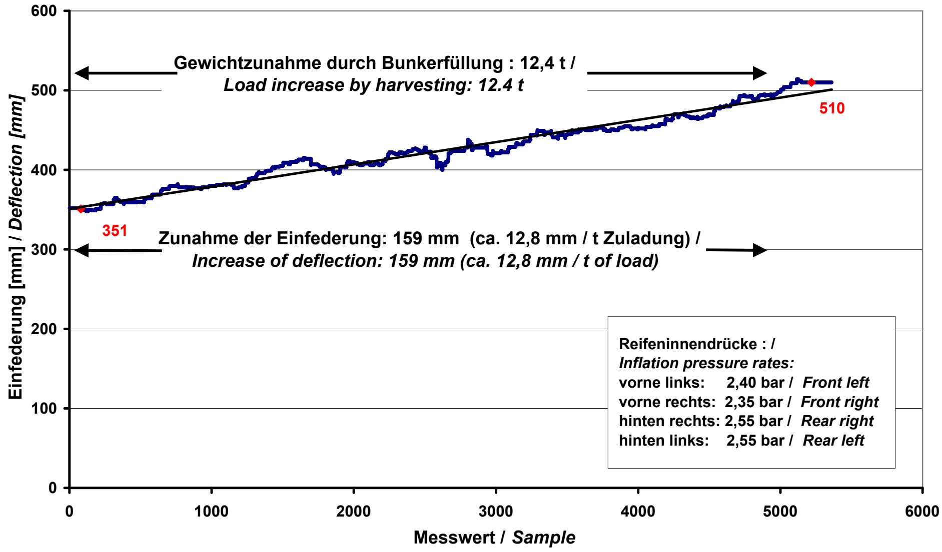
The deflection is the main factor to judge the load situation of tyres in use. For various air pressure-/speed combinations, according to **figure 2**, the maximum acceptable wheel load can be converted into a maximum acceptable tyre deflection by the relationship presented in **figure 3** and thus kept under control. This task can be performed by an on-board computer in which the tyre data is stored. As an almost free bonus, yield mapping on the basis of tyre deflection is thinkable in harvesting machinery.

One can assume: For the mechanical imposition of a tyre not only the wheel load is the important factor but also the deformation of the tyre material while rolling. Here it becomes evident that the deflection is the parameter with which the actual mechanical stress is directly documented. This value results from surface, tyre pressure and impacting weight load.

The Institute for Agricultural Technology and Biosystems Engineering of the Johann Heinrich von Thünen-Institute (vTI), and the Grasdorf Wennekamp Company with its “Soil Load Monitor” (**figure 1**), pursued the goal of finding the reference values for tyre pressure regulators – if possible fully automatically – on the basis of dynamically measured tyre deflection on the farm. This has proven to make sense. A tyre pressure regulator is only effective if the soil conservational potential of the tyres can be fully utilized through exact adjustment of tyre pressure without risking damage to the tyre.

With the measurement results in **figure 4** it is shown that the information of static wheel loads alone is mostly not adequate to optimally set the tyre pressure - the flexibility of the soil must also be considered. Even more significant is the influence of dynamic load shift, which can occur, for example, in ploughing, in work on slopes, or, in general, through chassis induced vibrations. These can lead to significant excesses of the static wheel load values and thus make higher tyre pressures necessary. From these relations it can be concluded that the actually occurring demands for the tyres are as a rule unknown. This uncertainty leads the farmer to more often opt for operating safety than for soil conservation when setting the tyre pressure. The possibilities of modern farm tyres, which can be driven with low tyre pressures and the resulting large contact areas, are thus not yet adequately used for soil protection.

Fig. 5



Cumulated deflections of 4 wheels of a Holmer Terra DOS sugar beet harvester filling the trunk up to 12.4 t

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