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Demands on an Electric Wheel Drive

The theoretical fundamentals of the description of the demands on a vehicle drive are known. Nevertheless, design without precise knowledge of the initial parameters is difficult. Extreme values lead to overdimensioning.
In preparation for the construction of a tractor with electric single wheel drive, measurement rides were carried out in Dresden in order to be able to consider the actual loads in their temporal course. The insights gained formed the basis for the design of the electric single wheel drive.

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Literature

Literature references can be called up under LT05412 via internet http://www.landwirtschaftsverlag.com/landtech/local/literatur.htm.

Hydraulic-mechanical powersplit transmissions can be considered the most important progress of the past years in the area of tractor technology. Since tractors with rigidly coupled all-wheel drive established themselves in the middle of the 1970s, the basic design of the chassis has not been changed significantly. An increase in productivity was mainly reached through greater engine power in heavy tractors providing more comfort. In current all-wheel tractors, the front wheel is generally driven at a speed determined by the design [1]. In order to be able to exploit the available maximum tractive force, differential locks in the axles are used. Different rolling radii and the uneven length of the paths to be travelled by each wheel lead to forced different wheel slip and are the reason why the designed tractive force and -power of the vehicle cannot always be exploited. Here the disadvantages of the central drive, where one transmission serves all wheels, manifest themselves.

In the future, an increase in productivity and efficiency of the vehicle drive can be reached if mechanical coupling between the wheels is given up. Each wheel must be supplied with the torque adapted to the individual requirements at an appropriate engine speed independent of the other wheels. Despite different conditions, every wheel can thus be run in an energy-efficient manner or exploit its full tractive force potential. Cars and off-road vehicles with electric and hydrostatic single wheel drive [2] as well as tractors with an electric central drive [3] already exist.

Demands on the Tractor Drive

Tractors are expected to be able to deliver their maximum tractive force - which is physically limited by the vehicle mass and the individual traction conditions between the wheel and the road - at low driving speeds (and when standing) immediately at any time. On the field, it must be assumed that continuous work at the slip limit is possible up to a technologically appropriate working speed (up to ~ 7 km/h).

Dynamically altered wheel loads lead to overdimensioning of the vehicle drive. The sum of the drive power installed in the four wheels must be larger than the power supplied by the energy source.

Design Criteria for the Electric Motor

Agricultural machinery development applies electric motor technology and must define the mechanical requirements and the marginal design conditions for the developers of electric motors. For the use of motors in mobile machines, minimum constructional space demand and minimum mass are crucial requirements.

For electric vehicles, high efficiency over the entire rpm range must be striven for. The basis for design is the large rpm range where power is constant [1; 7] and the rated and maximum torque to be delivered at the individual engine speed. It is known that standard electric motors can deliver at least the 1.6 fold amount of their rated power for short periods of time. The motor must not only be able to supply the required torque (short-time overload- and permanent torque), but it must also be possible to dissipate the generated waste heat under every required condition of use (especially in permanent use).

By first approximation, an electric motor can be designed based on theoretically determined characteristic maps of the wheel drive. The wheel hub torque is calculated from the sum of the torque required to overcome the rolling resistance (product of the wheel load Fo and the lever of rolling friction f) and the torque needed for the generation of the wheel's tractive force F_T (multiplied with the static radius r) [4]:

$$M = F_T \cdot r + F_G \cdot f \qquad \text{(eq. 1)}$$

For simplification, the driving force coefficient κ and the rolling resistance coefficient ρ are combined in the adhesion coefficient μ:

$$F_T = \kappa \cdot F_G \qquad \text{(eq. 2)}$$

$$\rho = f / r \qquad \text{(eq. 3 and)}$$

$$\mu = \kappa + \rho \qquad \text{(eq. 4)}$$

As a result, the following formula is used:

$$M = \mu \cdot F_G \qquad \text{(eq. 5)}$$

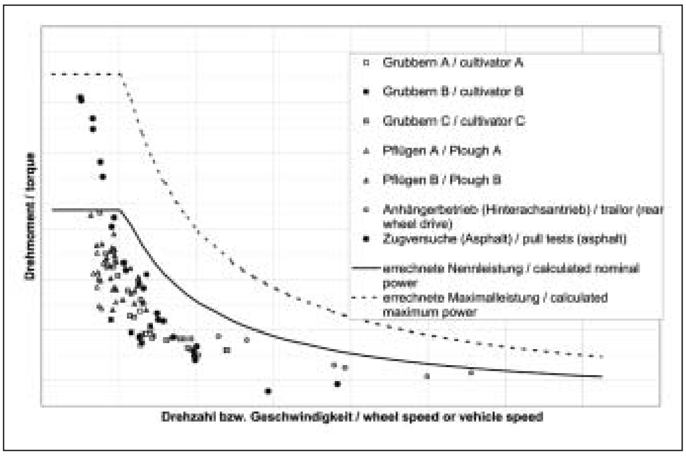

Fig. 1: Calculated and measured torque of wheel hub

Both for the wheel load F_G and the adhesion coefficient μ, only experimental values can be used for certain applications. Maximum values lead to an unnecessarily overdimensioned or non-realizable electric motor.

In former considerations, a permanent wheel load of 35% of the permissible gross vehicle mass was assumed. The adhesion coefficient determined was 0.65 for field work and 1.1 for paved roads. Extensive simulations only improve precision if the simulation model and the parameters used are verified based on practical measurements.

Along with other studies, measurements of wheel driving torque and wheel rpm were carried out on tractors. Here, the focus was on the creation of dimensioning fundamentals for mechanical elements of the drive train in the form of load spectra. Retrospectively, load spectra do not allow any conclusions about wheel power and its course to be drawn [6, 7, 8].

The temporal course of the torque in practical use is of decisive interest. Stochastically changing conditions of use and, hence, loads on the electric wheel hub lead to complex thermal loads, of which simple parameters only give an unreliable description.

Measuring Vehicle and Measuring Rides

Due to the lack of freely accessible, utilizable measurement data, a tractor (MB-Trac 1300) was equipped with measuring instruments at the Chair of Agricultural Machinery of the Technical University of Dresden. In order to measure the wheel driving torque, extension measuring tapes in a bridge circuit were applied to the tube piece of the bell hub of the planetary end drive. The measurement signals are transmitted via analog near-field range systems from the front wheels and via slip rings from the rear wheels. The rotational speed is measured with the aid of a crown gear on the brake drum and a proximity switch. In addition, a wheel sensor measures the real driving speed. The engine speed is recorded.

A representative single case does not exist. Equation 5 illustrates that the variables wheel load and adhesion coefficient determine the maximum drive torque. The place and the position of ballast on the tractor as well as the kind of implement and its coupling with the vehicle allow the wheel load to be influenced. The test vehicle was additionally loaded by a front-mounted weight and a weight in the loading area above the rear axle. Thus, the wheel load was increased beyond the ballast common in practice for this type of tractor. The goal of ballasting was not to come as close as possible to the values of the theoretical assumptions, but to cover the largest number of the cases which occur in practical use without having to test the numerous tractor-implement combinations.

Extreme tasks and disproportionately unfavourable ballasting of the test vehicle were deliberately excluded.

The test programme was divided into two main groups: measuring rides for the determination of the permanent torque to be delivered by the electric motor and measurements for the determination of the maximum torque.

In the first part, the tractor was used under practical conditions in combination with two heavy cultivators (3 m and 4.5 m) and a mounted reversible plough (4 shares, 1.8 m) with an undersoil packer at two locations under different conditions. The working depth of the implement was adapted to different gears. The cultivators were carried by the tractor or supported by packer rollers (hitch in float position). The plough was run with controlled lower links and a functionless or supporting upper link. Transport rides with two loaded trailers were carried out on the road and on the field.

In the second part of the test for the measurement of the maximum wheel driving torque, the tractor was equipped with an implement frame carrying an additional rear-mounted weight. During this test, the statically permissible rear axle load was almost reached. In this combination, the tractor was braked with a significantly heavier vehicle on an asphalted road. The chosen point of application of the tractive force was high in order to put additional load on the rear wheels at large tractive forces.

In the mentioned configuration and given machinery settings and working speeds common in practice, the limiting factor was always the power of the diesel engine and not the traction conditions. The range of maximum diesel engine power was used for evaluation. Figure 1 shows the measurement values of the wheel which carried the greatest load in comparison with the values calculated beforehand.

Conclusions

If based on theoretical assumptions of wheel load and adhesion coefficients, the drive is overdimensioned. Measured maximum power is considerably lower than the calculated values. The little overload power required as compared with the rated power or the maximum torque in the constant power range ($v >$ 7 km/h) has a positive effect on electric motor development.

In addition to the power to be delivered, the necessary torque decisively determines the constructional volume of an electric motor. Overdimensioning, which would allow significantly more maximum power to be generated as compared with permanent power, is not needed. However, this requires efficient cooling. The positive effects on the electricity demand of the drive frequency converters should also be considered.

The measurements illustrate the importance of balanced ballasting for the dimensioning of the wheel drive. Torque formation in the air gap is physically limited. Constructional space requirements restrict the size of the electric motor. Balanced ballasting enables more unfavourable wheel load distribution to be avoided. In order to reach the power output of modern tractors with realizable and affordable electric drives in practice, technical equipment for dynamic axle load shifting (shiftable ballast, shiftable axles) can be considered.