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Measuring the coefficient of friction of chopped materials

Forage harvesters are achieving ever great performance and throughputs. The type of material transportation means that these machines have very high friction loss levels. The product flow in the forage harvester must be analysed in order to reduce these losses. The friction coefficients of chopped grass and maize must first be determined. To obtain a precise measurement of the coefficients of friction, a test stand is constructed on which different tests can be carried out using various settings.

Keywords
friction, coefficient of friction, forage harvester

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The forage harvester is one of the most important machines in forage harvesting. It is used to chop grass and maize to ensure better preservation. The material is picked up by an appropriate front attachment and conveyed to the chopping drum by the compression rollers. The drum cuts the product to the preset length of cut, accelerates it and conveys it onward using kinetic energy. A modern forage harvester has a throughput of over 400 t/h and an engine performance of over 800 hp. In order to process this higher throughput, the product must be conveyed through the forage harvester at speeds of over 40 m/s. At this high performance level the losses in the product flow, e.g. friction, flow, acceleration and impact losses may be especially high and substantially increase the fuel consumption

The aim of this project is to determine the friction losses in a forage harvester. Some improvements will then be suggested which may reduce these losses.

Fig. 1

Test rig

A test stand needs to be built to be able to determine the coefficient of friction of chopped materials. Some data is available from previous testing, though this was measured at lower speeds and loadings.

Wieneke [1] measured friction coefficients of between 0.2 and 1.4 for grass. The big difference results from the variations in roughness of the surfaces.

Lobotka [2] carried out tests on chopped maize. He measured friction coefficients of 0.5 - 0.6.

Test stand

Measuring the friction coefficient of chopped materials is a major challenge. Because of the material structure, precise values for grass or maize are not possible, as they depend on several parameters. Variables include the moisture content of the material, the relative speed, the loading, length of cut and roughness of the surface. The most important parameter, however, is the material pairing. Substantial differences arise from the material sliding over different materials. By using the test stand, friction coefficients of chopped materials can be determined by with different material pairings and at different settings. The first stage of developing a test stand is drawing up a list of requirements. It should be possible to infinitely measure relative speeds up to 40 m/s and standard pressures up to 1 bar.

The test stand operates on a similar functional principle to that of a disc brake. The basic rotating disc can be fitted with various surfaces. The chopped materials in the material holder are pressed against the rotating disc from below by a pneumatic cylinder (see Fig. 1). The advantages of this principle are the even loading and the low speed differences between the inner and outer radius.

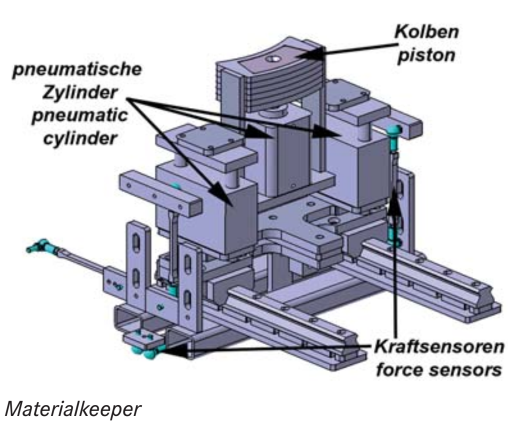
The coefficient of friction is determined by measuring the friction force tangentially to the surface and the normal force perpendicular to the surface. The material holder is attached to bars fitted with wire strain gauges (WSG), arranged to suit the relevant loadings. Three bars keep the material holder vertical and one governs its tangential orientation. There are two additional bars to stabilise the material holder in relation to the frame. During the test, the reaction forces are captured by the WSGs. The advantage of this solution is the ability to measure the coefficients of friction precisely, even at high speeds. The disc is driven by a hydrostatic drive, so that the relative speed between product and test surface can be set infinitely and precisely. The speed of the rotating disc is determined by a sensor and converted to an average speed over the whole radius. The pressure loading can also be infinitely adjusted by means of a special pneumatic pressure relief valve. The measurement time is adjusted by a delay valve, which returns all valves to the home position on completion of the measurement. This also moves the material holder back to the home position.

Key technical data:

- Disc diameter 500 mm
- Width of the test surface 50 mm
- Thickness of the test disc 5 mm
- Relative speed 5-40 m/s
- Pressure 0,05-1 bar
- Measuring period 0,2-3 sec

The measurements are taken with different lengths of cut and moisture content for the same chopped material sample. The chopped material is dried naturally to ensure that the structure of the grass remains unchanged. When measuring, only one parameter is changed at a time, in order to determine the effect of that parameter. First, the loading is kept the same and the speed changed, then the speed is kept constant and the loading varied. The test is repeated three times for each setting. The coefficient of friction is determined as an average of the data obtained.

Fig. 2



Results

The material being tested is freshly chopped grass with a length of cut of 17 mm. In order to determine the effect of the moisture content of the material the material was dried over a period of 4 days and a friction test carried out daily. The duration of all measurements was limited to 1 second, in order to obtain results that are as real as possible. One problematic aspect is that the product heats up substantially from the friction at high speeds and loadings. This also changes the coefficient of friction.

As stated above, during the tests the reaction forces are measured tangentially (friction force) and perpendicular to the surface (normal force) using wire strain gauges. The coefficient of friction is calculated in accordance with Coulomb's friction law.

$$\mu = \frac{F_{\text{Friction force}}}{F_{\text{Normal force}}}$$

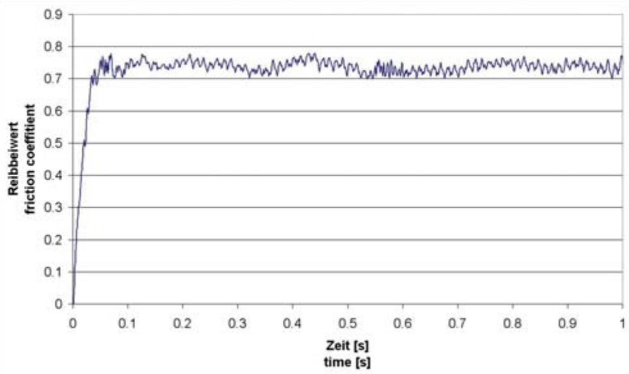
Fig. 3 shows an example of the coefficient of friction trend. At the start of the measurement, the coefficient rises steeply and reaches the actual value at constant loading with a low level of fluctuation. To enable the comparison of friction coefficients from different tests a standard must be defined to govern how the measurement is read off. The coefficient of friction is read off as soon as the preset value for the normal force is reached. This is particularly important at high speeds and heavy loading, as the structure of the material changes quickly due to the heat, which means that a delayed reading will lead to incorrect results. This solution ensures that the measurement results can be compared precisely.

Fig. 4 shows the coefficient of friction trend for different lengths of cut. It can be seen clearly that the effect of the length of cut is very low on grass. This is an interesting result, as with smaller lengths of cut, more particles come into contact with the surface. These additional contacts and the resultant adhesive power only have a very slight effect on the coefficient of friction.

Conclusion

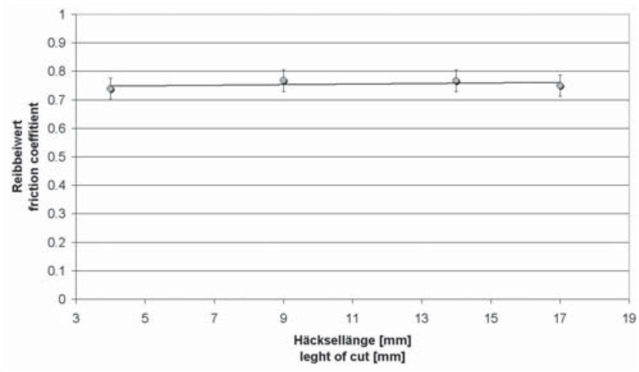
In order to be able to determine the friction losses in a forage harvester, the friction coefficients of grass and maize must first be determined. To do this, a test stand is constructed, with which the coefficient of friction between chopped green forage and various surfaces can

Fig. 3



Trend of coefficient of friction

Fig. 4



Friction coefficient by different lenght of cut

be measured. Previous tests have shown that the friction coefficient of grass is very high. It is above 0.7 and therefore increases the power requirement of the forage harvester.

Further tests must be carried out to determine the friction coefficient of chopped maize. Other tests will be undertaken at a later stage with different surfaces (roughness, profile, material). On the basis of these tests, solutions can be found for reducing the friction losses of the forage harvester.

Literature

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