Tiemo Schwenke, Munich

Three Decades of Mass Flow Rate and Quality Measurement of Crop Materials in Forage Harvesters

The developments for measuring mass flow, as well as determining the features and ingredients of crop material in forage harvesters (Fig. 1), are illustrated using selected patent applications. Descriptions of the case applications for these inventions are presented. The publications cited, as well as information about the state of the art or of the patent family, are available under [3, 4]. Papers with DE are valid for Germany. For EP and for WO papers, Germany is named as the contracting country (DE).

Dr.-Ing. Tiemo Schwenke was research associate at the TU Munich, Crop Production Engineering, Am Staudengarten 2, 85354 Freising,
e-mail: *tiemo.schwenke@gmx.de*

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Already in the 70's investigations on throughput measurement at forage harvesters [1] took place. E.g. in knowledge of throughput and moisture of the harvested crop, an accurate dosage of preservatives is possible. In addition a continuous moisture measurement with electrodes at drum sheet metals or drum tines of the pickup is intended in (*1*). The throughput is measured by the deflection of the hold-down device before the pickup drum by means of a potentiometer.

With a speed regulation the efficiency of a forage harvester can be improved. If the number of revolutions of the cutterhead drops under a minimum value or if the torque of the driving device rises over a maximum value, the driving speed is reduced. If both parameters are in acceptable ranges, the driving speed is regulated on a desired value (*2*). In addition to the driving speed also the feed speed of harvested crop and of the engine are controllable, dependent on the deflection of tiltable feed rolls or of the pressure load of stationary feed rolls. Thereby the cutting quality and efficiency are improved. The driver is relieved from monitoring and control tasks (*3*).

For throughput determination also differential pressure measurements at two planes of measurement in the spout are to be used. Thereby the distance of the two planes of measurement is to be selected as largely as possible. As transducers flaps are used, which project into the spout. Capacitive, optical or ultrasonic-based transducers are likewise applicable. With a missing mass flow signal, an automatic zero is accomplished. The number of revolutions of the cutterhead detects an incremental transducer. In knowledge of throughput, the controlling of the forage harvester and the admixture of additives are improved (*4*).

No.	Patent application/ specification	Filing / priority date	Date of publication of patent application / patent specification
(*1*)	DE 32 32 746 A1	3. 9.1982	8. 3.1984
(*2*)	DE 35 05 887 A1	20. 2.1985	5. 9.1985
(*3*)	DE 37 02 192 A1	26. 1.1987	4. 8.1988
(*4*)	DE 40 41 995 A1	27.12.1990	2. 7.1992
(*5*)	DE 195 24 752 A1	7. 7.1995	9. 1.1997
(*6*)	EP 0 753 720 A1	14. 7.1995	15. 1.1997
(*7*)	DE 196 48 126 A1	21.11.1996	28. 5.1998
(*8*)	EP 0 887 008 A1	27. 6.1997	30.12.1998
(*9*)	EP 0 931 446 A1	16. 1.1998	28. 7.1999
(*10*)	DE 199 03 471 C1	29. 1.1999	8. 6.2000
(*11*)	DE 199 22 867 A1	19. 5.1999	23.11.2000
(*12*)	WO 01/000005 A2	30. 6.1999	4. 1.2001
(*13*)	DE 100 30 505 A1	21. 6.2000	3. 1.2002
(*14*)	DE 101 54 874 A1	8.11.2001	28. 5.2003
(*15*)	DE 102 11 800 A1	16. 3.2002	2.10.2003
(*16*)	DE 102 20 699 A1	10. 5.2002	24.12.2003
(*17*)	DE 102 30 474 A1	6. 7.2002	15. 1.2004
(*18*)	DE 102 30 475 A1	6. 7.2002	15. 1.2004
(*19*)	DE 102 36 515 C1	9. 8.2002	25. 9.2003
(*20*)	DE 102 41 788 A1	6. 9.2002	1. 4.2004
(*21*)	DE 103 06 725 A1	17. 2.2003	16. 9.2004
(*22*)	DE 103 48 040 A1	15.10.2003	19. 5.2005
(*23*)	DE 10 2004 010 772 A1	5. 3.2004	6.10.2005
(*24*)	DE 10 2004 038 404 A1	7. 8.2004	23. 2.2006
(*25*)	DE 10 2004 038 408 A1	7. 8.2004	23. 2.2006
(*26*)	DE 10 2004 048 103 A1	30. 9.2004	20. 4.2006
(*27*)	DE 10 2004 052 446 A1	30.10.2004	18. 1.2007
(*28*)	DE 10 2005 017 121 A1	14. 4.2005	19.10.2006

Table 1: Publications of patent applications (A) and patents (C)

Optimized throughput and moisture measurement for yield determination

The employment of GPS to positioning of harvesting machines makes determination of local yield measured values possible, from which site-specific, plant-structural measures are derived. Therefore a continuous recording of positioning data of the harvesting machine as well as the measured values for throughput and characteristics of harvested crop is necessary. Thereby higher precision on the throughput measurement is required. For this, the testing of a radiometric measuring system in the spout took place [2].

Beyond that an optimization potential exists also for the well-known procedure for determination of press roll deflection by means of potentiometers by increase of the scanning rate. Additionally the torque at the cutterhead, on the attachment or at the engine is measured. These measured torque values are adapted to the changing sharpness of knives. If the deflected press roll approaches its upper or lower limits or if this affects, the measured throughput values are corrected with the measured torque values. Within the range of the lower limit otherwise a too high throughput would be determined and within the range of the upper limit a too small throughput (*5*). The distances between the press rolls are measurable also with a rope potentiometer. For the correction within the maximum deflection range of the spring-tensioned upper press roll force transducers are arranged, in order to measure the additional compression force at the limit range. A light barrier detects the mass flow in the spout and is used for the correction of a small harvested crop flow rate with minimum deflection of the press roll. The distance measurement is corrected additionally with the characteristics of the tension springs at the press roll. During increasing deflection the spring load and thus the density of the harvested crop (*10*) increase. The speed of the harvested crop is determined by the rpm of the stationary press roll.

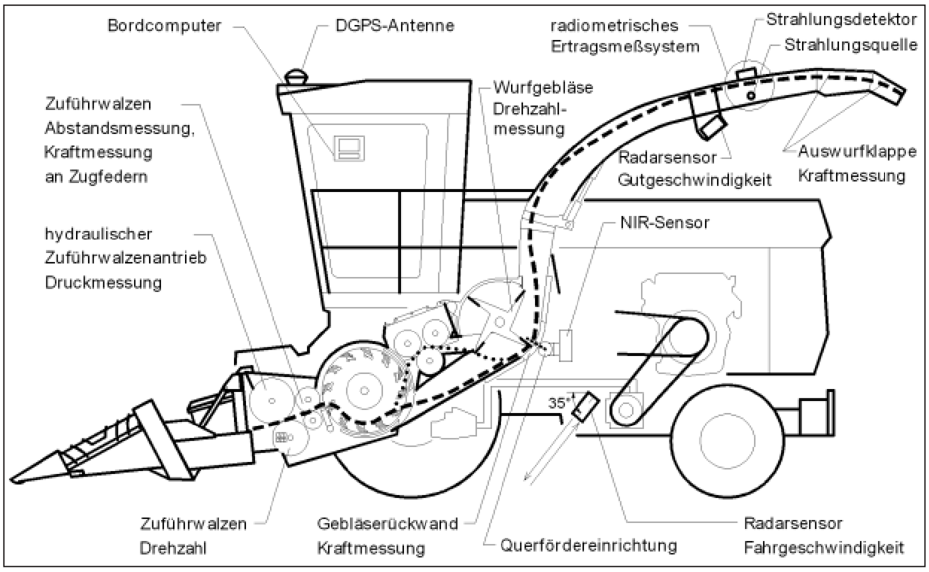

Fig. 1: Examples for measuring methods for mass flow rate and quality (Source: TU Munich, Chair of Agricultural Systems Engineering)

Instead of the light barrier for the recognition of mass flow, the vibrations caused by mass flow also are determinable with a microphone, an impact sound sensor (e.g. at the stationary knife) or by optical measurements (e.g. laser beam) of vibrating elements. Without measured vibrations the throughput is set to zero (*15*).

For throughput measurement,the top side of the spout offers for the detection of force, applied by mass flow. This force is transferred by a pivot-mounted, curved plate to a load cell. Working friction forces of mass flow are not detected with this arrangement. The mass flow speed is measured at the open lower surface or by a transparent section at the closed top side of the spout (*6, 8*).

With the employment of a microwave sensor in the spout, in particular abrasion problems of mechanical throughput measurements shall be avoided. The sensor works with the procedure of transmission, reflection, Doppler radar or pulse radar. The transmission procedure is applicable for the separate determination of throughput and crop moisture. Reflection measurements serve the moisture measurement. The speed and the layer thickness of the flowing through harvested crop are measurable with the Doppler radar procedure. The signals of the microwave sensor are corrected with temperature levels of harvested crop and output is crop moisture, throughput and crop temperature. Alternatively the surface moisture with infrared sensors can be determined (*7*).

Moisture sensors for the measurement of the electrical conductivity in the mass flow are subject to abrasion and soiling. To their avoidance as well as for the achievement of reliable measurement results, the measuring points directly after the cutterhead, directly after the blower or in a distance of the single to double blower housing diameter of the blower proved as favourable (*9*).

Alternatively also the withdrawal of a harvested crop sample from the cutterhead is feasible. This sample is compressed in a sample chamber, in order to avoid trapped air. From the position of the compression piston, the volume of the sample is determined. Using a pressure sensor the compression of the sample is measured and controlled. The relationship of volume and compression force of the sample can be used for the correction of throughput measurement on the press and feed rolls. Further, moisture and mass of the sample are determined (*21*).

With hydraulically propelled feed rolls the hydraulic pressure in the high pressure pipe is measured and in combination with the detected rpm of the feed rolls the throughput is computed. So the problem is evaded that low throughput lead to no deflection and high throughput lead to a maximum deflection of feed rolls, whereby the throughput measured values are falsified (*14*). For throughput measurement also the rear wall of the blower housing can be scanned for microscopic movements by impacting harvested crop with a laser interferometer. The measuring surface is formed between two solid joints with reduced material cross section, running across the conveying direction (*27*). For this also a force measurement at the rear wall of the blower is known (*12*).

Components and characteristics of harvested crop

For subsequent treatment of the chopped harvested crop also organic and not-organic components are of interest, beside its mass and moisture. For the measurement of components in the mass flow, optical spectrometers are to be used, which are installed together with a moisture sensor in the spout (*11*). In this connection the sampling for reference measurements is especially of importance. In addition a motor-driven tiltable guidance element in the spout can be installed. This is moved into the spout, opens it and leads a part of the mass flow into a probe unit (*18*).

A continuous sample taken at the blower for the determination of contents materials and characteristics of the harvested crop is known from (*19*). With a screw conveyor the branched harvested crop is compressed and supplied to an optical sensor (e.g. NIR or NIT sensor) to the spectrographic analysis. The wavelength spectra are compared with stored spectra on the on-board computer. The data for contents in the materials and characteristics of harvested crop, deposited to the stored spectra, are issued and site-specifically mapped with positioning data of the forage harvester.

The moisture or the components of harvested crop are possible parameters for the controlling of distance and contact pressure of the rolls of a kernel processor. Therewith the grains in harvested crop are partially fractured. With relatively high moisture, the roll distance is reduced and/or the contact pressure is increased. Based on the data of a moisture sensor the rolls can be adjusted automatically (*13*). Also the cutting length is controllable. Therefore the feed speed of harvested crop over the number of revolutions of the press rolls or the number of revolutions of the cutterhead is varied. The cutting length increases with the moisture (*16*).

Apart from moisture also the kind of forage plant must be considered during the control of the cutting length. Both parameters have a substantial influence on the compressibility of chopped material. The harvest attachment is detected with a sensor so the kind of harvested crop is determined. A moisture sensor (e.g. microwave sensor) behind the cutterhead detects the moisture in the chopped, relatively homogeneous mass flow. From the sensor data the optimal cutting length is determined and the capacity of the blower is regulated. With rising moisture content, the number of revolutions of the blower is increased (*20*).

Also the cutting height of the harvesting attachment is, dependent on soiling or measured components of a harvested crop in mass flow, controllable. In addition the mass flow with a spectrometer in the spout is analyzed (*24*).

The measuring point for a spectrometer in the spout requires a special configuration (*22, 23, 28*). For necessary cleaning of the measuring point the measuring instrument will be moved into the spout, in order to be cleaned by mass flow (*25*). During the use, the spectrometer must be recalibrated. Therefore black and white standards are used, which are moved automatically or manually into the path of rays (*26*).

Further utilization of measurement results

Apart from the aspects regarded so far, continuously stored operating data (e.g. throughput, working position of the harvest attachment, positioning data) supply important information also for the diagnosis, maintenance and the valuation of a forage harvester and its harvest attachments as well as for billing of contractors. With this data e.g. example operating hours, processed area, site information (positioning data), kind of harvested crop, operating speed, throughput or mechanical loads can be ascertained (*17*).

Literature

[1] *Ihle, G., und W. Dorniß* : Untersuchungen zur Mechanischen Messung des Durchsatzes am selbstfahrenden Feldhäcksler. Agrartechnik 27 (1977), H. 6, S. 265 – 266

[2] *Auernhammer, H., M. Demmel and P.J.M. Pirro* : Yield Measurement on Self Propelled Forage Harvesters. ASAE St. Joseph, 1995, Paper No. 95 1757

[3] Deutsches Patent- und Markenamt, http://depatisnet.dpma.de, Menüpunkt Recherche

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