Fürll, Christian; Schemel, Hartmut; Hempel, Heinz; Ellner, Janine and Hoffmann, Thomas

Energy-saving grinding of wet harvest grain with a grinding machine with wedge-shaped discs

A grinding machine with wedge-shaped discs was developed for grinding of wheat, barley, rye and maize with a moisture content up to 25 %. The grinding machine realised a mass flow > 40t/(h • m) with a energy consumption of < 3 kWh/t and with less than 1 % whole grains after crushing. The low specific energy consumption supplies an important contribution for energy conservation.

Keywords
Grain, reduction, processing

Abstract
Landtechnik 64 (2009), no. 6, pp. 403-405, 2 figures, 1 table, 3 references

More than 2/3 of all grain crops are used as feed-grain in livestock breeding. Recent tendencies owed to logistics and costs, have shown increasing relocation of storage and preservation to the farm. Particularly bigger farms produce their own feed-grain mixes from their harvest and store it in their own facilities. Aside from the drying of grain, in recent years the preserving storage of the freshly harvested grain with and without additives has proved to be energy saving as well as cost-effective.

An important step in this process is the milling of the grain directly after harvesting. Efficient logistic processing and the minimization of losses require the grain to be milled directly after harvesting, and to subsequently be stored and compressed in silos. Particularly the preservation without additives requires high storage densities to prevent the development of damaging micro-organisms.

Currently there are mainly impact-crushing machines or roller mills used for milling the grain.

Impact-crushing facilitates high mass flow rates, however, bought at high specific power consumption of up to 10 kWh/t. Roller mills can be operated with a power consumption of < 3kWh/t, but do often not facilitate the mass flow rates required by the process design.

Thus, the Leibniz Institute for Agriculture Engineering in Potsdam-Bornim has exercised trials for grinding wet harvest grain using grinding machines with wedge-shaped discs. The goal was to achieve high mass flow rates at reasonable power consumptions, and particle lengths accepted in animal feed.

Objective

The definition of the objective includes requirements regarding particle size, whole grain fraction, mass flow rates, and grain moisture. With respect to animal feed; pig feed requires more intensive grinding than cattle feed due to the particular digestion physiology. Trials for the assessment of the best degree of grinding of the grain in mast fodder mixes for pigs [1] have established that less coarsely grinded grain mixes have lead to better fodder exploitation, resulting in higher yield at slaughter. However, finer grain soy mix resulted in increasing appearance of malign stomach conditions and ulcers. Therefore, the proportion of particles with a size < 1 mm should not exceed 70 %.

Roughly outlined requirements to mean particle sizes after grinding $x_{50;E}$ are:

- Pig feed: $x_{50;E} \leq 1\,mm$
- Cattle feed: $x_{50;E} \leq 4\,mm$

In cattle feed mix, the grain should just be squashed to expose the inner grain, easing digestion. Another requirement refers to permitted fractions of whole grain, since cattle cannot digest whole grain. The permissible limit is ≤ 1 %.

Requirements to the process are reliability, continuity and low specific power consumption:

- reliable grinding for grain moistures up to approx. 25 %
- mass flow rate > 30 t/h
- energy consumption: < 3 kWh/t

The upper limit for grain moisture results from permissible limits for gas-tight storage. Mass flow rates are set by the threshing capacities of harvester combines conventionally used by farms.

Trials

Test machine. The test machine consists of a pair of grinding rollers with wedge-shaped discs (**figure 1**). The functional principle is known from a secondary chopping unit in forage harvesters [2]. Both rollers in a combing placement shape a zick-zacking mill gap. Keeping the same mill gap length as in cylindrical rollers, the length of the wedged shape rollers appears reduced, relating to advantages in machine dynamics. Pure compression load does only occur at those points of the mill gap with the same circumferential speed. Compression load and shearing load appear simultaneously at all other points of the mill gap. The gap width can be varied by adjusting the shaft distance. One shaft is mounted in fixed bearings in the housing; the other shaft is installed on spring mounted bearings on a rocker arm. This allows the roller to deflect upon ingress of foreign objects. Both shafts are driven separately by a motor with frequency drive control, allowing for different speeds.

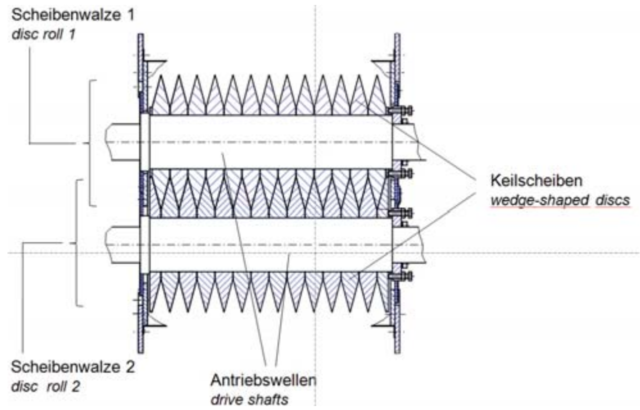
The wedge-shaped discs feature a outer diameter of 299 mm and a wedge angle of 30°. The radius of curvature of the wedge-shaped disc varies between 300 mm (middle) and 577 mm (liner). The ribbing of the wedge surfaces runs concentric towards the roller shafts with outward pointing cutting edge. In the actual grinding process; besides shearing loads in vertical direction, this ribbing facilitates further shearing loads in radial direction, thus increasing the efficiency of the milling. The variation of speed of the two grinding rollers can be facilitated independently between 600 and 2000 min^{-1} via variable frequency drive. The mill gap can be adjusted between 0.3 and 3.5 mm by deflecting a rocker arm bearing the spring loaded roller shaft. The effective grinding width of the test machine was limited to 0.3 m due to technological reasons and test drive capacity. The overall length of the V-shaped, shortened mill gap in this setting is approx. 1.1 m.

Execution of trial. During the trials the number of passages, roller speed, mill gap width, mass flow, grain moisture, and type of grain were varied to assess different parameters of construction, processing, and material. Detailed parameter combinations were carried out in the trials with wheat. The generated results were selectively examined in rye, barley and maize. Dosing rollers at the outlet of a wedge-shaped reservoir container facilitated the mass flow dosing. Power consumption was measured at both drives separately.

Results

The two-stage milling has proved to be expedient [3] in all types of grain (wheat, rye, winter barley, and maize). In throughputs of ≥ 40 t/h at a translated roller width of 1 m, the targeted specific power consumption of ≤ 3 kWh/t and a whole grain fraction of ≤ 1 % were met; and particularly in maize and partially in wheat those parameters were substantially undercut (**table 1**, **figure 2**). Only wheat with 25 % grain moisture the required power was 3.6 kWh/t. Compared to one-stage milling, a more favourable ratio between grain size and mill gap angle can be achieved in two-stage grinding. This results in better drawing-in of the grain into the milling gap, with clearly reduced work of friction. Disc speed and mill gap have to be adjusted to the grain type. However, differences within certain grain types were also established, e.g. wheat (**table 1**).

Fig. 1



Rolls of the crushing machine with wedge-shaped discs

In comparative tests with a hammer mill, a reduction of about 1/3 of specific power consumption at the same fraction of whole grain, and a mass flow increased by factor 4 translated to 1 m work width could be established for the two-stage wedge-shaped disc roller mill. The average particle size of the mill material, however, is bigger in wedge-shaped disc roller mills than in hammer mills. Test results from trials with a laboratory roller mill indicate higher specific power consumption, tough. Advantages of the wedge-shaped disc roller mill can achieve five-fold mass flow rates.

It can be assumed that further optimization of the construction parameters will result in substantial reductions of the specific energy demand, particularly in maize with up to 30 % grain moisture and wheat up to 20 % grain moisture.

The selected concentric ribbing of the wedge-shaped disc with outward pointing cutting edge did not support the drawing-in of the grain. A friction coefficient of about 0.15, matching a smooth, dry steel disc, was established. With increasing grain moisture the coefficient was further reduced, thus degrading the drawing-in of grain.

Using a container above the grinding unit best facilitated the drawing in of grain. Dosing with two counter-rotating smooth rollers at the outlet of the container has proven very practical. Thus a steady, measured distribution of good can be managed.

Conclusions

Grinding of grain with a wedge-shaped roller mill is efficiently applicable in a wide range of grain moisture down to particle sizes particularly used in cattle feed. Two milling passages have been proven beneficial within the selected constructional parameters. With specific mass flow rates > 40 t/(h • m), a specific energy demand of < 3 kWh/t and a whole grain fraction of < 1 % the set goals could be met.

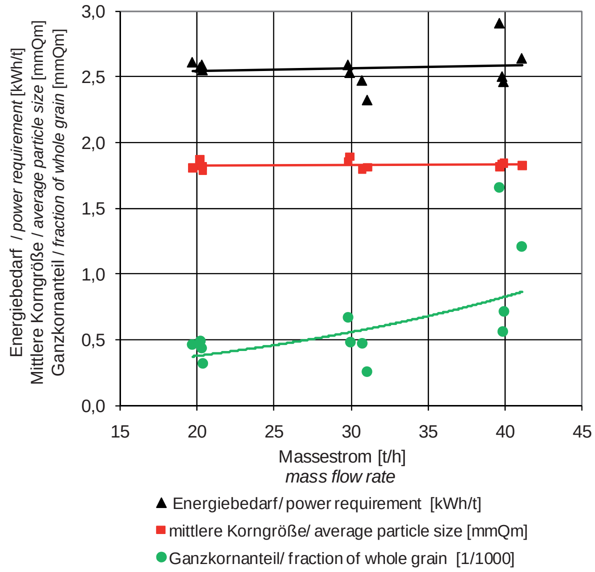
Table 1

Technical parameters of machine adjustments and achieved results

Kornfeuchte *grain moisture*	Mittlere Scheibengeschwindigkeit *average disc velocity*	Spezifischer Energiebedarf[1)] *specific energy consumption*[1)]	Spezifischer Massestrom *specific throughput*	Ganzkornanteil *fraction of whole kernels*
%	m/s	kWh/t	t/(h.m)	%
Weizen / *wheat*				
13	17.9/19.1	1.0	42	0.3
15	14.3	2.4	42	0.2
20	14.3	3.0	42	0.6
25	11.3	3.6	37	1.0
Mais / *maize*				
14	9.6	1.2	40	1.0
30	9.6	1.1	47	0.7
Roggen / *rye*				
13	9.6	2.3	42	0.8
Wintergerste / *winter barley*				
14	8.8	3.0	32	1.1

[1)] Mittelwert von 3 Messungen / *mean value of 3 measurements*

Fig. 2



Influence of mass flow rate on power requirement, average particle size, fraction of whole grain (wheat, 12 %, grain moisture, two stage milling)

Presumably, an optimization of constructive parameters can lead to further improvements concerning the reduction of particle size after grinding.

Literature

[1] Hoppenbrock, K.-H.; L. Bütfering und U. Schmidt: Unterschiedlicher Vermahlungsgrad von Getreidemastmischungen. Landwirtschaftszentrum Haus Düsse, Landwirtschaftskammer NRW, Berichte und Versuchsergebnisse 1996, http://duesse.de/schweine/versuche/ma_v_vermahlungsgrad.htm, Zugriff am 30.01.1997

[2] Patentschrift DE 4122338 C2: Nachzerkleinerungseinrichtung für Feldhäcksler. Erfinder: H. Friel und C. Schlegel. Anmeldetag: 5.7.1991

[3] Fürll, Ch.; H. Schemel, H. Hempel und J. Ellner: Zerkleinerungsmaschine für erntefeuchtes Getreide. AIF-Abschlussbericht, Leibniz-Institut für Agrartechnik Potsdam-Bornim, 2008

Authors

Prof. Dr.-Ing. habil. Christian Fürll headed the department „Post Harvest Technology“ at the Leibniz-Institute for Agriculture Engineering Potsdam-Bornim (ATB), Max-Eyth-Allee 100, 14469 Potsdam, until 2008 and is currently a visiting scientist at this department, E-Mail: cfuerll@atb-potsdam.de

Dr. rer. agr. Dipl. Ing. Thomas Hoffmann has been head of the department „Post Harvest Technology“ at the ATB since 2008, E-Mail: THoffmann@atb-potsdam.de

Dipl. Ing. Heinz Hempel and **Dr.-Ing. Hartmut Schemel** are scientists in the same department.

Dipl. Ing. (FH) Janine Ellner was a PhD-student in the same department.