Comparison of two possibilities for mowing machine material feed rate measurement under laboratory conditions

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ABSTRACT: The impact of materials and conditions (parameters) changes on mowing machine material feed rate measurement accuracy were measured under laboratory conditions. The influence of crop variety, crop maturity and moisture, and intensity of conditioning were tested. The impact of the changing parameters in two measurement methods (based on torque-meter and/or on impact plate) was studied. Eight files of torque-meter and/or impact plate measurement were obtained during our experiments. Statistical analysis was used for data evaluation. Two-sample comparisons were used for torque-meter measurement. It is evident from that evaluation that changing crop variety, crop maturity and intensity of conditioning can have statistically significant influence on the measurement based on torque-meter. For impact plate measurement the analysis of variance was used. It was found out that it is not possible to statistically determine the influence of tested factors on our measurement. Considering these results the material feed rate measurement based on impact plate is better from practical point of view.

Keywords: mowing machines; feed rate measurement; accuracy

A forage crop feed rate sensor can be useful in several applications of precision farming. Information about the variable feed rate of forage can be used for calculating site-specific forage crop yield for a yield map.

Flow rate measurement techniques for forage harvesters have been published previously. VANSICHEN and DE BAERDEMAEKER (1993) calculated the yield from the torque of the harvester's blower. Another possibility is to measure the distance between feeder rolls of the harvester (EHLERT, SCHMIDT 1995). Recently AUERNHAMMER et al. (1996) measured yield by using a nuclear gauge sensor placed in the spout of a forage harvester. A mass flow sensor for a pull type (trailed) forage harvester based on a reaction plate in the spout was constructed and tested by MISSOTTEN et al. (1997). This sensor was designed to be used for various crop properties (e.g. moisture, crop maturity, stand height, stand density) and crop type.

Site-specific measurement of biomass in growing crops has been proposed as a pivoted cylindrical body moving horizontally through a plant population (moving pendulum). The angle of deviation of this pendulum varies with the plant properties (e.g. stand density, stem thickness, crop maturity, material moisture). These measurements were performed on cereals (EHLERT, SCHMIDT 1996).

DEMMEL et al. (2002) used a principle based on the belt weighing technology for mowing machine material feed rate measurement. This system can be used for the mowing machines equipped with swather conveyor only.

Feed rate measurement techniques for mowing machines equipped with conditioner have been tested by KUMHÁLA et al. (2001). Results were obtained with mowing machine material feed rate measured by torque-meter placed on a conditioner shaft and by means of curved impact plate mounted on the machine's material output. The carried out measurements proved a very good linear relationship between the conditioner's power input, output frequency of the apparatus measuring the impact force by means of an impact plate, and material feed rate through the mowing machine. The calculated coefficients of correlation were about 0.95.

The objective of this research was to test these two yield mapping capabilities for modern mowing machines operated at different conditions. The influence of changing crop variety, crop maturity and moisture and intensity of conditioning were measured. The impact of changing parameters in both measurement methods (torque-meter and impact plate) was studied.

MATERIAL AND METHODS

Apparatus

The apparatus used for testing of material feed rate measurement possibility (KUMHÁLA et al. 2001) was used for our measurement. A ŽTR 216 H mowing machine (Agrostroj Pelhřimov Company, Czech Republic) was used for the measurements. This machine is equipped with two working drums and a finger conditioner. The working width of the machine is 2.15 m. The mowing machine was equipped with an electronic measuring unit developed in our laboratory. The mowing machine's conditioner shaft was supplied with a torque-meter based on resistant strain gauges and with

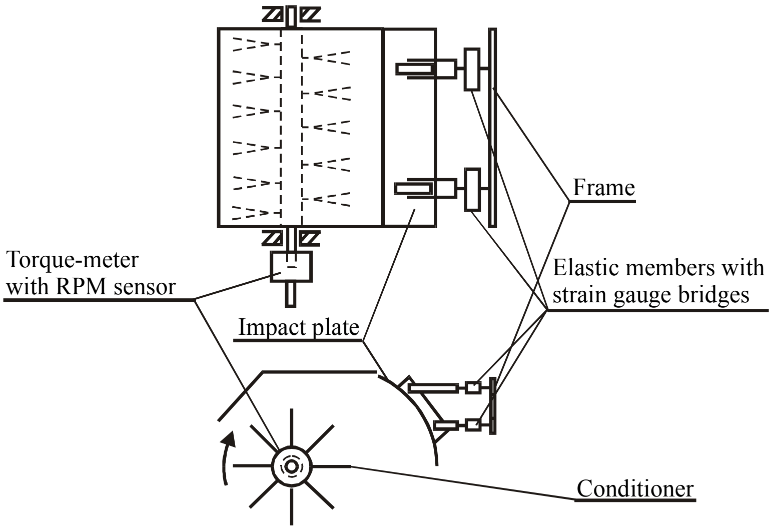

Fig. 1. Equipment for material feed rate measurement

a RPM optical sensor measuring number of conditioner shaft revolutions.

Besides the torque-meter, the mowing machine was equipped with a curved impact plate mounted at the exit of the machine. The material ejected from the mowing machine conditioner struck the impact plate. The force created from the change in direction was measured in this way. The curved impact plate was equipped with four elastic members with strain gauge bridges for force measurement. The equipment for this material feed rate measurement is shown in Fig. 1.

Voltage signals obtained by the strain gauges placed on the torque-meter and by the impact-plate four-bridge strain gauge were amplified and converted into frequency by an electronic measuring apparatus developed in our laboratory. The output frequency was proportional to the measured tension. All signals were processed with a one-chip microcomputer and the data obtained were transferred into a notebook for storage. The block diagram of this electronic apparatus arrangement is shown in Fig. 2.

The laboratory set-up was composed of a conveyer belt carrying a measured quantity of material, a tractor and a rotary drum-mowing machine equipped with the electronic measurement apparatus.

Experimental method

Two types of material were used for our measurement: alfalfa with grass mixture and grass from natural meadow. These crops were harvested on the same plot but at different crop maturity and moisture content. Moisture content varied from 82% to 72% in alfalfa with grass mixture and from 77% to 74% in grass. Two levels of

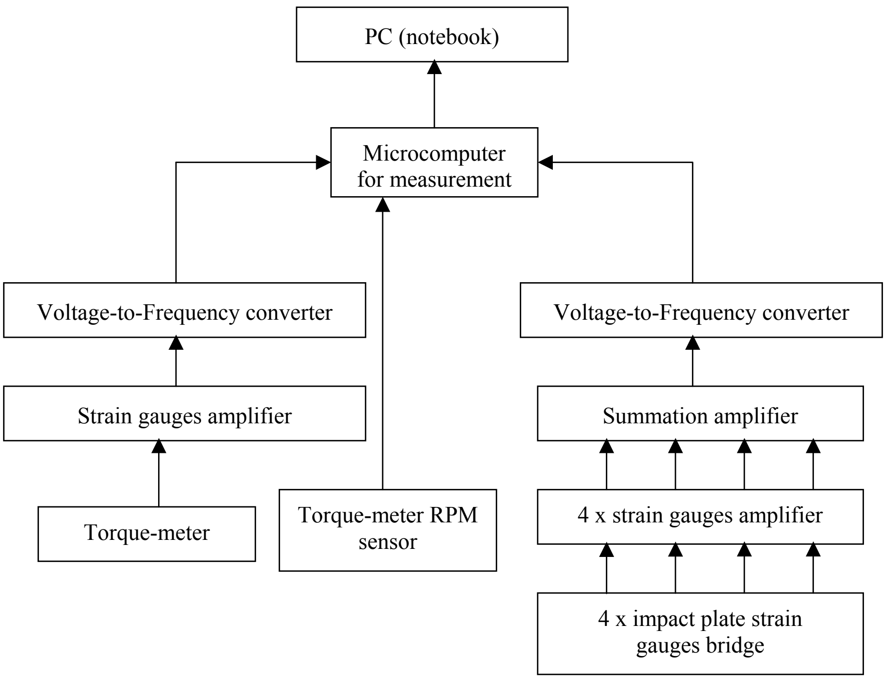

Fig. 2. Block diagram of electronic apparatus arrangement for material feed rate measurement

conditioning intensity were set up and tested during the measurement with each different material.

Material was transported into the mowing machine for approximately five seconds for each measurement using a conveyer belt. The signals from the torque-meter, RPM sensor and impact plate sensors were measured every half second. Ten values of torque-meter measuring apparatus output frequency, RPM, and output frequency of the apparatus measuring impact force by means of the impact plate arrangement were obtained from one single measurement. The measurement was repeated a minimum of three times for each determined amount of material, variety, crop maturity and intensity of conditioning. The values obtained from these measurements were used in calculation.

RESULTS AND DISCUSSION

Torque-meter

Eight files of torque-meter measurement were obtained during our experiments by described procedure. The files are named using following principle: All files achieved with grass measurement are marked starting with Gra and with alfalfa and grass mixture are marked starting with Alf. To compare the influence of crop maturity (and moisture), the measurement with the material from the same plot were repeated after two weeks. First number in file name indicates if the measured file was achieved in first measurement (i.e. Gra_ 1) or in second measurement (i.e. Gra_2). To study the influence of conditioning intensity two levels of this intensity were set up on the mowing machine conditioner for each material measured. Smaller intensity of conditioning is marked by con_2 and higher is marked by con_4. Using this algorithm, the file name (for example) Alf_1_con_4 indicates that this file results from the first measurement with alfalfa and grass mixture crop and higher intensity of conditioning was set up on the mowing machine conditioner.

The Statgraphics®Plus software was used for achieved data statistical evaluation. The analysis of variance was used for data evaluation in first step. It was necessary to test the null hypothesis that the standard deviations of achieved data are the same. The *P*-value 0.00266918 of Cochran's test and *P*-value 0.00000429378 of Bartlett's test was calculated. Since both of these calculated *P*-values are less than 0.05 there is a statistically significant difference amongst the standard deviations at the 95% confidence level. This unfortunately violates one of the important assumptions underlying the analysis of variance. It was not possible to use analysis of variance for data evaluation in this case.

For this reason it was decided to use two sample comparisons. Each file of measured data was compared with each other. Table 1 shows the results of two sample comparison for all files combination.

It follows from this table that from 28 tested pairs of files in 12 cases here a statistically significant difference exists between the means of two samples at the 95% confidence levels. Important from our point of view are the comparisons No. 1, 11, 24 and 27. In these cases very probably the change of one itself factor only affects the measurement.

In comparison No. 1 it was tested the function of measured device with the same grass from natural meadow with 77% moisture content. The intensity of conditioning only was changed. It is possible to derive from the result of this comparison that the set up intensity of conditioning is an important factor affecting the torque-meter measurement.

From the comparison No. 11 it follows another important finding. The first compared file was achieved during the measurement device function with alfalfa and grass mixture in optimal crop maturity for the harvest and higher set up intensity of conditioning. The second compared file vas achieved with grass in optimal crop maturity for the harvest and higher set up intensity of conditioning as well. The statistically important dif-

Table 1. Statistically significant difference (indicated by *t*-test) between the files obtained by torque-meter measurement

Comp. No.	Compared files	Difference (Yes\No)
1	Gra_1_con_2 – Gra_1_con_4	Yes
2	Gra_1_con_2 – Gra_2_con_2	No
3	Gra_1_con_2 – Gra_2_con_4	Yes
4	Gra_1_con_2 – Alf_1_con_2	No
5	Gra_1_con_2 – Alf_1_con_4	No
6	Gra_1_con_2 – Alf_2_con_2	Yes
7	Gra_1_con_2 – Alf_2_con_4	Yes
8	Gra_1_con_4 – Gra_2_con_2	No
9	Gra_1_con_4 – Gra_2_con_4	No
10	Gra_1_con_4 – Alf_1_con_2	Yes
11	Gra_1_con_4 – Alf_1_con_4	Yes
12	Gra_1_con_4 – Alf_2_con_2	No
13	Gra_1_con_4 – Alf_2_con_4	No
14	Gra_2_con_2 – Gra_2_con_4	No
15	Gra_2_con_2 – Alf_1_con_2	No
16	Gra_2_con_2 – Alf_1_con_4	No
17	Gra_2_con_2 – Alf_2_con_2	No
18	Gra_2_con_2 – Alf_2_con_4	Yes
19	Gra_2_con_4 – Alf_1_con_2	Yes
20	Gra_2_con_4 – Alf_1_con_4	No
21	Gra_2_con_4 – Alf_2_con_2	No
22	Gra_2_con_4 – Alf_2_con_4	No
23	Alf_1_con_2 – Alf_1_con_4	No
24	Alf_1_con_2 – Alf_2_con_2	Yes
25	Alf_1_con_2 – Alf_2_con_4	Yes
26	Alf_1_con_4 – Alf_2_con_2	Yes
27	Alf_1_con_4 – Alf_2_con_4	Yes
28	Alf_2_con_2 – Alf_2_con_4	No

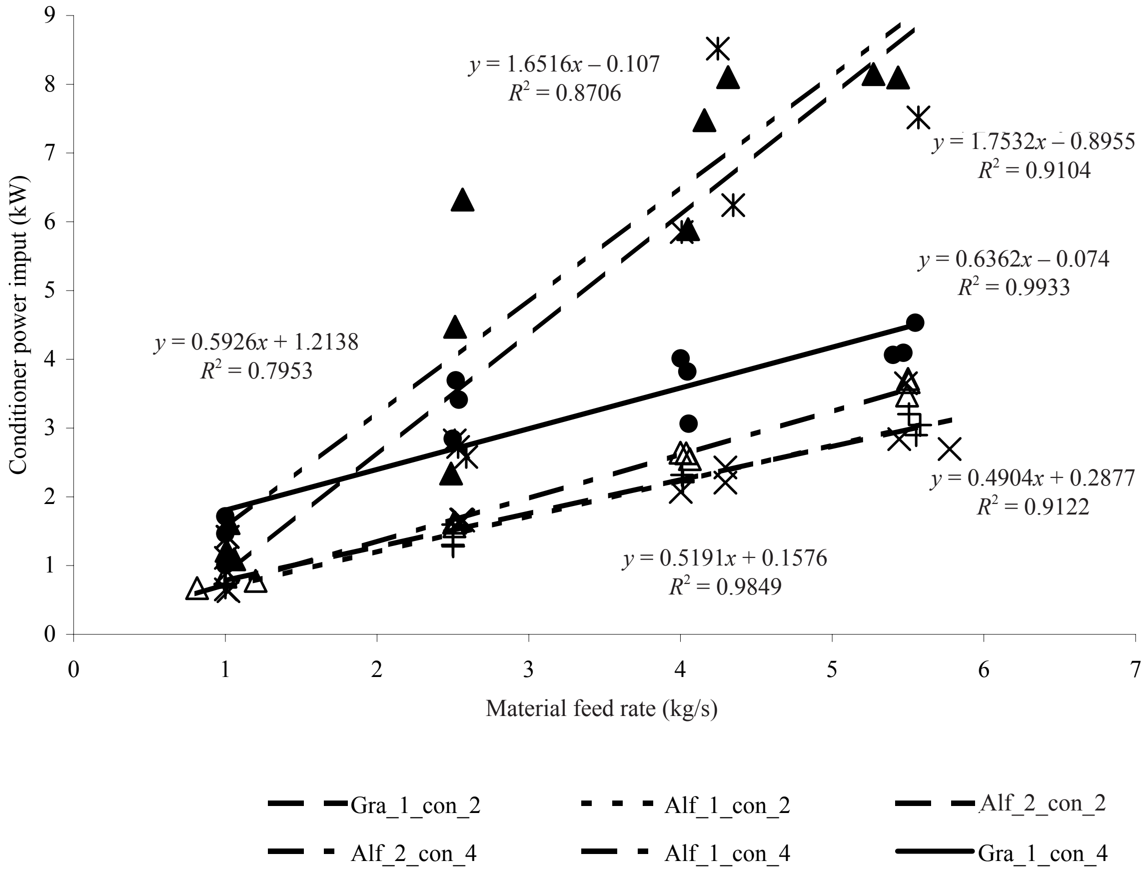

Fig. 3. Graphic comparison of tested files from torque-meter measurement

ference between these two files was detected as well. It is possible to derive from that comparison that the variety of harvested crop can influence the power input measured by torque-meter.

Comparison No. 24 and 27 tests files measured with alfalfa in optimal crop maturity (82% moisture content) with the files measured with older (harvested after two weeks) alfalfa and grass mixture crop from the same field (72% material moisture). If the files with the same set up intensity of conditioning are compared, in both cases exists a statistically important difference between these files. It follows from these comparisons that crop maturity can influence the power input measured by torque-meter as well. All files from comparisons No. 1, 11, 24 and 27 (with calculated coefficients for linear correlation) are charted in Fig. 3.

In other comparisons where the statistically important difference between two files was calculated, the combination of these three factors very probably influences the torque-meter measurement. It is not possible to detect which from the tested factors influence the measurement more than other ones.

Impact plate

Eight files of impact plate measurement were obtained during our experiments as well. Analysis of variance was used for data evaluation. It was necessary to test the null hypothesis that the standard deviations of achieved data are the same. The *P*-value 0.461494 of Cochran's test and *P*-value 0.878545 of Bartlett's test were calculated. Since the smaller of the *P*-values is greater than 0.05, there is not a statistically significant difference amongst the standard deviations at the 95% confidence level. It is possible to use the analysis of variance for data evaluation in that case. The results of analysis of variance are in Table 2.

The *F*-ratio, which in this case equals 0.612512, is a ratio of the between-group estimate to the within-group estimate. Since the *P*-value of the *F*-test is in this case greater than 0.05, there is not a statistically significant difference between the means of tested files at 95% confidence level. It follows from that analysis that it is not possible to find the mean significantly different from others. The influence of tested factors on impact plate measurement is not possible to be statistically determinated from our tests. All impact plate measurement values are charted in Fig. 4. Because no statistically significant difference between tested files was found, linear correlation is applied to all data. The calculated value of correlation coefficient is 0.94. This is with good agreement with measurements achieved in 2001.

CONCLUSIONS

The main aim of this work was to find the effects of various materials and conditions (parameters) and their

Table 2. Analysis of variance results for the files obtained during impact plate measurement

Source	Sum of squares	Df	Mean square	*F*-ratio	*P*-value
Between groups	13,669.6	7	1,952.81	0.61	0.7441
Within groups	244,620.0	83	3,188.19		
Total (corr.)	278,290.0	90			

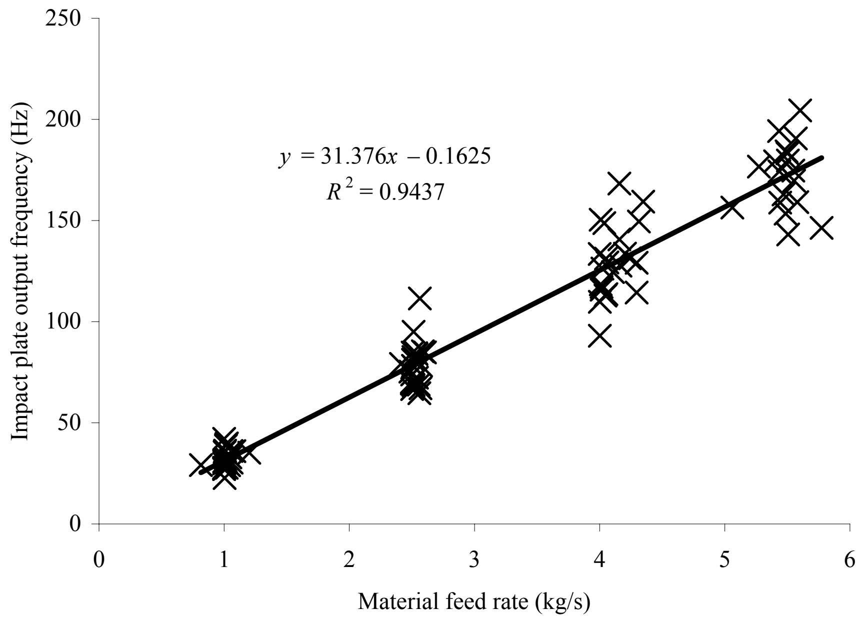

Fig. 4. Measured values from impact plate measurement

impact on accuracy of mowing machine material feed rate measurement under laboratory conditions. The influence of crop variety, crop maturity and moisture, and intensity of conditioning were measured. The impact of changing parameters in two measurement methods (torque-meter and impact plate) was studied.

It is clear from the carried out measurements than the change of intensity of conditioning itself or the change of crop maturity itself or the change of crop variety itself can account for a statistically significant difference between the files measured by torque-meter. All tested factors can have statistically significant influence on the measurement based on torque-meter for that reason.

In opposite, if the method based on impact plate is used, it is not possible to determine statistically significant influence of tested factors changes on impact plate measurement from our experiments. The measurement method based on using impact plate can be less sensitive to material and intensity of conditioning changes. Another advantage for the impact plate utilization can be its simplicity and lower costs in comparison with the torque-meter. It could be possible to recommend an infield measurement arrangement to obtain relationships under the real field conditions.

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Porovnání dvou možností měření průchodnosti materiálu žacím strojem v laboratorních podmínkách

ABSTRAKT: Na základě znalosti okamžité průchodnosti materiálu libovolným sklízecím strojem lze v kombinaci se signály o okamžité poloze stroje vytvořit výnosovou mapu sklízeného pozemku. Technika mapování výnosů se rozšiřuje také na stroje pro sklizeň pícnin. Průchodnost materiálu sklízecí řezačkou je např. možné určit prostřednictvím kontinuálního měření příkonu jejího metače, měřením vzdálenosti vkládacích válců, pomocí nárazové desky atd. Je rovněž možné pomocí kyvadla určit místní rozdíly ve výnosu stojícího porostu. U žacích strojů nebyly donedávna vyvinuty žádné metody okamžitého měření průchodnosti. Z poslední doby je známa metoda vážení překládacího dopravníku u žacích strojů, které jím jsou vybaveny. Na katedře zemědělských strojů Technické fakulty České zemědělské univerzity v Praze se již delší dobu zkoumají dvě možnosti měření okamžité průchodnosti žacím strojem, vybaveným prstovým čechračem pro úpravu posečené píce. První metoda je založena na průběžném měření příkonu čechrače pomocí torzního dynamometru; druhá metoda je založena na měření síly vyvíjené materiálem opouštějícím žací stroj na nárazovou desku. Již měření v roce 2001 prokázala velmi silnou lineární závislost údajů získávaných oběma metodami měření na průchodnosti materiálu strojem. Na základě různých diskusí nás zajímalo, do jaké míry každé z měření ovlivňuje druh sklízeného materiálu, jeho zralost a nastavená intenzita jeho úpravy na stroji. Hodnotili jsme proto odezvy celého systému na práci se dvěma sklízenými porosty (směska vojtěšky s trávou a luční tráva) v různých stupních jejich zralosti při různé nastavené intenzitě jejich úpravy. Pro zajištění co největší objektivity byla tato měření uskutečněna v laboratorních podmínkách. Výsledky experimentů byly statisticky vyhodnoceny pomocí programu Statgraphics®Plus. Na základě statistického hodnocení dosažených výsledků je možné konstatovat, že každý ze sledovaných faktorů sám o sobě statisticky významně ovlivňuje měření založená na práci torzního dynamometru. Naopak ani u jednoho ze sledovaných faktorů nebyl prokázán statisticky významný vliv na měření založená na principu práce nárazové desky. Z praktického pohledu je měření pomocí nárazové desky možné na základě dosažených výsledků považovat za výhodnější, protože nevyžaduje zvláštní kalibrace při změně sklízeného materiálu, jeho stáří nebo intenzity jeho úpravy. Je možné doporučit vyzkoušení práce obou systémů v polních podmínkách.

Klíčová slova: žací stroje; měření průchodnosti; přesnost

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