Measuring of pulling resistance in machinery with passive working organs

J. Musil, J. Červinka

Faculty of Agronomy, Mendel University of Agriculture and Forestry in Brno, Brno, Czech Republic

Abstract: A determination of the total pulling resistance of machinery is important in light of its dimensioning as well in light of energy requirements of processed operation. There are several methods to determine it. They can be divided to analytical methods (Goryachkin) and to methods of measurement in field-laboratory conditions using different kinds of force sensors. The most frequently used type is a sensor on the base of tensiometer, which was used during our work. Measured pulling resistance at three working speeds and at ranges of used depths of soil processing 82–122 mm was 9.6–17.4 kN with variation coefficient up to 10%. This measure has proved a dependence of the total pulling resistance on used depth of soil processing however dependence on speed of operation was practically insignificant. Machinery work quality was evaluated by determination of weight of plants matter on the field surface and by quantification of its percentage in total plant matter on the same area. The measured percentage range of plant matter on the field surface was 67.2–4.6% at working speed 8–14 km/h.

Keywords: tillage; disk harrow; measuring equipment; field experiments

In the course of cultivation of plants, the mechanical processing of soil (tillage) consists of many different operations and consumes a lot of energy, time and other resources. Results of research studies performed not only in the Czech Republic but also abroad indicate that as much as 35% of total diesel fuel is consumed for tillage operations. Manufacturers of agricultural machinery look for different methods how to save fuel when tilling the soil without compromising the requirements of quality (Páltik *et al.* 2003)

In recent decades, new tillage technologies have been introduced, mainly due to the progress in the field of crop cultivation, requirements of plants concerning the soil environment, anti-erosion measures, effects of mechanical processing of soil on its texture and properties and, last but not least, development of different new machines and tools. All these technologies are classified as "minimum tillage operations". As far as the methods of soil-bed preparation are concerned, the methods used are very different and involve not only very intensive methods of tillage and preparation of soil to substantial depths but also those that do sow seeds directly into non-processed soil, i.e. the so-called methods of zero or no tillage. The evaluation of consumption of energy for individual operations can be done on the base of the estimation (and measuring) of the pull resistance of machines (and/or machinery aggregations).

MATERIAL AND METHODS

Analytical methods of estimation of the total pull resistance of machines

To estimate the traction resistance of agricultural machinery in the course of ploughing the following equation is commonly used (in spite of the fact that it is very exact) but usually only for orientation calculations:

$$F = k \times a \times b \qquad \text{(N)} \qquad (1)$$

where:

a – depth of ploughing (m)

b – width of plough (m)

k – ploughing resistance (depending on the class and condition of soil) (Pa, kPa)

Basing on results of both theoretical studies and experiments, Goryachkin developed a rational equation enabling to calculate the ploughing resistance F:

$$F = F_G \times f + k \times a \times b \times n + \varepsilon \times v^2 \times a \times b \times n \quad \text{(N)} \quad (2)$$

The first member of this equation $F_G \times f$ indicates the passive resistance of plough in the course of movement and is not dependent on the depth of ploughing where F_G (N) is the weight (mass) of plough and f (–) is the coefficient of rolling resistance.

The second member of the above equation ($k \times a \times b \times n$) characterizes the useful resistance, which is spent to cut and deform the slice of soil. The coefficient k (Pa) is the specific resistance of soil, The parameter a (m) is the depth of ploughing, b (m) is the width of one ploughing body and n (–) gives the number of ploughing bodies.

The specific resistance of soil is defined as the strength required for tillage of unit soil area as measured perpendicularly in the plane, which is perpendicular to the direction of driving. Its magnitude is dependent on properties and type of soil and also on the shape and geometry of working parts of the machine (i.e. ploughing bodies).

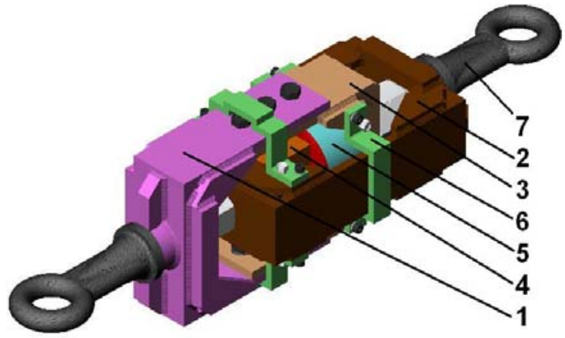
The third member ($F_3 = \varepsilon \times v^2 \times a \times b \times n$) gives the strength required for the putting of soil slice into movement and for its turning over. The coefficient ε ($N.s^2/m^4$) depends on the shape of the working surface of the ploughing body, soil properties and working speed v (m/s). Its magnitude ranges from 3 000 to 10 000 Ns^2/m^4 (Hůla *et al.* 1997).

The product ($a \times b \times n$) is de facto the size of the projection S (m^2) of processed soil area into the plane that is perpendicular to the direction of machine movement. Thus the Eq. (2) can be used also when calculating the traction resistance of other tillage machines, viz. in the following form:

$$F = F_G \times f + k \times S + \varepsilon \times v^2 \times S \quad \text{(N)} \quad (3)$$

Estimation of the magnitude of the total pulling resistance

Field tests and measurings are the most exact method of estimation of the total puling resistance of a machine. For such measurings sensors of different construction or design are used in practice. For the time being, sensors based on metallic and/or semiconductor tensometers are being used due to their exactness and high sensitivity; the magnitude of the measured force is converted (using the deformation of the so-called deformation member) into the deformation of the tensometer, which is attached to this deformation member.



1, 2, 3 – pulling rods; 4 – tensometric member; 5 – silentblock; 6 – slideway; 7 – connecting end

Figure 1. The device MČB1 for measuring of the puling resistance

Design and construction of the measuring device

When selecting the tensometric sensor it was decided to use a product manufactured by the company TEVAS. Products of this company are used above all as sensors of pressure forces and for that reason it was at first necessary to convert this type of force to a pulling force. In co-operation with the University Training Farm Žabčice we have developed and constructed a measuring device MČB1 (Figure 1). This device was dimensioned for the maximum pulling force of 4 kN.

The pulling force is transmissed through connecting ends fixed by means of nuts to pulling rods, which press to the tensometric member; this member is directly and across of a silentblock screwed to one and to the other pulling rod, respectively. Because of assembly reasons, one of these rods has two parts that are connected by means of fitted bolts.

The silentblock is required partly for the registration of forces caused by the suspension of the device and partly for the elimination of undesired shocks that could damage the tensometer.

The slideway assures a stabilised position of both pulling rods and their sliding under load. To prevent its damage due to a reverse shock the measuring device is furnished with a rubber shock dumper.

The databank is a device that stores continuously all recorded values of pulling resistance. After the end of measurings and connecting the databank with a notebook, the stored data are transmissed through a serial port into the computer and processed (e.g., by means of the Excel programme). Measured values

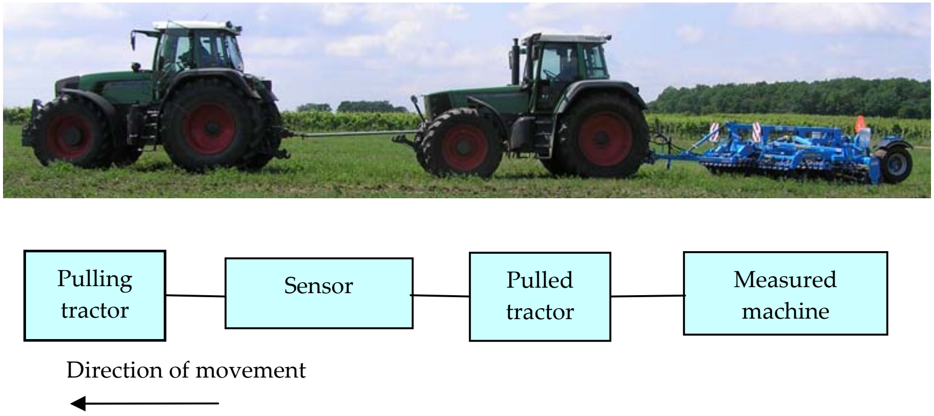


Figure 2. Arrangement of tractors and the measured machine

are stored in preset time intervals and the output values of the pulling force F are given in (N). The device can be also connected with an inductive indicator of revolutions.

To be able to record the momentary speed of operation v (m/s) a device was manufactured that consists of a bantam wheel assembled by means of stirrups to the tested machine and of a contactless inductive indicator of revolutions.

Measuring of the overall pulling resistance of the machine

When measuring the pulling forces of mechanisation devices two basic variants of arrangement can be used. If the measured machine is mounted by means of a three-point suspension (and this was our case), two tractors must be used for the measuring: the first one is the source of pulling force (pulling tractor Fendt 926 vario) while the other (Fendt 822 favorit) functions as a carrier (of the measured machinery). The tensometric sensor itself then links up both tractors and transfers the pulling force from the first tractor to the second one. The arrangement of both tractors is presented in Figure 2.

In case that the sensor of the pulling force can be mounted directly on the tractor it is not necessary to use the connecting device. In our field experiments the pulling resistance of the disc harrow DISKER DN 4.5 (Farmet-Česká Skalice) with the working width of 4.5 m was measured. On the ground of load-capacity of the sensor, the working mesh of the machine was reduced by unmounting both side disks. The resulting width was 2.65 m.

Characteristics of the experimental plot

Characteristics of cultivated soil (moisture content and specific density) were determined by means of a laboratory analysis of obtained soil samples. Soil compaction was determined by means of penetrometry.

Measured sectors

Prior to each measuring, sectors of the length of 100 m were measured out on experimental fields and a manipulation area of 20–30 m was left in front of them for the stabilisation of the operation parameters of the measured aggregate. The following values were recorded in each measured sector.

Measuring of exploitation parameters

Operational width. This parameter was measured using a tape line perpendicularly to the driving direction of the aggregate after its passing by; this was repeated 10 times in each case.

Depth of cultivation. The depth of cultivation was measured by means of a profilograph. Using this device, the position of sliding bars above the non-cultivated soil surface was read on the scale. Depths of cultivation were read after the passing by of the aggregate at the bottom of the furrow. Positions of individual bars on the intact soil surface were recorded in a table and used for the calculation of arithmetic means and/or variation coefficients. The same procedure was used when measuring the depth of furrow profiles.

Working speed. The working speed was adjusted on on-board computer of pulling tractor.

Slippage. After passing through the distance corresponding with five turnovers of the driving wheel of the pulling tractor the pathway was measured by the tape line. The known dynamic radius of the driving wheel enables to calculate the slippage δ using the equation:

$$\delta = \left(1 - \frac{L}{10\,\pi r_d}\right) \times 100 \qquad (\%) \qquad (4)$$

where:

L – distance passed through after five turnovers of the driving wheel (m)

r_d – the dynamic radius of tractor wheel (m)

Table 1. Specific soil density and moisture content in different depths of cultivated soil

No.	Depth (mm)	Specific density (g/cm^3)	Bulk density (g/cm^3)	Gravimetric moisture content (%)	Porosity (%)
1	100	2.643	1.479	17.81	44
2	200	2.652	1.492	17.363	43.69
3	300	2.659	1.936	11.04	27.2

Estimation of plant residues on the soil surface. To define the quality of tillage from the viewpoint of the capacity of discs to work in the plant residues into the soil the percentages of these residues on the soil surface were estimated with regard to different speed of the aggregate. This estimation was carried out in such a way that all residues were picked up and weighed on the area of 1 m^2 to calculate percentages of these residues as related to all plants that were on this area before tillage.

Variability of measuring. The variability of recorded values could be characterized by a variation coefficient:

$$v_x = \frac{s_{\bar{x}}}{\bar{x}} \times 100 \qquad (\%) \qquad (5)$$

where:

$s_{\bar{x}}$ – standard deviation (m)

$$s_{\bar{x}} = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \bar{x})^2}{\sum_{i=1}^{k} n_i}} \qquad (6)$$

RESULTS AND DISCUSSION

Plot characteristics

The compaction of soil on the plot that was used for measuring was estimated by a penetrometer. The recorded values are plotted in Figure 3.

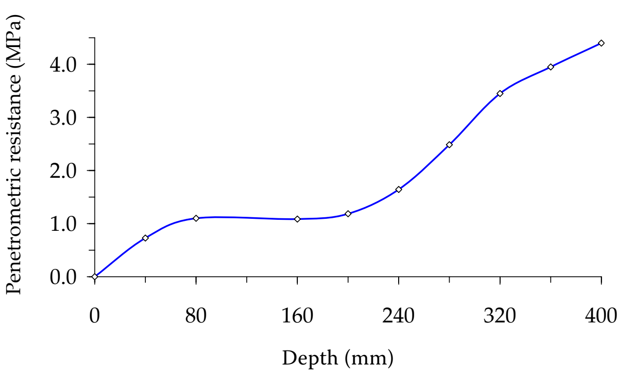


Figure 3. Dependence of penetrometric resistance of soil on the depth

Soil moisture content was estimated on the base of six measurings performed in different depths (Table 1).

Quality of tillage

The quality of tillage from the viewpoint of the capacity of disc harrow to work-in the plant residues was evaluated using the results of the estimation of percentages of plant residues remaining on the field after different speeds of the aggregate. The obtained results are presented in Table 2 and Figure 4.

As one can see in Figure 4, the increasing speed of the aggregate resulted in an increased capacity of the disc harrow to work-in the plant residues into the soil. When using speeds recommended by the manufacturer (i.e. 10–15 km/h) the capacity to work-in the plant residues was very good because only 5% of plant residues remained on the soil surface.

Measuring of pulling forces

The measured values of pulling forces and consumption of diesel fuel at the speed of 8–14 km/h are presented in Table 3. The course of the pulling force at the speed of 14 km/h is presented in Figure 5.

Under ideal conditions the time dependence of pulling forces should be linear and parallel with the x-axis. The variation coefficient expresses changes in recorded values. This variation resulted from non-

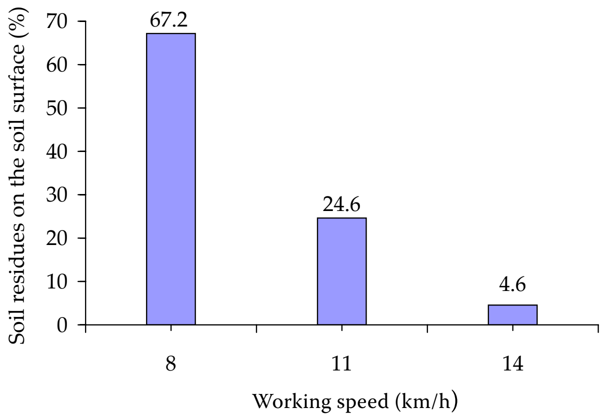


Figure 4. The dependence of plant residues on the aggregate speed

Table 2. Plant residues of alfalfa on the surface of cultivated plots

Speed (km/h)	Area	Weight (g)	Variance (g^2)	*CV* (%)	%	
–	1	1200	11255.56	9.7	100	maximum of plant residues 100%
	2	950				
	3	1210				
	4	1000				
	5	1030				
	6	1190				
Arithmetic mean		1096.7				
8	1	810	5422.222	10.0	67.2	percentages of plant residues on the soil surface
	2	820				
	3	600				
	4	700				
	5	750				
	6	740				
Arithmetic mean		736.67				
11	1	270	808.3	10.5	24.6	
	2	240				
	3	320				
	4	285				
	5	235				
	6	270				
Arithmetic mean		270				
14	1	55	45.1	13	4.6	
	2	60				
	3	50				
	4	55				
	5	40				
	6	45				
Arithmetic mean		50.8				

CV(%) – coefficient of variation

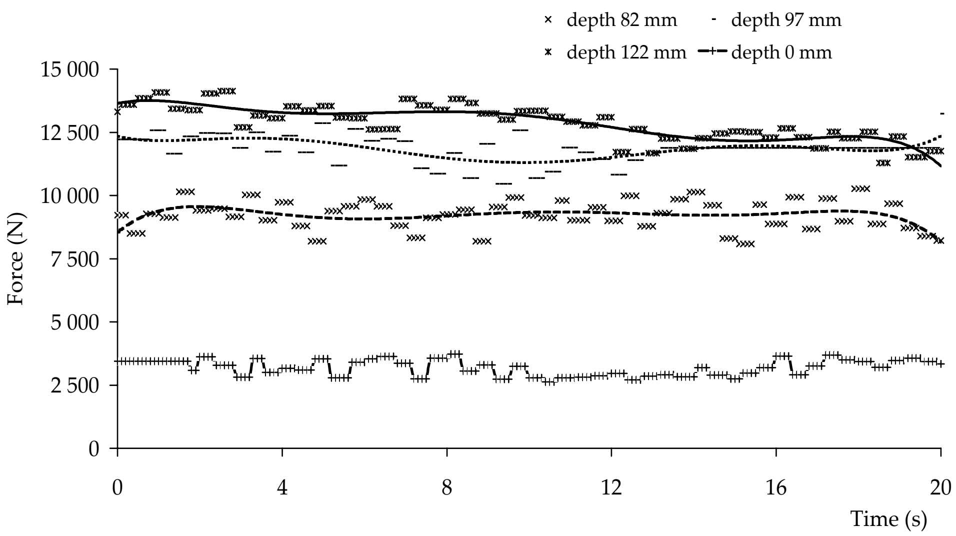


Figure 5. Graphical presentation of the course of pulling forces at different depths of tillage at the speed 14 km/h

Table 3. Measured values of pulling forces, working speed, fuel consumption and slippage

Depth (mm)		82			97			122			0
Speed (km/h)		8	11	14	8	11	14	8	11	14	14
Arithmetic mean of pulling force – *Ft* (kN)		9.1	9.03	9.24	11.58	11.34	11.84	12.51	12.82	12.87	3.18
Pulling force – F_{min} (kN)	minimum	7.36	7.72	8.09	9.65	10.25	10.46	10.7	11.39	11.29	2.63
	maximum	10.81	10.82	10.27	13.81	12.73	13.23	14.52	15.44	14.14	3.72
Variance – s_x^2 (kN^2)		0.57	0.42	0.32	0.82	0.30	0.30	0.67	0.73	0.49	0.10
Variance coeffficient –v_x (%)		8.3	7.2	6.1	7.8	4.8	4.6	6.6	6.7	5.4	9.9
Fuel consumption (l/h)		25.7	34.3	40.2	22.6	28.3	33	21.8	24.6	32.2	–
Slippage (%)		0.36	0.17	0.06	0.12	0.13	0.13	0.14	0.17	0.12	–

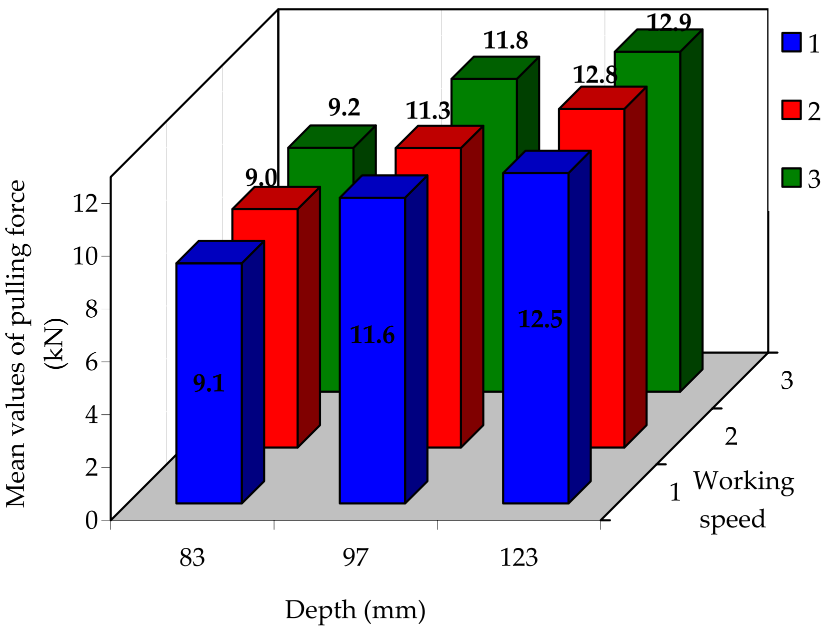


Figure 6. Graphical presentation of average values of recorded pulling forces as dependent on the depth of tillage and the speed of the aggregate

homogenous soil texture, bumpiness of plot surface and uneven tractor movement. In our experiments the variation coefficients were about 10% and this was considered as acceptable.

The dependence of the pulling resistance of the aggregate on working speed and tillage depth is presented in Figure 6.

CONCLUSIONS

Results of measurements of the overall pulling resistance of disk harrow indicate that its magnitude is dependent on depth of tillage, soil texture and moisture of cultivated soil. The effect of working speed upon the magnitude of pulling resistance is very small and practically negligible. It influenced above all the quality of tillage (Figure 4). Field experiments corroborated the quality of disk harrows.

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Abstrakt

Musil J., Červinka J. (2007): **Měření tahového odporu strojů s pasivními pracovními orgány**. Res. Agr. Eng., **53**: 47–53.

Stanovení celkového tahového odporu stroje je důležité jak z hlediska jeho dimenzování, tak z hlediska energetické náročnosti prováděné operace. Existuje několik metod, jak jej určit. Lze je rozdělit na metody analytické (Gorjačkin) a metody měření v polně-laboratorních podmínkách za použití snímačů síly pracujících na různém principu. Nejpoužívanějším typem je snímač na bázi tenzometrů, který byl použit i při našem měření. Naměřený tahový odpor při 3 pracovních rychlostech a rozmezí hloubek zpracování 82–122 mm byl 9,6–17,4 kN při variačním koeficientu do 10 %. Toto měření prokázalo závislost celkového tahového odporu na hloubce zpracování, avšak pouze nepatrnou, prakticky zanedbatelnou závislost na pracovní rychlosti soupravy. Měření kvality práce stroje z hlediska množství nezapravených zbytků na povrchu zpracovaného pozemku probíhalo zvážením rostlin na povrchu a spočítáním jejich podílu v hmotnosti všech rostlin odebraných z téže plochy. Po zpracování půdy pracovní rychlostí v rozmezí 8 až 14 km/h bylo zjištěno na povrchu půdy 67,2–4,6 % hmotnosti těchto rostlinných zbytků.

Klíčová slova: zpracování půdy; diskové brány; měřící zařízení; polní měření

Corresponding author:

Ing. Jan Musil, Mendelova zemědělská a lesnická univerzita, Agronomická fakulta, Zemědělská 1, 613 00 Brno, Česká republika
tel.: + 420 545 132 379, e-mail: h.musil@centrum.cz