IMPACT OF SPEED ON THE SOIL SLIDING RESISTANCE

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Abstract. Some investigations are carried out to determine the impact of speed on the soil sliding resistance. The frictional properties of soil are evaluated by the sliding resistance coefficient. It depends on the friction coefficient and soil adhesion, and it varies with specific pressure between the sliding surfaces. A developed computerised device is used for the determination of the soil sliding resistance, the friction coefficient and specific adhesion for several ranges of sliding speeds up to 5 m s^{-1}. As a result of investigations, data (tables and diagrams) have been obtained that show the dependence of the soil sliding resistance on its speed along a steel surface. It is evident from the obtained data that at increased speeds the sliding resistance of dry soils does not change or increases only a little. If the soil contains rocky particles that scrape the surface, the sliding resistance, when speed increases, can increase considerably. At increased speeds the sliding resistance of humid soils decreases to 16…20%.

Key words: soil sliding resistance, soil friction coefficient, soil adhesion, impact of speed.

Introduction

In most cases the movement of soil during its tillage proceeds along the steel surfaces of the operating parts of the tilling tools and machines. The sliding resistance of soil significantly affects the draft resistance of these tools [1, 11]. For instance, the sliding friction between steel and soil may exceed 35-50% of the total draft resistance in ploughing [1]. Therefore the problems of reducing the sliding resistance of soil along the operating parts of the tillage tools always attract great attention in both cases – when new structures are designed and when the existing machines are used.

In order to tackle these problems, one should know well the relationships which determine the value of the sliding resistance of soil along steel.

It has been discovered that the sliding resistance of one body against the other manifests itself in binomial formulae (Deryagin, Kragelski) in which one term is dependent on the roughness of surfaces but the other on the mutual molecular attraction of the sliding materials [5-10]. A one-term friction resistance formula (Amonton's law), which is predominantly used nowadays in technical calculations, is a particular case of general regularities. It is true for other materials at high loads, as well as for dry soils sliding along steel surfaces.

Soil is a relatively easily deformed material; in separate cases it is plastic with a pronounced stickiness.

It is common practice to evaluate the frictional properties of materials, including soil, by means of the sliding resistance coefficient. The latter depends on the friction coefficient and soil adhesion, and it varies with specific pressure between the sliding surfaces [2, 4].

In order to determine the coefficient of friction and the specific adhesion force, it is necessary to know a series of values of the soil sliding resistance coefficient at different values of the specific pressure between the surfaces. Therefore, in order to find out the regularities of varying frictional properties of soil, only those investigations are important in which the soil sliding resistance is assessed at several different values of the specific pressure between the sliding surfaces [4].

There are not sufficient data for characterising the impact of speed on the sliding resistance of soil. Some authors have opinion that speed has no influence on sliding resistance, some others – that with increasing speed the sliding resistance increases too, but others – opposite views, that with increasing speed the soil sliding resistance decreases [3, 6-10].

The purpose of investigations is to determine the soil sliding resistance, the coefficient of friction and the specific adhesion, depending on speed.

Materials and methods

A computerised device is developed for the determination of the soil sliding resistance, the friction coefficient and specific adhesion for several surfaces and the ranges of sliding speeds up to 5 m s^{-1}.

In order to clarify the nature of the sliding resistance for soil on the working surfaces of the tillage machines, Deryagins's binomial sliding (slipping) resistance formula is used as more adequate:

$$f = f_0\left(1 + p_a p^{-1}\right), \tag{1}$$

where f – the resistance coefficient of soil sliding along a surface;
f_0 – the friction coefficient of soil along a surface;
p – the specific pressure of the layer (soil) upon the surface;
p_a – the specific soil adhesion force to the surface.

In order to determine the coefficient of friction and the specific adhesion depending on sliding speed, the soil sliding resistance is assessed at a speed to 5 m s^{-1} and at several different values of the specific pressure between the sliding surfaces.

It is known from previous investigations [2, 4] that the variation in the soil sliding coefficient has an alternative hyperbolic regress. On its basis, by means of the method of least squares, the coefficients of soil friction f_0 and specific adhesion force p_a are determined, using formulas:

$$f_0 = \frac{\sum x^2 \sum y - \sum x \sum xy}{n\sum x^2 - \left(\sum x\right)^2},\quad f_0 p_a = \frac{n\sum xy - \sum x \sum y}{n\sum x^2 - \left(\sum x\right)^2},\quad p_a = \frac{f_0 p_a}{f_0}, \tag{2}$$

where $x = p^{-1}$; $y = f$; n – the number of measurements (at least 5).

Results

As a result of investigations, data (tables and diagrams) have been obtained that show the dependence of the soil sliding resistance on its speed along a steel surface. The following graphs show some examples of the changes of the soil sliding resistance along the steel surface depending on speed and specific pressure between the sliding surfaces (Fig. 1-9).

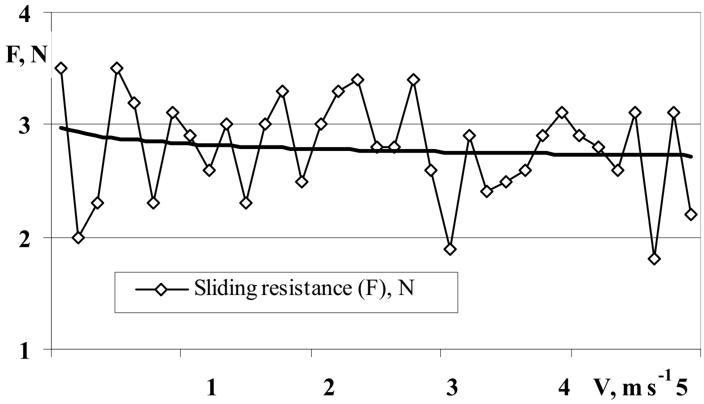

Fig. 1. **Sliding resistance of wet (W = 17%) loamy soil depending on speed**: the weight of the soil sample P = 4.7 N; specific pressure of soil upon the surface p = 0.06 N cm^{-2}

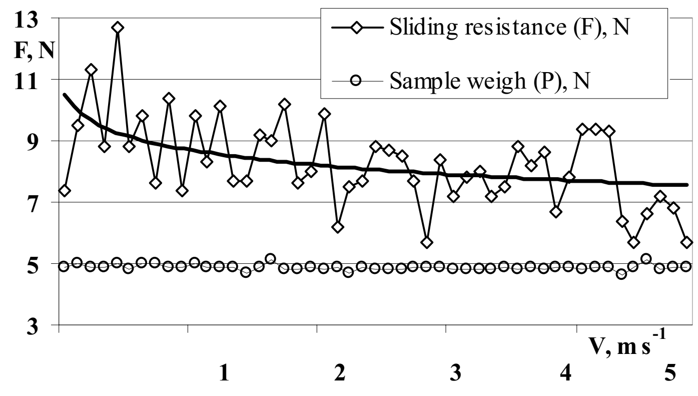

Fig. 2. **Sliding resistance of wet sandy soil depending on speed**: the weight of the soil sample P = 4.8 N; specific pressure of soil upon the surface p = 0.061 N cm^{-2}

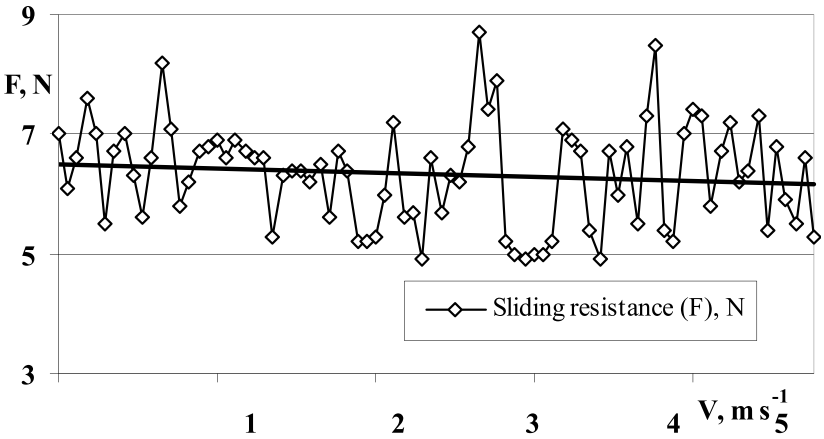

Fig. 3. **Sliding resistance of wet sandy soil, rich in humus, depending on speed**: the weight of the soil sample P = 4.7 N; specific pressure of soil upon the surface p = 0.06 N cm^{-2}

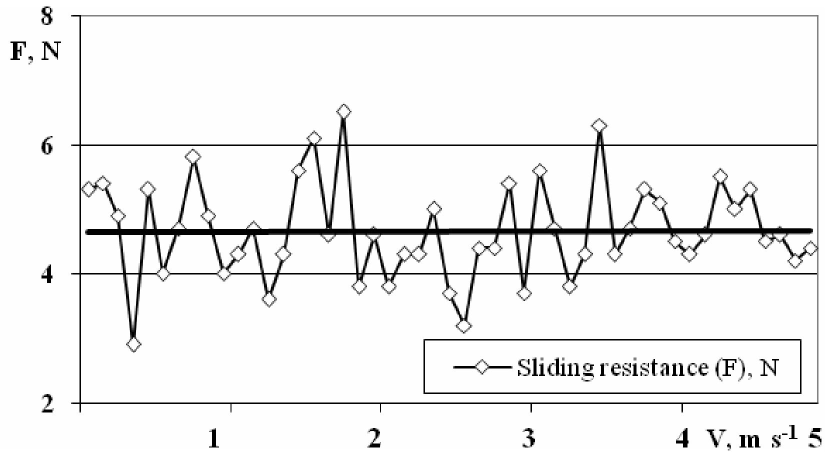

Fig. 4. **Sliding resistance of dry sandy soil, rich in humus, depending on speed**: the weight of the soil sample P = 5 N; specific pressure of soil upon the surface p = 0.064 N cm^{-2}

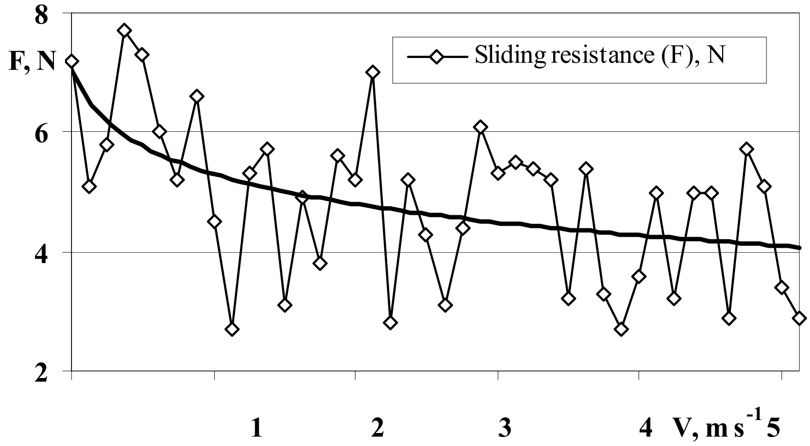

Fig. 5. **Sliding resistance of wet sandy loam depending on speed**: the weight of the soil sample P = 7 N; specific pressure of soil upon the surface p = 0.09 N cm^{-2}

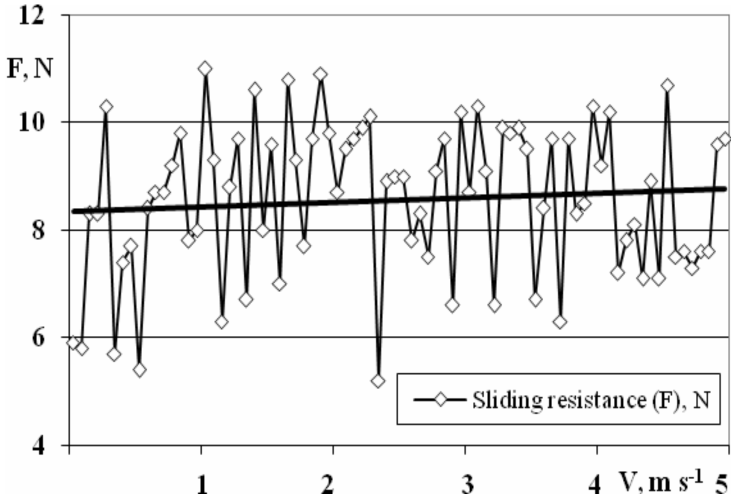

Fig. 6. **Sliding resistance of dry rocky sandy loam depending on speed**: the weight of the soil sample P = 9.3 N; specific pressure of soil upon the surface p = 0.19 N cm^{-2}

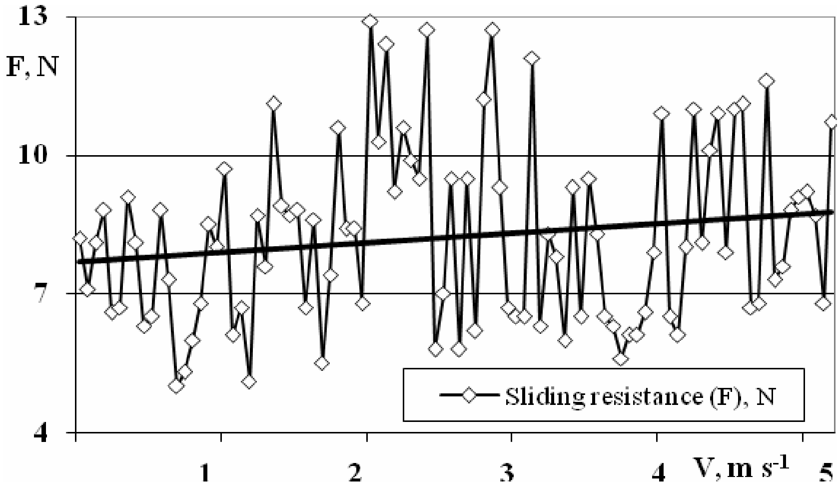

Fig. 7. **Sliding resistance of wet (W = 15%) clay soil depending on speed**: the weight of the soil sample P = 11 N; specific pressure of soil upon the surface p = 0.14 N cm^{-2}

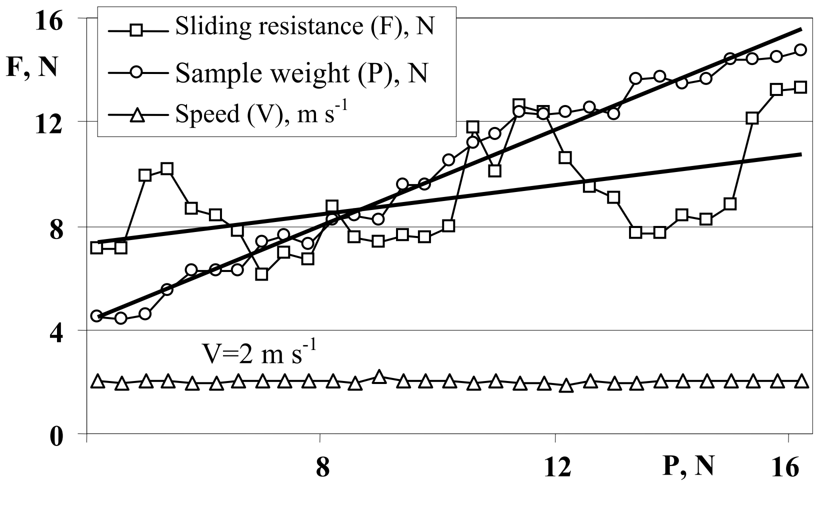

Fig. 8. **Sliding resistance of wet (W = 15%) clay soil depending on load at the speed v = 2 m s^{-1}**

Table 1. **Calculation of the coefficient of a sliding resistance**

Siding resistance F, N	7.9	8.2	8.5	8.7	9.1	9.4	9.6	9.9	10.2	10.5
Sample weight P, N	7	8	9	10	11	12	13	14	15	16
Sliding resist. coef. f	1.13	1.03	0.94	0.87	0.83	0.78	0.74	0.71	0.68	0.66
Spec. pressure p, N cm^{-2}	0.089	0.102	0.11	0.127	0.140	0.153	0.166	0.178	0.191	0.206

Table 2. **Data for the calculation of the coefficients of friction and specific adhesion**

The number of measurements	$1/x$	$f = y$	x	xy	x^2
1	0.089	1.129	11.220	12.663	125.888
2	0.102	1.025	9.818	10.063	96.383
3	0.115	0.944	8.727	8.242	76.155
4	0.127	0.870	7.854	6.833	61.685
5	0.140	0.827	7.140	5.907	50.980
6	0.153	0.783	6.545	5.127	42.837
7	0.166	0.738	6.062	4.461	36.500
8	0.178	0.707	5.610	3.967	31.472
9	0.191	0.680	5.236	3.560	27.416
10	0.206	0.656	4.909	3.221	24.096
n = 10	–	S_y = 8.371007	S_x = 7.3099455	S_{xy} = 6.4919367	S_{x2} = 5.734121679

Table 3. **Calculation the friction coefficient and specific adhesion**

Soil friction coefficient f_0	0.287748
f_0p_a	0.075007
Specific adhesion p_a, N cm^{-2}	0.26067
Contact surface S, cm^2	78.54

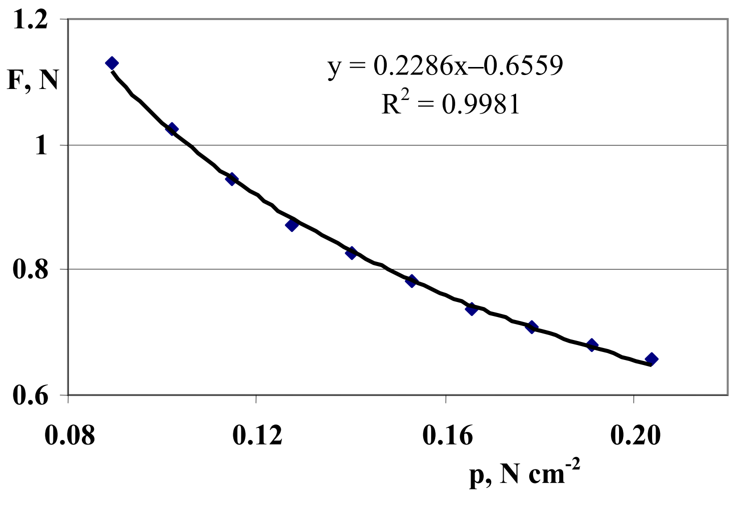

Fig. 9. **Sliding resistance of wet (W = 15%) clay soil depending on the specific pressure between the sliding surfaces at the speed v = 2 m s^{-1}**

As a result of investigations, relationships have been obtained for the sliding resistance of soils along a steel surface at their various mechanical compositions, moisture and pressure between the sliding surfaces, as well as data (tables and diagrams) that show the dependence of the soil sliding resistance on its speed.

Conclusions

1. It is evident from the obtained data that at increased speeds the sliding the resistance of dry soils does not change or increases only a little. If the soil contains rocky particles that scrape the surface, the sliding resistance at an increased speed can grow.
2. At increased speeds the sliding resistance of humid soils decreases to 14…30% (depending on the physical properties and humidity).
3. The sliding resistance of wet soils along a steel surface depends on the specific pressure between the surfaces. It falls when pressure increases, approaching asymptotically the marginal value.
4. Depending on the specific pressure between the surfaces, variations in the sliding resistance of wet soils conform to the character of the hyperbolic regression. By using the least-squares method the values of the friction coefficient and specific adhesion force of these soils are determined.

Proposals for Practice

In order to minimise the soil tillage energy intensity, the operating parts (their modification) of the machines should be used which ensure higher specific pressure of soil on them:

- the plough bodies with laminated (strip) or bar mouldboards,
- cultivator points and spring teeth with a convergent lifting surface (S-shaped spring teeth).

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