THEORY FOR ATTACHMENT OF TRACTOR-DRIVEN SUGAR BEET HARVESTING MACHINES

Prof. Eng. Volodymyr Bulgakov[1], PhD., Prof. Eng. Valerii Adamchuk[2], PhD., Assoc. Prof. Eng Zinovii Ruzhylo[1], PhD., Corresp. Memb. Prof. Eng Hristo Beloev[3], PhD., Prof. Eng. Boris Borisov[3], PhD., Assoc. Prof. Eng Georgi Mitev[3], PhD.

[1]National University of Life and Environmental Sciences of Ukraine
15, Heroyiv Oborony Str., Kyiv, 03041, Ukraine
[2]National Scientific Centre
"Institute for Agricultural Engineering and Electrification"
11, Vokzalna Str., Glevakha-1, Vasylkiv District, Kiev Region, 08631, Ukraine
[3]"Angel Kanchev" University of Rousse, 8, Studentska Str., 7017Ruse, Bulgaria

Abstract: *An analytical study is related to giving proof and selection of the optimal parameters for the units, consisting of a tractor and a tractor-driven sugar beet harvesting machine. A mathematical model is built on the basis of this study and describes the conditions for effective attachment and give opportunity for determination of the working speed and productivity. The calculations allow finding the optimal parameters of the mentioned above aggregates in relation to productivity and energy consumption.*

KEYWORDS: *MACHINE AGGREGATE, TRACTOR, SUGAR BEET HARVESTING MACHINE, MATHEMATICAL MODEL, WORKING SPEED, PRODUCTIVITY, OPTIMAL PARAMETERS.*

INTRODUCTION

High efficiency of the mobile agricultural machinery aggregates can be reached due to the achieving a proper ratio between the technical and operational parameters and external production conditions such as soil physical and mechanical properties, field slope, characteristics of the treated material, agrotechnical conditions of its treatment and etc.

Recently, the companies offer farmers a wide range of sugar beet harvesting machines, including tractor-driven ones. Typical machines can be two, three, four and six-row for harvesters.

The application of such types of machines increases the costs. Though, reducing the costs and resources consumption is a world tendency nowadays.

Analysis of the recent publications

A lot of research findings on the issue have been published, including recent ones, devoted to, for building of mathematical models related to the functioning of agricultural machines and machinery aggregates,[1-10].

The methods of building of mathematical models for tractor-driven agricultural machines, including sugar beet and flax harvesters are described in [2, 3, 6, 8].

Predicting the degree of rising productivity for the sugar beet harvesting machines, which depends on the relative capital inputs are presented in the fundamental manuscript, [11].

There is one part – a section of the optimal parameters for the tractor-driven sugar beet harvesting machines on the tractor power criteria is still not developed.

The effectiveness of tractor-driven sugar beet harvesting machines application should be estimated in combination with the power of a machine (the tractor). To determine its effectiveness is possible by using the quantity criteria, which describe their operational properties and technical perfection with sufficient degree of accuracy.

The number of such criteria should primarily include the productivity of the drawing unit, as well as, the productivity per 1 kW·h of the tractor power. Minimum of the operational costs and other parameters are also considered. [12].

Aim of the study

The purpose of the present study is the development of mathematical model related to the effective attachment of tractor-driven sugar beet machines, i.e. analytical determination of the aggregate's optimal parameters by using productivity and energy consumption criteria.

Methodology of the investigations

The method of building of calculated mathematical models for agricultural machines and units and their application are based on the presented study. The proper software has been developed.

Results and discussion

Well known analytical equations are used for the development of new mathematical models for the effective mounting of tractor-driven sugar beet machines. Those equations are broadly used in scientific research and specific operational calculations.

The productivity of certain machinery units, consists of tractor and a tractor-driven machine. It is determined by already available relation, [13]:

$$W = 0{,}1 B \cdot V_r \text{, ha/h,}$$

where B is the machine width, m; V_r – working speed of the machine, km/h.

From equation (1), it is clear that the productivity increases in proportion to speed and the working width.

We have to mention that this is not a direct proportionality, because the both quantities are independent. When the working width increases, the velocity decreases and vice versa. The functional relations between the velocity and the working width determine the draft balance and the aggregate power balance.

The equation of the power balance in the case when the power unit consists of the tractor and tractor-driven sugar beet harvesting machine has the following expression, [14]:

$$N_e \cdot \chi = \frac{R_a \cdot V_r}{3600 \cdot \eta_t (1-\delta)} = \frac{N_p \cdot B \cdot V_r \cdot H}{360 \cdot \eta_v} \text{, kW,}$$

where R_a is the draft resistance of the tractor-driven harvesting aggregate, N; N_p – relative loss of energy when the process of sugar beet harvesting is executed, kW·s·kg^{-1}; H – the yield of sugar beet, t/ha; N_e – the nominal engine power, kW; χ – the coefficient of the engine loading; η_t – the tractor's transmission efficiency coefficient; η_v – the PTO efficiency coefficient; δ – the skidding.

The tractor-driven sugar beet harvesting machine draft resistance will be determined by the following ration:

$$R_a = R_i + R_f + R_m \text{, N,} \qquad (3)$$

where R_i, R_f – the tractor resistance to lifting and rolling, N; R_m – drawing resistance of the sugar beet harvesting machine during operational time, N.

The left part of the drawing balance equation (2) numerically is equal to the tractor's drawing force and by this way insures overcoming of the resistance force, acting on the sugar beet harvesting aggregate. Namely:

$$R_i = mg \cdot sin\alpha, \tag{4}$$

$$R_f = mg \cdot f\, cos\alpha, \tag{5}$$

$$R_m = k \cdot B, \tag{6}$$

where: α – lifting angle, rad.; m – tractor's weight, kg; g – acceleration of the mass force, m/s^{-2}; f – resistance coefficient of the keel over the tractor; k – relative resistance of the sugar beet harvesting machine, N/m.

Coefficient k shows how all useful technical deformation which occurs during the harvesting period and movement resistance of the tractor driving a harvester change.

When the angle α value is low, then $sin\alpha \cdot 100$ represents the percentage of the lifting, i.

Considering equations (3) and (4), (5), (6) the balance equation (2) can be presented in the following form:

$$N_e \cdot \chi = V_r \frac{(kB + mg \cdot \psi)\eta_v + 10N_p B \cdot H\eta_t(1-\delta)}{3600 \cdot \eta_t \eta_v (1-\delta)}, \tag{7}$$

where ψ – resistance coefficient which equals: $\psi = sin\alpha + f\, cos\alpha$.

Setting up the equation (7) in relation of V_r enables to determine the meaning of the sugar beet harvesting machine velocity on the field:

$$V_r = \frac{3600 \cdot \chi \cdot N_e \eta_t \eta_e (1-\delta)}{(k\,B + mg\psi)\eta_v + 10N_p B \cdot H\eta_t(1-\delta)}, \tag{8}$$

km/h.

The productivity can be calculated by the unit's working speed V_r obtained from the equation (8) and by using the relation (1).

While solving the equation (8), the coefficients χ, η_t and η_v should be given and the unit skidding must be determined.

Different empirical equations are in use when the tractor's skidding curve is determined during the field experiments.

In this case, to define the skidding the following relation is in use, [14] and has the following expression:

$$\varphi = \varphi_m - a e^{-b\delta}, \tag{9}$$

where φ is coefficient of split weight use; φ_m – the coefficient of the grip; a, b is permanent coefficients, which depend on the tractor's type and filed conditions.

In equation (9), the dependence between the δ unit skidding and the φ coefficient of coupling weight usage is given in the implicit form that is not convenient for carrying out the calculations.

With the help of algebraic transformation (9), we can get a formula for spilling, much more convenient for calculation

$$\delta = -\frac{1}{b} ln \frac{\varphi_m - \varphi}{a}. \tag{10}$$

The variable φ in equation (10) can be calculated by using the expression:

$$\varphi = \frac{mg\psi + kB}{\lambda mg}, \tag{11}$$

where: λ is coefficient of the cleaved weight.

Equations (1), (8), (10) and (11) represent the mathematical model for adjustment of the tractor-driven sugar beet harvesting machine and allow to define analytically the velocity and productivity, with the aim to define the optimal value.

In the process of numerical calculations, it is necessary to pay attention on the agricultural requirements, related to the velocity of the sugar beet harvesting machines. It should be in the interval $1{,}5 \le V_r \le 4{,}0$ ms^{-1} and the limitation caused by the tractor's cohesion on the soil surface, i.e. $\varphi < \varphi_m$.

The software has been developed for the implementation of the mathematical model in Math CAD media. This allows to calculate the operational parameters of several types of tractors and tractor-driven machines. It helps to choose suitable tractors for drawing the sugar beet harvesting machines and define the optimal field conditions.

It is possible to set up the mass m, engine's power N_e, coefficient λ, for each tractor's type. The coefficient's value of φ_m, a and b give specific levels for each field conditions. The sugar beet yield H, the relative losses during the technological process N_p, the maximum percentage of field slope i, the coefficient of resistance to tractor movement f and the PTO efficiency η_v for each numerical calculation have been mentioned at the very beginning.

The transmission coefficient of efficiency η_t is changed in accordance to the tractor type, (for chain driving tractor it is equal to $\eta_t = 0{,}87$, and for wheeled tractors $\eta_t = 0{,}92$).

The relative resistance of the tractor-driven sugar beet harvesting machine k is setting up and ranges for each tractor type from 6000 up to 10000 N/m.

The change of working width for each sugar beet harvesting machine is between 0.90 m and to 2.7 m and has 0.45 m pitch i.e. it is changed from two-rows up to 6 rows as combination.

A separate file is created for each combination of the numerical calculations and consist of relative resistance for each working width for the sugar beet harvesting machines and corresponding velocity V_r, productivity W, drawing resistance R_a, coefficient of using the attached weight φ and the skidding δ.

To calculate the parameters of the mathematical model a specific (average) values of the parameters were applied such as sugar beet yield *H* = 30 t/ha; relative energy losses accompany the sugar beet harvesting process $N_p = 1{,}75$ kWh/kg; the coefficients $\chi = 0{,}90$; $\eta_v = 0{,}95$; $f = 0{,}07$.

It is necessary to mention that sometimes the field slope is more than 5% and the relative resistance of the tractor-driven sugar beet harvesting machine (its average value) is

$k = 6000...10000$ N/m (the pitch of relative resistance change is $\Delta k = 1000$ N/m).

The technical data of the row-crop tractors which are used to drive sugar beet harvesting machines are presented in table 1, [14].

About 72 combinations have been developed for the placed input parameters and this allowed to obtain the optimal parameters for the tractor-driven sugar beet harvesting machine. They are attached to different types of tractors.

Table 1. *Technical characteristics of the row-crop tractors*

Drawing Class*, way of application	mg, kg	N_e, kW	φ_m	a	b
0.9 Wheel, universal soil tillage	3000	36,8	0,6	0,75	8,81
1.4 Wheel, universal soil tillage	3810	58,9	0,6	0,75	8,81
2 Chain, universal soil tillage	4580	51,5	0,67	0,753	47,6

*There is a specific tractors' classification which is based not on the engine power, but on the draft force of the tractor measured by 1000 kg·m/s^2. It is called 'Drawing Class'.

For tractor from class 0.9 has the maximum productivity $W = 0,60$ ha/h when the working width is $B = 0,9$ m; the pulling resistance of tractor-driven sugar beet harvesting machine is $k = 7000$ N/m and the velocity is $V_r = 6,63$ km/h.

In conclusion, the pulling class of the tractor ensures the maximum productivity when 2-row tractor-driven sugar beet harvesting machine is applied.

For the tractors 1.4 pulling class, the maximum productivity $W = 1,02$ ha/h can be obtained under two levels of the pulling resistance of the tractor-driven sugar beet harvesting machines $k = 7000$ N/m and $k = 9000$ N/m when the working width is $B = 1,80$ m and the velocity is $V_r = 5,68$ km/h and the working width is $B = 2,70$ m (six-row combination).

These indicators are obtained for the of 4-row tractor-driven sugar beet harvesting machine. In case of 2.7 m width and relative resistance of the tractor-driven sugar beet harvesting machine $k = 10000$ N/m, tractor from 1.4 class do not ensure the productivity caused by the lack of grip between the soil and the wheels.

For chain tractors from class two (2) the maximum productivity $W = 1,03$ ha/h will be when the working width is $B = 2,7$ m, the relative resistance of the sugar beet harvesting machine $k = 7000$ N/m and the velocity is $V_r = 3,80$ km/h.

In case of $B = 2,7$ m the working width and pulling resistance of the sugar beet harvesting machine $k = 10000$ N/m, the productivity is $W = 0,86$ ha/h and the working velocity is $V_r = 3,18$ km/h.

Conclusions

1. A new mathematical model for an effective attachment of the tractor-driven sugar beet harvesting machines has been developed. It which describes the conditions of the optimal attachment and gives an opportunity to define the velocity and the productivity of various machine combinations.
2. As a result of numerical modeling by using the PC program showed that the chain-moving tractor Class 2 will provide enough productivity working with tractor-driven sugar beet harvesting machine in two modes of the relative resistance which mean working in light and medium soils.
3. Wheeled tractors will ensure enough productivity when 2- or 4-row tractor-driven sugar beet harvesting machines are in use.
4. The results of the analysis and developed software for numerical modeling enable to define the optimal parameters for sugar beet harvesting machines, as well as for other combinations of tractor and harvesting machines. To define the optimal parameters is possible due to applying of the criteria of productivity and energy consumption.

REFERENCES:

1. Vasilenko P.M., Vasilenko V.P. Metodika postroeniya raschetnyih modeley funktsionirovaniya mehanicheskih sistem (mashin i mashinnyih agregatov) Uchebnoe posobie. – Kiev: USHA, 1980. – 137 p.
2. Vasilenko P.M. Ob uravneniyah dvizheniya mobilnyih mashinnyih agregatov. Sbornik trudov po zemledelcheskoy mehanike T. II. – Moskva: Selhozgiz, 1952. – pp. 76-84.
3. Vasilenko P.M. Elementi teorii ustoychivosti dvizheniya pritsepnyih selskohozyaystvennyih mashin i orudiy. Sbornik trudov po zemledelcheskoy mehanike T. II. – Moskva: Selhozgiz, 1954. – pp. 202-211.
4. Vasilenko P.M. Vvedenie v zemledelcheskuyu mehaniku. – Kiev: Selhozobrazovanie, 1996. –252 p.
5. Vasilenko P.M., Kuzminskiy V.G. Uravnenie dvizheniya samohodnyih mashinnyih agregatov pri troganii s mesta i razgone // VASHNIL. Zemledelcheskaya mehanika. T. V, Sbornik trudov / pod red. V.A. Zheligovskogo. – Moskva: Mashinostroenie, 1965.
6. Bulgakov V.M., Gorbovoy A.Yu. Teoriya dvizheniya lnouborochnyih kombaynov. Monografiya.– Lvov: Izdatelstvo LvTsNTI, 2007. – 115 p.
7. Guskov V.V., Velev N.N., Atamanov Yu.E. i dr. Traktoryi. Teoriya. – Moskva: Mashinostroenie, 1988. – 376 p.
8. Timofeev A.I. Analiz energeticheskogo rezhima rabotyi traktornogo agregata pri razgone // VASHNIL. Zemledelcheskaya mehanika. Tom V. Sbornik trudov / pod red. V.A. Zheligovskogo. – Moskva: Mashinostroenie, 1965. – pp. 391-405.
9. Kutkov G.M. Traktoryi i avtomobili. Teoriya i tehnologicheskie svoystva. – Moskva: KolosS, 2004. – 504 p.
10. Nadyikto V.T. Osnovyi agregatirovaniya modulnyih energeticheskih sredstv. Monografiya. – Melitopol: KP "MMD", 2003. – 240 p.
11. Pogorelyiy L.V. Industrializatsiya agropromyishlennogo kompleksa. – Kiev: Tehnika, 1984. – 200 p.
12. Kirtbaya Yu.K. Rezervyi ispolzovaniya mashinno-traktornogo parka.– Moskva: Kolos, 1982. – 319 p.
13. Posobie po ekspluatatsii mashinno-traktornogo parka. – Moskva: Kolos, 1971. – 279 p.
14. Kolobov G.G., Parfenov A.P. Tyagovyie harakteristiki traktorov. – Moskva: Mashinostroenie, 1972. – 157 pp.11.