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Zasnova trosilnika za hlevski gnoj z matematičnim modelom

Conceptual Design Of A Stable-Manure Spreader Using A Mathematical Model

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Prispevek opisuje zasnovo matematičnega modela za numerično analizo raztrosa organskega gnoja. Izdelana je numerična analiza raztrosa za trosenje nazaj in primerjana z raztrosom trosilnika Jeantil EP 2060 Epandor 3. Na podlagi postavljenega matematičnega modela so bili ugotovljeni optimalni parametri raztrosa, ki dajo najboljše uporabnostne karakteristike trosilnika. Matematični model je temeljil na načelu sredobežnega meta.

(Ključne besede: trosilniki, gnoj hlevski, modeli matematični)

This paper describes a mathematical model for a numerical analysis of the distribution of organic manure. A numerical analysis of the backward distribution of solid stable manure was performed and its results were compared with the real distribution of a Jeantil EP 2060 Epandor 3 spreader. The optimal distribution parameters, which yield the best spreader operation characteristics, were determined using the mathematical model, which was based on the principle of centrifugal throw.

(Keywords: spreaders, solid manure, mathematical models)

0 UVOD

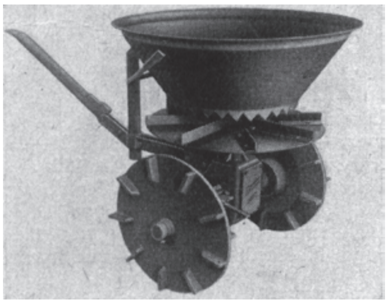
Organski gnoj in s tem hlevski gnoj je eden najboljših krmilij dobre rasti v zemlji. V drugi polovici dvajsetega stoletja so se pojavila umetna gnojila, ki so poskušala delno nadomestiti naravno gnojenje. S tem naj bi povečali količino pridelkov na hektar zemlje. Količine gnojil in pridelkov so se zelo povečale, vendar se je s tem porušilo tudi ravnovesje v naravi. Pridelki so bili umetno prisiljeni k rasti. Tako se jim je zmanjšala tudi kakovost. Zemlja je vedno bolj onesnažena, zato se uveljavlja zopet naravno kmetovanje, kar pomeni, da lahko rast spodbujamo samo z naravno pridobljenimi gnojili (kompost, hlevski gnoj). Gnojenje z organskim gnojem bo postalo tako vse bolj pomembno.

Hlevski gnoj je eno od najugodnejših krmilij dobre rasti v zemlji. Ker pa je trosenje s hlevskim gnojem težaško opravilo (sl. 1b), so prve trosilnike hlevskega gnoja izdelali v prvi polovici devetnajstega stoletja. Ti trosilniki so bili vlečeni s konji, pogon so dobivali prek voznih koles. Trosilniki so bili izdelani tako, da so opravljali svojo funkcijo zadovoljivo ob najmanjši potrebni moči. Pri trosilnikih hlevskega gnoja je pomembno to, da delo opravijo hitrejše in bolje, kakor ga lahko opravimo ročno (sl. 1a). Glede na to trosilnik z dovolj veliko

0 INTRODUCTION

Organic manure, for example stable manure, is one of the best regulators of good growth in soil. In the second half of the twentieth century, artificial fertilizers were developed and their purpose was to serve as partial substitutes for natural fertilization. The intention was to increase the amount of produce per hectare of land. The amount of fertilizers used and the yields have increased considerably since then, but at the same time the natural balance in nature has been disrupted. When plants are artificially forced to grow, their quality decreases. All over the world, the soil is becoming more and more polluted, so that natural agricultural methods involving only the use of naturally produced fertilizers (compost, stable manure) for stimulating plant growth are again on the increase. Fertilization with organic manure is thus becoming increasingly important.

Stable manure is one of the best regulators of plant growth in soil. However, since the distribution of stable manure is hard work (Figure 1b), the first stable-manure spreaders were made as early as the first half of the nineteenth century. They were horse-drawn and driven via wheels, and performed their function satisfactorily, requiring minimal power. For any solid-manure spreader, it is most important that the work is performed quicker and better than can be accomplished manually (Fig. 1a). With a sufficiently high rotating



(a)

(b)

Sl. 1. *Trosenje gnoja v preteklosti: (a) - s pomočjo vlečne sile, (b) - ročno*
Fig. 1. *Manure distribution in the past: (a) - the spreading of manure using power, (b)- the manual spreading of manure*

vrtilno frekvenco trosilnih valjev bolj enakomerno raztrosi gnoj po površini, kakor bi bilo to mogoče opraviti ročno.

frequency of the distribution rollers, manure spreaders can distribute manure over the fertilized surface more uniformly than can be achieved manually.

1 TROSILNI MATERIAL

Pri trosenju organskega gnoja so pomembne fizikalne lastnosti gnoja [2]. Predvsem so pomembne mehanske lastnosti, ker raztros gnoja poteka po načelu sredobežnega meta. Med pomembnejše lastnosti spadajo:

- Masa in gostota.
  Odvisni sta od vrste gnoja in suhe snovi v gnoju, ki pa sta v naslednji povezavi. Čim večji je delež suhe snovi v gnoju, tem manjšo gostoto ima. Različne vrste gnoja imajo različne vrednosti gostote. Tako se gostota hlevskega gnoja (gnoj goveje živine) giblje med 700 kg/m^3 in celo do 1000 kg/m^3 (Preglednica 1).
- Koeficient trenja, ki spada med statično-dinamične fizikalne lastnosti
  Odvisen je od mase, podlage in sestave gnoja (suha snov-voda). Na sliki 2 je prikazana odvisnost koeficienta trenja od gostote gnoja. Tako ima bolj vlažen gnoj (večja gostota) manjši koeficient trenja od bolj suhega. Koeficient trenja , ki ga navaja literatura [2] in [3], je med 0,7 in 1,3 (Pregl. 1), vendar navaja tudi možnost manjših vrednosti. Točne vrednosti koeficienta trenja določene vrste gnoja bi lahko dobili edinole s poskusnimi meritvami.

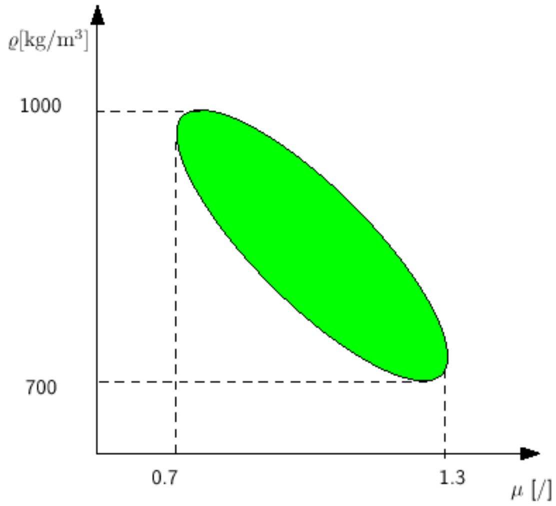
1 MATERIAL

The physical properties of organic manure are very important for its distribution [2]. It is primarily the mechanical properties that are relevant, because the distribution of manure is performed according to the principles of centrifugal throw. Other important properties include:

- The mass and the density.
  These depend on the type of manure and its dry-matter content. They are related as follows: the greater the dry-matter content of the manure, the lower its density. Different types of manure have different density values. The density of stable (cattle) manure thus ranges between 700 kg/m^3 and 1000 kg/m^3 (Table 1).
- The coefficient of friction, which belongs to the static-dynamic physical properties.
  This coefficient depends on the mass of the manure, the surface on which it slides, and its composition (dry matter vs. water). Figure 2 shows the variation of the coefficient of friction with the density of the manure. More moist manures (greater density) thus have a lower coefficient of friction than drier types of manure. The coefficient of friction stated in the literature [2] and [3] ranges between 0.7 and 1.3 (Table 1), but the possibility of lower values is also mentioned. The exact value of the coefficient of friction for a particular type of manure can be obtained only by experimental measurements.

Preglednica 1. *Splošne fizikalne lastnosti gnoja*
Table 1. *General physical properties of manure*

Koef. trenja gnoj/jeklo Coefficient of friction manure/steel -	Gostota Density kg/m^3
0,7 – 1,3	700 – 1000



Sl. 2. *Diagram raztrosa koeficienta trenja*
Fig. 2 *Diagram of the scatter of the coefficient of friction*

Širok raztros podatkov (sl. 2) je za zasnovo matematičnega modela in primerjave z raztrosom trosilnika Jeantil EP 2060 Epandor 3 neuporaben, zato je bil izveden poskus za pridobitev podatkov, ki so bili izmerjeni v razmerah pri trosenju gnoja. Podlaga, na kateri smo merili koeficient trenja in oprijemanja, je bila hrapava pobarvana pločevina. Tako smo se želeli čim bolj približati dejanskem stanju pri trosenju. Izmerili smo koeficient trenja v gibanju in koeficient trenja v mirovanju – oprijemanja. Izvedli smo po sedem meritev za vsak koeficient in izračunali povprečje:

Vlažen gnoj: koeficient trenja $\mu_t = 0{,}52$
koeficient oprijemanja $\mu_l = 0{,}56$
Suh gnoj: koeficient trenja $\mu_t = 0{,}67$
koeficient oprijemanja $\mu_l = 0{,}77$

Analiza rezultatov je pokazala, da se koeficient trenja poveča pri gnoju z večjim deležem suhe snovi v njem. Podobne rezultate navaja tudi literatura [2], [3] in [9]. Koeficient oprijemanja pa je v povprečju za 10% večji kakor koeficient trenja pri gibanju.

Wide data scatter (Fig. 2) would be useless for designing a mathematical model and its comparison with the scatter of the Jeantil EP 2060 Epandor 3 manure spreader. For this reason, a data-acquisition experiment was performed first. The parameters were measured under the conditions generally present during manure distribution. The surface on which the static and dynamic coefficients of friction were measured was rough, painted sheet metal. This was selected in order to obtain the best possible approximation to the real conditions of manure distribution. The coefficients of friction were measured during movement and at rest. For each of the two types of coefficients, seven measurements were performed and the averages were calculated:

Moist manure: dynamic coefficient of friction $\mu_t = 0.52$
static coefficient of friction $\mu_l = 0.56$
Dry manure: dynamic coefficient of friction $\mu_t = 0.67$
static coefficient of friction $\mu_l = 0.77$

The analysis of the results showed that the coefficient of friction is greater for manures with higher dry-matter contents. Similar results are also reported in the literature [2], [3], and [9]. The static coefficient of friction is 10% higher, on average, than the dynamic coefficient of friction.

2 ANALIZA RAZTROSA

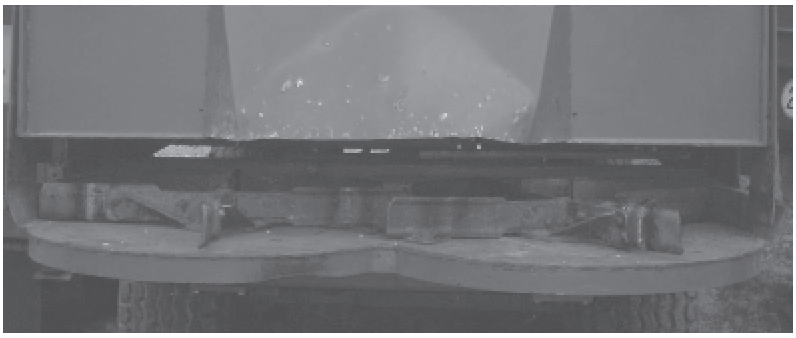
Organski gnoj je nehomogen material, za katerega je izredno težko napovedati, v katero smer in do kam bo delec gnoja letel, ko zapusti trosilno napravo [9]. Njegove fizikalne lastnosti so odvisne od številnih vplivov (vrsta gnoja, delež vode, homogenost itn.), vendar fizikalno načelo raztrosa ostaja navkljub vsem vplivom in pogojem trosenja enako.

Zaradi širokega razpona spremenljivih fizikalnih parametrov gnoja je težko konstruirati trosilno napravo, ker pred preizkusom naprave ne vemo, kakšna bo slika trosenja. Slika trosenja namreč pove enakomernost porazdelitve gnoja

2 ANALYSIS OF THE MANURE DISTRIBUTION

Organic manure is a nonhomogeneous material for which it is extremely difficult to predict the direction and range of motion of its pieces once they leave the spreader [9]. The physical properties of organic manure depend on many influences (type of manure, its water content and homogeneity, etc.), but the physical principle of manure distribution remains the same in spite of all the variable influences and conditions.

Because of the wide range of the variable physical parameters of manure, the designing of a spreading device is difficult. This is because the manure-distribution histogram is not known until the device is tested in the field. This histogram shows the uniformity of manure



Sl. 3. *Trosilna naprava – trosenje nazaj*
Fig. 3. *Manure spreader – backwards distribution*

prečno in vzdolžno na smer trosenja [9]. Namen zasnove matematičnega modela za numerično analizo raztrosa je, da s pomočjo predhodne numerične analize raztrosa organskega gnoja po načelu sredobežnega meta [12] izboljšamo zasnovo in detajle konstrukcije trosilne naprave, ki jo snujemo. Na pravilnost numerične analize najodločilneje vpliva matematični model potovanja delcev gnoja in predpostavljeni robni pogoji.

distribution transversely and longitudinally to the direction of spreader movement [9]. The purpose of designing a mathematical model for the numerical analysis of manure distribution is to improve the conceptual design and the structural details of the designed manure-spreading device using a prior numerical analysis of the organic manure distribution according to the principle of centrifugal throw [12]. The accuracy of the numerical analysis is most crucially affected by the mathematical model of manure-piece trajectories and the assumed boundary conditions.

2.1 Matematični model

Matematični model je treba izbrati zelo previdno, saj je pravilnost izračunov neposredno odvisna od njegove izbire. Ker se analiza gradi po načelu sredobežnega meta [12], smo morali uporabiti tehnično načelo rotorja, ki pospeši delček gnoja. Ker še ni poznanega matematičnega modela za izračun meta gnoja, izberemo takšnega, da rezultate lahko primerjamo z izmerjenim raztrosom pri sedanjih napravah. Za primerjavo smo izbrali dobro znano trosilno napravo za trosenje nazaj (sl. 3):

– Jeantil EP 2060 Epandor 3 (široko trosilna naprava - trosenje nazaj)

Zanjo je značilno, da je narejena iz dveh rotorjev. Njuna hitrost zagotavlja, da delci gnoja odletijo iz rotorja. Rotor je zgrajen iz mirujoče plošče, po kateri drsijo lopatice. Te so osrednje vpete na gred, ta pa je povezana prek mehanskega prenosa s kardansko gredjo traktorja. Oba rotorja imata enako vrtilno frekvenco in se vrtita navzven. Geometrijska oblika rotorjev in tehnično načelo delovanja sta popolnoma poznana, prav tako njun položaj glede na gnojeno površino.

Matematični model (sl. 4) temelji na načelu sredobežnega meta [12]. Program, ki je izvajal numerični izračun, je bil izdelan v programskem jeziku C [11]. Za osnovo numeričnega izračuna vzamemo delec organskega gnoja, ki prileti naključno na rotor, na katerem dobi velikost hitrosti in smer

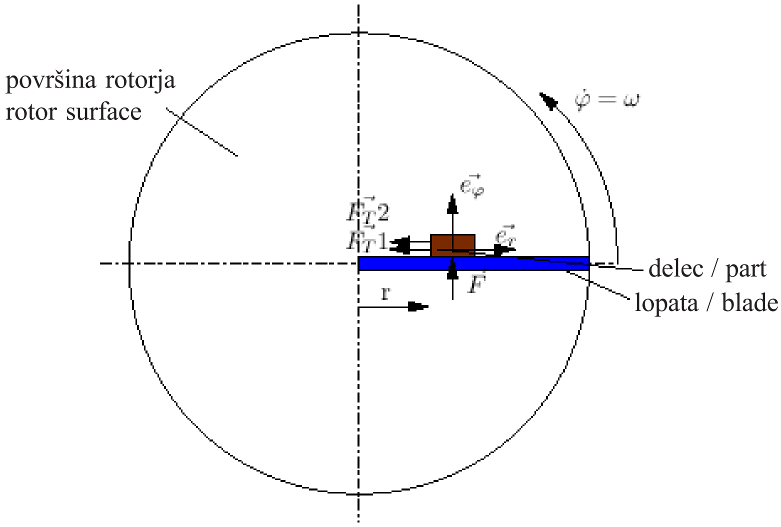
2.1 Mathematical model

The mathematical model needs to be selected very carefully, as the accuracy of the calculations directly depends on it. Since the analysis is based on the principle of centrifugal throw [12], the engineering principle of manure-piece acceleration by a rotor had to be used. Since no mathematical model is known as yet for the calculation of manure trajectories, we selected one that enabled a comparison with the measured real manure distribution for an existing spreader. The following well-known manure spreader for backward distribution was chosen for the comparison (Fig. 3):

– Jeantil EP 2060 Epandor 3 (manure spreader with a wide swath range and backward manure distribution)

This spreader is characterized by two rotors. Their speed is set so as to guarantee that manure pieces will leave the rotor. The rotor consists of a stationary plate, along which the blades slide. The blades are centrally attached to a shaft, which is connected via a mechanical transmission to the tractor's power take-off shaft. Both rotors have the same rotating frequency and rotate outwards. The rotors' geometry and the engineering principle of their operation is known, and so is their position with respect to the fertilized surface.

The mathematical model (Fig. 4) is based on the principle of centrifugal throw [12]. The program for performing the numerical calculations was produced in the C programming language [11]. As the basis for the numerical calculation, we took a piece of organic manure that randomly lands on the rotor and is accelerated by it to a velocity that is a vector defined by its magnitude



Sl. 4. *Matematični model za trosenje nazaj*
Fig. 4. *Mathematical model for backward manure distribution*

(vektor). Kot rezultat je podan histogram porazdelitve delcev gnoja v prečni smeri glede na trosilno napravo. Stopnje v postopku numeričnega izračuna, ki jim more matematični model zadostiti, so naslednje:

– Dovajanje delca na rotor

Delce je treba naključno dovajati na rotor, saj postopek odmetovanja poteka povsem naključno. Tako predvidimo, da drobilni valji naključno in enakomerno dovajajo delce gnoja na površino rotorja. Površina rotorja, ki je obenem plošča pod lopaticami, je okrogle oblike (odvisna je od vrtenja lopat) in miruje. Dovajanje delcev na površino je določala naključnostna funkcija. Program je nato izračunal lego delca glede na os vrtenja (kot in polmer).

– Potovanje delca po rotorju

Delec je na površini rotorja ”čakal” lopato. Lopata je potovala od kota 0^0 do 720^0. Ko je lopata prispela v lego delca, se je ta pričel gibati izsredno (posledica sredobežne sile) in obodno (prisilno gibanje zaradi gibanja lopate) [12]. Upoštevali smo delovanje sile trenja (koeficient trenja je bil poprej izmerjen s preizkusom) na delec zaradi drsenja ob lopatici in ob podlagi. V gibalni diferencialni enačbi (1) in (2) za trosenje nazaj ni bilo treba upoštevati mase delca gnoja, tako je gibanje delca po rotorju neodvisno od njegove mase. Mase delca ni bilo treba upoštevati, ker smo obravnavali, da delec potuje v brezzračnem prostoru in pri tem ni zračnega upora na delec.

and direction. The results are presented in the form of a histogram of manure-piece distribution transversely to the manure spreader. The stages of the procedure for the numerical calculation, which must be taken into account in the mathematical model, are as follows:

– Feeding of manure pieces to the rotor

Manure pieces should be delivered to the rotor at random, as the process of manure distribution needs to be entirely random. It is thus planned that the crushing rollers will deliver manure pieces to the rotor’s surface in a random and uniform manner. The rotor’s surface, which is at the same time also the plate beneath the blades, is round in shape (because of the blade rotation) and stationary. The randomness of feeding manure pieces to the surface is ensured by using the random function. The program then calculates the manure piece’s position with respect to the axis of rotation (angle and radius).

– Movement of manure pieces along the rotor

Each manure piece “waits” for the blade on the rotor’s surface. The blade travels from 0^0 to 720^0. Once the blade reaches the position of the manure piece, the piece begins moving radially (as a result of the centrifugal force) and tangentially (forced movement because of the blade movement) [12]. The mathematical model takes into account the force of friction (the coefficient of friction was measured beforehand with an experiment) onto the manure piece because of its sliding along the blade and along the surface. In the motion differential equations (1) and (2) for backward manure distribution, it is not necessary to take into account the manure piece’s mass, so that its movement along the rotor is independent of its mass. The mass can be discounted, because it is assumed that the manure piece travels in an airless space and therefore there is no influence of air resistance on the piece.

$$\bar{e}_r : -F_T 1 - F_T 2 = m \cdot \bar{a}_r = m \cdot (\ddot{r} - r \cdot \dot{\varphi}^2) \quad (1)$$

$$\vec{e}_{\varphi} : F = m \cdot \vec{a}_{\varphi} = m \cdot (r \cdot \ddot{\varphi} + 2 \cdot \dot{r} \cdot \dot{\varphi}) \quad (2).$$

Gibalna enačba [12] je sestavljena iz dveh delov. Prvi del (1) popisuje gibanje delca v izsredni smeri ($\vec{e}_r$), drugi del (2) pa v obodni smeri ($\vec{e}_\varphi$). Na delec v izsredni smeri deluje sila trenja med delcem in lopato (F_T1) in sila trenja med delcem in površino rotorja (F_T2), ki zavirata delec, ter sredobežna sila ($m \cdot a_r$), ki delec pospešuje navzven. V obodni smeri deluje na delec sil F in sila zaradi obodnega pospeševanja delca ($m \cdot a_\varphi$). Sila F je reakcija trenja med podlago in delcem zaradi krožnega gibanja delca. Rotor ima stalno kotno hitrost (ω).

The motion equation [12] consists of two parts. The first part (Eq. 1) describes the movement of a manure piece in the radial direction ($\vec{e}_r$), and the second part (Eq. 2) describes its movement in the tangential direction ($\vec{e}_\varphi$). In the radial direction the piece is acted upon by the force of friction between the piece and the blade (F_T1) and the force of friction between the piece and the rotor surface (F_T2), which both decelerate the piece, as well as the centrifugal force ($m \cdot a_r$), which provides for outward acceleration of the piece. In the tangential direction the piece is acted upon by force F and a force resulting from the tangential acceleration of the piece $m \cdot a_\varphi$). Force F results from the friction between the piece and the surface on which it slides because of the piece's circular movement. The rotor has a constant angular velocity (ω).

– Potovanje delca od rotorja do gnojene površine

Ko delec zapusti rotor, ima določeno hitrost in smer [12]. Model rotorja je narejen tako, da delec lahko zapusti rotor samo na določenem področju. To področje imenujemo kot izstopa. Njegovo potovanje do gnojene površine računamo po fizikalnem načelu za poševni met v prostoru. Pri računanju potovanja delca ((3) in (4)), ko delec zapusti rotor, moramo poznati oddaljenost rotorja od tal (h) (položaj rotorja glede na gnojeno površino), mesto na robu rotorja (r,ω), kjer delec zapusti rotor in hitrosti delca (v_x). Dolžino dometa izračunamo tako, da določimo čas (t_p), v katerem bo delec padel na tla. Nato čas množimo s hitrostjo (v_x), ki jo ima v prečni smeri delec in tako dobimo domet (L_x).

– Movement of the manure pieces from the rotor to the surface to be fertilized

Once the manure piece leaves the rotor, it has a certain velocity and direction [12]. The rotor's model is made in such a way that the piece can leave the rotor only from a certain area, which is called the exiting-area angle. The manure piece's trajectory towards the fertilized surface is calculated according to the physical principle of spatial centrifugal throw. For the calculation of manure-piece travel (Equations 3 and 4) once it leaves the rotor, one needs to know the rotor's distance from the ground (h) (i.e., its position with respect to the fertilized surface), the point on the rotor's edge (r,ω) where the piece leaves the rotor, and the piece's velocity (v_x). The piece's range is calculated by determining the time (t_p) it will take to reach the ground. This time is then multiplied by the piece's transverse velocity (v_x) in order to obtain the range, i.e., length (L_x).

$$t_p = \sqrt{\frac{2 \cdot h}{g}} \quad (3)$$

$$L_x = t_p \cdot v_x \quad (4).$$

2.2 Robni pogoji

Pravilnost rezultatov je odvisna od robnih pogojev, ki jih upoštevamo. Že manjša sprememba enega od robnih pogojev lahko bistveno spremeni rezultate, ki jih dobimo. Na dolžino dometa vpliva več dejavnikov:

– Področje dovajanja in izstopanja delcev gnoja iz rotorja.

Za dobro značilnico - sliko trosenja je izredno pomembno, kje bo delec priletel na rotor in kje bo delec zapusti rotor. Področje dovajanja je omejeno in je na površini rotorja.

2.2 Boundary conditions

The accuracy of the results depends on the boundary conditions that are used. Even a small change in one of the boundary conditions can result in a significant change in the obtained results. The range of motion of the manure pieces is affected by several factors:

– Manure delivery and exiting areas on the rotor

For a good manure-distribution diagram, the areas where the piece will land on the rotor and from where it will leave the rotor are extremely important. The landing area is limited and is located on the rotor's surface.

– Koeficient trenja in zračni upor

V izračunu in postavitvi matematičnega modela smo upoštevali koeficient trenja (μ), ne pa koeficienta zračnega upora. Velikost koeficienta trenja smo izbrali glede na rezultate poskusnih meritev, ki smo jih poprej izvedli. Koeficient zračnega upora ima večji vpliv na delce z večjo hitrostjo (*v*) in daljšim časom potovanja delca (t_p) od rotorja do gnojene površine.

– Hitrosti

Načelo sredobežnega meta je odvisno od hitrosti (*v*), ki jo delec gnoja prejme na rotorju. Velikost hitrosti je odvisna od vrtilne frekvence rotorja (*n*) in od premera (*d*) rotorja.

- Položaj rotorja

Oddaljenost rotorja oziroma osi rotorja od tal (*h*) vpliva na velikost dometa.

3 REZULTATI NUMERIČNE ANALIZE

Rezultate numerične analize bomo prikazali v obliki histograma prečnega raztrosa. Histogram vzdolžnega raztrosa je neuporaben kot rezultat numerične analize, saj pri definiranju robnih pogojev ne moremo oceniti števila delcev gnoja na enoto potovanja trosilnika. Histogram prečnega raztrosa pokaže dejansko kakovost trosilnika. Naša želja je, da je raztros v prečni smeri čim bolj enakomeren. Slika 5 prikazuje iz ptičje perspektive položaj delcev

– Coefficient of friction and air resistance

In the calculations and the setting up of the mathematical model, the coefficient of friction (μ) was taken into account, but not the coefficient of air resistance. The magnitude of the coefficient of friction was selected with respect to the results of experimental measurements, which were performed in advance. The coefficient of air resistance exerts a greater influence on pieces which have a higher velocity (*v*) and a longer time of travel (t_p) from the rotor to the fertilized surface.

– Velocity

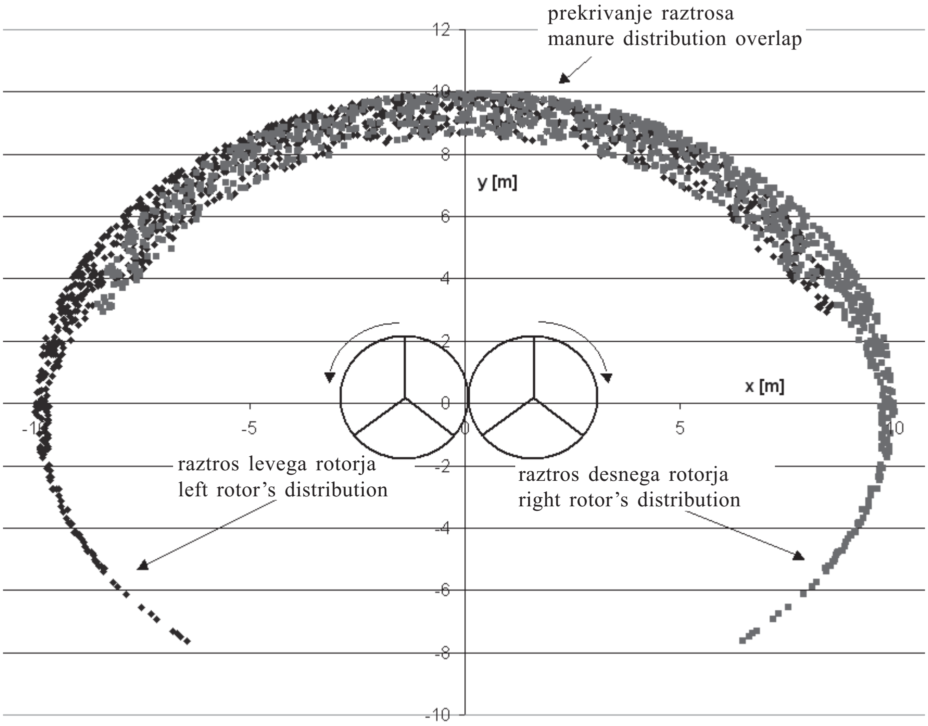
The principle of centrifugal throw depends on the velocity (*v*) to which a manure piece is accelerated on/by the rotor. The magnitude of this velocity depends on the rotor's rpm value (*n*) and its diameter (*d*).

– Rotor position

The distance of the rotor or rotor axis from the ground (*h*) also affects the manure piece's range of motion.

3 RESULTS OF THE NUMERICAL ANALYSIS

The results of the numerical analysis are presented in the form of a histogram of transverse manure distribution. The histogram of longitudinal distribution is useless as a result of the numerical analysis, because the number of manure pieces per unit of distance covered by the spreader cannot be estimated when defining the boundary conditions. The histogram of transverse distribution shows the spreader's actual quality. The aim is to maximize the uniformity of the transverse distribution. Figure 5 shows a bird's eye



Sl. 5. *Rezultati analize raztrosa široke trosilne naprave(ptičja perspektiva)*
Fig. 5. *Results of manure distribution analysis for a manure spreader with a wide swath (bird's eye perspective)*

organskega gnoja na gnojeni površini glede na položaj rotorjev. Ta slika o sami kakovosti raztrosa ne pove nič, obvesti pa nas o področju na gnojeni površini, ki ga pokrivajo delci iz posameznega rotorja.

Rezultate analize trosenja smo primerjali z rezultati meritev trosilne naprave podjetja Jeantil EP 2060 Epandor 3 [8]. Za pravilnost postavitve matematičnega modela smo upoštevali predvsem širino trosenja.

Kakor smo že omenili, prikazuje slika 4 rezultat numerične analize raztrosa delcev organskega gnoja iz ptičje perspektive. Svetlejše točke, so delci gnoja, ki priletijo iz desnega rotorja, temnejše, pa delci gnoja, ki priletijo iz levega rotorja. Rotorja se vrtita na mestu in navzven, kar je tudi prikazano na sliki 5. S slike je razvidno, da bomo s prekritjem delcev iz levega in desnega rotorja poskusili doseči najprimernejšo površino, na kateri bo raztros gnoja enakomeren.

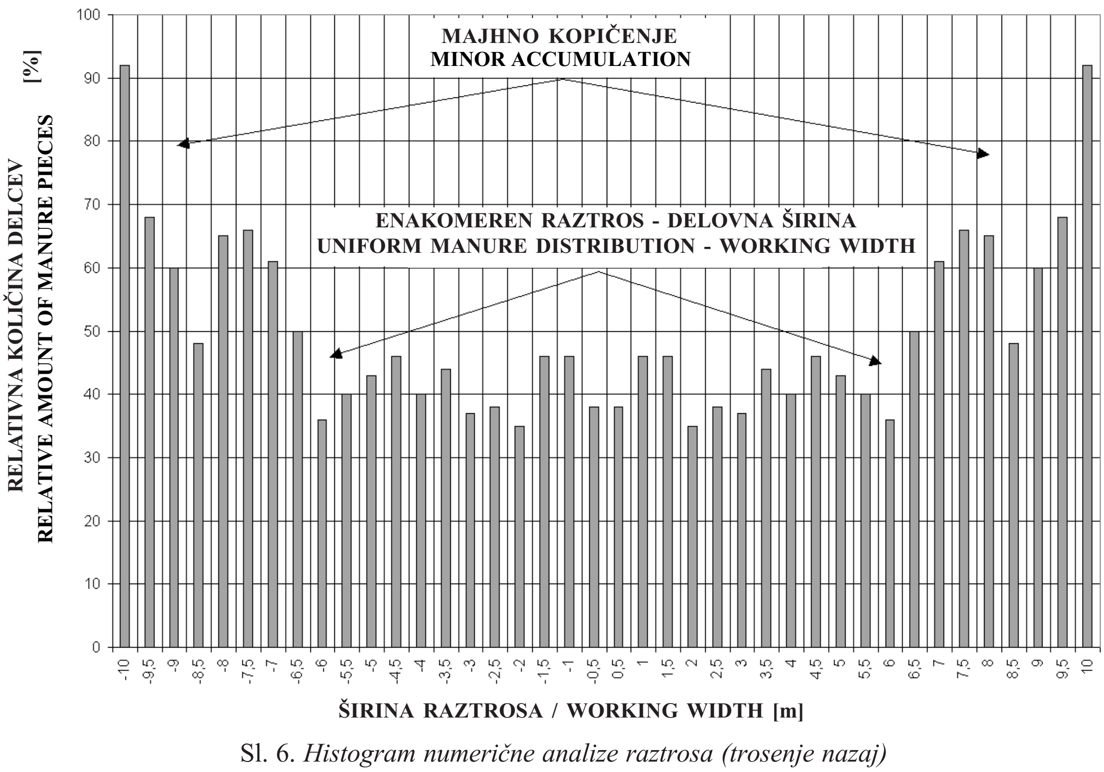
Najprej moramo potrditi matematični model in robne pogoje, ki smo jih predpostavili. Slika 6 je histogram prečnega raztrosa numerične analize, na podlagi katerega bomo potrdili naše predpostavke v primerjavi z izmerjenim histogramom prečnega raztrosa trosilnika Jeantil EP 2060 Epandor 3 (sl. 7). V našem primeru smo opazovali le širino trosenja in odstopanja od enakomerne porazdelitve delcev gnoja v histogramu prečne porazdelitve. Na sliki 5 vidimo, da je enakomerna porazdelitev zagotovljena na širini 12 m. Na dejanskem primeru (sl. 7) je to na

view of the position of organic manure pieces on the fertilized surface with respect to the rotor position. This figure tells us nothing about the quality of the distribution, but it does provide information on the area of the fertilized surface covered by manure pieces coming from an individual rotor.

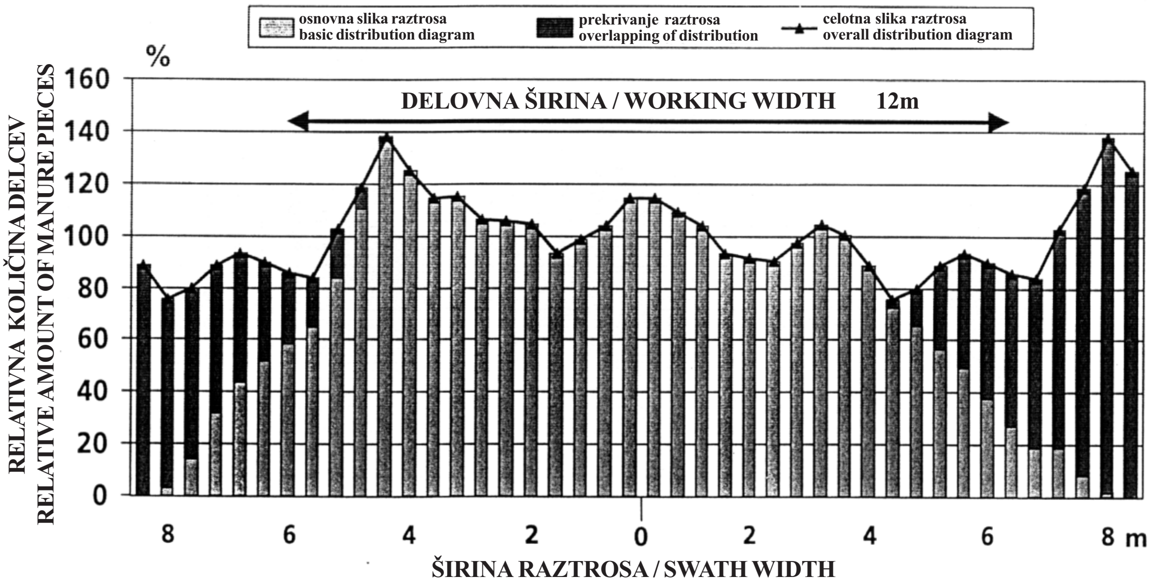
The results of the manure distribution analysis are compared with the results of measurements performed on the Jeantil EP 2060 Epandor 3 manure spreader [8]. The swath width is primarily used in verifying the mathematical model.

As was already mentioned above, Figure 5 presents the results of the numerical analysis of the organic manure-piece distribution from the bird's eye perspective. The lighter points represent manure pieces coming from the right rotor, while the darker ones represent those coming from the left one. The rotors rotate both in place and outwards, as shown in Figure 5. It can be seen in this figure that we have tried to achieve an optimal area of uniform manure distribution by overlapping the left and right rotor swaths.

Firstly, the mathematical model and the assumed boundary conditions need to be verified. Figure 6 is a histogram of the transverse distribution obtained by a numerical analysis, on the basis of which our assumptions will be confirmed via a comparison with the measured histogram of the transverse distribution of the Jeantil EP 2060 Epandor 3 manure spreader (Fig. 7). In our case, only the swath width and the deviations from a uniform distribution of manure pieces in the transverse distribution's histogram are observed. Figure 5 shows that in this case a uniform distribution is ensured over a width of 12 m. For the real case (Fig. 7), this width is 10 m. There is a difference in the



Sl. 6. *Histogram numerične analize raztrosa (trosenje nazaj)*
Fig. 6. *Histogram of the numerical analysis of manure spreading (backwards distribution)*



Sl. 7. *Histogram meritve prečne porazdelitve trosilnika Jeantil EP 2060 Epandor 3 [8] (trosenje nazaj)*
Fig. 7. *Histogram of the measurements of transverse manure distribution for the Jeantil EP 2060 Epandor 3 manure spreader [8] (backwards distribution)*

širini 10 m. Razliko opazimo v največji širini raztrosa in v količini na robu. Pri numerični analizi so vrednosti na robovih večje od sredinske enakomerne porazdelitve, pri dejanskem primeru se količina delcev zmanjšuje. To razliko lahko razložimo s tem, da v matematičnem modelu nismo upoštevali zračnega upora. Vemo, da se zaradi vpliva zračnega upora hitrost delcu spreminja s kvadratom, kar za naš primer pomeni, da se delcu hitrost zmanjšuje. Če se hitrost zmanjšuje z oddaljevanjem delca od trosilne naprave, pomeni, da se največji domet delca zmanjšuje. Tako dobimo več delcev v območju enakomernega raztrosa, manj pa ob robovih (sl. 7). Ta trditev spodbija rezultate naše numerične analize, vendar moramo vedeti, da nismo upoštevali vpliva zračnega upora (sl. 6). Zaradi zračnega upora se domet delcev zmanjša, kar pa pomeni, da se povečana količina na robovih (sl. 6) zmanjša in porazdeli v področje enakomernega dometa. Zmanjša se tudi največja širina dometa. To pomeni, da širina raztrosa analize ustreza dejanskemu primeru, ker je v dejanskem primeru (sl. 7) za 25% manjša, kakor pri izračunu (sl. 6).

4 UGOTOVITVE IN SKLEP

Ugotovitve:

- Koeficient trenja ima na dolžino dometa zelo majhen vpliv.
- Trenje na enakomernost raztrosa nima vpliva.
- Masa na enakomernost in dolžino dometa nima vpliva, ker se v gibalni enačbi krajša. Ne upoštevamo zračnega upora.

maximum swath width and the amount of manure on its edge. In the numerical analysis the amount of manure on the edge exceeds that found within the central portion with a uniform distribution, while in the real case this amount decreases towards the edge. This difference can be explained by the fact that air resistance was not taken into account in the mathematical model. It is known that because of the influence of air resistance the velocity of a manure piece varies as a square, which in our case means that the piece's velocity decreases. If the velocity decreases with the manure piece's distance from the spreader, this means that the piece's maximum range is decreasing. In this way, more pieces are obtained in the area with a uniform distribution and fewer ones along the edges (Fig. 7). This assertion is contrary to the results of our numerical analysis; however, it should be remembered that in our analysis the influence of air resistance was ignored (Fig. 6). Because of the influence of air resistance, the range of motion of manure pieces decreases, and this in turn means that the increased amount of the manure on the edges (Fig. 6) is actually reduced and distributed to the area with a uniform range. The maximum range width is also reduced, which means that the swath width obtained by the analysis corresponds to the real case, because in the real case (Fig. 7) it is 25% smaller than the calculations have shown (Fig. 6).

4 FINDINGS AND CONCLUSION

Findings:

- The coefficient of friction has a very small influence on the range of motion of manure pieces;
- Friction has no influence on the uniformity of manure distribution;
- Mass has no influence on the uniformity and range, because it is cancelled out in the motion

– Odločilni vpliv na enakomernost raztrosa ima področje, na katerega dovojamo gnoj in področje, v katerem delci gnoja lahko zapustijo rotor.
– Največji domet je odvisen predvsem od obodne hitrosti rotorja.
– Zračni upor mnogo bolj vpliva na porazdelitev delcev na robovih (zunaj področja enakomernega raztrosa), kakor v področju enakomernega raztrosa.

V osnovi je mogoče potrditi nastavljeni matematični model, saj smo izračunali širino raztrosa za 25% večjo kakor ga ima dejanski primer, kar pa pomeni, da bi se z upoštevanjem zračnega upora naši rezultati gibali v področju širine raztrosa dejanskega primera. Področje enakomernega raztrosa se v dokajšnji meri pokriva s področjem enakomernega raztrosa dejanskega primera, kar pomeni, da so bile predpostavke matematičnega modela pravilne in prav tako tudi predvideni robni pogoji.

Opravljeni izračuni in nastavljeni matematični model je lahko osnova za sodoben način k celovitega konstruiranja ([1] in [10]) trosilnih naprav, saj bi s predhodno numerično analizo lahko deloma usmerili konstrukterja že v prvi fazi snovanja k iskanju takšnih rešitev ([4] do [6]), ki bi zagotavljali boljšo kakovost raztrosa in s tem večjo učinkovitost trosilne naprave.

equation. The air resistance was ignored;
– The area to which manure is delivered and the area from which the pieces can leave the rotor both have a crucial effect on the uniformity of the distribution;
– The maximum range of manure pieces depends primarily on the rotor's tangential velocity;
– The air resistance has a much greater effect on the manure-piece distribution along the edges (outside of the area of uniform distribution) than in the area of uniform distribution.

The produced mathematical model can therefore be considered essentially verified: the swath width was calculated to be 25% greater than for the real case, which means that if air resistance was taken into account, our results would range within the swath width for the real case. The area of uniform distribution corresponds quite well to the area of uniform distribution for the real case, which means that the assumptions of our mathematical model were correct and so were the selected boundary conditions.

The performed calculations and the produced mathematical model can serve as the basis for modern approaches to the global design ([1] and [10]) of manure spreaders, as prior numerical analysis can be used to partially direct the design engineer towards solutions that ensure a better quality of manure distribution and thus greater efficacy of the manure spreader during the initial phase of design ([4] to [6]).

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