http://vestnik.mrsu.ru
ISSN Print 2658-4123
ISSN Online 2658-6525

УДК 621.3.083.92:633.853.74 DOI: 10.15507/2658-4123.030.202002.219-231

Simulation of Sesame Seeds Outflow in Oscillating Seed Metering Device Using DEM

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Introduction. Sesame crop is one of the most important export crops in many countries around the world, especially in Africa. To meet the agricultural requirement of precision planting, various types of precision seed planters have been developed. Numerous studies were carried out to study the optimisation of the parameters of the precision planting. One of these parameters, affecting the quality of the precision seeder, is the grain outflow from the seed metering device.
Materials and Methods. In order to maintain good continuous performance of an oscillating seeder, it is important to monitor seed flow in real-time and adjust oscillation parameters automatically. Existing research methods, such as prototyping and monitoring the process using a high-speed camera, by reason of the random movement of particles, do not allow obtaining sufficient data to understand trajectories and velocities of particles and existing equations for particle motion when simulating the sowing process do not allow taking into account the interaction of particles that having various shapes, rolling and sliding friction coefficients, and the elastic modulus of particle materials and a working body. In this study, the outflow rate of sesame seeds in an oscillating seed metering device was modeled using the simulation method based on the discrete element method. The aim of this study is to create a simulation model of an oscillating-type sowing planter using the sowing sesame seeds as an example for evaluating the effectiveness of this model, and the possibility of further optimization and prediction of sowing seeds with this device.
Results. The analysis of the results showed that during the simulation, the sowing rate of sesame seeds when leaving the oscillating seed metering holes has significant differences in number and direction. The results of the modeling process in this study showed that when opening a hole in the oscillating seeder, a number of sesame seeds from 0 to 4 were coming out of it. The resulting model allows monitoring the behavior of each particle of a sesame seed, analyzing its trajectory, speed, and forces acting on it at any one time, and varying the parameters to obtain the dependence of uneven seeding on the kinematic and geometric parameters of the device.
Discussion and Conclusion. The obtained simulation results provide an effective method for predicting the consumption of sesame seeds from the oscillating seed meter, which serves as the basis for optimizing the kinematic and geometric parameters of the oscillating sowing device in order to increase its efficiency. This model is universal and can be adapted to sow other crops.

Keywords: discrete element method, sesame seeds, oscillating seed metering, precision seeder, seeds motion

For citation: Sharaby N.N., Doroshenko A.A., Butovchenko A.V. Simulation of Sesame Seeds Outflow in Oscillating Seed Metering Device Using DEM. *Inzhenerernyye tekhnologii i sistemy* = Engineering Technologies and Systems. 2020; 30(2):219-231. DOI: https://doi.org/10.15507/2658-4123.030.202002.219-231

Моделирование истечения семян кунжута при колебательном дозировании семян устройством с использованием DEM

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Введение. Кунжутная культура является одной из самых важных экспортных культур во многих странах мира, особенно в Африке. Чтобы удовлетворить сельскохозяйственные требования точного высева, были разработаны различные типы сеялок. Проведены численные исследования по изучению оптимизации параметров прецизионного высева. Одним из таких параметров, влияющих на качество работы прецизионной сеялки, является истечение зерна из дозатора семян.
Материалы и методы. Чтобы поддерживать хорошие непрерывные рабочие характеристики в колеблющейся сеялке, важно следить за расходом семян в режиме реального времени и автоматически регулировать колебательные параметры. Существующие методы исследования, такие как создание прототипа и наблюдение за процессом с использованием скоростной съемки, из-за хаотичного движения частиц не позволяют получить достаточное количество данных для понимания траектории и скорости перемещения частиц (существующие уравнения движения частиц при моделировании процесса высева не позволяют учесть взаимодействие частиц, имеющих различные формы), коэффициенты трения качения и скольжения, модули упругости материалов частиц и рабочего органа. В этом исследовании поток семян кунжута в колеблющейся сеялке точного высева был воссоздан с использованием метода имитационного моделирования метода дискретных элементов. Целью исследования являлось создание имитационной модели высевающего аппарата вибрационного типа на примере высева семян кунжута и последующей оценки эффективности его модели, а также возможности дальнейшей оптимизации и прогнозирования высева семян этим аппаратом.
Результаты исследования. Анализ результатов показал, что во время моделирования скорость высева семян кунжута при выходе из отверстия имеет существенные различия по величине и направлению. Приведенные в статье результаты показывают, что при открытии отверстия в высевающем аппарате из него выходит от нуля до четырех семян. Полученная модель позволяет проводить наблюдения за поведением каждой частицы семени кунжута, проводить анализ ее траектории, скорости движения и сил, действующих на нее в любой момент времени, а также при варьировании параметров получать зависимости неравномерности высева от кинематических и геометрических параметров работы устройства.
Обсуждение и заключение. Полученные результаты имитационного моделирования обеспечивают эффективный метод прогнозирования расхода семян кунжута в колеблющемся дозаторе семян, что служит основой для оптимизации кинематических и геометрических параметров работы вибрационного высевающего аппарата с целью повышения эффективности его работы. Данная модель является универсальной и может быть адаптирована к высеву других сельскохозяйственных культур.

Ключевые слова: метод дискретных элементов, семена кунжута, колебательный дозатор семян, прецизионная сеялка, движение семян

Для цитирования: Шараби, Н. Н. Моделирование истечения семян кунжута при колебательном дозировании семян устройством с использованием DEM / Н. Н. Шараби, А. А. Дорошенко, А. В. Бутовченко. – DOI 10.15507/2658-4123.030.202002.219-231 // Инженерные технологии и системы. – 2020. – Т. 30, № 2. – С. 219–231.

Introduction

Sesame crop is one of the oldest oil-producing crops around the world which has a high ability to adapt to tropical and semi-tropical regions. Sesame seeds are widely involved in making healthy foods, which is increasingly in demand significantly nowadays, moreover, they have positive effects on human health because of their content of nutrients, antioxidants, minerals, and vitamins. The annual global consumption of oils and edible fats are about 120 million (MT) [1]. Sesame seeds are a rich source of protein such as soybeans, which makes them a high nutritional and healthy value[1].

There is a major difference for production both sesame seeds and sesame oil from one region to another around the world, however, despite the rise of sesame production in Asia and Africa compared to Europe as showed in Table 1[2]. The low cultivated area and production of the sesame seeds in numerous countries are due to some fundamental factor such as usually grown in less fertile soils, low labor and lack of nutrient management properly. Furthermore, using the traditional methods of sowing sesame seeds such as hand planting, and limited use of mechanically planting such as row planter is one of the major causes for low yields.

Sesame seeds are sown or planted manually via hand or mechanically using different methods such as hand-operated seeder or tractor – operated seed drills as well as a precision planter. While precision sowing for sesame seeds is the best method between different sowing techniques compared with other methods, as it is used for accurately place single seeds or groups of seed almost equidistant apart along a furrow, however, using precision planting for sowing sesame seeds is still limited compared to other crops like cereals [2].

Literature Review

The planting distance for sesame varies according to the seed varieties, for example, the recommended planting distance for sesame in is 10–20 cm between plants in the same row and 40–60 cm between rows according to sesame varieties. Generally, planters may contain a central hopper for whole rows or individual hopper for each row, which contain the seeds and transported them downwards to the seed metering device, and then the seeds fall into the seed delivery tube that conveys the seeds into the seedbed. The seed metering device aims to keep the seed spacing uniformity along the row and between rows or is restricted to transfer seeds from the seed hopper and deposit it into the seed delivery tube, therefore,

Table 1

The production output of sesame seed and oil around the world

Region	Sesame seed (million tons)	Sesame oil (million tons)	Total production (tons)
Asia	2.1800	0.809	2.9890
Africa	0.8090	1.337	2.1460
America	0.1760	0.023	0.1990
Australia	0	0.002	0.0020
Europe	0.0014	0.031	0.0324

Source: FAO 2012

[1] Onyibe J.E., Tologbonshe E.B., Ubi E.O. Beniseed Production and Utilisation in Nigeria. Extension Bulletin No. 154. Zaria: Ahmadu Bello University. 25 p.

[2] Food and Agriculture Organization (FAO). Available at: http://www.fao.org/faostat/en/#data/QC (accessed 26.03.2020). (In Eng.)

its performance affects the uniformity of seed distribution directly. The cultivation of sesame seeds using the row planter helps to maintain equal planting spacing within and between rows to enhance production and give high yield. There is no widespread use of sesame seeds planter in many countries around the world, where there are few and limited in the form of partnerships programs between international and local organizations in some countries that producing sesame seeds as is the case in Ethiopia for developing prototypes and local made row sesame seeds planter for small-scale farmers (The programme on Integrated Seed Sector Development – ISSD)[3]. While for large-scale farmers, as in one of the sesame cultivation programs in northwest Ethiopia supported by the Sesame Business Network (SBN) in collaboration with some Ethiopian agricultural institutions[4].

Based on the research studies conducted on the sesame crop, it is necessary to overcome the challenges that stand in the way of increasing the sesame yield and quality, which is a major export crop in many countries. In addition to the interest in the utilization and development of sowing or planting sesame seeds technologies on the rows while keeping the equal distances between the seeds along the row and between the rows using a precision seed planter, which saves time, costs, reduce the seeds used in agriculture as well as improving the sesame production. Sesame seeds have an irregular shape, thus existing mechanical metering devices cannot meet its precision seeding, and damaged seeds are a critical problem. Therefore, pneumatic metering technology has been widely developed for precision seeding because its high accuracy and maintaining the integrity of the seeds from damage at great operating speeds, but it needs high power requirements [3; 4]. The objective of this paper is to simulate the process of sesame seeds being fed into oscillating seed metering model for precision seed distribution, which is considered as a low-cost planting seeder with minimum power requirement for operation. Then, according to the monitoring results, the unit will be developed to achieve the uniformity of seed distribution for sesame seeds.

Precision seed metering unit

Seed metering device is used for transfer seeds from the seed box and deposit it into the delivery system that conveys the seeds into the seedbed. The aim of seed planting using precision planter is to achieve precise seed distribution within the row. The achievement of the set seed spacing majorly depends on the machine technical variables such as the type of seed meters, the planter forward speed, overall gear ratio between drive wheel and seed rotor, seed meter drive and to some extent on seed quality [5]. The good design of a seed metering unit is necessary for satisfactory performance of any precision planter. The assessment of distance between plants and seed rate as provided by the planters is also important in analyzing its performance. Therefore, seed meter is the most important part on planter and its performance affects the uniformity of seed distribution directly [6]. There are two kind of seed metering technology: pneumatic metering technology and mechanical metering technology.

Analysis of the monitoring seeds rate method

The rate of seeds outflow that come out from seed metering unit can be determined experimentally. One of the methods is to observe and measuring seeds population uniformity in the real-time using

[3] Walsh S., Thijssen M.H. Programme on Integrated Seed Sector Development in Ethiopia. 2015 Annual report. Wageningen UR: Centre for Development Innovation; 2016. 48 p. Available at: https://edepot.wur.nl/395911 (accessed 26.03.2020). (In Eng.)

[4] Sesame Business Network Newsletter. April 2015. Issue 6. 8 p. Available at: https://agriprofocus.com/upload/post/Issue_6,_April_2015_English1443299081.pdf (accessed 26.03.2020). (In Eng.)

different types of seeds sensor (Optoelectronic sensors, Radio waves sensors) are widely used because of their low cost and high accuracy. Optoelectronic sensors can be installed in different positions along the seed tube; input, middle or output of the seed tube, and widely used because of their low cost and high accuracy. The sensor detects each grain and sends it to the seed controller display[5]. Optical sensors utilize light beams so they have some big problems as; count seeds and dust in field during planting because they can't tell the difference between dust and seed, doubles look like singles, the problem of dust coating the sensor eyes and failing all together. To solve these problems, high-frequency radio waves sensor is used which developed by Precision Planting Inc. to monitor seed mass instead of seed shape to avoid the influence and interference of dust during planting process[6]. Radio wave sensor uses high-frequency waves to look at dropping seeds from different angle. This gives the sensor to distinguish a single seed from a double, dust or from any other material because they all register a different mass. Therefore, in recent years, numerous authors have used the Discrete Element Method (DEM) to simulate the motion of grain materials and analyze flow rate of many different types of seeds from the seed metering unit. Where the application of numerical simulations provides a feasible alternative to physical experiments and plays an important role in various industrial applications. The Discrete Element Method was recognized to be a numerical tool for simulating grain material after the publication of the Cundall and Strack [7].

Materials and Methods

Oscillating seed metering unit

Oscillating seed metering device has numerous benefits and far ranging compared to mechanical metering technology and pneumatic metering technology, and as a result, it simplifies maintenance as there are no longer drive chains, no driven by ground wheel, no drive shafts, no clutches and sprockets system as in mechanical seed metering devices. In addition, high accuracy planting cannot be occurred for traditional seed metering precision planters due to the sliding of ground wheel and chain vibration, especially at high forward speeds. In addition, it does not contain a pneumatic system which consists of a fan installation for solid fertiliser and a vacuum system with fan for single grain metering as in pneumatic seed metering devices, Hence the power requirement is less.

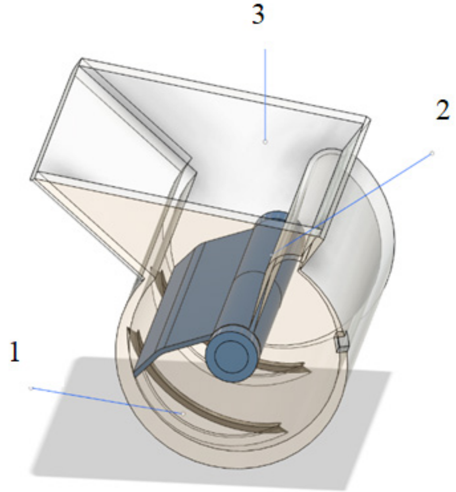
The structure of the oscillating seed metering system was shown in Figure 1. In the design of the oscillating seed metering device, the input of seeds is made passively, by filling from the hopper and deposit into the oscillating seed metering system that transmit the seeds by an oscillating movement to the soil through seed tubes after they left the holes. It is simple in design as it didn't need to require additional power consumption and hasn't impact on the damage of grain material. The necessary condition for improving the continuous working performance of an oscillating seeder is that the seeds should be uniformly discharged during falling into the seed delivery tube to the soil surface because this can maintain equal spacing between the seeds along the furrow.

Results

The flow rate of sesame seeds from seed metering device can be predicted using DEM, which includes a set of physical, mathematical and numerical methods designated to calculate outflow processes characteristics. To obtain the most realistic calculation, software systems enable to

[5] Horsh. Planting and Seeding. Available at: https://www.horsch.com/us/products/planting-and-seeding (accessed 26.03.2020). (In Eng.)

[6] WaveVision. Available at: https://www.precisionplanting.com/products/product/wavevision (accessed 26.03.2020). (In Eng.)



F i g. 1. The general view of the oscillating seed metering unit:
1 – hole; 2 – oscillating seed meter; 3 – hopper

simulate heterogeneous bulk medium having properties as close as possible to the original. EDEM Simulation was chosen as a software package for further calculations.

DEM simulations

DEM is a discontinuous numerical method for analyzing the dynamic behavior of the granular materials at particle interaction level and its use is becoming more popular [8]. In the DEM, Newton's second law of motion and Euler's dynamics equation are usually used to describe the translational and rotational movements of each material and particulate assemblies and uses a contact law to resolve contact forces. The overall system behaviour is determined as a result of individual material interactions [9; 10]. It has been successfully applied to the process simulation in agriculture [11–14] as well as DEM has been used in several analyses to study particle dispersion mechanisms in many agricultural machines as in seed feeding device [15–18]. Although there have been many studies of seed-metering devices, most previous studies have not addressed the seed motion in an oscillating seed metering device. In order to represent the various shapes of agricultural seeds, a multi-sphere approach method was adopted to describe complex material geometries, as the most commonly used technique to describe complex material geometries uses multi-spherical particles, in which a certain number of spheres were "glued" together [19–21], or using optimized spherical harmonics for describing non – spherical particle shapes whether regular or irregular shapes [22].

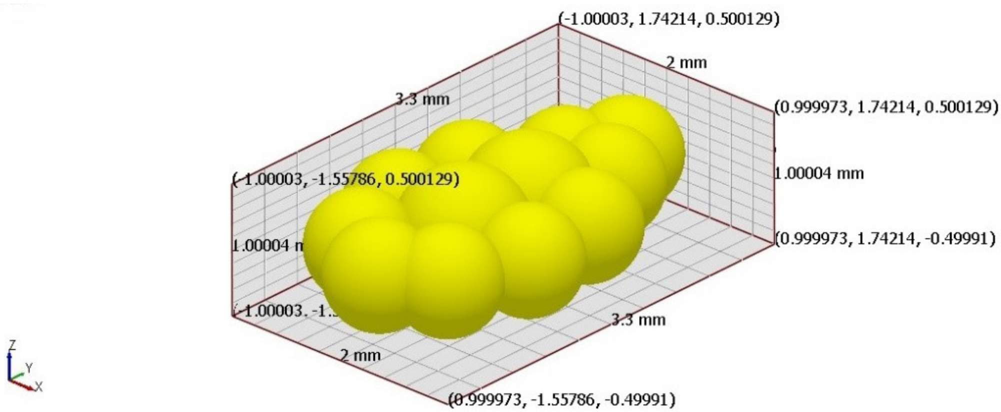
Particle model

The commercial three-dimensional DEM software (EDEM, Edinburgh, UK) was used in simulations. Three-dimensional models of oscillating seed metering device are imported into EDEM, the shape of the oscillating part model was rectangular with dimensions 57 mm × 22 mm according to the structure of the oscillating seed metering and made of stainless steel. In this study, the particle of sesame seeds is taken as the object of research, so sesame seeds motion in an oscillating seed metering unit is simulated under oscillation motion with displacement magnitude is 17.5 degrees.

Due to the difference of agricultural materials such as grain and seeds in their form and so they have a very wide range of forms like spherical, ellipsoidal, and diamond with round or sharp-edged. Consequently, the size of the products ranges from below a millimeter to tens of centimeters. The simplified measurement of the three dimensions of the shape: length, width, and thickness, which is frequently used is not enough to accurately describe complex shapes [23]. Therefore, the complex shapes of particles are often used for DEM modelling process by clusters of rigidly joined overlapping spheres known as the multi-sphere method. The contact of multi-sphere particles is described via the contacts between their sub-spheres. Accuracy of the description of mechanical behavior is influenced by the number of particles combined into a cluster [24]. The major advantage of using spheres is the lower computation time in comparison with the real structures. As well as, the non-spherical particles demand more advanced algorithms and are more difficult to model [25]. But the main disadvantage of using spheres is that the flow patterns of the real particle shape cannot be described. Therefore, according to the physical properties of sesame seeds, a triaxial ellipsoidal particle model was established using multiple spheres. To generate an ellipsoidal structure from the spheres, several spheres must be symmetrically connected in a row. However, with an increasing number of particles, the elliptical shape increases, the mechanical time step of a discrete simulation decreases, and the computational time increases. Therefore, to replicate an ellipsoidal sesame seeds and to save computational time, several arrangements and numbers of spheres were checked in the particle flow simulations to find the optimal number of spheres for sesame seeds, which were 12 spheres. To describe the real particle behavior in our numerical model, clumps of 12 joint spheres were formed together. Its semi-axes were 3.3, 2 and 1mm as illustrated in Figure 2. The material properties and interaction properties are the most two substantial categories of material parameters for DEM modelling. Therefor the mechanical properties of the materials (Poisson's ratio, shear modulus, and density) and particle contact parameters (Coefficient of restitution, static friction and rolling friction) used in EDEM simulations are respectively listed in Tables 2 and 3.

EDEM simulation condition

Figure 3 illustrates the component parts used in the simulation, referred to as the oscillating element, a hopper for feeding sesame seeds to the unit, and holes for



F i g. 2. Snapshot of a three-dimensional model for sesame seeds

Table 2

Mechanical properties of the materials used in the EDEM simulation

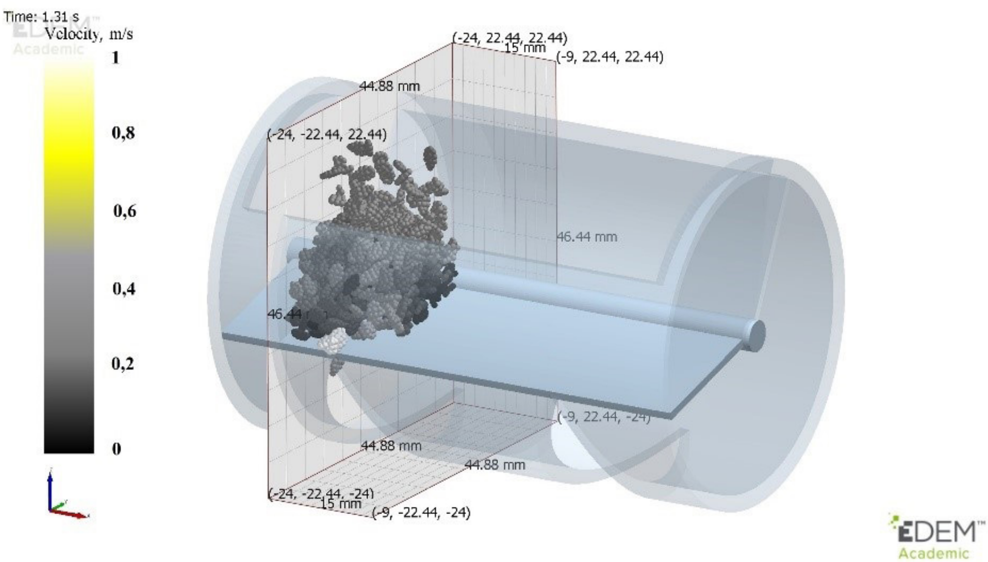
Material properties	Sesame seeds	Steel
Poisson's ratio	0.05	0.303
Shear modulus (Pa)	$1 \cdot 10^7$	$7.93 \cdot 10^{10}$
Density, kg/m^3	850	7 800

Table 3

Interaction parameters used in the EDEM simulation

Contact parameters	Sesame seeds / Sesame seeds	Sesame seeds / Steel
Coefficient of restitution	0.20	0.28
Coefficient of static friction	0.35	0.52
Coefficient of rolling friction	0.10	0.15

output the seeds to soil surface. At the beginning of the calculation, sesame seeds were generated, after filling from the hopper, sesame seeds moving under the effect of oscillation motion by oscillating element. To study the characteristics of the outflow of sesame seeds with time during the simulation, a boundary area with 15 × 44.48 × 46.44 mm was taken in the direction of *X*, *Y*, and *Z* axes respectively for simulation, so that the modelling zone is surrounded by walls from all its faces except in the upper boundary. The angle of displacement magnitude for oscillating seed metering is equal to 17.5 degrees up and down. The method of coloured particles was used for continuous discharge during simulation to detect the different sesame seeds velocities as shown in Figure 3. These parame-



F i g. 3. Snapshot of simulation condition in EDEM ters correspond to the mode of oscillating seed metering unit operation, where its scheme was presented above.

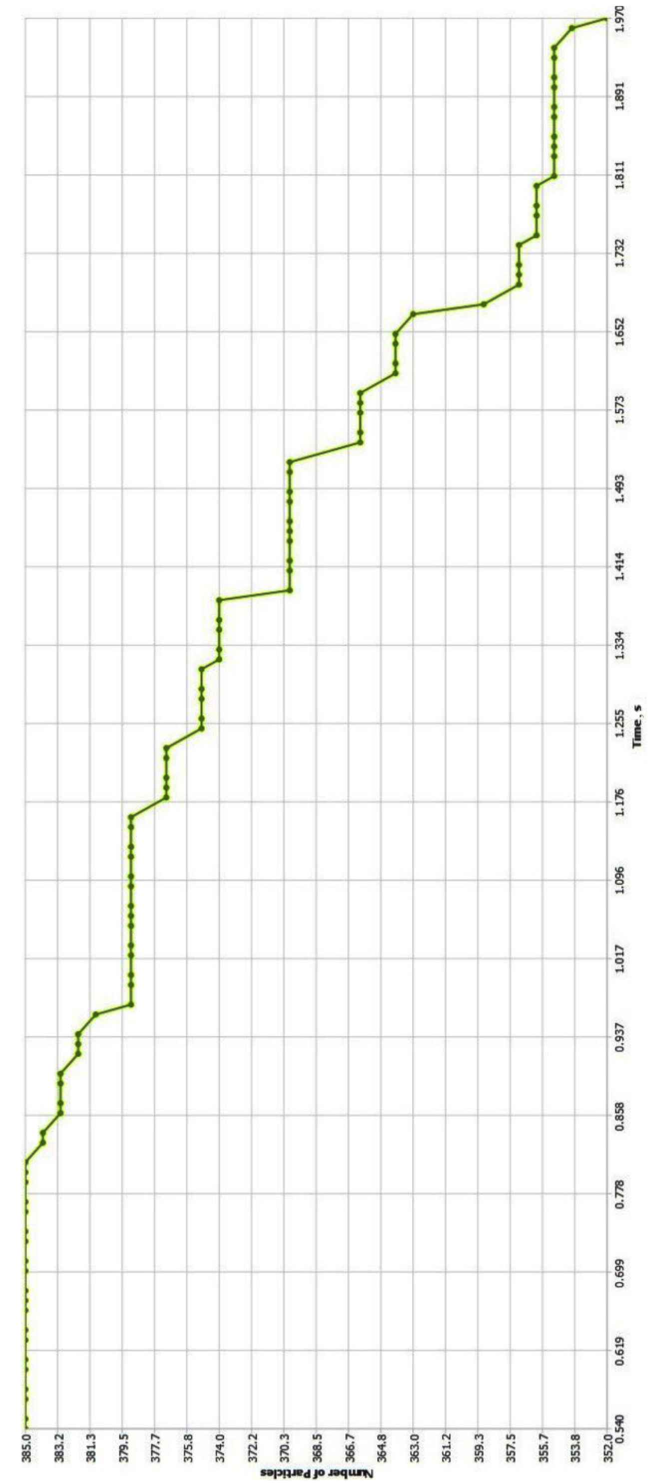
To determine the outflow rate of an equivalent spherical particle having the same volume as the sesame seeds. The sesame seeds were drop and free fall from the hopper under the influence of gravity moves freely into the oscillating seed metering after that the seeds move under oscillation motion with displacement magnitude is 17.5 degrees via an oscillating element with frequency 16 Hz during the modelling process. In addition to parameters that describe the constitutive material of the particles, the simulation time step and number of particles are necessary for the simulation setup. The simulation of the continuous sesame outflow was done using a periodic boundary condition of the geometry. Figure 4 shows the simulation results of continuous sesame seeds discharge in the oscillating seed metering model using DEM simulations. The average flow rate of sesame seeds was about 33 seeds at time 1.43 s with a time step around 0.08 s.

Discussion and Conclusion

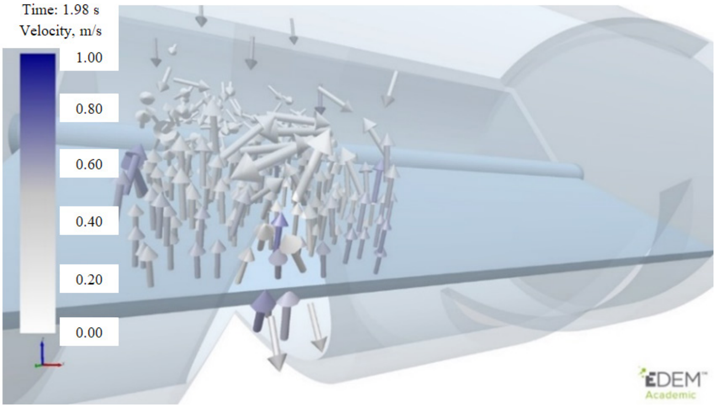
It can be seen that from DEM simulations at the beginning of the modelling process, there are no sesame seeds were coming out of the holes into seed tube for 3 steps and then there was regular outflow of sesame seeds with from oscillating seed metering device at the rate of one seed in the most time but there was also the exit of more than one seed together and sometimes did not come out any seeds, as a result of the seeds moving in different directions after colliding with the oscillating element and not just in the vertical direction as presented in Figure 5. The results obtained illustrate the inconsistency of sesame seeds discharge during the modeling process because the obtained values for the seeds outflow from the device. Which this results in sometimes not coming out any of the sesame seeds from the device or coming out for more than one seed together from the holes at the same time to the soil surface. This observation could be due to the random movement of sesame seeds in several directions after moving by oscillating element used in the model in oscillating seed metering device during the simulation and before dropping into the seed tube.

DEM simulation results for sesame seeds outflow in oscillating seed metering device have shown that the paper thus provides an effective method for prediction the sesame seed outflow as well as the EDM model has been used to better understand seed movement mechanism in an oscillating seed metering unit. This is necessary and important for automatically adjusting the oscillation parameters to enhance the uniform discharge of seeds in seed metering device to solve the problem of determining the grain outflow rate in the design of grain planting machines, and to improve the continuous working performance of an oscillating seeder for precision planting.

Further studies by the authors will look to improve the DEM model by developing the design of the oscillating element and including more input parameters in modelling process in order to control the seed flow rate individually and control the direction of movement of seeds after the collision by oscillating element to give uniformity in seed outflow from oscillating seed metering unit. In addition, creating a mathematical and computational model to simulate the sesame seeds by combining of the obtained particle flow model with adding some improvements in the design of the oscillating element.



F i g. 4. Dependence of particle discharge at the time during the simulation



F i g. 5. A snapshot of velocity and direction of particles motion during the simulation using EDEM in oscillating seed metering unit

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Received 21.11.2019; revised 14.01.2020; published online 30.06.2020
Поступила 21.11.2019; принята к публикации 14.01.2020; опубликована онлайн 30.06.2020

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Заявленный вклад соавторов:

Н. Н. Шараби – анализ теоретических и практических материалов по теме исследования, анализ научных источников по теме исследования, критический анализ и доработка текста; А. А. Дорошенко – научное руководство, математическое моделирование объекта исследования, анализ результатов исследования; А. В. Бутовченко – научное руководство, постановка задачи, определение методологии исследования, критический анализ и доработка решения.

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