Theoretical Study Of A Spading Machine With A Horizontal Arm

Yordan Stoyanov

Technical University - Sofia, Plovdiv Branch,
Department of Transport and Aircraft Equipment and Technologies,
25 Tsanko Diustabanov str.,4000 Plovdiv, Bulgaria

Corresponding Author: yordan.stoyanov@tu-plovdiv.bg

Abstract. The article uses the software product to synthesize the kinematic model of a spading machine with horizontal arm in different operating modes of PTO and working speed at spading machine. Dimensions of the kinematic units are set according to the dimensions of the units of real machines. The trajectory of motion of the working body upon which the size and shape of the soil chips depend is analyzed. The soil chip thickness depends on the operating modes of a spading machine which includes different rotating speed of PTO and different working speed of agricultural tractor also replacement of any part of spading machine with another with different size. The different operating modes definite different parameters of cross-section area of a soil chip.

INTRODUCTION

In our country primary soil tillage is done mainly by turning the surface layer at a depth of about 30 cm and is practically used in growing all filed crops requiring such tillage. For this purpose, mainly ploughshares are used and the operation is carried out after harvesting the previous crop, that is, during the summer-autumn season. Surface treatments preceding sowing are carried out during the spring season [3].

In growing vegetable crops outdoors or in greenhouses intensive methods are used and the time between primary tillage and sowing or transplanting is minimal. In these cases it is preferable to carry out the primary tillage with machines with active working organs to provide a grain-size soil composition suitable for the subsequent operations. The primary tillage with them can be done at elevated soil moisture without distorting the microrelief, which is important if watering is by gravitation. According to Coleman [2], primary tillage machines with active working organs are suitable for organic farming and according to their working principle, they are: with rotary working organs (rotary ploughs) and with reciprocating movement (spading machines). Spading machines virtually imitate manual turning of the soil by using a soil with a spade.

According to some authors [5], the advantages of the spading, i.e. the better residues incorporation and the absence of the soil compacted layer, cannot be easily evaluated, because in this case the crop yield and quality should be checked for a significant time period.

The spading machines models is currently on the market are all based on the connecting rod-crank mechanisms, also called articulated quadrilateral mechanism. This system is based on a bridge (the fixed part faced to the tractor rear side), a rod opposed to the bridge that bears the spade, a crank (crankshaft) and a rocking arm (timing bar) (figure 2). The machine operates the cut of a slice of soil, which is torn off and launched behind the machine, so that it is crumbled [4].

Type of mechanisms of spading machine whit horizontal rod (figure 2) are discussed in detail by many authors [1, 8, 9, 11].

The time needed for cutting the soil chip is determined depending on the constructive parameters and the operating mode of the performing unit [5].

According to some authors, the spading machine [6] with active drive ensure maximum improvement of soil structure by intensive crushing, aeration of the cultivated soil layer and its separation in fractions. In coarse soil aggregates and residues from grown vegetables remain on the surface, preventing soil from claying, drying, wind and water erosion. Provides excellent levelling of the soil surface, a prerequisite for precise execution of subsequent technological operations.

The objective of the present paper is to study a spading machine whit horizontal arm by kinematic model created by a specialized engineering software.

MATERIAL AND METHODS

With software product SAM [10] are synthesis kinematic models of spading machine with horizontal arm and determination of soil chip thickness in operating mode of PTO (Figure 1).

The following unit dimensions were used to draw the mechanism of the spading machine (Figure 2):

- knee length 1 (crankshaft rotation radius) – 0,110 m;
- arm length for mounting the working body 2 – 0,720 m;
- length of working body 3 (spade) – 0,25 m;
- distances between the crankshaft axis and the hinge for mounting the timing bar on the frame points O_1O_2– 0,630 m;
- length of the timing bar 4 – 0,262 m.

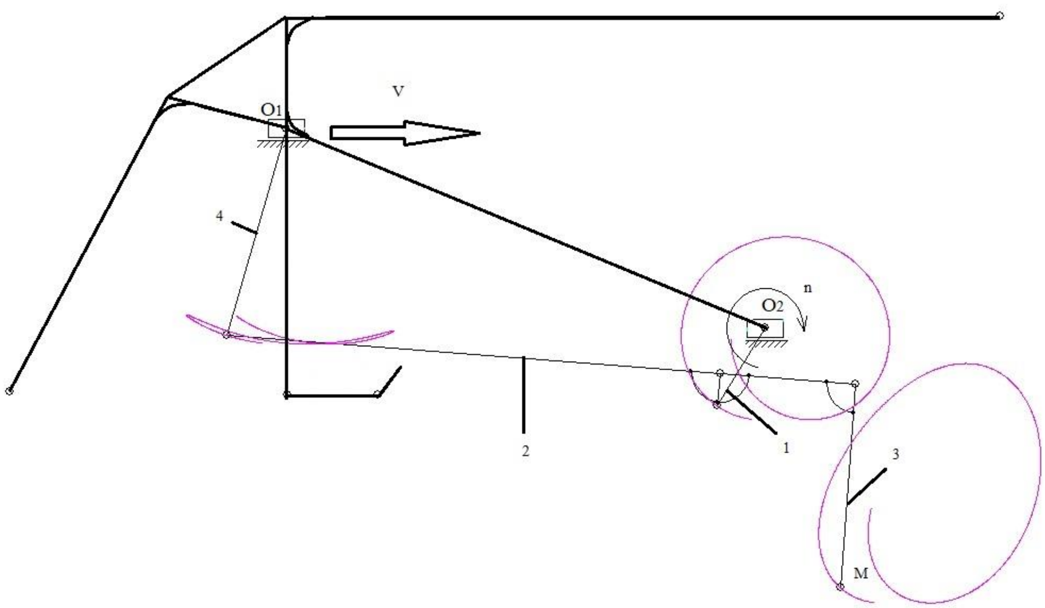

FIGURE 1. Using the software product SAM for synthesizing a kinematic model of a spading machine with horizontal arm: 1 – crankshaft; 2 – arm; 3 – working body (shovel); 4 – timing bar.

It is assumed that the tractor with which the machine is aggregated moves in five gear ratios in gearbox and the changing of engine rotations corresponds to 540 and 1000 PTO depending on the operation mode. Working velocity Vw which takes the following values 0,073 m/s, 0,116 m/s, 0,146 m/s, 0,231 m/s, 0,28 m/s by using tractor creeper range. Creeper range allows very low operating speed of the tractor machine their gear ratios. The spading machines reducer use three gears with gear ratios of individual parts: 5,407, 6,25, 7,407. Depending of operation mode of PTO and corresponding gear of spading machine reducer the soil chip thickness will be different size. The crankshaft velocity of rotation of the machine are 100, 86,4 72,9 min^{-1} for 540 min^{-1} of PTO and 184,9, 160, 135 min^{-1} for 1000 min^{-1} of PTO.

The trajectories of movement of selected points in the machine mechanism have been built, the absolute velocity of the working body and the parameters of the soil chips at operation of the spading machine have been determined.

RESULTS AND DISCUSSION

In diagram present at (Figure 2) of a spading machine with horizontal arm created by using software product. The trajectories of point M of the working body (spade) 3 of the machine are shown. The trajectory of point B is divided into sections at 90° and also correspond to the rotation angle of the machine crankshaft. Accordingly, the absolute velocity at point M of the working body has different meanings at different rotation angle of the machine crankshaft.

Figure 3 is a graphical representation of the variation of the absolute velocity of the M (lower end of the working body) relative to the crankshaft rotation angle. It can be seen that within a small interval of rotation of the machine crankshaft the velocity of point M increases significantly. In this interval the soil is overthrown by the working body, and therefore higher velocity, respectively greater kinetic energy of the overthrown layer is needed in order to obtain better fragmentation of the soil.

The values of the trajectory and the absolute velocity of point M of the working body of the machine are shown in Table 1. It shows that the total length of the road traversed by point M of the working body of the machine does not change and is about 1 m per revolution of the crankshaft. The absolute velocity of the working body increases with an increase in PTOS rotation frequency to 1,31 m/s at 540 min^{-1}. The absolute velocity of the working body reaches its maximum in the range between 90º and 135º of the crankshaft rotation.

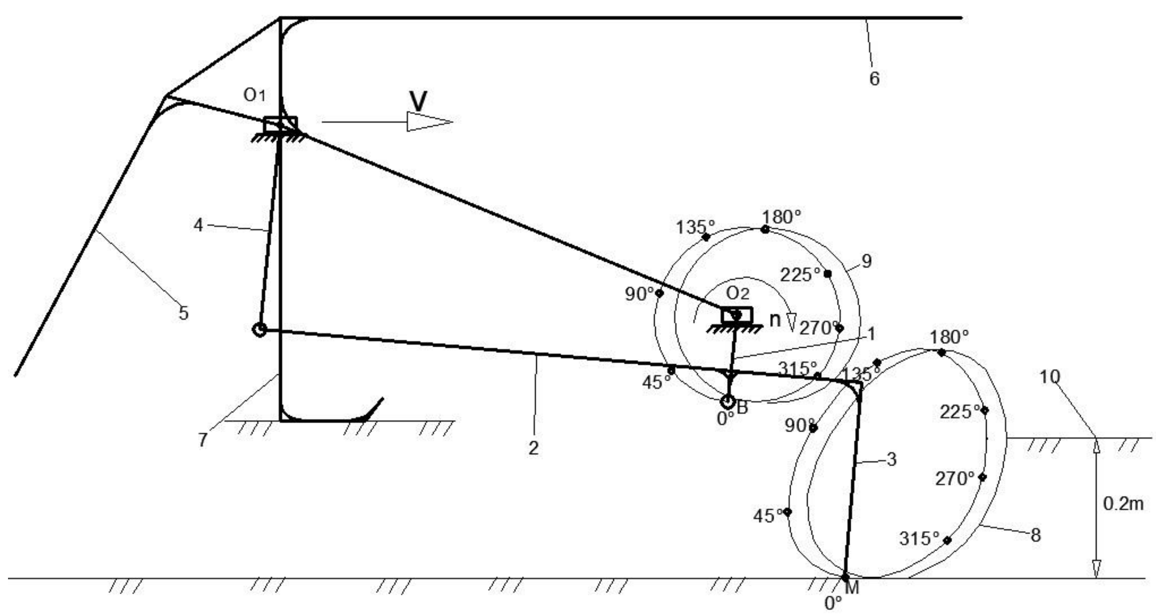

FIGURE 2. Diagram of a spading machine with horizontal arm:
1 – crankshaft; 2 – arm; 3 – working body (shovel); 4 – timing bar; 5 – deflector cap; 6 – deflector cap; 7 – sliders; 10 – soil layer; 8 – trajectory of movement of point M of the working body (the shovel); 9 – trajectory of movement of point B of the crankshaft.

Figure 4 is a graphical representation of the variation of the path of the M (lower end of the working body) relative to the crankshaft rotation angle. In one full rotation of the crankshaft of a spading machine the passed path is almost 0,8 m. The values of the path will be different in another operating mode.

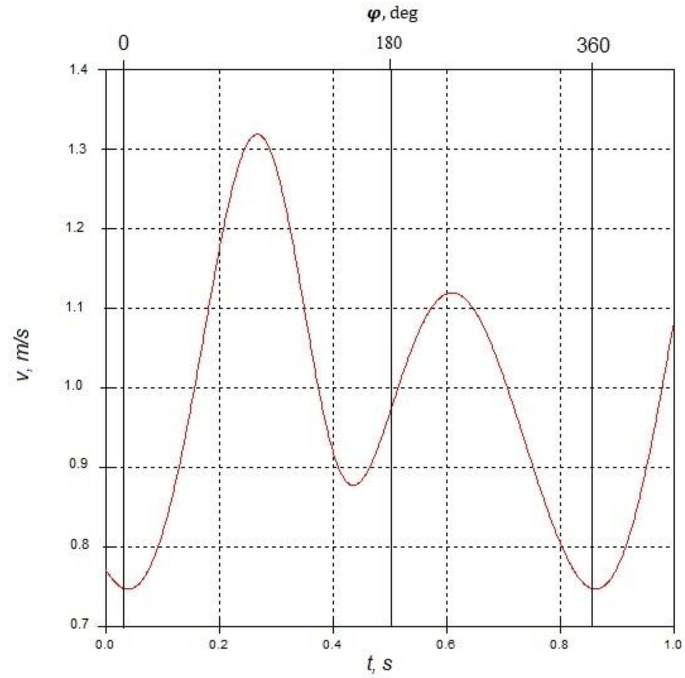

FIGURE 3. Diagrams for absolute velocity V at point M in the mechanism of the spading machine according to the angle φ of rotation of the machine crankshaft

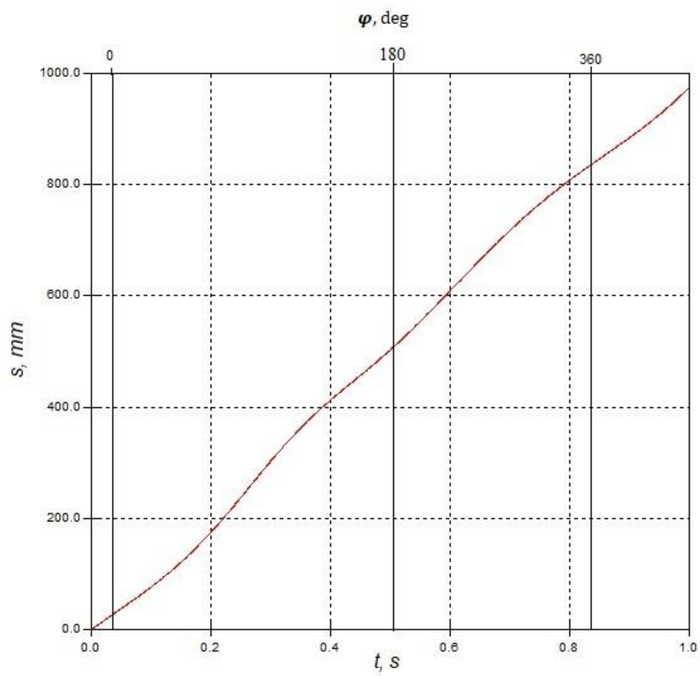

FIGURE 4. Diagrams for passed path at point M in the mechanism of the spading machine according to the angle φ of rotation of the machine crankshaft

The trajectory covered by point M on the spade on the vertical plain OXY (Figure 5) can be divided depending on the process carried out by the spade into the following sections:

- A – B – inserting the spade into the soil;
- B – C – overthrowing the soil;

- C – D – moving the spade for the next insertion.

The soil chip is the area surrounded by points ADOB. It can be seen that it has almost Rectangular cross section. The thickness of the chip is equal to the distance between points A and D, which is the step of the working body. In individual sections, the absolute velocity value changes as follows: when the spade penetrates into the soil it is the lowest; when the soil aggregates are dropped off the spade, the speed reaches its maximum; when shifting the spade for subsequent penetration into the soil, the speed is slightly higher than that at insertion.

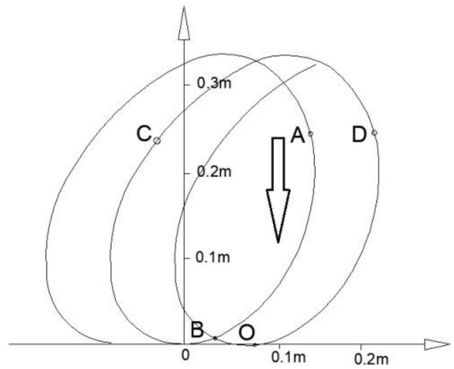

FIGURE 5. Trajectory of point M on the working body of the spading machine with horizontal arm.

The soil chip thickness is calculates by the expression (1) and values are shown in Table 2. By using tractors creeper gears and transmissions reductor ratios and their multiplied ranges are obtained many soil chip thickness values.

TABLE 1. Values of absolute velocities and the distance covered by point M of the spade depending on the crankshaft rotation angle of the machine

Crankshaft rotation angle, °	**Absolute velocity V, m/s**
At rotation frequency of PTOS n = 540 min-1	
45	1,0
90	1,31
135	1,2
180	0,88
225	0,95
270	1,1
315	0,97
360	0,75
Max	1,32
Min	0,75

At the accepted operating parameters it is 0.60 m. The step of the machine is determined analytically by the expression

$$\boldsymbol{X} = \frac{\boldsymbol{60.V_w.i}}{\boldsymbol{n}}, \boldsymbol{m}, \quad (1)$$

where *Vw* is the progressive speed of the machine, *m/s*;

i – the transmission ratio of the reductor of the spading machine. $i_1 = 5{,}407$, $i_2 = 6{,}25$, $i_3 = 7{,}407$;

n - rotation speed of the tractor power take-off shaft, *min*$^{-1}$

TABLE 2. Values of different size of soil chip thickness depends of different operation modes of PTO and working speed.

n(PTO), min^{-1} / n(engine), min^{-1}			540 / 1944			
Tractor creeper gear	I	II	III	IV	V	
$V_W, m/s$	0,073	0,116	0,146	0,231	0,28	
X, m	0,043857	0,06969	0,087714	0,13878	0,168218	i_1
X, m	0,050694	0,080556	0,101389	0,160417	0,194444	i_2
X, m	0,060079	0,095468	0,120158	0,190113	0,23044	i_3
n(PTO), min^{-1} / n(engine), min^{-1}			1000 / 1954			
X, m	0,023683	0,037633	0,047365	0,074941	0,090838	i_1
X, m	0,027375	0,0435	0,05475	0,086625	0,105	i_2
X, m	0,032443	0,051553	0,064885	0,102661	0,124438	i_3

CONCLUSION

An analysis of the kinematics of a spading machine with horizontal arm and the soil chip thickness has been made by using a specialized engineering software. It has been found out that the speed of the working body varies considerably depending on the rotation angle of the machine crankshaft. The trajectory of the working body and the shape of the soil chip shredded by it is determined.

ACKNOWLEDGMENTS

The authors would like to thank the Research and Development Sector at the Technical University of Sofia for the financial support.

REFERENCES

1. A. Ambekar. Mechanisms and machine theory. ISBN-978-81-203-3134-1, 2007. Prentice-Hall of India.
2. E. Coleman. The New Organic Grower, 1995. Chelsea Green, White River Jct., VT.
3. N. Delchev and K. Trendafilov, Y. Stoyanov. Study of the kinematics of a spading machine by using engineering software. ARTTE Vol. 5, No. 4, ISSN 1314-8788 (print), 2017, ISSN 1314-8796 (online), doi: 10.15547/artte.2017.04.001.
4. D. M. Giordano and D. Facchinetti and D. Pessina. The spading machine as an alternative to the plough for the primary tillage, Journal of Agricultural Engineering, 2015, volume XLVI: 445.
5. D. Guglev. THEORETICAL RESEARCH ON A VERTICAL ROTARY SOIL TILLAGE UNIT. Agricultural sciences, Plovdiv, 2009, volume I, issue 2, ISSN 1313 – 6577.
6. D. Guglev. Defining the critical kinematic parameters of rotary harrow with vertical axis of rotation**.** AGRICULTURAL SCIENCE AND TECHNOLOGY, VOL. 3, No 3, 2011, pp 237 – 239.
7. N. Kachinsky. Physics of the Soil. Part 1, 1st ed., High School, Moscow, 1965, p. 323 (Ru).
8. M. Kolovsky. Advanced Theory of Mechanisms and Machines. ISBN 978-3-642-53672-4. 2000, DOI 10.1007/978-3-540-46516-4.
9. A. Mata. Fundamentals of Machine Theory and Mechanisms. ISBN 978-3-319-31968-1, 2016, DOI 10.1007/978-3-319-31970-4. Springer International Publishing Switzerland.
10. SAM Mechanism design by Artas Engineering Software [Online]. Available: http://www.artas.n0l [2017-12-18].
11. G. Sandor. Advanced mechanism design: Analysis and Synthesis. ISBN 0-13-572396-5. 1984, Prentice-Hall, Inc., Englewood cliffs, New Jersey 07632.
12. I. Tenu and P. Carlescu and P. Cojocariu and R. Rosca. Impact of agricultural traffic and tillage technologies on the properties of soil. Resource Management for Sustainable Agriculture Vikas Abrol and Peeyush Sharma, 2012, http://dx.doi.org/10.5772/47746.