Scientific Journal of Silesian University of Technology. Series Transport
Zeszyty Naukowe Politechniki Śląskiej. Seria Transport

Volume 105 **2019**

p-ISSN: 0209-3324

e-ISSN: 2450-1549

DOI: https://doi.org/10.20858/sjsutst.2019.105.17

Journal homepage: http://sjsutst.polsl.pl

Article citation information:
Škrabala, J., Hajdučík, A., Medvecký, Š., Brumerčík, F. Optimalisation of the blade movement of the mower. *Scientific Journal of Silesian University of Technology. Series Transport*. 2019, **105**, 213-222. ISSN: 0209-3324.
DOI: https://doi.org/10.20858/sjsutst.2019.105.17.

Jozef ŠKRABALA[1], Adrián HAJDUČÍK[2], Štefan MEDVECKÝ[3], František BRUMERČÍK[4]

OPTIMALISATION OF THE BLADE MOVEMENT OF THE MOWER

Summary. This article presents the correct adjustment of the mower's blade movement relative to the forward movement of the mower. Everywhere around us are gardens, parks and meadow, which gives us reason to solve issues with mowing. The first part of this article shows agricultural machines, which are used today and the principle of correct cut of grass stalks. The next part shows the method of adjusting the mower's blade speed. Design of a simple model was done with the use of Solid Edge Premium CAD. For computation, MSC Adams was used and post-processing was done with the use of Matlab. The connection between MSC Adams and Matlab was created by co-simulation.
Keywords: mower's blade, mowing, movement, kinematics

[1] Faculty of Mechanical Engineering, University of Žilina, Univerzitná 1 Street, 010 26 Žilina, Slovakia. Email: jozef.skrabala@fstroj.uniza.sk
[2] Faculty of Mechanical Engineering, University of Žilina, Univerzitná 1 Street, 010 26 Žilina, Slovakia. Email: adrian.hajducik@fstroj.uniza.sk
[3] Faculty of Mechanical Engineering, University of Žilina, Univerzitná 1 Street, 010 26 Žilina, Slovakia. Email: stefan.medvecky@fstroj.uniza.sk
[4] Faculty of Mechanical Engineering, University of Žilina, Univerzitná 1 Street, 010 26 Žilina, Slovakia. Email: frantisek.brumercik@fstroj.uniza.sk

1. INTRODUCTION

Everywhere around us are grassy places, which give us the idea to design special mountain mower with respect to the quality of cut. This mower is intended to mow private gardens, city parks, grass fields and hardly accessible areas. Nowadays, there are so many types of mowers, which are intended for various areas of mowing. Nevertheless, users will not avoid using their combination. Furthermore, the right type of mowing machine has to be chosen for a given area. The main reason mountain mower can replace multiple machines is that the construction is adapted for unfavourable conditions, and uses autonomous control, which increases access for limited terrain. Also, this mower is designed for the highest possible quality of cut, with which the blade's design is directly related. To achieve these assumptions, it is necessary to determine the correct blade's teeth geometry [12, 13, 16]. Thereafter, it is necessary to determine the speed of the blade relative to the mower's movement for proper and healthy cutting [3-6].

2. MOWER MACHINES

Generally, mower machines are special agricultural machines for mowing plants. Mowers developed with the evolution of humanity. Gradually, mowers evolved from hand scythes, through a horse-drawn mower to today's types. Today, there are many types of mower designed to mow different lands. The most common types are:

- hand mower:
  - scythe,
  - sickle,
  - manual mower,
- petrol and electric mower:
  - rotary mower,
  - drum mower,
  - string trimmer,
  - brush cutter,
- tractor mower.

To better understand the problem, two groups of mowers have been created with respect to the type of mowing:

- rotary mower:
  - horizontal,
  - vertical,
- reciprocating bar mower:
  - cutting without support,
  - cutting with support.

2.1. Rotary mower

Typical mower of this group is the gasoline rotary mower, which is shown in Fig. 1. Their great advantage is the possibility to attach a basket that could also harvest the leaves. The cutting height is usually adjustable from 3.5 to 5 cm. The right choice of rotary mower depends on the frequency of mowing, size of the area and demands of the operator. For example, depending on the size of the mowed area, the right blade size has to be chosen (blade size 32 cm –up to 200 m^2, 40 cm – up to 350 m^2, 45cm – up to 500 m^2, 53cm – up to 1000 m^2 and longer – over 1000 m^2). There are many types of blades, but the quality of the cut is mainly influenced by their sharpening. The cut of the stalk by a rotary mower is characterised as a cut without support [11, 17].

Fig. 1. Rotary mower [15]

2.2. Reciprocating bar mower

The reciprocating bar mower is marked with sickle bars. This type of mower is a very special type of agricultural machine, which is shown in Fig. 2. Sickle bar mowers are divided into two groups:

- sickle bar with support (Fig. 3a),
- sickle bar without support (Fig. 3b).

Fig. 2. Sickle bar mower [15]

The cut without support is characterised by a very high blade speed, which often exceeds 30 $m.s^{-1}$. This type of cut is executed by stalk tearing, which adversely affects the health of the plant. Schematic illustration of the blade without support is shown in Fig. 3a), where position 1 stands for the blade.

On the contrary, the cut with support has little demands on the speed of the blades. The cut occurs already at the velocity of 2 $m.s^{-1}$ and it could be compared to stalk shearing. Fig. 3b shows the blade (position 1) and the support (position 2) [1, 2].

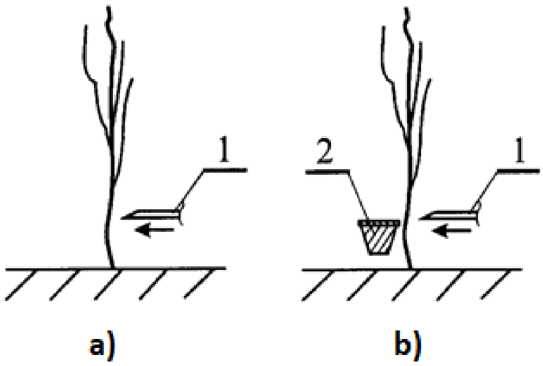


Fig. 3. Types of cutting: a) without support b) with support

3. SOLUTION OF KINEMATICS OF MOWER BLADES

The solution of the kinematics of mower blades is done via the kinematic analysis of blades movement relative to the forward movement of sickle bar mower [18]. In this case, there is a double stroke bar considered – a reciprocating movement of both bars [12].

3.1. Modelling mower and its parts

A simple model was created in CAD software [7, 10], which is shown in Fig. 4. The simplifications will not affect the results, because they are not related to machine kinematics. They also have a positive impact on the complexity of the mathematical model and thus accelerate the computational time.

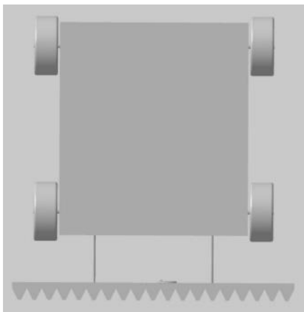


Fig. 4. Simplified model of the mower

The next step was to import the CAD model into the MSC.Adams software, where all parts have been modelled (Fig. 5).

By defining the relations between the parts, we used the fixed joint, translational joint and revolute joint connections. Additionally, we used two types of motions: rotational and translational motion and a driving motor [8, 9].

Fixed joint is used on the ground because it has zero degrees of freedom (DOF). Revolute joint is created between two parts and it is related to one axis. This connection is used to define the wheels and rotational parts of the crank mechanism. Translational joint is created between two parts with defined direction. This joint is used between the ground and the vehicle body and also between the body and the bars [19].

The contact is defined between the wheels and the ground. Also used is the Coulomb friction model to prevent the wheels from slipping.

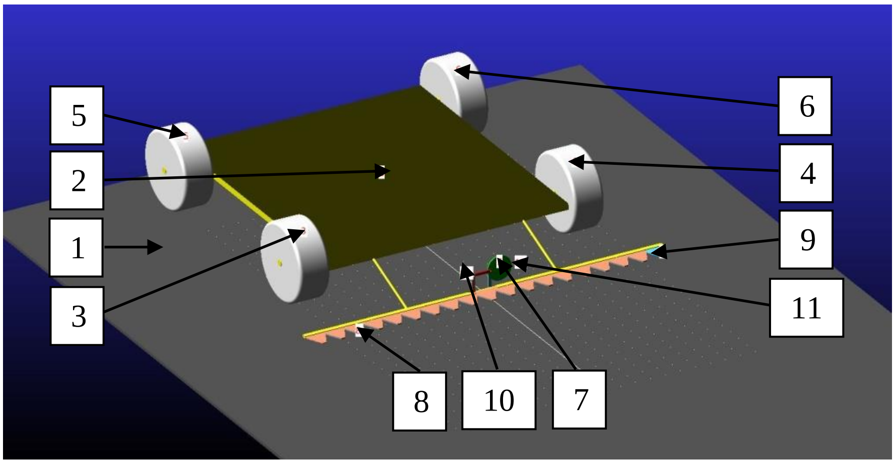


Fig. 5. Parts of the mower:
1 – ground; 2 - body of the vehicle; 3 - right front wheel; 4 - left front wheel;
5 - rear right wheel; 6 - rear left wheel; 7 - drive rail; 8 - upper bar; 9 - bottom bar;
10 - top handlebar; 11 - lower handlebar

3.2. The principle of mower tracking

To illustrate the paths of each blade (the top and bottom bars), it is necessary to create the points (markers), which will be monitored. These points will be used for kinematic analysis in MATLAB [14, 15]. Fig. 6 illustrates individual markers on the top sickle bar (points A to G). The markers were created also on the second bar – Fig. 7.

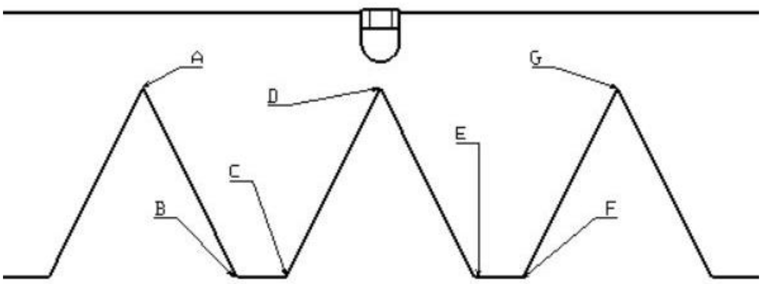


Fig. 6. Markers of the top sickle bar (A – G)

3.3. Mathematical model

First step of the solution was to make a simple mathematical model of the solved problem. The reciprocating movement of the blades is solved as a simple crank mechanism (Fig. 8).

For the solution of this mechanism, the vector method is used. It is one loop multi-element case, where the rotational movement is transformed into the translational movement. The computation of basic parameters of the crank mechanism follows according to Fig. 9.

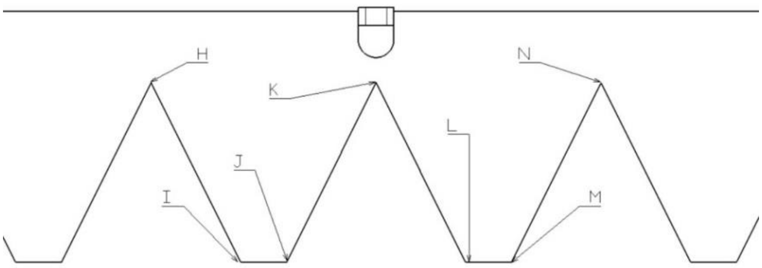


Fig. 7. Markers of the lower sickle bar (H – N)

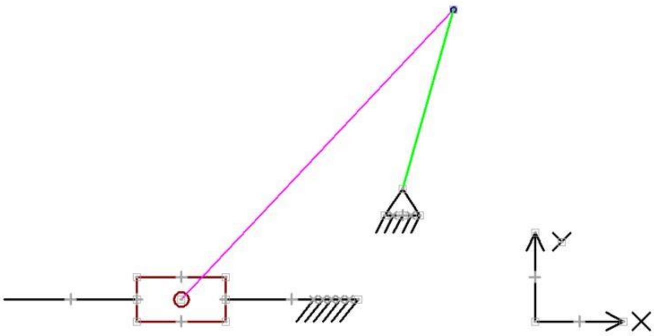


Fig. 8. Schematic drawing of a crank mechanism

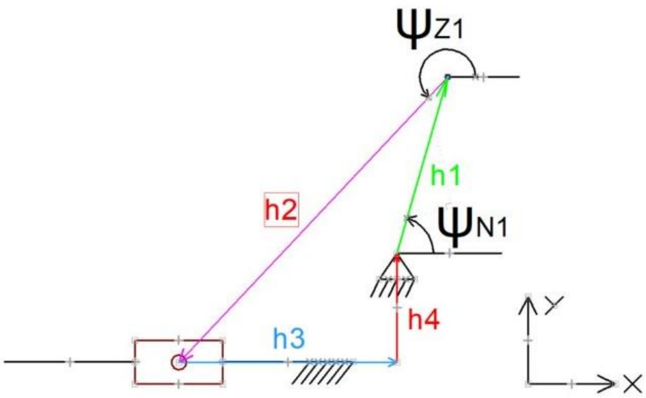


Fig. 9. Block scheme for computation of the crank mechanism

The number of kinematic loops can be calculated as:

$$k = s - u + 1 = 1. \tag{1}$$

The kinematic loops equations are defined as:

$$\vec{h}_1 + \vec{h}_2 + \vec{h}_3 + \vec{h}_4 = \vec{0}. \tag{2}$$

$$\text{x axis: } h_1 \cos\psi_{N1} + h_2 \cos\psi_{Z1} + h_3 = 0, \tag{3}$$

$$\text{y axis:. } h_1 \sin\psi_{N1} + h_2 \sin\psi_{Z1} + h_4 = 0 \tag{4}$$

3.4. Co-simulation and data processing

MATLAB Simulink is used for co-simulation with MSC Adams, because there are more opportunities to analyse the received data. First step was to choose input and output signals, which will be exported to MATLAB. As the input signals, the velocity of the mower and the angular velocity of the crank mechanism were determined. The paths of all markers were the output signals. After exporting procedure, a Simulink program was generated. This program was represented by a simple block diagram, which is shown in Fig. 10.

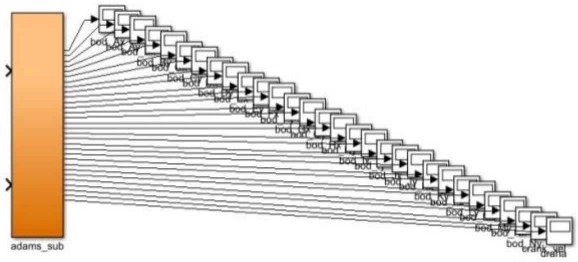


Fig. 10. Simulink generated scheme

Subsequently, the scheme was copied into the new program, where the inputs (velocity of the mower and angular velocity of crank mechanism) are set. The outputs were the observed point's positions and the control speed of the crank mechanism. After the calculation procedure, all data were exported to the Simulink workspace, where they were stored as vectors.

After running the simulation, all data were started to process and analyse the issue of the lawn mowing quality. The starting point's vectors are created to display the geometry of the bars on the graph – top bar with red colour and the lower bar with blue colour (Fig. 11). According to the definition of the slider vectors of the individual points, the paths of the knife blades acting on the given movements are plotted on the graph. After the paths of the individual points rendering, the passed areas were coloured. There could be seen in places of the bends of the stalk, the places of the cutting of the stalk and the places with the uncut grass blades remained.

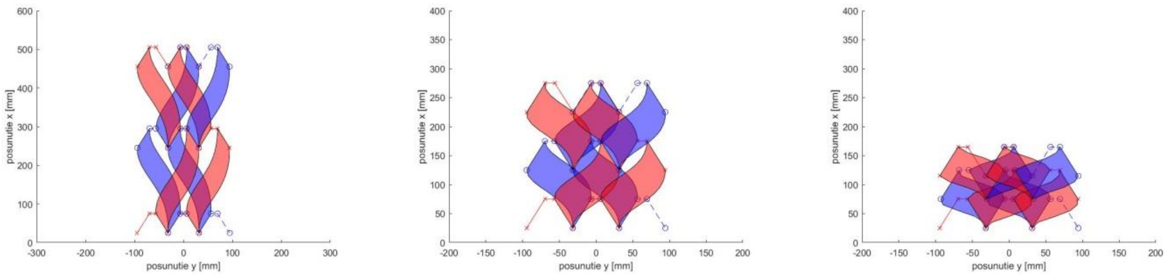
4. RESULTS AND DISCUSSION

Depending on the setting of the crank mechanism, speeds relative to the forward motion of the mower can occur in these three situations after analysis [18]:

- right cut of the plants (Fig. 11a),
- bending of the plants (Fig. 11b),
- skipping of the uncut plants (Fig. 11c).

The last type of mowing is the worst. There are usually unmowed places because the trajectory of blade's shapes does not cover the entire mowed area. This case occurs when the angular velocity of the crank mechanism is low relative to the mower motion.

When the stalks are bent, that is a case of high crank speed. This state is energetically unfavourable. This requires passing the same trajectory more times by mowing.



a) b) c)

Fig. 11. Blade movement:a) Right mowing; b) Bending of stalks; c) Unmowed places

When the right cut occurs, the energetic demands are optimal and the stalks damages are minimal. Optimal speeds based on the performed analysis are shown in Tab. 1.

Tab. 1

Optimal angular velocity of crank mechanism relative to mower movement

Mower speed ($m.s^{-1}$)	Crank speed (min^{-1})
1	850
1,5	1100
2	1350

The kinematic analysis in MSC Adams demonstrates the possibilities of solving complex tasks of mutual motion. The results of the solution were verified on the second prototype of mountain mower (MM2). All performed tests were successful.

Acknowledgement

The research is supported by the Cultural and Educational Grant Agency of the Ministry of Education, Science, Research and Sport of the Slovak Republic under project No. 046ŽU-4/2018.

References

1. Caban J., P. Drozdziel, J. Vrábel, B. Šarkan, A. Marczuk, L. Krzywonos, I. Rybicka. 2016. „The research on ageing of glycol-based brake fluids of vehicles in operation". *Advances in Science and Technology* 10(32): 9-16.
2. Caban J., A. Marczuk, B. Šarkan, J. Vrábel. 2015. „Studies on operational wear of glycol-based brake fluid". *Przemysł Chemiczny* 94(10): 1802-1806.
3. Czech Piotr. 2012. „Determination of the course of pressure in an internal combustion engine cylinder with the use of vibration effects and radial basis function - preliminary research". Communications in Computer and Information Science 329: 175-182. DOI https://doi.org/10.1007/978-3-642-34050-5_21. Springer, Berlin, Heidelberg. ISBN:978-3-642-34049-9. ISSN: 1865-0929. In: Mikulski Jerzy (eds), Telematics in the transport environment, 12th International Conference on Transport Systems Telematics, Katowice Ustron, Poland, October 10-13, 2012.

4. Czech Piotr. 2011. „Diagnosing of disturbances in the ignition system by vibroacoustic signals and radial basis function - preliminary research”. Communications in Computer and Information Science 239: 110-117. DOI https://doi.org/10.1007/978-3-642-24660-9_13. Springer, Berlin, Heidelberg. ISBN:978-3-642-24659-3. ISSN: 1865-0929. In: Mikulski Jerzy (eds), Modern transport telematics, 11th International Conference on Transport Systems Telematics, Katowice Ustron, Poland, October 19-22, 2011.
5. Faturík Lukáš, Libor Trško, Slavomír Hrček, Otakar Bokuvka. 2014. „Comparison of structural design in high and ultra-high cycle fatigue regions”. *Transactions of FAMENA* 38(4): 1-12. ISSN 1333-1124.
6. Figlus Tomasz, Mateusz Koziol. 2016. „Diagnosis of early-stage damage to polymer - glass fibre composites using non-contact measurement of vibration signals”. *Journal of Mechanical Science and Technology* 30(8): 3567-3576. ISSN 1738-494X. DOI: 10.1007/s12206-016-0717-1.
7. Gąska Damian, Tomasz Haniszewski. 2016. “Modelling studies on the use of aluminium alloys in lightweight load-carrying crane structures”. *Transport Problems* 11(3): 13-20. DOI: 10.20858/tp.2016.11.3.2. ISSN: 1896-0596.
8. Glowacz Adam, Zygfryd Glowacz. 2017. „Diagnosis of the three-phase induction motor using thermal imaging”. *Infrared physics & technology* 81: 7-16. ISSN 1350-4495. DOI: 10.1016/j.infrared.2016.12.003.
9. Glowacz Adam, Zygfryd Glowacz. 2017. „Diagnosis of stator faults of the single-phase induction motor using acoustic signals”. *Applied acoustic* 117A: 20-27. ISSN 0003-682X. DOI: DOI: 10.1016/j.apacoust.2016.10.012.
10. Haniszewski Tomasz, Damian Gaska. 2017. “Numerical modelling of I-Beam jib crane with local stresses in wheel supporting flanges - influence of hoisting speed”. *Nase More* 64(1): 7-13. DOI: 10.17818/NM/2017/1.2. ISSN: 0469-6255.
11. Kai-Sheng Wang, Chen-Kang Huang. 2018. “Intelligent Robotic Lawn Mower Design”. *International Conference on System Science and Engineering (ICSSE).* DOI: 10.1109/ICSSE.2018.8520053.
12. Kohár Róbert, Slavomír Hrček. 2014. „Dynamic Analysis of a Rolling Bearing Cage with Respect to the Elastic Properties of the Cage for the Axial and Radial Load Cases”. *Communications – Scientific Letters of the University of Zilina* 16(3A): 74-81. ISSN 1335-4205.
13. Koziol Mateusz, Tomasz Figlus. 2017. „Evaluation of the Failure Progress in the Static Bending of GFRP Laminates Reinforced With a Classic Plain-Woven Fabric and a 3D Fabric, by Means of the Vibrations Analysis”. *Polymer composites* 38(6): 1070-1085.
14. Rudecki M., O. Kildisheva. 2013. „A modified sickle bar mower: increased flexibility for harvesting native plant seeds”. *Native Plants Journal* 14(3): 257-260. DOI: 10.3368/npj.14.3.257.
15. Siregar Ikhsan, Anggi Ridho, Dinda Gustia, Agung Triono, Yulia Shafira. 2018. “Product design of a lawn mower tool for agriculture”. *Conference Series Materials Science and Engineering* 420(1): 1-11. DOI: 10.1088/1757-899X/420/1/012140.
16. Skrúcaný Tomáš, Branislav Šarkan, Tomasz Figlus, et al. 2017. „Measuring of noise emitted by moving vehicles”. *MATEC Web of Conferences* 107: 00072. ISBN: 978-1-5108-4114-7. DOI: https://doi.org/10.1051/matecconf/201710700072.
17. Škrabala Jozef. 2018. „Design of the remote controlled mower“. Diploma thesis, Bratislava: Slovak University of Technology in Bratislava.

18. Škrabala Jozef, Adrián Hajdučík, Štefan Medvecký. 2019. "Optimization of mower blades movement considering to mower´s motion". *Novus Scientia.* Proceedings of XVI. International Scientific Conference of PhD students of engineering faculties of technical universities and universities. Košice: Technical University of Košice. ISBN 978-80-553-3249-9.
19. Thomas D.G. 1992. *Fundamentals of Vehicle Dynamics*. Society of Automotive Engineers. 495 p. ISBN 1560911999.

Received 07.09.2019; accepted in revised form 26.11.2019