Advances in Engineering, volume 126
5th International Conference on Machinery, Materials and Computing Technology (ICMMCT 2017)

Bionic Moldboard Surface Combination of Mathematical Modeling and Optimization Design

Tao Luo[1,a], Zhuoshi Li[2,b *], Na Wang[3,c] and Lizong Cao[4]
[1,2,3,4] Jilin Agricultural University, Changchun, Jilin,130118, China
[a]leezs643@sina.com, [b]lzs036@163.com,[c]499360221@qq.com

Keywords: mathematical modeling; bilevel programming; bionic; moldboard

Abstract. According to the characteristics of geometric and non - smooth surface of soil fauna, we improved the mathematical model of the existing bionic moldboard,and constructed the optimization model of combined convex hull and corrugated bionic moldboard. In this paper, the convex hull of the mantis and the corrugations of the sheath wings are combined and modeled to obtain the bimodal model of the combined bionic moldboard. It is found that this combination optimization model has better effect of reducing viscosity and reducing resistance.

Introduction

Since the 1980s,the people have studied on desorption dunction and reducing mechanism of soil animals which living in soil from the Perspective of Engineering Bionics.It is found that the typical soil animal body surface and the soil-bearing parts have the anti-stick and soil structure,such as pangolins,mounds,ants and earthworms[2].The non-smooth surface structure can effectively achieve the effect of anti-sticking soil.Based on a large number of experimental research,the mathematical model of biomimetic bulldozer is obtained.So that the performance of the release of soil moldboard off the soil in-depth studying.

This paper is based on bionics and most of the existing bionic model.The combination of corrugated bionic bulldozers and convex hull bionic moldboards is optimized and set their own advantages.In order to achieve the ability to enhance the viscosity reduction resistance and reduce energy consumption.The main purpose is to improve the overall effect of bionic moldboards,thereby improving the efficiency of the work of the bulldozers[1-3].

Fundamentals and assumptions

1) Basic principles

In the existing soil adhesion theory,the contact area between soil and soil and fire parts is one of the important factors affecting soil adhesion.The friction of the soil to non-smooth surfaces conforms to the Coulomb formula[4],

$$F = CA + P\tan\theta \tag{1}$$

Where F is the frictional resistance, C for soil cohesion, A the contact area between the soil and the earth parts, P the positive pressure on the surface of the soil, θ for the soil friction angle.

2) Basic assumptions

3) Calculation Formula of Soil Pressure Depth

In order to evaluate the performance of the ground vehicle, the following load and subsidence relationship is proposed for the homogeneous soil:

$$p = \left(\frac{k_c}{d} + k_\phi\right)z^n \tag{2}$$

Where n is the deformation index, d is the length of the short side of the load surface, p is the unit area load, k_c and k_ϕ are the cohesive deformation modulus and the friction deformation modulus, respectively, z is the depth of subsidence.

$$h = 100\left(\frac{p}{100k_c / b} + k_\phi\right)^{\frac{1}{\mu}} \quad (3)$$

Where p is the bearing capacity of the board on a unit area, μ is the deformation index, k_c is the cohesive deformation modulus of the soil, k_ϕ is the internal friction deformation modulus of soil, b (cm) is the width of the bionic bulldozer, h (cm) is the soil pressure depth[5].

Establishment of Bionic Moldboard Combination Optimization Model

According to the observation and statistical analysis of the non - smooth surface of typical soil animals and the bionic analogy of the geometrically non - smooth surface morphology of the corrugated. a, b, l is given a positive number,Where a, b are the height and width of the bulldozer respectively, l is the length of the front part of the bulldozer.The units are cm.

(1)Dung beetle bionic bulldozing plate surface mathematical description of the formula

$$z_r = \begin{cases} T(x - kU),\ kU \le x \le kU + \dfrac{U}{\sqrt{T^2 + 1}},\ and 0 \le x \le nU, 0 \le y \le b \\ \sqrt{U^2 - (x - kU)^2},\ kU + \dfrac{U}{\sqrt{T^2 + 1}} \le x \le U + kU and 0 \le x \le nU, 0 \le y \le b \\ 0, -l \le x \le 0,\ nU \le x \le a, 0 \le y \le b \end{cases}$$

Where $T > 0$ - parameters related to crest height; $U > 0$ - parameters of the distance between adjacent peaks; $k = 0,1,\cdots,n-1$ Is an integer; $n = [a/U]$ (Rounding) the number of parameters for the ripple.

(2)Mathematics dung beetle head bionic bulldozing plate surface described formula

$$z_c = \begin{cases} U\sqrt{\dfrac{1 - (x - 0.6(4k + 1)T)^2}{0.36T^2} - \dfrac{(y - 0.6(4s + 1)T)^2}{0.36T^2}}, \\ (x, y) \in D and x \in [0, 0.6(4m - 2)T],\ y \in [0, 0.6(4n - 2)T], \\ 0, (x, y) \notin D and x \in [0, a],\ y \in [0, b], \\ 0,\ x \in [-l, 0],\ y \in [0, b], \end{cases}$$

Where $T > 0$ - and the convex hull define the radius of the projection plane; $U > 0$ - the height of the convex hull;

(3) Bionic moldboard and soil contact area

In order to optimize the model of bionic moldboard surface.We use the formula for calculating the surface area of the surface

$$S = \iint_D \sqrt{1 + z_x^2 + z_y^2}\, dxdy$$

Where z - the surface surface of the surface expression; D - the requested surface in the projection area of the xoy-plane.The expression of the contact area between the bionic moldboard and the soil is obtained.

We only consider the case of at least one of the corrugations and convex hulls. We assume that the lower half of the bulldozing plane is the convex part of the corrugated upper part.The contact area between the combined bionic moldboard and the soil is as follows:

(1) The lower half of the soil parts of the corrugated bionic bulldozer area

$$S_r(T,U) = S_0 + n(S_1+S_2) + (S_3 - S_1) + (S_4 - S_2) + S_5$$
$$= lb + (n-1)\left[(x_2 - x_1)b\sqrt{1+T^2} + bU(\arcsin(\frac{x_3}{U}) - \arcsin(\frac{x_2}{U}))\right]$$
$$+ bx_2\sqrt{1+T^2} + bU(\arcsin(\frac{x_4}{U}) - \arcsin(\frac{x_2}{U})) + bx_5$$

$$x_1 = \frac{\frac{TU}{\sqrt{T^2+1}} - h}{T}, x_2 = \frac{U}{\sqrt{T^2+1}}, x_3 = \frac{T}{\sqrt{U^2 - (\frac{TU}{\sqrt{T^2+1}} - h)^2}}, x_4 = U \quad x_5 = a - nU,$$

(2) The upper part of the upper part of the soil blasting type bionic slippery area

$$S_c(a_x, a_y, U) = S_0 + mnS_1 + (m+n+1)(S_2 - S_1) + S_4$$
$$= lb + mn\int_{x_1}^{x_2}\int_{y_1(x)}^{y_2(x)} f(x,y)dxdy + (m+n-1)\int_{-a_x}^{a_x}(\int_{y_3(x)}^{y_4(x)} f(x,y)dx)dy + x_3 b \qquad x_1 = x_2 = -a_x\sqrt{1-\frac{(U-h)^2}{U^2}},$$
$$x_3 = a - (4m-2)0.6T$$

$$y_1(x) = y_2(x) = -0.6\mathrm{T}\sqrt{1 - \frac{(U-h)^2}{U^2} - \frac{x^2}{0.36T^2}},,$$
$$y_3(x) = -0.6\mathrm{T}\sqrt{1-\frac{x^2}{0.36T^2}}, \qquad y_4(x) = 0.6T\sqrt{1-\frac{x^2}{0.36T^2}}$$
$$f(x,y) = U\sqrt{1 - \frac{(x-0.6(4k+1)T)^2}{0.36T^2} - \frac{(y-0.6(4s+1)T)^2}{0.36T^2}}$$

(3) Combinatorial planning optimization model

Basing on the corrugated bionic bulldozer and the convex hull type bionic moldboard which can achieve better viscosity reduction resistance effect.For the design of different soils with a reduction in viscosity reduction function of the combination of optimized bionic bulldozers.We need to determine the value of T, U,respectively, using $S_r(T,U)$ and $S_c(T,U)$ to a minimum,and the combined optimization model and the corresponding optimal design scheme of the combined bionic bulldozer are obtained.as follows:

$$\min \mathrm{S_r}(T,U) \quad \text{and} \quad \min S_c(T,U)$$
$$s.t.(T,U) \in I_1 \qquad s.t.(T,U) \in I_2$$

Where I_1, I_2 is the constraint set,meet the general form of bilevel planning.

The height and width of the combined bionic moldboard are set to a, b.According to the assumptions and soil animal body surface statistics that the bulb spacing should not be too small.It may be to set a lot of lower limit 10^{-3},It is known that the upper limit of the peak spacing $w_{\max} = \min\{5b/b-1, a\}$ and the upper limit of the crest height $h_{\max} = 0.03b$ and the relationship between the moldboard width and the moldboard height are as follows:

$$I_1 = \left\{(T,U) \mid 10^{-3} \le U \le \min(\frac{5b}{b-1}, a), 10^{-3} \le \frac{TU}{\sqrt{T^2+1}} \le 0.03b\right\}$$
$$I_2 = \left\{(T,U) \mid 10^{-3} \le 0.6T \le \min(\frac{5b}{b-l}, a\,or\,b), 10^{-3} \le U \le 0.03b\right\}$$

Conclusion

The results of this paper are in good agreement with the conclusions of conventional qualitative analysis, which shows that the method is reasonable and feasible.The corresponding combination of bionic push on the moldboard surface mathematical model.The results show that it is of some significance to establish the mathematical description of the combined bionic moldboard surface.

Acknowledgement

Jilin Aggricultural University National College Students Innovation and Entrepreneurship Training Program Project.

Jilin Agricultural University Undergraduate Science and Technology Innovation Fund Project.

References

[1] Ren Luquan, Tong Jin, Li Jianqiao, and so on. Soil adhesion and biomimetics of soil-engaging components:a review [J]. J Agric Engng,2001,79(3): 239-263.

[2] Luquan Ren, Qian Cong, et al. Reducing adhesion of soil against loading soil using bionic electro-osmosis method[J]. J Teramechanics,2001,38(4): 211-219.

[3] Ren Luquan, final gold, Li Jianqiao, etc. Biological desorption and mechanical bionic one more cross-disciplinary new technology field [J]. China Mechanical Engineering,1999,10 (9): 984-986.

[4] Chen Bingcong. Soil-vehicle system mechanics [M]. Beijing: China Agricultural Machinery Press,1981.

[5] Huang Zuyong, Li Changku translation. Ground vehicle principle [M].Beijing: Machinery Industry Press,1985.