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A Study On Obstacle-surmounting Performance of Sand Milling Vehicles

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Abstract: According to the changing characteristics of the geological environment of Gobi desert pollution abatement area, this paper introduces a kind of milling vehicle of 3point supporting type. The general equilibrium equations under the simultaneously surmounting obstacle by front wheels were derived using a simplified obstacle surmounting mechanical mode. As in a complex environment, the key terrain obstacle parameters are uncertain and the traction force to surmount the obstacle is also uncertain. This paper uses fuzzy sets method for terrain angle and the traction force needed by the vehicle to surmount the obstacle was calculated. By establishing a wheel-road model and using multi-dynamics software, the simulations showed that the theoretical results were reliable.

1. Introduction

In the selection test of pollution control engineering machinery at home and abroad, milling machine has unique advantages,it is suitable for large area surface contaminated soil collection operation, and is easy to realize deep and precise control. This milling machine is mainly applied to the Gobi desert, which geological and geomorphic characteristics are quite different from those of some foreign test sites.Therefore, a higher ability to override of the vehicle is must. At present, the crawler, legged and wheeled is the main obstacle walking mechanism.And the one legged structure is adaptable, but the efficiency is the lowest; the crawler structure obstacle capability is stronger, but the efficiency is not higher,which has large volume and weight; wheeled vehicles due to high energy utilization rate, and by simple mechanism and control the realization of high speed and stable running of popular, but has relatively poor climbing ability [1-2].

This paper introduces a kind of 3 point support for milling vehicles. The vehicle can ensure that the four wheels are completely in the driving process which adopts 3-point support, and the rear wheel adopts articulated structure. The vehicle has strong obstacle surmounting capability on complex and unstructured pavement. In this paper, terrain angle is used to describe any road obstacle in complex environment. Due to the change of terrain and obstacles, the size of the terrain angle is uncertain. The fuzzy set method is used to solve this problem well. By establishing a general mechanical model of vehicle crossing obstacle, we calculate the traction force needed by vehicles to surmount obstacles, which not only provides enough traction for obstacle surmounting, but also avoids the waste of traction.

2. The model structure

2.1 The basic structure of milling vehicle

The milling machine can be divided into milling subsystem, conveying system, lifting system, hydraulic system, measurement and control system, frame system and so on. The basic structure is shown in Figure 1.

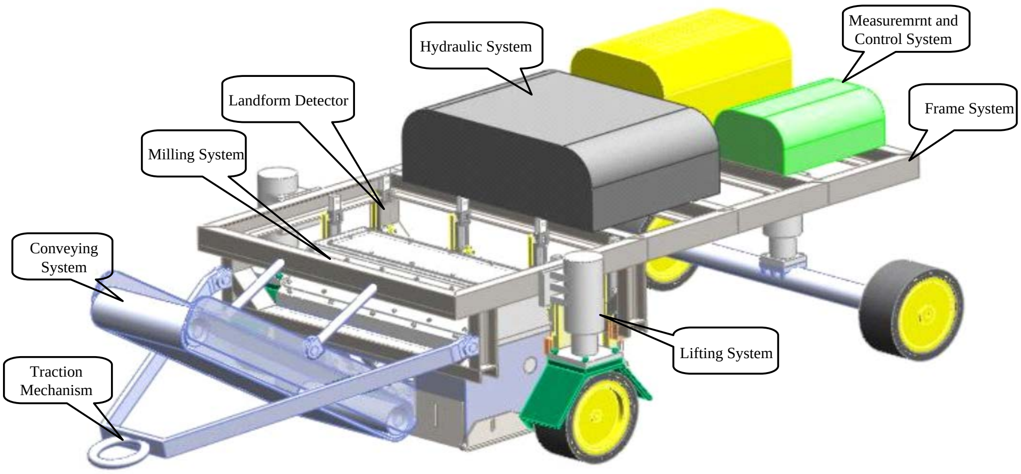
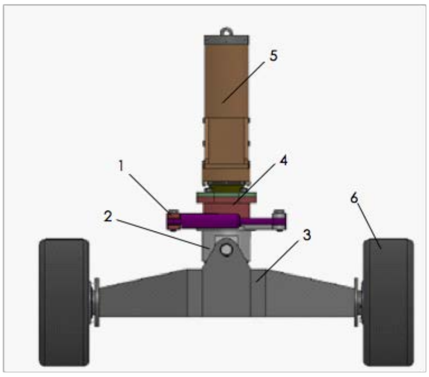


Figure 1. The structure of the milling vehicle

The frame system is mainly used to carry out the functional parts of the test platform, such as milling and collecting device, hydraulic system, control system and related parts, etc. and completes the posture adjustment of the test table during milling process.

The frame adopts a 3 points support structure, and its own non driving system is carried out by a special vehicle towing the traction device at the front of the frame.

The design of steering mechanism installed on the rear axle steering system, chassis, steering drive cylinder telescopic rod according to the direction of elongation or contraction, leading to mutual rotation between the outer cylinder and the rotating shaft mechanism, the shaft and the rear wheel shaft through a connecting pin gradient, which can ensure the rear wheels on the ground at the same time, increase the stability of the vehicle. The rear axle shaft system diagram is shown in Figure 2.



1-steering oil cylinder; 2-articulated support; 3-rear wheel gradient shaft; 4-steering mechanism; 5-lifting leg; 6-rotating shaft;

Figure 2. The diagram of rear axle system

2.2 The structure of pavement model

The pavement condition under the complex environment, the types of barriers are out of order, gravel, gully, slope, undulating ground, so with any kind of obstacle surmounting capability analysis of moving mechanism obstacles to a model is not perfect, this paper, a terrain angle is used to describe any road obstacle [3-4].

As shown in Figure 3, establish the instantaneous coordinates at the contact points of each wheel ground, C_i, i=1, 2, 3, 4. The Z axis of the coordinate system is perpendicular to the ground, and the X axis along the tangent direction of the terrain, and the Y axis is perpendicular to the wheel inward. The wheel coordinate system is fixed with the car body. The angle between the z' axle of wheel coordinate and the corresponding x' axle of wheel-ground instantaneous coordinate system is the ground contact angle of the wheel, expressed as β_i, i= 1, 2, 3, 4.

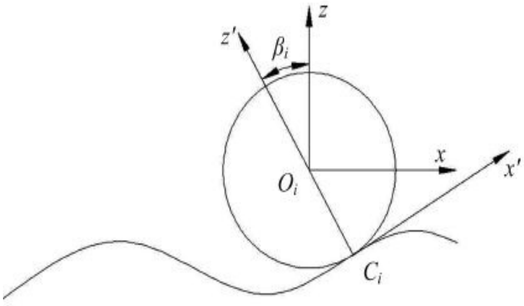


Figure 3. The contact model of wheel-pavement

3. The mathematical model vehicle crossing obstacle

3.1 The contact model

Although rigid wheels are no longer used as walking mechanism components in contact with the ground, they are easy to be expressed mathematically and verified experimentally because of their simple geometry, and elastic tires on very soft soil can be regarded as rigid wheels. When the milling machine runs on the sand surface, the strength of the soil on the sand surface can be seen as soft soil, which is much less than the strength of the wheel. Therefore, the wheel of the milling machine is simplified to rigid wheels for consideration [5-7, 9].

How to determine the contact force of wheels and road surface accurately and quickly is of great significance to correctly analyze the dynamic behavior of milling and planning vehicles. In virtual prototype can simulation the rigid wheel contact with the ground, in the basic module, set up all of the wheels and the entity model of the ground is feasible, can use the contact force between the wheel - the road to achieve, based on the analysis of the Hertz elastic contact theory, using dynamic simulation software ADAMS is more convenient and quick to get a wheel - the road surface, the contact force between the but contact force simulation parameters selection has a great influence on the accuracy of the calculation results (8-9).

In Hertz elastic contact theory, two sides contact can be regarded as the problem of two cylindrical collisions with variable curvature radius.

In the Figure 4, a represents the effective size of the contact area, *R* represents the relative radius of curvature, R_1 and R_2 respectively represent the effective radius of each rotating body, and *P* represents the normal force on the object.

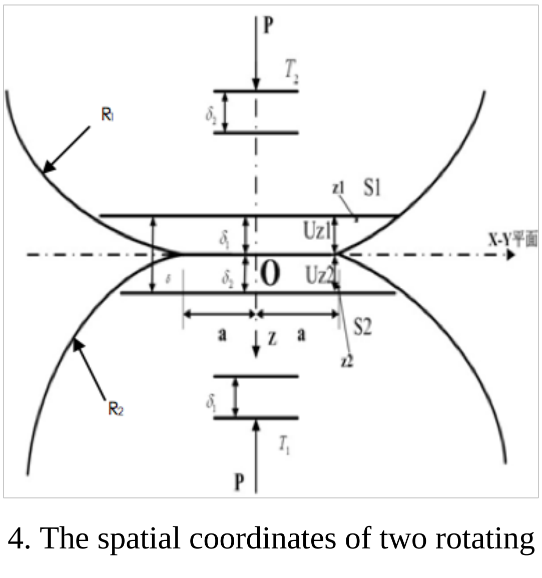


Figure 4. The spatial coordinates of two rotating bodies

When two elastic objects without considering friction collide with each other, if the deformation is confined to the vicinity of the contact area, the deformation between them can be directly obtained by the static elastic contact theory, and at this time, the theory is quasi-static.

According to Hertz contact theory, the relation between deformation and total load is:

$$\delta = (9P^2/16RE^{*2})^{1/3} \tag{1}$$

Formula 1 shows that the relationship between normal force P and δ.

$$P = K\delta^{1/2} \tag{2}$$

Where K is the coefficient of contact stiffness which depends on the material and shape of the two impact objects.

$$K = 4/3R^{1/2}E^* \tag{3}$$

$$\begin{cases} \dfrac{1}{E^*} = \dfrac{1-v_1^2}{E_1} + \dfrac{1-v_2^2}{E_2} \\ \dfrac{1}{R} = \dfrac{1}{R_1} + \dfrac{1}{R_2} \end{cases} \tag{4}$$

Where: E_1, E_2 are the Young's modulus of elasticity of two contact objects;v_1, v_2 are the Poisson's modulus of elasticity of two contact objects; R_1 is equivalent radius of wheel and R_2 is equivalent radius of road surface.

3.2 The front wheel override model

Due to the complexity and variability of terrain, the vehicle obstacle avoidance model is diversified. However, generally speaking, it can be divided into two categories: symmetrical obstacle model and asymmetrical obstacle model. According to these two models, and according to the characteristics of milling and planning vehicles themselves, taking two typical driving conditions, namely, simultaneous front wheel overpass and single-side front wheel overpass, as examples, a balance equation [3] [10-11] for the general situation of front wheel overpass is given by simplifying the mechanical model.

The force model of the front wheel passing over the barrier is shown in Figure 5. At this point, the obstacle passing model is asymmetrical and is relatively complex to analyze. As can be seen from Figure 5, the balance equation of the front wheel of a bicycle when encountering obstacles is:

$$\begin{cases} \sum\limits_{i=1,2} T_i \cos\beta_i - \sum\limits_{i=1,2} N_i \sin\beta_i - \sum\limits_{i=1,2} F_{f_i} \cos\beta_i + T_3 - F_{f_3} = 0 \\ \sum\limits_{i=1,2} T_i \sin\beta_i + \sum\limits_{i=1,2} N_i \cos\beta_i - \sum\limits_{i=1,2} F_{f_i} \cos\beta_i + N_3 - G = 0 \\ \sum\limits_{i=1,2} T_i R + \sum\limits_{i=1,2} F_{f_i} R + T_3 R - F_{f3} R - N_3 L + G L_1 = 0 \\ T_1 \sin\beta_1 + N_1 \cos\beta_1 - F_{f1} \sin\beta_1 - T_2 \sin\beta_2 - N_2 \cos\beta_2 + F_{f2} \sin\beta_2 = 0 \end{cases} \tag{5}$$

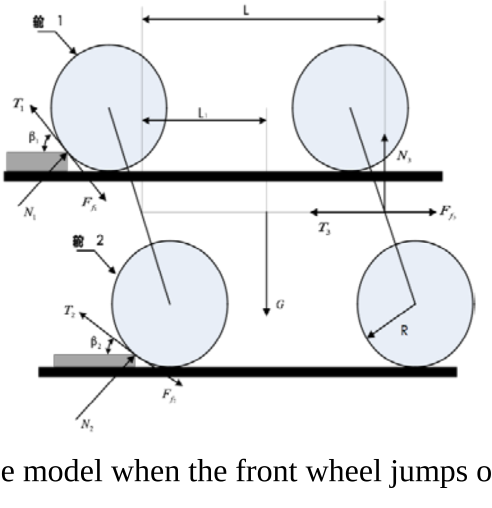


Figure 5. The force model when the front wheel jumps over the obstacle.

Where T_i is the traction force of the front and rear wheels, Ni is the reaction force of the obstacle to the front and rear wheels, F_{fi} is the rolling resistance of the front and rear wheels, G is the total gravity of the articulated vehicle, R is the radius of the wheel, L is the wheelbase, and L_i is the distance from the center of gravity to the front axle.

From Eq. (5), it can be seen that it is the mechanical model of unilateral front wheel obstacle surmounting when $\beta_1$orβ_2= 0; at that time, it is the mechanical model of two front wheels obstacle surmounting when β_1=β_2; and it is the general mechanical model expression of front wheel obstacle surmounting when $\beta_1 \neq \beta_2 \neq 0$.

3.3 The calculation of vehicle obstacle crossing traction force

Because there is no driving system in the vehicle itself, the special vehicle can walk by towing the traction device located in the front of the frame, so the calculation of the traction force is particularly important.

The Rolling resistance F_{fi} can be expressed as a vehicle.

$$F_{f_i} = N_i f_i \tag{6}$$

Where f is the rolling resistance coefficient between the wheel i and the ground.

Effective traction T_i should be satisfied

$$T_i \le N_i \varphi_i \tag{7}$$

Where $\varphi_{\rm i}$ is adhesion coefficient.

According to formula (7), another form of effective traction T_i can be written as

$$T_i = \delta_i N_i \varphi_i \tag{8}$$

Where δ_i is effective traction coefficient. $\delta_i \in [0,1]$

The formula (6) (8) is substituted (5) and is arranged in matrix form:

$$KN = A \tag{9}$$

Where**:**

$$K = \begin{bmatrix} C_{\beta1}, -S_{\beta1} - f_1 C_{\beta1}, \delta_2\varphi_2 C_{\beta2} - S_{\beta2} - f_2 C_{\beta2}, \delta_3\varphi_3 - f_3 \\ S_{\beta1}, C_{\beta1} - f_1 C_{\beta1}, \quad \delta_2\varphi_2 S_{\beta2} + C_{\beta2} - f_2 C_{\beta2}, \qquad 1 \\ R, \qquad f_1 R \quad , \qquad \delta_2\varphi_2 R + f_2 R, \qquad \delta_3\varphi_3 R - f_3 R - L \\ S_{\beta1}, C_{\beta1} - f_1 S_{\beta1}, -\delta_2\varphi_2 S_{\beta2} - C_{\beta2} + f_2 S_{\beta2}, \qquad 0 \end{bmatrix} \qquad N = [T_1, N_1, N_2, N_3]'$$

$$A = [0, G, -GL_1, 0]'$$

It can be seen from equation (9) that matrix K and column vector N are functions of topographic Angle β, rolling resistance coefficient f_i, adhesion coefficient $\varphi_{\rm i}$ and effective traction coefficient δ_i. With the change of topography, it is difficult to accurately describe the value β at any time, so the concept of fuzzy setting [12] is used to represent topographic Angle parameters.

3.4 The concept of fuzzy set

Fuzzy set: let U be the domain of variable u, and u represents an element on U of universe. A real valued function on U is used μ_B to represent,

$$\mu_B : u \to [0,1] \tag{10}$$

A fuzzy set is a set with ambiguous boundaries. For a fuzzy set, an element can belong to the set and not belong to the set, and so on. The boundaries are ambiguous or the boundaries are fuzzy. Fuzzy sets allow an element to be characterized or described as a membership degree of a set to a certain extent, and the degree to which an element belongs to a set is achieved by a numerical value between "0" and "1". Mapping a specific element to a suitable membership degree is achieved by membership functions. The membership function can be a curve of any shape. The shape depends on whether it is easy and effective to use. The only constraint is that the range of membership function is [0, 1]. The commonly used membership functions in fuzzy systems are Gaussian membership function, bilateral Gaussian membership function, bell membership function, trapezoid membership function and triangle membership function.

For simple triangle membership functions, the expression is:

$$f\left(x,a,b,c,d\right)=\begin{cases}0 & x\le a\\ \dfrac{x-a}{b-a} & a\le x\le b\\ \dfrac{c-x}{c-b} & b\le x\le c\\ 0 & c\le x\end{cases} \tag{11}$$

When the domain U is a finite set of points, immediately $U=\{u_1,u_2,\ldots,u_n\}$,

Where $u_i=\mu_B(u_i)i=1,2,\cdots n$

The fuzzy set on U can be represented by the vector B:

$$B=\left\{u_1,u_2,\cdots u_n\right\} \tag{12}$$

For any B, equation (10) can be expressed as

$$K(B)X(B)=A \tag{13}$$

It can be figured out

$$T_i\in\left\{T_1,T_2,\cdots T_n\right\},\, N_i\in\left\{N_1,N_2\cdots N_n\right\}$$

When the vehicle passes through the barrier, the condition of the minimum traction force that can pass through the obstacle is:

$$\begin{cases}T_i=T_{i\max}\\ N_i=N_{i\min}\\ T_i\le N_i\varphi_i\end{cases} \tag{14}$$

4. The vehicle surmounting simulation calculation

According to the structural model and contact theory in FIG. 1, the virtual prototype model of the milling and planning vehicle in the obstacle environment as shown in FIG. 6 is established.

The model is a simulation and analysis model of multi-rigid-body system, and the whole frame is simplified as a component. Multi-body power structure is established between the lifting system and the turning system, and the tire model and the ground are connected according to the wheel-road model. Elastic and damping constraints are added to the system to increase its stability.

The road surface is equipped with potholes, gentle slopes, steps and other faults to simulate the road fault under different conditions.

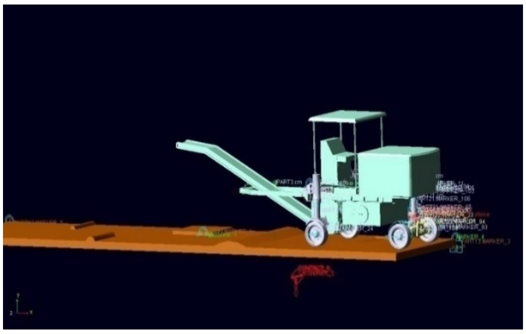


Figure 6. The virtual prototype model of the milling

4.1 Unilateral obstacle crossing simulation

When the single side of the current wheel crosses the barrier, set $\beta_2=0$. The topographic Angle is the interval variable, which $\beta_1 \in [\pi/6(1-10\%), \pi/6(1+10\%)]$, and the topographic Angle is taken. Roll resistance coefficient of front and rear wheels. $f_i=0.1, \varphi_i=0.5, \delta_i=1$, L=3.5m, $L1$=1.75m, G=50000N, R=0.33m.

According to equation (9), the pressure of the corresponding wheels and the corresponding traction force are calculated, as shown in table 1.

Table 1. The pressure and traction force of one-side overpass wheel.

T1(N)		N1(N)		N2(N)		T3(N)	
T1min	T1max	N1min	N1max	N2min	N2max	N3min	N3max
1642	6175	34852	37207	27675	27680	344700	344712

According to the barrier crossing condition, the data in table 1 was substituted into the judgment condition equation (14).

$$T_{1\max} < N_{1\min}\varphi_1$$

Therefore, under the above conditions, when the traction is equal to 6175N, the mill can pass through the obstacle.

4.2 The two-wheel obstacle crossing simulation

When the wheels pass the barrier at the same time, the terrain Angle is the interval variable. It is assumed that the terrain Angle is consistent when the wheels pass the barrier, that is, the terrain Angle is taken and the triangular membership function is adopted. Other parameters are the same as those of a single wheel.

According to equation (9), the pressure of the corresponding wheels and their corresponding traction are calculated, as shown in table 2.

Table 2. The Pressure and traction force of two-side overpass wheels.

T1(N)		N1(N)		N2(N)		T3(N)	
T1min	T1max	N1min	N1max	N2min	N2max	N3min	N3max
1642	6176	34440	35662	34440	35662	344700	344715

According to the barrier crossing condition, the data in table 1 was substituted into equation (14).

Therefore, under the above conditions, when the traction is equal to 6176N, the mill can pass through the obstacle.

To sum up, when the traction force is 6176N, the obstacles can be passed.

According to the simulation results of multi-body dynamics, the traction force is set as T1max, and the milling planer can pass through the obstacle smoothly.

5. Conclusion

In this paper, a 3-point supporting milling and planer vehicle is introduced in view of the changing geological environment characteristics in the gobi desert pollution control area. By simplifying the mechanical model, the general equilibrium equation of the front wheel is established. This article adopts the method of fuzzy set to represent terrain Angle, but in a complex environment, played a key role of vehicle obstacle barrier parameter uncertainty is very common, front and rear wheels rolling resistance coefficient, the traction coefficient, the adhesion coefficient can lead to smoothly through the obstacles of the traction used uncertain, the next step of work, the more parameters interval through the influence of the obstacle will be the key to a vehicle. By establishing the wheel-pavement contact model and using the multi-body dynamics software to model the milling planer and simulate the obstacle pass, the theoretical results are proved to be reliable by simulation.

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