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Analysis of lateral running of small crawler transporter on slope

Guangzhong Hu [1, a], Guangyu Xie [2, b], Xiuquan Cao [2, c, *], Zhiyuan Deng [1, d], Yuhang Zhang [1, e], Tingting Chen [1, f], Lixian Xie [1, g]

[1] Sichuan University of Science & Engineering School of Mechanical Engineering Yibin, China

[2] Key Laboratory of Intelligent Manufacturing of Construction Machinery Sichuan University of Science & Engineering Yibin, China

[a] hgzdhx@163.com, [b] a827818442a@qq.com, *, [c] 279288082@qq.com, [d] dzy541329965@qq.com

[e] 1039493466@qq.com, [f] 1370171456@qq.com, [g] 535468706@qq.com

Abstract. The lateral climbing force of a crawler transporter is analyzed with the help of relevant theoretical formulas. Discrete element software and multi-body dynamics software were used to carry out coupling simulation for tracked vehicles, and orthogonal test was used to analyze the main and secondary factors affecting the lateral climbing of tracked vehicles. The results show that the main factors affecting the lateral climbing of tracked transporters are respectively the track gauge, the lateral deviation of the center of gravity and the vertical height of the center of gravity.

Keywords: Track transport; Lateral driving; Coupling simulation; Orthogonal test.

1. Introduction

It is difficult to transport all kinds of agricultural products on the complex topography, and it is difficult for ordinary agricultural transport vehicles to carry out related work. At present, under the implementation of the "Rural revitalization" strategy [1], improving the adaptability of agricultural transport vehicles to hilly landforms has become an urgent problem to be solved.

Bekker[2] established the relationship between soil and vehicle rolling resistance and load. Janosi[3] et al. proposed that the shear model of plastic ground mechanical properties is simpler than Bekker's, which has become a widely used shear model now. Thuvesen[4] introduced the motion equation of vehicle and used ADAMS to simulate the whole vehicle, so as to determine the influence of different vehicle parameters on its driving performance when driving on soft ground. Liu Yu, Xie Niobi et al. [5] used Recurdyn simulation to analyze the climbing, ditching and obstacle crossing of different road surfaces.

The relevant research shows that most of the research focuses on theoretical analysis and simulation optimization, and there are relatively few studies on the passability of agricultural transport vehicles in hilly areas. In this paper, the coupling of discrete element and multi-body dynamics [6] was used to simulate the maximum lateral climb of crawler transporter, and the main and secondary factors affecting the maximum climb were analyzed by orthogonal test, and it was concluded that the track gauge and center of gravity position were the main influencing factors, providing a reference for the optimization design of small crawler agricultural transporter.

2. Transverse transmissibility theory analysis

2.1. Lateral ride stability on slopes

The evaluation criterion of lateral driving stability is based on the state of the tracked transport vehicle driving on the lateral slope, whether there will be side slip and lateral turnover [7].The study of its maximum roll Angle is one of the important indexes to analyze its driving stability. FIG. 1 shows the simplified stress analysis diagram of the tracked transporter.

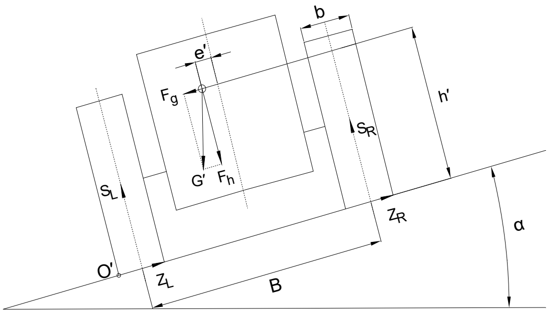

Fig. 1 Schematic diagram of force on lateral slope

Where,B is track track gauge,b is track width,h'is the height from the center of gravity to the slope,αis the slope,Fg is the component force of the center of gravity of the tracked transporter along the slope horizontal direction,G'is the center of gravity perpendicular to the horizontal direction,Fh is the component force of the center of gravity of the tracked transporter perpendicular to the slope horizontal direction,ZL and ZR are respectively the adhesion force of the track in contact with the slope pavement.SL and SR are the resultant vertical reaction of the two tracks contacting the support section of the slope ground respectively,and e'is the transverse deviation distance of the center of gravity.

When the tracked transporter begins to tip over at the limit Angleα,the force on SR at this time is 0,and the force acting on SL will offset to the point O'and tip over around the point O'.According to the force balance analysis,it can be obtained:

$$\alpha \le \arctan\left[\frac{0.5(B+\mathrm{b})-\mathrm{e}'}{\mathrm{h}'}\right]$$

As can be seen from the formula, when the track runs on a transverse slope, it is only related to the track gauge, track width, transverse offset of the center of gravity and the vertical height between the center of gravity and the slope. The lateral slip of a tracked transporter on a lateral slope is one of the unstable states. If the adhesion between the track and the slope pavement is just equal to the component force of the center of gravity along the slope, the corresponding adhesion coefficient is φ_Z, as shown below:

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$$Z_L + Z_R = G'\sin\alpha$$

If there is no lateral slip, then it can be deduced that:

$$\alpha \le \arctan\varphi_z$$

The driving force is not considered in the formula, but when the track is running at a constant speed, the mutual contact with the slope road will act on the driving force and lateral reaction force at the same time. Lateral slip occurs when the combined force of the driving force and the lateral reaction force is just greater than or equal to the lateral adhesion force.

3. Co-simulation analysis for recurdyn and edem

The chassis system of the tracked transporter is composed of driving wheel, bearing wheel, tensioning wheel and guiding wheel. The engine provides power to the driving wheel through the transmission. The teeth on the driving wheel meshed with the chain rail on the track, and the track and the ground would have a relative movement trend. As the driving force increases, the track begins to move relative to the ground. The driving wheel, bearing wheel, and guide wheel will move on the chain rail, and finally drive the whole machine movement. Because the left and right tracks can be turned separately, the turning radius of the tracked vehicle is small.

3.1. Coupling model of multi-body dynamics and discrete element method

The current soil theory and finite element method have limitations on the dynamic analysis of soil, while the discrete element method [8] regards the soil pavement as a continuous discrete independent unit, which is solved through the basic equation of Newton's second law and the central difference method, and explains the morphological changes of soil media through the mutual position and movement of each unit [9].

3.2. Simulation modeling

Modeling of tracked transport vehicles. As shown in Figure 2. Particle parameters in edem and related parameters of track chassis are shown in the table.

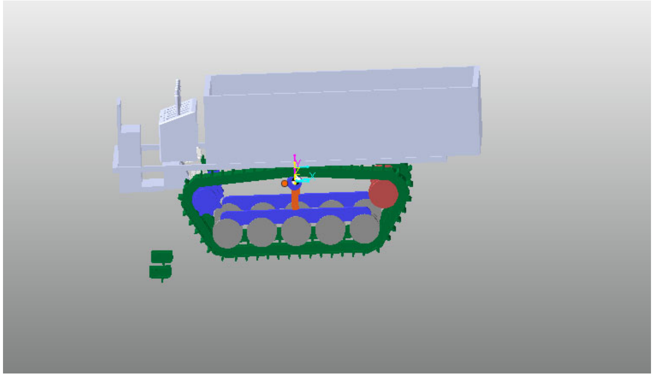


Fig. 2 Simplified model of track transporter

Table 1 Basic parameters of track chassis

parameter	Parameter value	parameter	Parameter value
Full load mass/kg	2329	Driving wheel radius/mm	109
Radius of tensioning wheel/mm	103	Track grounding length/mm	1000
Track width/mm	250	gauge/mm	770

Table 2 Soil particles and contact mechanics parameters

name	Parameter value	name	Parameter value
Particle gap	0.4	Poisson's ratio of rubber tracks	0.475
Poisson's ratio	0.25	Shear modulus of rubber track/Pa	7.966×10^{9}
Shear modulus/Pa	1×10^{7}	Density of rubber track/(kg·m^{-3})	1130
density/（kg·m^{-3}）	2600	Particle static friction coefficient	0.2
Particle recovery coefficient	0.35	Particle rolling friction coefficient	0.05

3.3. Orthogonal test and analysis

The main factors affecting the maximum lateral slope were analyzed by orthogonal experimental design. Track intertrack gauge B, track width b and the vehicle's center of gravity position are taken as factors A, B, C and D respectively, as shown in Table 3.

Table 3 Simulation factors and levels

level	factor			
	gauge B/mm	Track width b/mm	Vertical height of center of gravity h'/mm	Lateral deviation distance of center of gravity e'/mm
1	770	200	500	50
2	670	250	450	100
3	590	300	400	150

Taking the maximum slope Angle α as a test index, the scheme and results of orthogonal test are shown in the table below. The orthogonal table of 3 levels and 5 factors was selected for processing, and the results were shown in Table 4. The maximum gradient of transverse driving is 35° and the minimum gradient is 15°. The range analysis is carried out to determine the primary and secondary factors and the optimal combination, and the results are shown in Table 5.

Table 4 Simulation scheme and results

Test number	factor				Maximum slope
	A	B	C	D	α/°
1	1	1	1	1	30°
2	1	1	2	2	29°
3	1	2	1	3	24°
4	1	2	3	1	35°
5	1	3	2	3	26°
6	1	3	3	2	32°
7	2	1	1	3	18°
8	2	1	3	1	30°
9	2	2	2	2	24°
10	2	2	3	3	22°
11	2	3	1	2	22°
12	2	3	2	1	28°
13	3	1	2	3	15°
14	3	1	3	2	21°
15	3	2	1	2	18°
16	3	2	2	1	24°
17	3	3	1	1	22°
18	3	3	3	3	17°

Table 5 Range analysis

K_{1j}（level1Data sum）	176	143	134	169
K_{2j}（level2Data sum）	144	147	146	146
K_{3j}（level3Data sum）	117	147	157	122
K_{1j}（level1Average value）	29.333	23.833	22.333	28.167
K_{2j}（level2Average value）	24.000	24.500	24.333	24.333
K_{3j}（level3Average value）	19.500	24.500	26.167	20.333
R_j（k）$=K_{ijmax}-K_{ijmin}$	9.833	0.667	3.834	7.834
Primary and secondary factors	A>D>C>B			
Optimal combination	$A_1B_3C_3D_1$			

The greater the extreme value reflected in Table 5, the greater the influence of the influence factor on the test index. Therefore, the order of the influence of the test factor on the maximum slope is as follows: track gauge > lateral deviation distance of the center of gravity > vertical height of the center of gravity > track width. In order to further understand the significance of each factor's influence on the test indicators, the variance analysis is carried out, and the analysis results are shown in Table 6 below.

Table 6 Analysis of variance

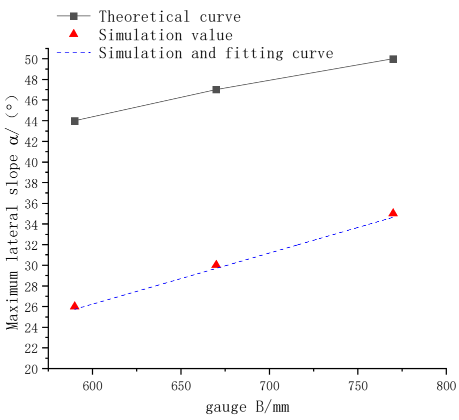
Source of variance	Sum of squares	Degree of freedom	Mean square sum	F value	Significance level
model	709.389	1	709.389	2946.692	**
A	96.444	2	48.222	200.308	**
B	0.111	2	0.056	0.231	0.798
C	12.111	2	6.056	25.154	**
D	60.778	2	30.389	126.231	**
error	2.167	9	0.241		
summation	171.611	17			

It can be seen from Table 6 that the track gauge, the vertical height of the center of gravity and the lateral deviation distance of the center of gravity have significant influences. It can be seen from F value that the four factors have A>D>C>B influences on the maximum gradient of the lateral climb.

3.4. Single factor simulation analysis

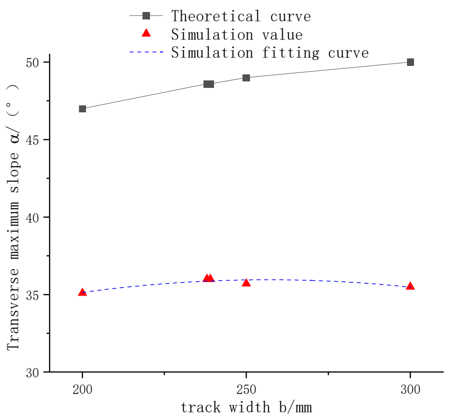
In order to objectively reflect the influence of the above four factors on the maximum lateral slope, the above optimal levels are selected respectively, that is, A, B, C and D are taken as 770mm, 250mm, 400mm and 50mm respectively. The other factors are taken as variables for simulation analysis, and the influence rules of each factor on the maximum slope are obtained, as shown in Figure 3、Figure 4、Figure 5、Figure 6.

According to the simulation curve and the theoretical curve, the slope increases with the decrease of the vertical height of the center of gravity and the transverse deviation distance of the center of gravity, and increases with the increase of the track B, thus improving the climbing ability of the tracked transporter. The theoretical curve of track width b increases with the increase of its value, but its simulation value reaches a maximum of 36° when b is 238mm and 239mm.



(a)b=250mm,h′=400mm, e′=50mm

Fig. 3 Different gauge



(b) B=770mm,h′=400mm,e′=50mm

Fig. 4 Different track widths

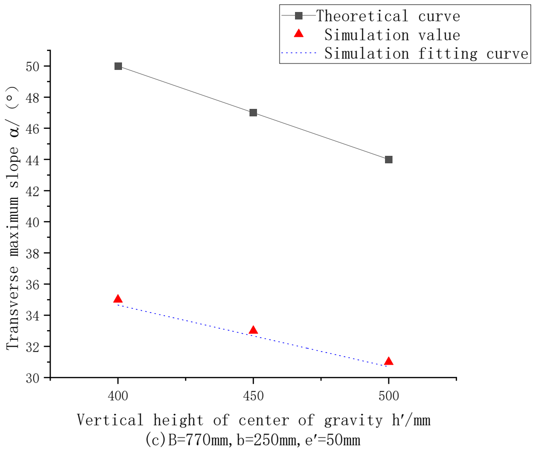


Fig. 5 Different vertical heights of center of gravity

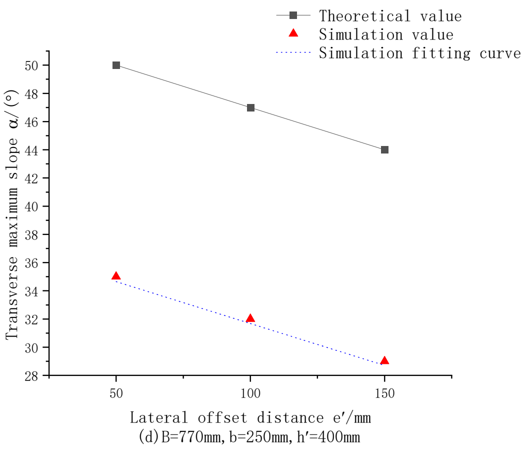


Fig. 6 Lateral shift of different centers of gravity

As can be seen from FIG. 5, with the numerical changes of track gauge, track width, vertical height of center of gravity and lateral migration of center of gravity, the trend of simulation curve is consistent with that of theoretical curve. However, the theoretical calculation does not take into account the load of the vehicle body, the type of road surface, the speed of the vehicle, acceleration and other conditions, which makes the simulation values are smaller than the theoretical values. In view of the deviation between the theoretical value and the simulation value, it is analyzed, and the results are shown in Table 7.

Table 7 Relative deviation between simulation value and theoretical calculation

factor	level	Theoretical value/°	Simulation value/°	Relative deviation/%	Relative deviation mean/%
A	1	50	35	42.86	56.25
	2	47	30	56.67	
	3	44	26	69.23	
B	1	47	35.1	33.90	37.33
	2	49	35.7	37.25	
	3	50	35.5	40.85	
C	1	44	31	41.94	42.41
	2	47	33	42.42	
	3	50	35	42.86	
D	1	50	35	42.86	47.15
	2	47	32	46.88	
	3	44	29	51.72	

It can be seen from Table 7 above that the relative deviation caused by the track is the largest, and the relative deviation is the largest when the track is 590mm. This is because the change of gauge will affect the position of the center of mass, which is equivalent to the increase of the lateral deviation of the center of mass and further cause the decrease of its maximum slope. In addition, the relative deviations of each factor affecting the maximum slope in descending order are track gauge, lateral shift of center of gravity, vertical height of center of gravity and track width, which are basically the same as the order affecting the maximum slope α. Therefore, the greater the influence on α, the greater the deviation between the simulated value and the theoretical value.

4. Conclusion

(1) The force analysis was carried out on the movement process of agricultural tracked transporter during lateral climbing, and the maximum lateral slope theory was used for analysis. It was found

that the track gauge, track width, vertical height of center of gravity and lateral deviation of center of gravity were the main factors affecting the lateral climbing performance of tracked transporter.

(2) The coupling simulation model of edem and recurdyn was established, and the maximum lateral climbing slope of crawler-transporter under different centroid positions and different track widths was obtained by orthogonal test. According to the variance analysis of the test data, the main and secondary factors that significantly affect the lateral climbing slope of the crawler transporter are respectively: track gauge, lateral deviation of center of gravity, vertical height of center of gravity and track width.

(3) A single factor variable simulation test is carried out for track gauge, track width, vertical height of center of gravity and lateral migration of center of gravity respectively, and the simulation value is compared with the theoretical value. It can be seen that the relative deviation of track is the largest, and increasing track gauge can improve the lateral climbing slope. Reducing the vertical height of the center of gravity and the lateral deviation distance of the center of gravity can also improve the lateral climbing slope of the tracked transporter.

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References

[1] The CPC Central Committee and The State Council.《Opinions of the CPC Central Committee and The State Council on Comprehensively Promoting Rural Revitalization and Accelerating Agricultural and Rural Modernization》[Z].2021

[2] Yang Congbin.Study on adhesion characteristics and Optimization of high speed track and soft ground[D]. Beijing Institute of Technology,2015

[3] Janosi Z,Hanamoto B.Analytical determination of drawbar pull as a function of slip for tracked vehicles in deformable soils.In:Procfirstint M.I.Lyasko[J].Journal of Terramechanics 47(2010)423–445 443 conf on terrain–vehicle systems,Edizioni Minerva Tecnica,Torino;1961

[4] Wu Guorui. 2007.Simulation study on working Stability of deep-sea crawler cobalt crust mining vehicle. [Master's thesis].Hunan: Central South University

[5] Liu Yu, Zhang Tuo, Xie Ni, et al. Multi-body dynamics modeling and verification of small agricultural tracked chassis[J]. Transactions of the Chinese Society of Agricultural Engineering,2019,35(7):39-46.

[6] Hong Jiazhen, Liu Jinyang.Computational Dynamics and Modeling of mechanical systems[M]. Beijing: Higher Education Press, 2011:1-287.

[7] Luoyang Tractor Research Institute, Ministry of Machinery and Electronics Industry. 1994.Tractor Design Manual (Volume 1). Beijing: China Machine Press:252～261

[8] CUNDALL P A, STRACK O L.A Discrete Numerical Model for Granular Assembles[J].Geotechnique, 1979, 29(1):47-65.

[9] Wang Bo, Yu Zhezhou, Yuan Jun, Fu Hong, Yu Jianqun.A new CAE software based on MBD and DEM coupling[J]. Journal of Jilin University (Science Edition), 2020, 58(02):371-378.