Research on Application of Wheels with External Track Technology under Soft Road Condition

Youshan Hou¹a, Chao Wang¹b and Wenbin Cai¹

1China North Vehicle Research Institute, Huaishuling No.4 Courtyard, Fengtai District, Beijing
Email: a houyoushan2008@126.com, b 13488684909@163.com

Abstract. Wheeled vehicles usually adopt external track when passing through soft road conditions. Taking the large wheelbase four-wheel vehicle as the example, based on recurdyn, the dynamic simulation analysis of two driving modes of wheeled vehicles and wheel with external track was completed, focusing on the comparative analysis of ground specific pressure, hook traction, wheel sinkage and other aspects. The results show that the vehicle passability under the soft condition is improved after the wheels are attached to the track, the vehicle's theoretical grounding is 86.7% less than the reduction, and the hook traction is nearly 10 times higher. However, for the large wheelbase structure, the track between the two wheels needs to improve the passability by adding load-bearing wheels.

1. Introduction

Because of the wheels’ large ground specific pressure and the soft road condition, wheeled vehicles usually adopt external track on the tire to improve the passability and prevent the wheels from falling into the soft road condition. When passing through the soft road condition. The wheels with external track of wheeled vehicle is shown in figure 1[1-3].

Take the large wheelbase four-wheel vehicle as the example, by comparing the ground specific pressure and the drawbar pull of the two kinds of driving systems, wheel type and wheel with external track type, to comprehensively evaluate the vehicle passability under the soft road condition. Base on recurdyn dynamics simulation analysis, the dynamic simulation analysis of two driving modes of wheeled vehicles and wheel with external track is completed, and an optimized improvement scheme is proposed to improve the passing performance.

Figure 1. Wheels with external track
2. Theoretical Analysis of Ground Specific Pressure

Vehicle ground specific pressure [4-5] refers to the average ground specific pressure. Generally, the smaller the ground ratio value is, the smaller the vehicle's settlement on the soft beach road surface is, and the lower the driving resistance is, the better the vehicle's passability is. The calculation formula of ground specific pressure is

\[ q = \frac{mg}{S} \times 1000 \]  

Among them, \( q \) - ground specific pressure, kPa; \( m \) - vehicle weight, kg; \( S \) - ground area, m\(^2\). The simplified large wheelbase four-wheel vehicle’s technology parameters showed in table 1.

| Table 1. Technical parameters of wheels and tracks |
|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| Total weight    | Tire size       | Tire pressure   | Tire load       | Track idth      | Track grounding length |
| 10000kg         | 335/80R22      | 2bar~5bar       | 2448kg          | 0.4m            | 2.4m             |

Substituting the data in table 1 into formula (1), the ground specific pressure under two driving modes, wheel type and external track type, can be obtained. The calculation and comparison results are shown in table 2.

| Table 2. Ground pressure comparison results |
|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| Driving mode    | Total grounding area(m\(^2\)) | Ground specific pressure(kPa) | Note |
| Tire            | 0.26            | 383             |                 |
| External track  | 1.92            | 51              |                 |
| The variable    | 1.66            | 332             |                 |
| The variable ratio (%) | 638 | 86.7 | |

It can be seen from table 2 that assuming that the load load of the total weight of four wheels of vehicles of 10 tons is evenly distributed on the two tracks, the total ground area of the four wheels after the external track is theoretically increased by 638%, and the ground area is 86.7% less than the ground load reduction.

3. Vehicle Hook Traction Calculation and Analysis

The vehicle supporting passability is often judged by vehicle hook traction, which refers to the difference between soil thrust and soil resistance (compaction resistance, soil bulldozing resistance and soil cohesive resistance). Among the soil resistance, soil compaction resistance and soil bulldozing resistance are the main influencing factors [4]. The soil thrust and soil resistance of the four-wheeler under the two driving modes of wheel type and wheel with external track are calculated respectively, and the vehicle passability under the soft road condition is determined by comparative analysis.

| Table 3. Soil performance parameter |
|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| Ground type     | Humidity /%     | Sinkage index / | Cohesive module | Friction module | Shear modulus K/m | Cohesion coefficient c/kPa | Friction angle \( \phi \)/(°) |
| Wet sand        | 15              | 0.7             | 5.27            | 1515.04         | 0.025            | 1.72            | 29              |
| Note: Nc=40 Nr=18[4] |

For the convenience of analysis, the following assumptions are made [5]:
1) The rolling resistance of tire deformation is ignored;
2) Only consider the rigid characteristics of tires;
3) Soil pressure is evenly distributed under the track.

The vehicle's soil thrust, soil compaction resistance and soil pushing resistance are respectively:
\[ F_{c1} = (Ac + W \tan \varphi) \left[ 1 - \frac{K}{S_r I} \left[ 1 - \exp \left( -\frac{S_r I}{K} \right) \right] \right] \]

\[ F_{r1l} = \frac{1}{(3 - n)^{\frac{2n+2}{2n+1}}} (n + 1) \left( k_c + b k_{\varphi} \right) \left[ \frac{3W}{2} \right]^{\frac{2n+2}{2n+1}} \]

\[ F_{r1h} = b \left[ cz_1 \left( N_c - \tan \varphi \right) \cos^2 \varphi + 0.5 z_1^2 \gamma_s \left( \frac{2N_r}{\tan \varphi} + 1 \right) \cos^2 \varphi \right] \]

In formula (2), \( A \) – the ground area of driving wheel, \( m^2 \); \( c \) - Soil cohesion coefficient, \( Pa \); \( W \) – Vertical tire load, \( N \); \( \varphi \) – Friction angle,\(^\circ\); \( K \) – Soil shear modulus, \( m \); \( l \) – Length of tyre grounding, \( m \); \( n \) – Soil sinkage index; \( k_c \) -Soil cohesive module, \( kN \); \( m \)(n+1); \( k_{\varphi} \) -Soil Friction module, \( kN \). \( m \)(n+2); \( D \) – Wheel diameter, \( m \); \( b \) – Wheel width, \( m \); \( z_1 \) -Wheel sinkage, \( m \).

\[ z_1 = \left[ \frac{3W}{(k_c + b k_{\varphi}) \sqrt{D(3 - n)}} \right]^{\frac{2n+2}{2n+1}} \]

\( N_c, N_r \) - Coefficient of soil bearing capacity; \( \gamma_s \) - Soil weight per unit volume, \( N \). \( \gamma_s = 26500N \).

The comprehensive analysis is conducted on the hook traction of two driving modes, wheel type and wheel with external track. The analysis results are shown in figure 2.

It can be known that in the wheel driving mode, when the vehicle's slip rotation rate reaches about 40\%, the vehicle can only generate effective hook traction to drive the vehicle forward. That is, when the slip rotation rate is lower than 40\%, the soil thrust is less than the soil resistance in the wheel-walking mode, and the vehicle cannot move forward. In the external track mode, when the track slip rate reaches about 10\%, the whole vehicle can generate enough traction to drive the vehicle forward. Under wheel driving mode, the maximum hook traction produced is about 6000N. However, under the crawler driving mode, the maximum hook traction produced reached about 57000N, which was nearly 10 times of the hook traction under the wheel mode.

From the theoretical analysis and calculation, it can be seen that the external track of the wheel not only reduces the grounding pressure of the vehicle, but also effectively improves the effective driving force of the vehicle in the soft road condition.

---

**Figure 2. Diagram of hook traction contrast**
4. Dynamic Simulation Analysis
The Based on the Recurdyn dynamic simulation software, the dynamic simulation models of wheel and wheel with external track are established.

It can be seen from figure 3 that the corresponding wheel settlement amount is about 100mm under the wheel condition, and the wheel settlement amount is about 90mm after the wheel external track is mounted, which reduces by about 10mm. As can be seen from figure 4, the corresponding wheel load in the wheeled state is about 2.4 tons, and the load on the wheel after the wheel external track is about 2.8 tons. On the contrary, the wheel load is increased. This is due to the fact that after the wheel external track, there is a tension force on the track, and the load on all tires is increased.

![Figure 3. Comparison of wheel sinkage of two driving modes](image1)

![Figure 4. Comparison of wheel loads in two driving modes](image2)

From the dynamic simulation analysis, it can be seen that the wheel with external track scheme has improved the vehicle's passability in the soft and wet road condition, but the improvement is not obvious. The improvement of wheel subsidence is only about 10mm, and the improvement of the corresponding ground specific pressure (related to subsidence) is also lower than the theoretical
calculation value above (see table 2). The reason is that the theoretical deduction above is based on the
uniform load of the track, while in fact, due to the large wheelbase, the track arches in the soft area
between the two axle Bridges, as shown in FIG.5, that is, the main load is still borne by the wheel.
Therefore, under large wheelbase, the scheme of external track on wheels has an effect on providing
passability, but the effect is not obvious. It can be improved by adding a load wheel between two
vehicle Bridges to improve the uniform distribution of track load and the passability of external track
on wheels.

![Figure 5. Arch in the middle of external track](image)

![Figure 6. Scheme of additional load wheel](image)

Figure 5. Arch in the middle of external track

Figure 6. Scheme of additional load wheel

As can be seen from figure 7, in the scheme of external track on wheels, after adding a load wheel
to the track between two wheels, the wheel subsidence of the whole vehicle is significantly reduced,
and the corresponding normal ground specific pressure is also reduced. Moreover, the more load
wheels are added between the two wheels, the more uniform the crawler load is, and the less the wheel
subsidence and the grounding ratio pressure are.

![Figure 7. Wheel sinkage comparison](image)

5. Conclusion
(1) Completing the theoretical analysis and calculation of the two driving modes of wheel type and
wheel with track, with emphasis on the analysis and calculation of the ground area, ground specific
pressure and hook traction. The results of theoretical calculation show that the scheme of external
track on wheels improves the vehicle's passing performance in soft road conditions. After the wheels
are attached to the track, the vehicle's grounding ratio is 86.7% less than the reduction, and the hook
traction is increased by about 10 times.

(2) The dynamic simulation model of two walking modes is established and the dynamic
simulation analysis is completed. The analysis results show that the scheme of external track on
wheels can improve the vehicle passing performance in the soft road condition, but in the case of large
wheelbase, the larger wheelbase arrangement is not conducive to the vehicle passing performance.
(3) In view of the large wheelbase wheel with external track scheme, an optimization and improvement scheme is proposed: adding a load wheel in the track junction area between the two wheels can effectively improve the vehicle's passability, and the more load wheel, the more uniform the crawler load, the more conducive to improve the passing performance.

6. References
[1] Kejian Zhang. Vehicle ground mechanics [M].Beijing: National defense industry press, 2002. 1.
[2] Jide Zhuang. Automotive tyrology [M].Beijing: Beijing institute of technology press, 1995.
[3] Jude Liu. Vehicle sand travel theory [M].Beijing: Mechanical industry press, 1996.
[4] Zhisheng Yu. Automobile theory [M].Beijing: Mechanical industry press, 2009. 3.
[5] Hongwu Pu, Junwen Xing, Xiangzheng Meng. Passing Ability Simulation Study for Tracked Triangular Wheeled Vehicle Based on RecurDyn [J]. Journal of hunan institute of science and technology (natural science edition), 2013, 26(2):24-27.