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Chassis design of inspection robots for safety assessment in hydraulic tunnels

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ABSTRACT
During the construction and operation of hydraulic tunnels, robot inspection has become a trend in safety supporting system, which not only saves time and labor, but also greatly reduces operating costs. Existing inspection robots have deficiencies such as poor ground adaptability and insufficient power when they patrol in the tunnel, resulting in failure of completing the task. This paper, according to the special pavement environment of hydraulic tunnel, designed a six-wheel drive vehicle chassis with multi-degree freedom to imitate terrain. The design of the chassis was introduced. Besides, the RecurDyn software was used for simulation analysis.

KEY WORDS: Hydraulic tunnel; inspection; chassis; simulation

INTRODUCTION

Under normal circumstances, the construction period of the hydraulic tunnel is long, and a large number of safety inspections are required during the construction process [1]. At present, artificial inspection is often used. Due to the complicated internal environment of the tunnel and the long inspection line, this will undoubtedly increase the labor cost. The emergence of tunnel inspection robots solves this problem to a certain extent [2], but the existing inspection robots have wheel subsidence during operation, unable to cross the convex obstacle or even overturn when crossing the obstacle. Manpower is also needed to rescue the robot in distress. It is necessary to design a new chassis to solve the above problems.

The complex environment of the construction site of the hydraulic tunnel requires that the inspection robot system must have an extremely high terrain adaptability, and the body suspension is the most critical component to solve this problem [3]. The structural design of the body suspension affects the performance of the inspection robot chassis, and the vehicle's passability, driving safety and load capacity are closely related. The chassis passability is prioritized during design, maintain the classis's excellent adhesion to the ground during walking. The six-wheel chassis with three-rockers has two longitudinal rockers and one lateral rocker arm, which can greatly improve the overall performance of the vehicle. In addition, tire subsidence is prone to occur in muddy land, and it is considered to increase the number of tires and the width of the tire to solve this problem. Compared with the traditional four-wheel chassis, the chassis has improved obstacle performance and operational stability. Compared with the traditional six-wheel chassis with differential balancing mechanism, the three-rock suspension can simplify the structure and reduce the design difficulty.

THE BASIC STRUCTURE OF INSPECTION ROBOT CHASSIS

The ability of the chassis to pass through complex terrain is not only related to the size of the obstacles on the road, but also to the physical dimension of the body and its centroid position. Increasing the size of the body allows the vehicle to pass through larger obstacles, but the bulky body also affects its overall quality and is prone to sinking on soft roads. In order to ensure the obstacle passing ability of the vehicle, the size and quality of the chassis should be balanced [4].

The ability of the chassis to pass through the tunnel surface during the inspection process is divided into two parts: support passability and profile passability. The former indicates the reliability of passing on the soft ground, which is related to the characteristic of the soil and the quality of the chassis and the size of the tire's area of thrust surface. The latter represents the ability of the vehicle to cross geometric obstacles, such as bulges, gravel, drains, etc. Generally, the construction site environment is complicated. When the chassis is driven on unstructured roads, the main reason for its loss of passability is that it cannot cross the geometric obstacles[5].

The chassis features a six-wheel structure and a rocker suspension system with three degrees of freedom. The left and right sides of the front part of the vehicle respectively have a rocker arm that can swing in the longitudinal plane, and a rocker arm that can swing in a lateral plane at the rear. The drive system uses hub motors, each with a separate servo drive. One of the great advantages of the hub motor is to reduce the size of the drive system, thereby reducing the body quality and optimizing the balance between size and centroid. The rocker arm and the body are hinged, the hinge point is mounted with a limit device and the spring is damped to limit the rotation angle and the rotation speed of the rocker arm. The rocker suspension structure is shown in Figure 1. The SolidWorks 3D model is shown in Figure 2. The parameters of the chassis are shown in the Table 1.

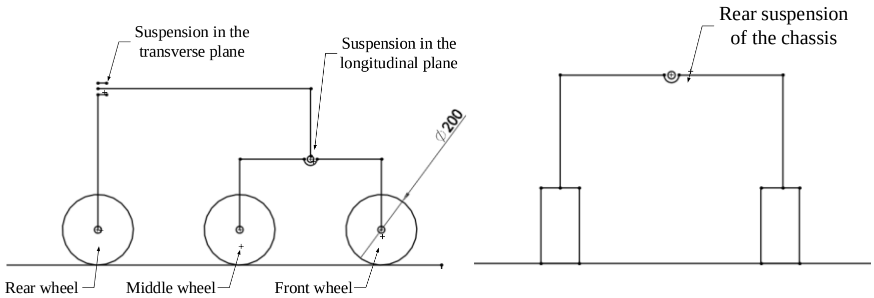


Figure 1 Suspension structure diagram

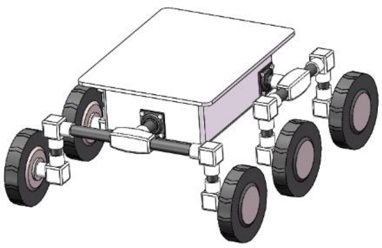


Figure 2 3D model

Table 1 Parameters of the chassis

Parameter name	Date	Parameter name	Date
Size	820 mm×600 mm×340 mm	Wheel Width	60 mm
Wheel Diameter	200 mm	Speed	1 m/s
Drive Power	200 W	Chassis Quality	40 kg

SUPPORT PASSABILITY ANALYSIS

The support passability describes the ability of the chassis to smoothly pass the soft road surface [5]. The support passability failure in the tunnel environment is often due to wheel subsidence, so the wheel sinking is mainly analyzed here. Vehicle subsidence occurs when passes through a soft road surface, such subsidence between wheel and soil are inevitable, as shown in Figure 3. In the figure, Z is the wheel sinking amount; W is the vertical load on the wheel; ω is the wheel turning speed; V is the wheel running speed. Usually, according to the soil deformation or mechanism of wheel subsidence, the wheel subsidence is divided into two parts: static subsidence and dynamic subsidence [6].

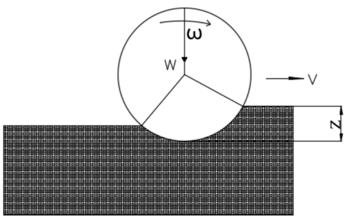


Figure 3 Subsidence of the wheel

Static Subsidence

When the chassis and the ground are relatively stationary, the soil is compacted under the gravity of the chassis, at which point the soil deformation is called the static subsidence. The subsidence model can be calculated using the empirical formula of Bekker rigid wheel static subsidence [7].

$$Z_0 = \left[\frac{3W}{(3-n)(k_c + bk_\varphi)\sqrt{D}} \right]^{\frac{2}{2n+1}} \tag{1}$$

Z_0—Amount of the static subsidence
W—Load on the wheel
n—Soil subsidence index
k_c, k_φ—Soil cohesive deformation modulus and friction deformation modulus
b—Wheel width
D—Wheel diameter

It can be seen from the formula (1) that when the quality of the chassis is constant, appropriately increasing the width of the wheel can reduce the amount of static subsidence. The outside of the hub motor in this system is solid rubber, which is considered here as a rigid wheel.

Dynamic Subsidence

When the chassis moves relative to the ground, the rotation of the wheel and the weight of the chassis together cause the subsidence of the soil to be called the dynamic subsidence. The wheel dynamic subsidence is divided into sliding subsidence and excavation subsidence. The excavation subsidence is caused by the contact part soil being planed when the wheel slips, this phenomenon is related to the volume of the fetal groove, and is not affected by the mechanical properties of the soil and the wheel parameters. Here only the analysis of the sliding subsidence is carried out and the analysis of the tunneling subsidence is no longer carried out.

Sliding Subsidence

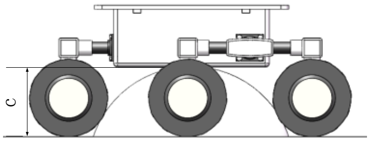
The damaged area of the loose soil under the wheel increases with the increase of the wheel slip rate. When the slip rate tends to zero, the damage zone also tends to zeros [8]. The wheel subsidence caused by the wheel slipping relative to the ground is called sliding subsidence. In this regard, Bekker gives the empirical formula for sliding subsidence [7]:

$$Z_j = \frac{j\left[p - cN_c - \gamma(N_q z + 0.5bN_r) \right]}{C + p\tan\varphi + rN_q j} \tag{2}$$

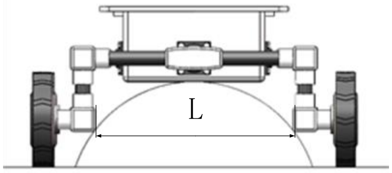
Z_j—Amount of the sliding subsidence
γ—Volume density of soils
j—Shear displacement
N_C、N_q、N_γ—Carrying capacity factor
C、φ—Soil cohesion and internal friction angle
p—Vertical load on the wheel
It can be obtained from the formula (2) that appropriately increasing the wheel width in the sliding subsidence model can effectively reduce the amount of subsidence.

PROFILE PASSABILITY

Profile passability is the ability to describe the chassis through bumpy roads and obstacles [5]. The minimum off-ground clearance C of the chassis reflects the high of the vertical obstacle that it can pass while traveling on a flat road, and in the design C=180 mm, as shown in Fig. 4(a). The suspension distance L on both sides of the chassis indicates that the maximum obstacle width can be passed, and in the design L = 420 mm, as shown in Fig. 4(b).



(a) Side view



(b) Front view

Figure 4 Maximum profile size of the obstacle

The chassis is passively adapted to the terrain, considering the safety of the suspension during travel and the stability of the vehicle body, the angular limit is set at the hinge of the suspension, so that the maximum height of the obstacle that the wheel can over is limited. After safe calculation, the front suspension of chassis can swing at an angle of 33°, at which point the wheel can pass the maximum obstacle height of 180 mm. As shown in Figure 5[9].

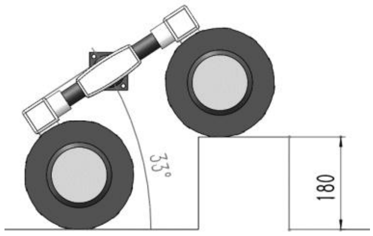


Figure 5 Maximum height of the obstacle can the wheel over

SIMULATION

Draw the 3D model in SolidWorks and generate a *.(x_t) type file, which is then imported into the Recurdyn simulation software. The parameters in the text are used in the simulation process. The parameters are as follows: (1) Mass：M=40kg; (2) Size：L = 820mm, W = 600mm, H = 340mm; (3) Wheel diameter: R = 200mm, Wheel width: B = 60mm; (4) Centroid height: H_m=180mm.

Furthermore, rigid contact between the ground and the wheel is adopted. The maximum static friction coefficient between the wheel and the ground is f_s=0.7, the dynamic friction coefficient is f_d=0.6, the rolling resistance coefficient is f=0.20, and the wheel rotation speed is 0.5 m/s.

Create simulated terrain as shown in Figure 6, including vertical obstacles and single-sided bridge obstacles and slopes. The height of the vertical obstacle is 100mm and 170mm respectively, and the slope angle.

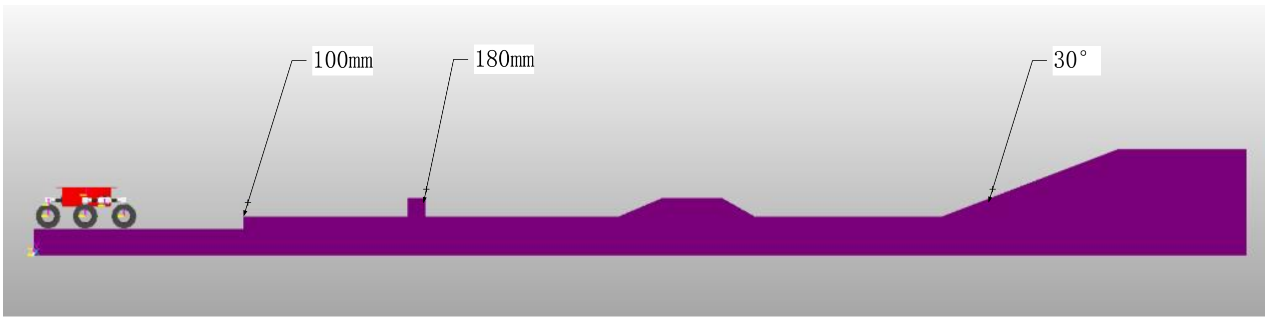


Figure 6 Terrain used in the simulation

Simulation results: The chassis structure has superior performance in terms of passability, and can stably cross the vertical obstacle of 180 mm. After the obstacle of the single side bridge, the vehicle body is slightly offset, and the offset is within the controllable range. The result is shown in Figure 7. The suspension swing angle is analyzed, and the maximum swing angle is less than 33°, which is within the safe range as shown in Figure 8.

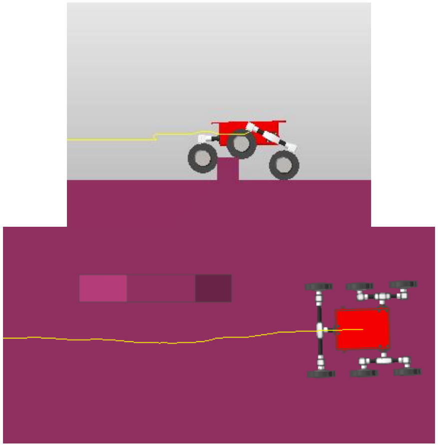


Figure 7 Result of the simulation

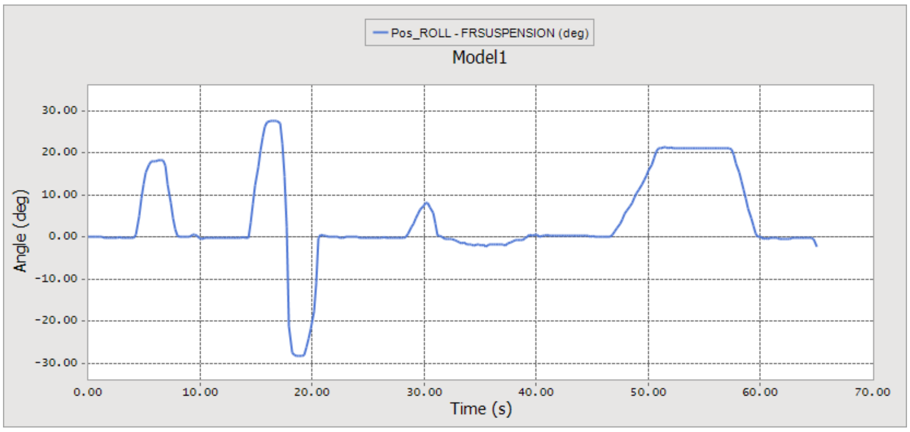


Figure 8 Swing angle of the suspension

CONCLUSIONS

Chassis system design based on the application, according to environmental changes to design a suitable product, combined with the pavement of the tunnel construction site, focus on solving the problem of wheel subsidence and the ability of obstacle. According to the simulation results, the chassis meet the requirements of obstacle and can walk stably on various bumpy roads. The chassis three hinged suspension, with 3 degrees of freedom of space passive adjustment ability, can realize the multi-degree of freedom imitation terrain, effectively avoid the overturning in the process of obstacle. The chassis has three hinged suspensions, with them the chassis can realize multi-degree of freedom to imitate terrain, effectively avoiding overturning during obstacle crossing. By increasing the number and width of the wheels, the subsidence rate on the soft pavement is effectively reduced.

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