Continuous Transient Impact Response Analysis of Drive Axle Housing

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Abstract. Continuous transient impact response analysis of the drive axle housing was performed based on static analysis as the vehicle cross the obstacle. The whole process was divided into four stages. Both the static strength when the vehicle travels at constant speed and continuous transient impact response when the vehicle slowing down, climbing obstacle and falling back to the ground from the obstacle were calculated. The rigidity and strength of the drive axle housing in the whole process were analysed. The results indicate that the drive axle housing has excessive strength but insufficient rigidity. And the result also provides useful reference for optimization design and lightweight of drive axle housing.

1 Introduction

Automotive drive axle housing, as the main carrier of the vehicle, its strength and stiffness related closely to the safety of the vehicle. The traditional design of drive axle housing is mostly based on static analysis considering impact load factor [1-3], or dynamic analysis based on modal analysis and fatigue life analysis [4, 5]. The former focused on safety. And the latter fully considered the relationship between the natural frequency of the structure and the external load frequency so as to avoid the resonance.

In fact, the main causes of the failure of the drive axle housing usually are the impact forces acting on the axle caused by the road roughness [6] and other various complicated conditions such as emergency braking [7]. The stress caused by these dynamic loads usually is many times greater than static stress. The calculation in [7] shows that the stress of the axle housing during emergency braking exceeds the yield limit of the material.

Therefore, the analysis of stress and strain under dynamic load impact of the axle housing can help to improve the reliability of the vehicle. In this article, a drive axle housing used on heavy truck is taken as an example. The finite element method is used to establish the model of the drive axle housing. The steady analysis at constant speed and the continuous transient response at emergency brake deceleration, climbing the obstacle and falling back to the ground were carried out. The stiffness and strength under these complicated conditions were analysed and investigated. The conclusion is helpful for improving the design of drive axle housing and improving the reliability of the vehicle. It also demonstrated the possibility of lightweight of the drive axle housing.

2 Force Analysis of the Drive Axle Housing

The curb parameters of the heavy truck vehicle and material parameters of the drive axle housing were shown in Table 1:

\begin{table}[h]
\centering
\begin{tabular}{|c|c|c|}
\hline
Maximum total design mass & 25000 Kg & Tire diameter \ 0.54 m \\
\hline
Horizontal distance between front axle and mass centre axis & 1.295 m & Centroid height when full loaded \ 1.229 m \\
\hline
Horizontal distance between rear axle and mass centre axle & 1.305 m & Poisson’s ratio \ 0.3 \\
\hline
Elastic modulus & 175 GPa & Yield Strength \ 480 MPa \\
\hline
\end{tabular}
\caption{Curb parameters of the vehicle and material parameters of drive axle housing.}
\end{table}

When a vehicle passes by roadblocks, it can be divided into four stages: driving at constant speed, deceleration, climbing the roadblocks and falling back. Where, according to the different order of the latter two stages, the vehicle can complete a process of cross the obstacles or ditches. In these four stages, driving at constant speed is a steady-state process, while the remaining three stages will experience sharp changes in the impact of short-term load. However, as the speed is low when the car crosses the obstacles or ditches, the relationship between the obstacle height and the vehicle parameters and the load information of the drive axle housing can be obtained by solving the equilibrium equations of statics [8].
2.1 Stage of Driving At Constant Speed

The force that the drive axle bears when the vehicle running at a constant speed in the no wind environment can be calculated by the following equation:

\[ F_2 = G \cdot a/(a+b) \]  

where, \( G \) is the total weight of vehicle suspension, \( a \) is the distance between the mass centre of the vehicle and the centre of the front axle. \( b \) is the distance between the mass centre of the vehicle and the centre of the rear axle.

2.2 Stage of Brake Deceleration

When the vehicle brakes, in addition to the vertical reaction force, the drive wheel is also subject to tangential braking force and braking torque, which attempt to hinder the vehicle from moving forward. If the braking force is large enough, the car can get the maximum braking deceleration as:

\[ \alpha = -k_c \cdot g \]  

The negative sign represents the deceleration, \( k_c \) is the sliding adhesion coefficient of the road, for asphalt or concrete (dry) pavement, it takes 0.75 [8].

The load increment of the rear axle caused by the maximum brake deceleration is:

\[ \Delta F_2 = m \cdot \alpha \cdot H/L \]  

where \( m \) is the total mass of the vehicle. \( H \) is the distance between the mass centre of the vehicle and horizontal road surface. \( L \) is the vehicle wheelbase.

Thus, the maximum braking force in the horizontal direction and the vertical load of the driving axle at the brake stage are \( F_{2x} = (F_2 + \Delta F_2) \cdot k_c \) and \( F_2 + \Delta F_2 \), respectively, the direction of braking force is opposite to the running direction of the vehicle.

2.3 Stage of Climbing Obstacles

When the vehicle encounters obstacles such as steps and ditches, since the speed is low enough, the relationship between the obstacle height and the vehicle parameters can be obtained by using the statics equilibrium equation. For rear axle-driven vehicles, the rear wheel is the key factor that determines the height of the steps that the vehicle can overcome [8]. The maximum height of the steps can be calculated using the following formula:

\[ h_s = 0.5a(1-1/\sqrt{1+k_c^2})D \]  

where \( D \) is the diameter of the rear tire.

The force that the rear wheel of a vehicle borne as it cross the step is shown in Fig. 1, the equilibrium equation set is:

\[ fF_1 + F_2 \cos \alpha - k_c F_2 \sin \alpha = 0 \]
\[ F_1 + F_2 \sin \alpha + k_c F_2 \cos \alpha - G = 0 \]
\[ k_c F_2 D/2 + F_1 L - Gb - fF_1 D/2 = 0 \]  

using the maximum obstacle height calculated from formula (4), the force on the drive axle housing can be obtained.

2.4 Stage of Falling Back From the Obstacle

When the vehicle falls back to ground surface from the obstacle, the driving axle does approximately a free-fall movement, and the time that how long it takes can be calculated according to the obstacle height.

3 FE Model of Drive Axle Housing

When performing the FE analysis of the drive axle housing, some necessary simplifications should be done [1]. In this article, the small holes on the axle housing solid model are ignored. The chamfers and fillets located on the upper surface and outer surface of the leaf springs seat are also ignored since our emphasis is inspect the stiffness and strength of the drive axle housing. However the chamfers and fillets exist in the assembly areas between the spring seat and the drive axle housing are retained. The geometric model and FE model of the drive axle housing constructed based on these simplification are shown in Fig.2. The FE model is locally refined at the spring seat and the connection between semi-axle sleeve and axle housing, since there are chamfers and fillets at these areas.
4 Finite Element Results and Analysis

According to the load handling method mentioned above, the load of the drive axle housing in each stage is calculated. The load is applied to the nodes on the outer surfaces of the axle housing, these surfaces located between the inner and outer bearings on both sides. The constraint is applied to upper surface of the spring seats on both sides. Specifically, the translation of the spring seats in the vehicle traveling direction and the vertical direction, the rotation in the axial direction of the axle housing and the axial translation of the bridge centre node are constrained.

In the process that the vehicle cross the obstacles, the length of time it experiences mainly determined by the deceleration braking stage. During the braking process, the stress and strain of the driving axle housing change obviously as the brake works, which is generally last between 0.2-0.9s [8]. In this paper, three conditions as emergency braking (brake application time 0.2s), normal braking (brake application time 0.5s), and slow braking (brake application time 0.8s) were analysed to examine the stress and deformation characteristic of driving axle housing in the process of overcoming obstacles. When the vehicle is driving at a constant speed, the time integral effect is turned off in the FE analysis to simulate the steady state of the vehicle. In the stage of climbing the obstacle, the load calculated based on the static equilibrium equation is adopted, and the continuous braking time of the three conditions is the same as one minute. In the stage that the vehicle falls back to ground from the obstacle, the three conditions also lasted the same time.

4.1 Strength and Rigidity Analysis

From formula (4), the obstacle height that the vehicle can overcome can be calculated. This paper analyses the stress and deformation characteristics of the drive axle housing when passing the highest obstacle without considering the vehicle's running inertia. Fig. 3 and Fig. 4 show the stress and deformation distribution of the axle housing in the process of crossing obstacles with normal brake.

It can be seen from Fig. 3 that the maximum stress of the drive axle housing is much smaller than the yield stress of 480MPa during the whole process. The maximum stress in the whole process occurs at the end of braking, which is caused by the combination of bending and torsion caused by braking. However, the maximum stress at this time is 174.36MPa, so the safety factor is 480 / 174.36 = 2.753. Compared with the conventional design, the safety factor is still slightly more than that of 2.5. Thus, based on the static analysis of the drive axle housing design, its strength is sufficient.

In addition, it can be seen from Fig. 3 that the maximum stress position of the axle housing changed during the whole process. In the stages of constant speed driving, braking deceleration stage and falling back from obstacles, the maximum stress point of the axle housing occur at the front lower edge of the drive axle housing, and the maximum stress point transferred to the upper edge when climbing the obstacle. This is mainly because that there is no change of the vertical constraint compared to the other load steps when climbing the obstacle. But the value and direction of the load borne by the drive axle housing changed obviously.
Figure 3. Stress distribution cloud at various stages of normal braking.

Figure 4. Deformation distribution cloud at various stages of normal braking.

As can be seen from Fig. 4 that the maximum deformation of the drive axle housing during the entire process reaches 2.76mm, which occurs when the drive axle falls back to the road surface from the obstacle and is located at the outer bearing sleeve of the drive axle housing. The wheelbase of this drive axle is 1.8m, so the maximum wheelbase deformation per meter is 2.76 / 1.8 = 1.53mm / m. This value is slightly exceeding the standard value 1.5mm/m prescribed in the "Automotive drive axle bench test evaluation criteria", the automotive industry standard made by PRC, named QC / T534-1999. So, the rigidity of this drive axle housing is slightly insufficient under continuous impact. Of course, this lack of rigidity is inextricably linked to the simplification of our numerical model. For example, the cancellation of half shaft, the main decelerator and its housing, differential and other devices is bound to reduce the ability to resist the deformation of the drive axle housing, and other reasons as application position of constraints and load will also provide some distribution. In addition, as can be seen from Fig. 4, the maximum deformation point of the drive axle housing changes during the whole process. At the end of the braking deceleration stage, the point of the largest deformation of the driving axle housing changes from one side of the outer of the bearing sleeve to the other side, but the value of deformation is...
reduced after changing to the other side; this is advantageous for the rigidity increase of the axle housing. This is because the left and right geometry of the drive axle housing is not completely symmetrical, so the deformation of the bearing sleeve on both sides of the drive axle housing that under the same constraints and load conditions must be different, which may leads to the change of the maximum deformation point.

4.2 Comparison of Different Brake Process

Fig. 5 shows the time history curve of the maximum stress change of the drive axle housing during emergency braking, normal braking and slow braking.

![Figure 5](image1.png)

*Figure 5. Maximum stress time history curve of driving axle housing at different brake process.*

It can be seen from Fig. 5 that at the end of braking, climbing and falling back, the difference of stress changes in these three conditions is not large. The difference is that in the braking process, the shorter the brake action time, the greater the stress gradient of the axle housing, but the change of the stress gradient has little effect on the safety of the drive axle housing. Braking time only affects the braking distance and driving comfort. The effect on the strength of the drive axle housing is only the shift of the point of maximum stress shown in Fig. 3. However, as the overall safety factor is large, so from the perspective of strength, the axle housing is safe enough.

Fig. 6 shows the time history curve of the maximum deformation of the drive axle housing during emergency braking, normal braking and slow braking.

![Figure 6](image2.png)

*Figure 6. Time history curve of maximum deformation of driving axle housing at different brake process.*

Conclusions

Under the premise of not considering the load impact factor, based on the principle of structural statics, the force analysis of the process of vehicle crossing obstacles is carried out, and the transient dynamic analysis of the drive axle housing under continuous impact is carried out based on this. The results show:

1. The drive axle housing in use has sufficient strength but insufficient rigidity as the vehicle is full loaded. It needs to be further strengthened.
2. The current structural design inspected the intensity more, but sometimes the stiffness is the main factor that restricts the reliability and durability of the structure.
3. From the strength point of view, the heavy truck drive axle housing has a larger margin of safety, and the lack of stiffness can be improved by changing the form and location of the supporting structures. For example, welding the ribs in the appropriate position within the axle housing to add parts that bearing mainly the tension or compression load, thus can make up its ability to resist bending and torsion. Thus thinner steel plate can be used to make the drive axle housing. This provides space for the lightweight design of the drive axle housing, especially with the maturity of high-strength steel thermoforming technology.
4. The continuous transient impact calculation work in this paper is based on the structural static analysis, without considering the impact of kinematic factors. Further analysis, combined with the kinematic principle, will provide more useful reference for the reliability analysis and lightweight of the drive axle housing.

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