Effect of Suspension System Stiffness on Dynamic Load Action Chassis Multi-purpose Forest Fire Fighting Vehicle

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PAPER INFO

Paper history:
Received 01 April 2022
Received in revised 19 April 2022
Accepted 28 April 2022

Keywords
Multimaterial Forest Fire Fighting Vehicle
Suspension System
Dynamic Load
Stiffness

ABSTRACT

Multi-purpose forest fire fighting vehicles include a combination of fire fighting equipment such as a high-pressure water pump, create corridor fire insulation cutting machine, vacuum and high wind speed bowling machine, extinguish the fire sandblast apparatus that is mounted on the URAL 4320 active three axles vehicle. When installing fire fighting equipment on vehicles, increases the load, affecting the vehicle’s load distribution, angularity, and stability. Therefore, to ensure structural rigidity, the suspension system is redesigned to increase rigidity. However, alteration of the suspension stiffness will change the dynamic load acting on the chassis. This research presents the results of research on the influence of suspension stiffness on dynamic loads acting on the chassis of a multi-purpose forest fire fighting vehicle. The survey results showed that an increasing the suspension stiffness will increase the dynamic load acting on the chassis, and reduce the durability of the chassis in particular and the details of the vehicle in general. The research outcomes are the basis for evaluating the working life of the chassis in subsequent studies.


1. INTRODUCTION

According to statistics, Vietnam has about 10 million hectares of natural and planted forests. In the dry season, the potential risk is very high, leading to thousands of forest fires, causing great economic losses, and destroying the ecological environment of the country. The main method of forest fire fighting is to use rudimentary equipment such as hoes, consequently, the effectiveness of forest fire fighting is not high [1]. The multi-purpose forest fire fighting vehicle manufactured by Vietnam has improved the effectiveness of forest fire fighting, meeting the requirements in the process of fighting forest fires deep, far from water sources and residential areas (Figure 1). When designing and installing forest firefighting equipment on the vehicle, the vehicle's load increases, so the stiffness of the suspension must be increased so that the vehicle does not bevel compared to the original design. However, when changing the suspension stiffness, will affect the dynamic load acting on the chassis and other details on the vehicle, affecting the durability and working life of the part [1-4].

Automobile loads were studied in early automobile vibration research with the aim of reducing dynamic loads, and improving the destructive strength and long-term durability of automobile assemblies and components [5]. When the car moves on the road, there will be dynamic loads that destroy the road [6, 7], on the contrary, the road surface also reacts, causing dynamic loads to increase, tires to be worn, and dynamic safety is lost [8, 9].

When operating, the driver controls the vehicle by 3 actions: acting on the accelerator, brake, and steering wheel; the parameters shown are longitudinal acceleration, horizontal and vertical accelerations. Together with the weight of the vehicle, the above accelerations act on the wheel vertically through the suspension. From the roadside, activation by the bumpy road will cause the wheel to oscillate vertically, generating a dynamic load [5]. The maximum dynamic load will affect the breaking strength, cyclic dynamic loads will affect fatigue life. Dynamic load depends on

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Vehicle structure including suspension stiffness, tire stiffness, influence from the roadside, and vehicle speed [10-12]. In order to reduce the dynamic load acting on the car, there are two research directions, namely the study of the suspension system and the study of the influence of the road. The investigation on the influence of suspension stiffness was studied by the authors [13-16]. Dynamic load studies of multi-purpose forest fire fighting vehicles with research work have experimented to determine the dynamic load when the vehicle goes through the bump [17]. Other research works mainly on conventional vehicles. After being designed, the vehicle's load increases [1]; so to ensure rigidity, the suspension system is designed to increase rigidity to prevent the vehicle from tilting when fully loaded. When changing the suspension stiffness will affect the dynamic load acting on the chassis. Therefore, it is necessary to determine the dynamic load when the vehicle is working in order to serve as a scientific basis for completing the structure of the multi-purpose forest fire fighting vehicle.

2. RESEARCH CONTENT

2.1 Build a Multi-purpose Forest Fire Fighting Vehicle Model

Applying the object separation method, we build a mechanical model of the vehicle. The objects on the vehicle are defined as follows: Object 1 consists of masses that are not suspended on the front axle, symbol \( m_1 \); object 2 consists of masses that are not suspended on the middle axle, symbol \( m_2 \); object 3 consists of masses that are not suspended on the rear axle, symbol \( m_3 \); Object 4 is a vehicle with a mass equal to \( m_4 \), moments of inertia \( I_{4zx} \) and \( I_{4zy} \); Object 5 is a driving water pump with a mass equivalent to \( m_5 \), moments of inertia \( I_{5zx} \), \( I_{5zy} \); Object 6 is a fire sprinkler with a mass equivalent to \( m_6 \), moments of inertia \( I_{6zx} \), \( I_{6zy} \); Object 7 includes the masses of the front tree cutting devices, symbol \( m_7 \); Item 8 includes the mass of the grass cleaning equipment, symbol \( m_8 \); Object 9 includes the masses of sandblasting hoe equipment, symbol \( m_9 \); Object 0 is the line (background object).

To build the model, we have the following assumptions:
- The mass of the car is distributed symmetrically about the longitudinal plane;
- Since vehicles operating on hilly roads with large undulations are the main sources of oscillation excitation, the excitation source from the engine should be ignored;
- Ignore collisions with the elastic lugs of the suspension and wheel separation of the tires.

From the above analysis and construction of vehicle design drawings, we determine the parameters of the model including:

\[ C_{IL}; C_{IR}; C_{2L}; C_{2R}; C_{3L}; C_{3R}; \] stiffness of the left and right tires of the front, middle and rear axles;
\[ C_{4L}; C_{4R}; C_{5L}; C_{5R}; C_{6L}; C_{6R}; \] stiffness of left and right suspension elastic of the front, middle and rear axles;
\[ C_{7L}; C_{7R}; C_{8L}; C_{8R}; \] stiffness of the left and right elastomers of the front and rear racks;
\[ K_{9L}; K_{9R}; K_{10L}; K_{10R}; K_{11}; \] drag coefficient of left and right tires of the front, middle and rear axles;
\[ K_{12L}; K_{12R}; K_{13L}; K_{13R}; K_{14L}; K_{14R}; \] drag coefficient of left and right suspension elastic of the front, middle and rear axles;
\[ K_{15L}; K_{15R}; K_{16L}; K_{16R}; \] drag coefficient of left and right front and rear axles;
Figure 3. Multi-purpose forest fire fighting vehicle model: 1. Chassis of the vehicle; 2. Front axle; 3. Middle axle; 4. Rear axle; 5. Water pump for fire fighting; 6. Fire sprinkler; 7. Tree cutting structure creates a white corridor; 8. Lawn cleaning machine clears the way

$q_{1L}; q_{1R}; q_{2L}; q_{2R}; q_{3L}; q_{3R}$: left and right road profiles at the front, middle, and rear wheel; 

$M_{ct1}$: Torque of water pump components and sprinklers; 

$M_{ct2}$: Resistance moment of white tape cutter components; 

$M_{ct3}$: Resistance torque of rear lawn mower components; 

$M_{ct4}$: Resistance moment of sand-generating equipment components.

$l_{1}, l_{2}$: Distance from the center of the vehicle to the center of the front axle and the connection point between the rear springs and the chassis. 

$l_{3}, l_{4}$: Distance from the connection point between the rear springs and the chassis to the center of the middle and the rear axle.

2. 2. Set up the System of Equations to Balance the Force on the Vehicle
Applying Dalambe’s principle to each body whose origin is at the object’s static equilibrium position, we have:

2. 2. 1. For the Front Axle
The model of separation of objects on the front axle is depicted in Figure 4. Matlab Simulink is applied to solve the front axle force balance equation, the diagram is shown in Figure 5. Matlab Simulink is also applied to solve the force balance equation to determine the dynamic load acting on the chassis through the suspension system (Figure 6).

\[
m_{y1} \ddot{z}_{y1} = -F_{z1L} - F_{z1R} + F_{z4L} + F_{z4R}
\]

\[
I_{y2} \ddot{\phi}_{y2} = (-F_{z1L} + F_{z1R})d_1 + (-F_{z4L} + F_{z4R})d_4
\]
balance equation to determine the dynamic load acting on the chassis through the suspension system (Figure 7).

\[
m_2 \ddot{z}_2 = -F_{z2L} - F_{z2R} + F_{z5L} + F_{z5R}
\]

(3)

\[
I_{z2} \ddot{\phi}_{z2} = (-F_{z2L} + F_{z2R}) \dot{z}_2 + (-F_{z5L} + F_{z5R}) \dot{d}_1
\]

(4)

2.2.3. For the Rear Axle  The model of separation of objects on the rear axle is depicted in Figure 8. Matlab Simulink is applied to solve the force balance equation to determine the dynamic load acting on the chassis through the suspension system (Figure 9).

\[
m_3 \ddot{z}_3 = -F_{z3L} - F_{z3R} + F_{z6L} + F_{z6R}
\]

(5)

\[
I_{z3} \ddot{\phi}_{z3} = (-F_{z3L} + F_{z3R}) \dot{z}_3 + (-F_{z6L} + F_{z6R}) \dot{d}_6
\]

(6)

2.2.4. For Vehicle  Similarly, we can build the object separation model for the vehicle and build the vehicle's force balance equations.

\[
m_4 \ddot{z}_4 = -F_{z4L} - F_{z4R} + F_{z7L} + F_{z7R} + F_{z8L} + F_{z8R}
\]

(7)

\[
I_{z4} \ddot{\phi}_{z4} = (F_{z4L} + F_{z4R}) \dot{z}_4 + (F_{z7L} + F_{z7R}) \dot{l}_t + (F_{z8L} + F_{z8R}) \dot{l}_s
\]

(8)

\[
I_{z4} \ddot{\phi}_{z4} = (F_{z4L} - F_{z4R}) \dot{d}_4 + (F_{z7L} - F_{z7R}) \dot{d}_7 + (F_{z8L} - F_{z8R}) \dot{d}_7
\]

(9)

2.2.5. For Water Pump Drive  Similarly, we can build the object separation model for water pump drive and build the vehicle's force balance equations.

\[
m_5 \ddot{z}_5 = -F_{z5L} - F_{z5R} + F_{z9}
\]

(10)

\[
I_{z5} \ddot{\phi}_{z5} = (F_{z5L} + F_{z5R}) \dot{d}_5 + (F_{z7L} + F_{z7R}) \dot{l}_t + (F_{z9}) \dot{l}_9
\]

(11)

\[
I_{z5} \ddot{\phi}_{z5} = (F_{z5L} - F_{z5R}) \dot{d}_6 + M_{z5}
\]

(12)

2.2.6. For Sprinklers  Similarly, we can build the object separation model for sprinklers and build the vehicle's force balance equations.

\[
m_6 \ddot{z}_6 = F_{z6L} + F_{z6R} + F_{z10}
\]

(13)

\[
I_{z6} \ddot{\phi}_{z6} = (F_{z6L} + F_{z6R}) \dot{l}_1 + (F_{z10}) \dot{l}_1
\]

(14)

\[
I_{z6} \ddot{\phi}_{z6} = (F_{z6L} + F_{z6R}) \dot{d}_7
\]

(15)

2.3. Surveying The Force Balance Model on a Multi-purpse Forest Fire Fighting Vehicle

2.3.1. Determine the Parameters of the Model

The parameters of the vehicle model are summarized in Table 1 [1, 4].
TABLE 1. Parameters of multi-purpose forest fire fighting vehicle

<table>
<thead>
<tr>
<th>Order</th>
<th>Technical Symbol</th>
<th>Technical Symbol</th>
<th>Unit</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Front axle mass</td>
<td>( m_1 )</td>
<td>kg</td>
<td>1020</td>
</tr>
<tr>
<td>2</td>
<td>Middle axle mass</td>
<td>( m_2 )</td>
<td>kg</td>
<td>1000</td>
</tr>
<tr>
<td>3</td>
<td>Rear axle mass</td>
<td>( m_3 )</td>
<td>kg</td>
<td>1000</td>
</tr>
<tr>
<td>4</td>
<td>Vehicle mass</td>
<td>( m_4 )</td>
<td>kg</td>
<td>5800</td>
</tr>
<tr>
<td>5</td>
<td>Water pump mass</td>
<td>( m_5 )</td>
<td>kg</td>
<td>250</td>
</tr>
<tr>
<td>6</td>
<td>Fire sprinkler mass</td>
<td>( m_6 )</td>
<td>kg</td>
<td>1500</td>
</tr>
<tr>
<td>7</td>
<td>Stiffness of front wheel tire</td>
<td>( C_{L1} )</td>
<td>N/m</td>
<td>569964</td>
</tr>
<tr>
<td>8</td>
<td>Stiffness of middle wheel tire</td>
<td>( C_{L2} )</td>
<td>N/m</td>
<td>569964</td>
</tr>
<tr>
<td>9</td>
<td>Stiffness of rear wheel tire</td>
<td>( C_{L3} )</td>
<td>N/m</td>
<td>569964</td>
</tr>
<tr>
<td>10</td>
<td>Damping coefficient of front wheel tire</td>
<td>( K_{L1} )</td>
<td>N.s/m</td>
<td>6497</td>
</tr>
<tr>
<td>11</td>
<td>Damping coefficient of middle wheel tire</td>
<td>( K_{L2} )</td>
<td>N.s/m</td>
<td>6497</td>
</tr>
<tr>
<td>12</td>
<td>Damping coefficient of rear wheel tire</td>
<td>( K_{L3} )</td>
<td>N.s/m</td>
<td>6497</td>
</tr>
<tr>
<td>13</td>
<td>The stiffness of front axle suspension without changing stiffness</td>
<td>( C_{AB} )</td>
<td>N/m</td>
<td>203000</td>
</tr>
<tr>
<td>14</td>
<td>The stiffness of middle axle suspension without change stiffness</td>
<td>( C_{AB} )</td>
<td>N/m</td>
<td>322000</td>
</tr>
<tr>
<td>15</td>
<td>The stiffness of rear axle suspension without changing stiffness</td>
<td>( C_{AB} )</td>
<td>N/m</td>
<td>322000</td>
</tr>
<tr>
<td>16</td>
<td>The stiffness of front axle suspension with change stiffness</td>
<td>( C_{AB} )</td>
<td>N/m</td>
<td>401952</td>
</tr>
<tr>
<td>17</td>
<td>The stiffness of middle axle suspension with change stiffness</td>
<td>( C_{AB} )</td>
<td>N/m</td>
<td>527042</td>
</tr>
<tr>
<td>18</td>
<td>The stiffness of rear axle suspension with change stiffness</td>
<td>( C_{AB} )</td>
<td>N/m</td>
<td>527042</td>
</tr>
<tr>
<td>19</td>
<td>Damping coefficient of the front axle</td>
<td>( K_4 )</td>
<td>N.s/m</td>
<td>18900</td>
</tr>
<tr>
<td>20</td>
<td>Damping coefficient of the middle axle</td>
<td>( K_4 )</td>
<td>N.s/m</td>
<td>18900</td>
</tr>
<tr>
<td>21</td>
<td>Damping coefficient of the rear axle</td>
<td>( K_4 )</td>
<td>N.s/m</td>
<td>18900</td>
</tr>
<tr>
<td>22</td>
<td>The stiffness of the front bearing</td>
<td>( C_7 )</td>
<td>N/m</td>
<td>203000</td>
</tr>
<tr>
<td>23</td>
<td>The stiffness of the rear bearing</td>
<td>( C_4 )</td>
<td>N/m</td>
<td>203000</td>
</tr>
<tr>
<td>24</td>
<td>Damping coefficient of the front bearing</td>
<td>( K_7 )</td>
<td>N.s/m</td>
<td>18900</td>
</tr>
<tr>
<td>25</td>
<td>Damping coefficient of the rear bearing</td>
<td>( K_7 )</td>
<td>N.s/m</td>
<td>18900</td>
</tr>
</tbody>
</table>

2. 3.2. Determining the Forest Ground Bump

The purpose of determining the forest ground bump is to serve as an input parameter to determine the dynamic load acting on the chassis. To determine the bump of the forest ground, we must carry out a test. The method of determination is to use the number 2 wheel with an accelerometer sensor to determine the acceleration, then use Dasylab 5.0 software to determine the forest ground elevation.

In order to be able to accurately determine the position of the bumps according to the contour, a Kistler accelerometer must be used, speed sensor \( V_1 \), the device that receives and processes measurement data is a computer DEWETRON 3000. During the movement, the vehicle will pull wheel No. 2 rolling on the forest ground, the wheel axle will record the correct forest ground profile and the Kistler sensor will record the acceleration value and transfer it to the computer for processing. Constantaneous with the signal of the accelerometer sensor is a signal from the sensor from \( V_1 \) to measure the actual moving speed of the vehicle. Thus, at the specified location of the forest ground profile, the bumpy height at that location can be determined.

2. 3.3. Survey Results of Dynamic Load Assessment

Using Matlab Simulink, we survey and determine the force acting on the chassis when the vehicle moves on the forest ground.

Figure 10. Describe the diagram to determine the bump on the forest ground. 1- Forest ground; 2- wheel 2; 3- Kistler sensor mounting position; 4- link bar; 5- spring; 6- car mount

Figure 11. Measurement of forest ground bump
vehicle moves on the forest road at different moving speeds. In this survey, the author investigates the corresponding suspension stiffness of the base vehicle and the suspension stiffness when it is designed into a forest fire truck to evaluate the dynamic load change. Due to the working characteristics of forest fire trucks with low travel speed [1], the speed of survey vehicles is from 10 km/h to 20 km/h.

When the vehicle is in motion, due to the excitation force of the road surface contour, the dynamic load is applied to the chassis as described in Figures 15 and 16. With a vehicle speed of 10 km/h, the value of the dynamic load acting on the chassis is relatively equal when the suspension stiffness changes. Without changing the suspension stiffness, the maximum dynamic load value on the rear axle is 54833 N, when changing the suspension stiffness, the maximum dynamic load on the rear axle is 58383 N. The maximum dynamic load value when increasing the stiffness is 1.06 times higher than when the hardness is not changed.

When the vehicle speed increases, the excitation force from the road surface causes an increase in dynamic load, making the value of the dynamic load acting on the chassis also increase compared to the case of the vehicle traveling at 10 km/h, described in Figures 16 and 17. With a vehicle speed of 15 km/h, without changing the suspension stiffness, the maximum dynamic load value on the rear axle is 55873 N, with changing the suspension stiffness, the maximum dynamic load on the rear axle is 61912 N. The maximum dynamic load value when increasing the stiffness 1.08 times compared to the original suspension stiffness.
When the fire fighting vehicle moves at a speed of 20 km/h, without changing the suspension stiffness, the maximum dynamic load value on the rear axle is 58015 N, with changing the suspension stiffness, the maximum dynamic load value on the rear axle is 62225 N. The maximum dynamic load value when increasing the stiffness 1.07 times compared to the original suspension stiffness. The maximum dynamic load acting the chassis without changing and changing the suspension stiffness is summarized in Table 2.

Figures 20 and 21 describe the maximum dynamic load value acting on the chassis at the front and rear axles. The results show that when increasing the suspension stiffness and vehicle movement speed, the dynamic load increases, which is consistent with the laws of physics.

**TABLE 2.** Maximum dynamic load acting the chassis without changing and changing the suspension stiffness

<table>
<thead>
<tr>
<th>Vehicle speed</th>
<th>$C_{1A} = 203000$</th>
<th>$C_{2A} = 322000$</th>
<th>$C_{1B} = 401952$</th>
<th>$C_{2B} = 527042$</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 km/h</td>
<td>31960</td>
<td>34109</td>
<td>54833</td>
<td>58383</td>
</tr>
<tr>
<td>15 km/h</td>
<td>32603</td>
<td>35654</td>
<td>55873</td>
<td>61912</td>
</tr>
<tr>
<td>20 km/h</td>
<td>33405</td>
<td>36251</td>
<td>58016</td>
<td>62225</td>
</tr>
</tbody>
</table>
3. CONCLUSION

The base vehicle URAL 4320 vehicle with permissible payload according to the manufacturer's design is used to make a multi-purpose forest fire truck with enhanced payload, operating on forestry roads with complex terrain. The calculation to determine the force acting on the frame close to the base car to ensure durability when converting the vehicle's features is necessary. The content of the study used the method of separation of objects according to Dalambe's principle and build force balance equations and apply Matlab Simulink to solve. The study will be expanded to fully investigate the operating conditions of the vehicle corresponding to the installation of fire fighting equipment with more uses to improve the effectiveness of forest fire fighting.

4. REFERENCES

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Persian Abstract

ویژگی تلفیق آتش نشانی جکفی چند منظوره شامل تجهیزات آتش نشانی مانند پمپ آب فشار قوی، ایجاد دستگاه برش عایق را در راه انداخته است. با این حال، تغییر سفتی سیستم تعلیق باعث افزایش بار دینامیکی وارد بر شاسی و کاهش بار دینامیکی یک چهارد وارد بر شاسی و کاهش دوام شاسی به طور خاص و جزئیات خودرو به طور کلی می شود. نتایج بررسی نشان می دهد که افزایش سختی سیستم تعلیق باعث تغییر موارد و نتایج دارد که افزایش سختی سیستم تعلیق باعث تغییر موارد و نتایج دارد. نتایج بررسی نشان می دهد که افزایش سختی سیستم تعلیق باعث تغییر موارد و نتایج دارد. نتایج بررسی نشان می دهد که افزایش سختی سیستم تعلیق باعث تغییر موارد و نتایج دارد.