Assessment on Effect of Load Frequency to Durability of Chassis of the Multi-Purpose Forest Fire Fighting Vehicle

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Abstract
Chassis is the main structural component of the automobile; it is subject to any damage due to fatigue or destruction during the operation of the automobile. Therefore, it is important to research and assess the durability of the chassis. In particular, studying the effect of load frequency on chassis durability is very important in the assessment of chassis durability. An objective of this study was to investigate the effect of load frequency, from the road surface and engine to chassis durability when the multi-purpose forest fire fighting vehicle operates in some cases when moving on the road. The assessment of the effect of load frequency on the chassis durability of the multi-purpose forest fire fighting vehicle contributes to input parameters for the determination and assessment of fatigue problem and breaking strength of the chassis.

Keywords: Chassis, load frequency, multi-purpose forest fire fighting vehicle, chassis durability

1. Introduction
The multi-purpose forest fire-fighting vehicle is manufactured by Vietnam and has been considered as one type of equipment in integrating many forest fire fighting functions. Their major functions include cutting trees, cleaning garbage grass, opening roads to create a fire isolation corridor; and using at firing sprinkler with wide spray area; creating high-pressure wind spray on the fire. Also, this vehicle uses sandy soil in place of fire extinguishing and is based on the basis of URAL 4320 vehicles. One of the main obstacles is vibrations can cause high-stress concentration resonance on the frame destruction structure or may cause fatigue on the frame during operation.
a) Base vehicle Ural 4320  

b) Multifunction forest fire fighting was built

**Figure 1.** Multi-purpose forest fire fighting vehicle

The main equipment of multifunction forest fire fighting vehicle is shown in Figure 2 [11].

![Diagram](image.png)

1) Tree cutting mechanism; 2) Tree cleaver; 3) Body; 4) Water sprayer; 5) Seat; 6) Cabin; 7) Water tank; 8) Back cover; 9) Pipe; 10) Table; 11) Ploting small nozzle; 12) Floorboard; 13) Dig system; 14) Lawn cutting mechanism.

**Figure 2.** General design multifunction forest fire fighting vehicle

**Table 1.** Specification of multifunction forest fire fighting vehicle

| Order | Specification                              | Unit            | Value   |
|-------|--------------------------------------------|-----------------|---------|
| 1     | Power                                      | Hp              | 180     |
| 2     | Fire extinction speed                      | meter/minute    | 12      |
| 3     | Flame height is extinguished               | m               | 9       |
| 4     | Translational speed                        | km/h            | 25      |
| 5     | Longitudinal grade vehicle works           | degree          | < 15°   |
| 6     | Cross slope vehicle works                  | degree          | ≤ 5°    |
| 7     | Empty weight                               | kg              | 17.230  |
| 8     | Full weight                                | kg              | 12.130  |
| 9     | Container capacity water                   | m³              | 5.1     |
| 10    | Pump delivery                              | m³/h            | 10      |
| 11    | Length of intake water                     | m               | 300     |
Studies of the fluctuation of automobile chassis show the importance of the fluctuation of automobile chassis. For example, the durability of the chassis can contribute to ensuring passive safety and can improve the life of the chassis. The chassis is of interest because it is a system of beams that plays the role of receiving and transmitting reacting force during the operation of automobiles with different road conditions. In addition, the chassis is also influenced by vibrations from engines and power train. A primary concern of chassis is the vibration of car-mounted detail assemblies can cause fatigue at installation locations. A considerable amount of literature has been published on the durability of frames in static and dynamic problems. No previous study has investigated the effect of frequencies of external forces on the frame strength [3, 4, 9, and 10]. Currently, there are no data on the durability of the frame to prevent forest fire engines under the influence of frequency according to the method of theoretical testing by software. The importance and originality of this study are that it contributes to assessing the influence of frequency to the durability of light truck frames in particular and the scientific basis in the process of completing the design of forest fire engines.

2. Building models

2.1. Building a chassis model

Traditionally, chassis of multi-purpose forest fire fighting vehicle model has been built by Solidworks software according to the actual size of the chassis. The chassis is made of 40CR steel material with a specific weight 7850 kg/m³, modulus 205 GPa, tensile strength 980 Mpa. The yield point is at 785 Mpa.

![Figure 3. A 3D chassis model](image1)

![Figure 4. A finite element model](image2)

In this study, the authors have simplified the actual geometric structure elements without affecting the results of the problem such as holes and removed studs. To identify longitudinal beams and cross beams with absolute rigidity, welds of cross beams with longitudinal beams were not included. For analysis of entire load of engine, cargo boxes are distributed on the surface of the chassis.

2.2. Building finite element model

The construction of finite element model was used in designing and analyzing problems. The meshing process of the chassis model used in this study is based on the structural characteristics of the frame and the lower model control criteria of ANSYS software [1, 2, and 8]. Using of this process is useful in determining the accuracy of finite element model used.

To reduce the problem size and to increase accuracy for finite element model while still ensuring computational time, hexahedral elements with 20 nodes (Hex 20) and tetrahedral elements with 10 nodes were used (see Tet 10). As can be seen from Figure 4, the finite element model of multi-purpose forest fire fighting vehicle chassis comprises of 174223 elements, 376982 nudes and average element quality that reaches 0.725.
3. Analyze results

3.1. Chassis's own vibrations

The chassis's own vibration analysis is a linear analysis method to determine the frame's own vibration frequency [4, 5]. Determine the specific vibration frequency of the chassis to avoid resonance occurs. Therefore, the determination of the frame's own vibration frequency is the basic math in the design process. In the separate oscillation analysis, when the mass matrix [M] and stiffness matrix [K] constant, there is no value in weighting on the chassis.

In this study, the linear analysis method was used to investigate the frame's vibration frequency [4,5]. To avoid the resonance, the specific vibration frequency of the chassis was used. For designing a basic math process, the determination of the frame's vibration frequency was used.

\[
[M]\{u\}+[K]\{u\}=0
\]  

(1)

Table 1 provides the results of the analysis of the mode of vibration and mode of the frame's vibration by Ansys software.

| Mode | Frequency (Hz) | Total Deformation (mm) | Mode | Frequency (Hz) | Total Deformation (mm) |
|------|----------------|------------------------|------|----------------|------------------------|
| 1    | 17,812         | 3,4996                 | 11   | 100,58        | 4,6058                 |
| 2    | 31,436         | 2,4011                 | 12   | 103,55        | 8,8978                 |
| 3    | 54,127         | 4,1007                 | 13   | 111,42        | 13,564                 |
| 4    | 63,506         | 2,347                  | 14   | 114,53        | 2,8216                 |
| 5    | 64,404         | 4,5987                 | 15   | 115,75        | 14,297                 |
| 6    | 76,248         | 5,0434                 | 16   | 124,61        | 6,1435                 |
| 7    | 77,961         | 4,4542                 | 17   | 129,88        | 6,6524                 |
| 8    | 82,337         | 3,3608                 | 18   | 133,73        | 6,9162                 |
| 9    | 98,081         | 3,1975                 | 19   | 138,64        | 15,304                 |
| 10   | 100,21         | 3,2097                 | 20   | 140,1         | 14,795                 |

Table 2. The form and frequency of individual vibration of multi-purpose forest fire fighting vehicle chassis

The result of the analysis of table 2 shows the chassis fluctuates with 20 different modes of vibration from 0 to 82 Hz. At the initial frequencies, the chassis is mainly bending in the Y direction. Strong vibrations occur only at node 3 onwards. The table above illustrates the large displacement value appears only in some modes. However, this displacement only occurs in horizontal bars.
3.2. Influence of road surface bumps to vibrating chassis

The analysis of random vibration [6] was used to determine the parameters of the frame structure such as deviation, displacement, velocity, acceleration. This study also involves the response of the frame model to vibration and fatigue life structure.

Regarding random vibration analysis, the current study found that Ansys uses energy spectra or Power Spectral Density (henceforth PSD) to determine the reaction of the frame structure with the stimuli of the external force acting at random frequencies. Further analysis showed that the average value of the probability data can be distributed by Gaussian. Spatial frequency \( n \) is calculated by the number of cycles per meter of the road (cycle/m). The line profile is a variation of the bumping height along the longitudinal axis of the road. PSD is the energy spectral density function of the bumping height of the pavement calculated by frequency \( n \) or angular frequency \( \Omega \):

\[
G_d(n) = G_d(n_0) \left( \frac{n}{n_0} \right)^w \quad \text{or} \quad G_d(\Omega) = G_d(\Omega_0) \left( \frac{\Omega}{\Omega_0} \right)^w
\]  

(2)

The \( n \) is for spatial frequency (cycle/m). The symbol \( n_0 \) is the reference value of \( n \) (taken \( n_0 = 0.1 \) cycle/m). The \( G_d(n_0) \) is the frequency spectrum at the frequency number \( n_0 \) (taken according to table 2). The symbol \( \Omega \) is an angular frequency (rad/m), \( \Omega_0 = 1 \) rad/m. To calculate the types of motor road, \( w \) index is usually chosen by 2.

ISO 8608: 1995 distinguishes the types of roads (streets, highways and non-road terrain) according to the energy spectrum density. It is also divided into eight categories with conventional symbols from A to H. The letter A is the best quality road surface type, the next letters describe the poor quality sugar and the last letter H is the worst road condition.
Further analysis revealed that the chassis is a structure subjected to complex forces with random fluctuations when traveling on uneven roads. In addition, the chassis is subjected to random vibrations of the engine during operation, powertrain and wheel axles. The chassis during operation is affected by many vibrations so that the random vibration analysis uses the power spectral density with the values determined according to the standard in ISO 8608: 1995 [7] with test speed at 20 km/h and type of D-E and E-F.

| Type of road | Parameters describing bumpy space frequency, n | $G_d(n_0)\ [10^{-6}\ m^3]$ | $n_0 = 0.1$ cycle/m |
|--------------|---------------------------------------------|-----------------|----------------|
| A – B        | $k$ - 3                                     | Min 24          | Max 25         |
| B – C        | $k$ - 4                                     | 25              | 26             |
| C – D        | $k$ - 5                                     | 27              | 28             |
| D – E        | $k$ - 6                                     | 29              | 210            |
| E – F        | $k$ - 7                                     | 211             | 213            |
| F - G        | $k$ - 8                                     | 213             | 214            |
| G - H        | $k$ - 9                                     | 215             | 216            |
| H +          | --                                         | 217             | --             |

During the calculation process when the vehicle moves, the energy density value is changed according to the formula.

$$ f = v n_c \quad \text{and} \quad G_d(f) = \frac{G_d(n_c)}{v} \quad (3) $$

Consider the road E-F, power spectral density space and random load density according to frequency available:

| Type of road | Parameters describing bumpy space frequency, n | $G_d(n_0)\ [10^{-6}\ m^3]$ | $n_0 = 0.1$ cycle/m |
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Further analysis revealed that the chassis is a structure subjected to complex forces with random fluctuations when traveling on uneven roads. In addition, the chassis is subjected to random vibrations of the engine during operation, powertrain and wheel axles. The chassis during operation is affected by many vibrations so that the random vibration analysis uses the power spectral density with the values determined according to the standard in ISO 8608: 1995 [7] with test speed at 20 km/h and type of D-E and E-F.

Table 4. Power spectral density in D-E road space

| $n_c/m^1$ | 0.125 | 0.25 | 0.5 | 1   | 2   | 4   | 8 |
|------------|-------|------|-----|-----|-----|-----|---|
| $G_d(n_c)/10^{-6}\ m^3$ | 134,4 | 33,6 | 8,4 | 2,1 | 0,525 | 0,13125 | 0 |

Table 5. Random load density according to D-E road frequency

| $f/Hz$   | 0.6944 | 1,3888 | 2,7777 | 5,5555 | 11,111 | 22,222 | 44,444 |
|----------|--------|--------|--------|--------|--------|--------|--------|
| $G_d(f)\ [10^{-6}\ (m^3/Hz)]$ | 24,192 | 6,048 | 1,512 | 0,378 | 0,0945 | 0,023625 | 0 |

During the calculation process when the vehicle moves, the energy density value is changed according to the formula.

$$ f = v n_c \quad \text{and} \quad G_d(f) = \frac{G_d(n_c)}{v} \quad (3) $$

Consider the road E-F, power spectral density space and random load density according to frequency available:

Table 6. Power spectral density in E-F road space

| $n_c/m^1$ | 0.125 | 0.25 | 0.5 | 1 | 2 | 4 | 8 |
|------------|-------|------|-----|---|---|---|---|
| $G_d(n_c)/10^{-6}\ m^3$ | 134,4 | 33,6 | 8,4 | 2,1 | 0,525 | 0,13125 | 0 |

Table 7. Random load density according to E-F road frequency

| $f/Hz$   | 0.6944 | 1,3888 | 2,7777 | 5,5555 | 11,111 | 22,222 | 44,444 |
|----------|--------|--------|--------|--------|--------|--------|--------|
| $G_d(f)\ [10^{-6}\ (m^3/Hz)]$ | 24,192 | 6,048 | 1,512 | 0,378 | 0,0945 | 0,023625 | 0 |
The present results of random vibration calculations are analyzed on Ansys. The change in velocity and acceleration according to the frequency are shown in Figures 9 to 12.

**Figure 9.** Speed change according to frequency in road D-E

**Figure 10.** Acceleration change according to frequency in road D-E

**Figure 11.** Speed change according to frequency in road E-F

**Figure 12.** Acceleration change according to frequency in road E-F

The analysis results show that on D-E and E-F lines when the vehicle moves at 20 km/h, the change in speed and acceleration according to the largest frequency appears at 24, 42 Hz. It seems possible that these results are due to the chassis is not resonated when traveling on the D-E and E-F lines at a speed of 20 km/h. A possible explanation for these results may be the largest oscillator frequency value are outside the individual oscillator of the frame.
4. Conclusion

This study set out to present the influence of the frequency of some external forces to stimulate the durability of multi-purpose forest fire fighting frame in some practical working conditions. The present study was designed to study of durability and design of a part assembly. The empirical findings in this study provide a new understanding of the effect of other detail clusters on the chassis such as powertrain and engine assemblies, and to extend our knowledge of evaluation of the oscillation and frame durability.

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