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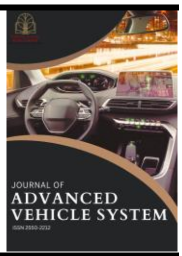

Eigenfrequency Analysis of Railway Vehicle Leafsprings Suspension using Finite Element Method

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ABSTRACT

The vehicle system in general is very concerned with the comfort and safety of the driver. One of the determining criteria for vehicle safety is the use of a good suspension system. The vehicle suspension system being investigated in this work is a railway car which is a modification of the TATA ACE EX-2 pickup vehicle. Based on the modification of pickup vehicles, the trajectory of pickup vehicle specifications varies, so it is necessary to pay attention before and after modification, as well as high vibrations. In this study, the researcher used manual mathematical calculations and the finite element method with his SOLIDWORKS software to perform a quantitative analysis of leaf spring suspension systems for track-finding vehicles. Based on the results of vibration testing conducted, it is known that the frequency that occurs is 4.27 Hz, but the simulation results show that the frequency of the front leaf springs is 199.67 Hz, 351.18 Hz, 356.91 Hz, 648, and 57 Hz. This shows that it varies between 739.42 is hertz. The rear leaf spring frequencies are 206.83 Hz, 286.4 Hz, 346.05 Hz, 636.33 Hz, and 715.68 Hz. This means that no destructive resonance occurs in the leaf springs.

1. Introduction

The transportation system in general is very concerned about the comfort and safety of the rider. One that supports this is the application of a good suspension system, the suspension system functions to absorb surprises, vibrations, swings, and shocks received by vehicles when crossing the bumpy, hole and uneven roads [1]. The suspension system itself consists of spring components and damping components located between the body and the wheels [2]. The spring components in the suspension system have relatively low stiffness compared to normal rigidity, making it possible to accept the force imposed on them according to a certain level [3]. The main function of the spring components in the suspension system is to provide a reflection value due to the load received so as to provide comfort [4].

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The suspension system of the vehicle studied in this study is a railroad patrol vehicle which is the result of a modification of the TATA type ACE EX-2 pick-up vehicle shown in Figure 1. The suspension system on the car is a leaf spring suspension.

Fig. 1. Railway patrol vehicle

Based on the modification of the pick-up vehicle, it is necessary to conduct a study because of differences in the trajectory of the pick-up vehicle specifications before being modified, and after being modified to cross the railroad tracks which results in high vibrations.

Vehicle vibration on the rails is affected by several factors, such as wear between the wheels and the rails, the magnitude of the error in the distance between the rails, and the degree of deviation of the curvature of the rails [5]. Sources of vibration for vehicles on rails include Disturbances in superstructures such as wessels, rail joints, and rail crossings; the unevenness of the rail track which is influenced by the geographical environment; discontinuities in the track: significant gradients, ends or changes in the track direction, wear of rails and wheel bandages which increase vibration towards the horizontal [6]; increased rail bending which causes vibration in the vertical direction [7]. Vibration on the rail creates a continuous dynamic force on the leaf spring suspension system and causes fatigue [8]. If the frequency acting on the structure is equal to the eigenfrequency of the structure then the structure will experience stronger vibrations and can result in damage [9]. Based on the existing gaps, the researcher will analyze the failure analysis as a result of the eigenfrequency of the construction of the leaf spring suspension system on the lane monitoring vehicle.

2. Methods

In this study, the simulation analysis of the finite element method uses the SOLIDWORKS 2021 software. Simulation and modeling are carried out to make it easier to make circuit designs, minimize the risk of failure when experiments are carried out, and minimize the estimated costs required to carry out experiments [10]. Finite element method simulation analysis procedures include: Preparing the software, creating a 3D model of a leaf spring system, entering material properties in the 3D model of a leaf spring system, the process of entering the style load, meshing process of the 3D model of leaf spring system, finite element method simulation running process and analysis of the results in the form of mode shapes from eigenfrequency in leaf spring construction.

The analysis process using the Solidworks finite element method in this study is shown in Figure 2.

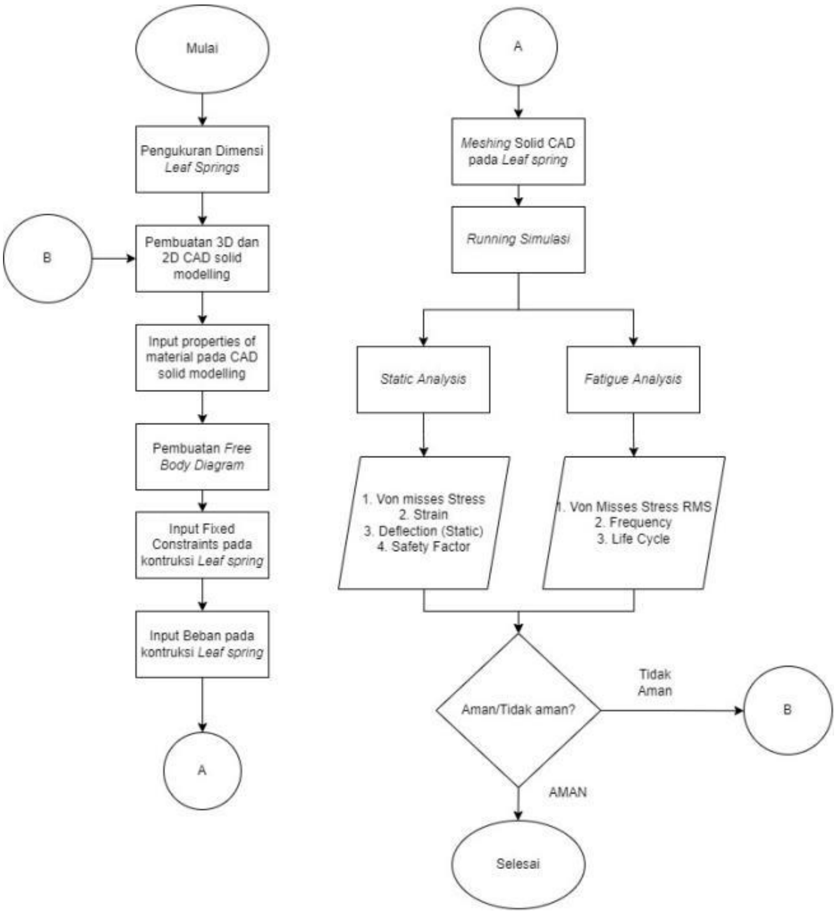

Fig. 2. Finite element method calculation flowchart

3. Results and Discussion

3.1 Measurement Dimensions and Material Properties

Based on the measurement results on leaf springs, the data shown in Table 1 is obtained.

Table 1
Measurement results spring L

	Front leafspring	Rear leafsprings
Thickness(t)	7mm	7mm
Length(L)	83 cm	83 cm
Number of layers (n)	2	3

Based on the results of dimensional measurements, it is found that:

The mass of the vehicle on the front axle (m_F) : 785 kg
The mass of the vehicle on the rear axle (m_R) : 562 kg
wheelbase length (l) : 2110 mm
Vehicle mass (m) : 1546 kg
Force on front wheels (Fzf) : 450,66 kgf
Force on rear wheels (Fzr) : 322,34 kgf
Frequency that occurs (Hz) : 4.27 Hz

Based on the results of the spectrometer and mechanical testing of the material on the leaf spring, the chemical composition data is shown in Table 2.

Table 2
Elements spring material composition leaf

Elements (%)					
C	Si	M N	P	S	Fe
0.505	1.58	0.787	0.0277	0.0068	Balance

Based on this composition, the material complies with EN 46 (silicone-manganese spring steel) with the following mechanical characteristics: yield stress (1092.23 MPa), ultimate stress (1340.57 Mpa) elongation (8.07 %), hardness (414.5 HV).

3.2 Calculation Front EigenFrequency Leafspring Simulation

When viewed from the side, the distribution of force received by the spring and the position Leaf springs and shock absorbers on the body can be seen in Figure 3.

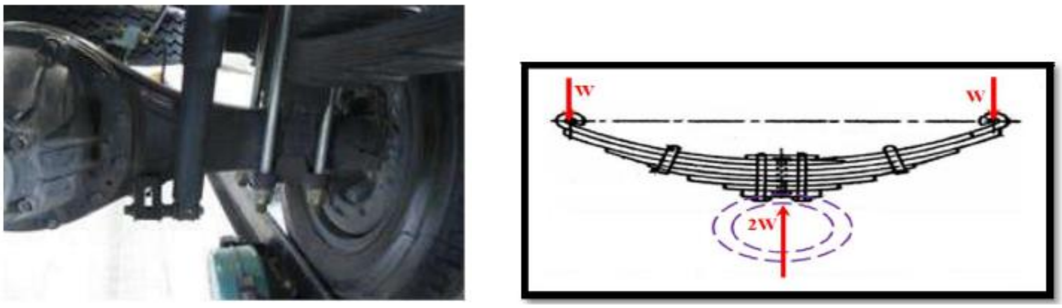

Fig. 3. The position of the Leaf spring and the free body diagram on the spring

Leaf spring suspension leaf springs are mounted above the rear axle and leaf springs are mounted below the rear axle. Most leaf springs are mounted right in the middle of the length of the spring so that the front and rear are the same length.

Fig. 4. The position of the leaf spring wheel seen from the side

In heavy vehicles such as trucks and buses, leaf springs experience a pressure difference between empty and fully loaded. To meet the load when transporting the vehicle. At the end of the longest plate springs are formed for installation. Meanwhile, the back of the top steel plate is connected to the frame using a swing that can move freely when the length of the spring varies due to the influence of changes in load.

After measuring the frequency that occurs in the vehicle by conducting vibration testing, an eigenfrequency simulation is carried out. Leaf spring modelling for solid work calculations can be seen in Figure 5.

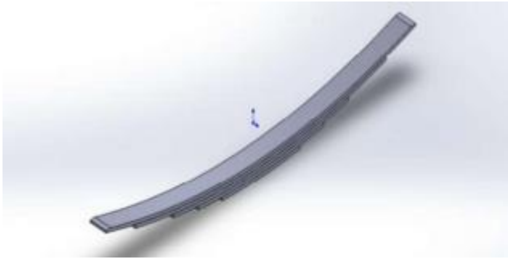

Fig. 5. Geometry modeling

If the frequency value that occurs is the same as the frequency value in the eigenfrequency simulation (natural frequency), a resonance will occur which will damage the leaf spring. Eigenfrequency simulation is carried out using 5 types of forms (modes) eigenfrequency.

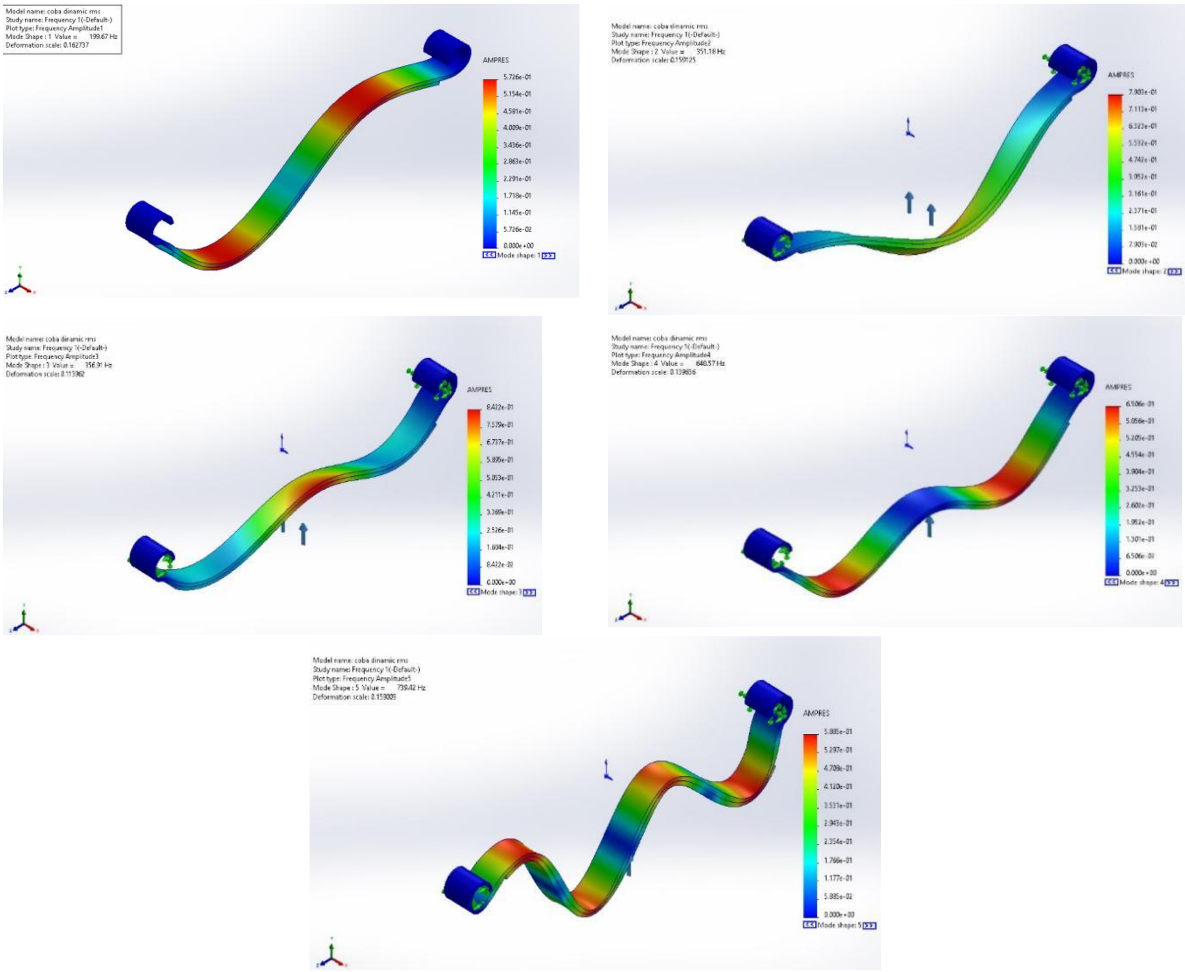

Fig. 6. Spring eigenfrequency simulation front leaf

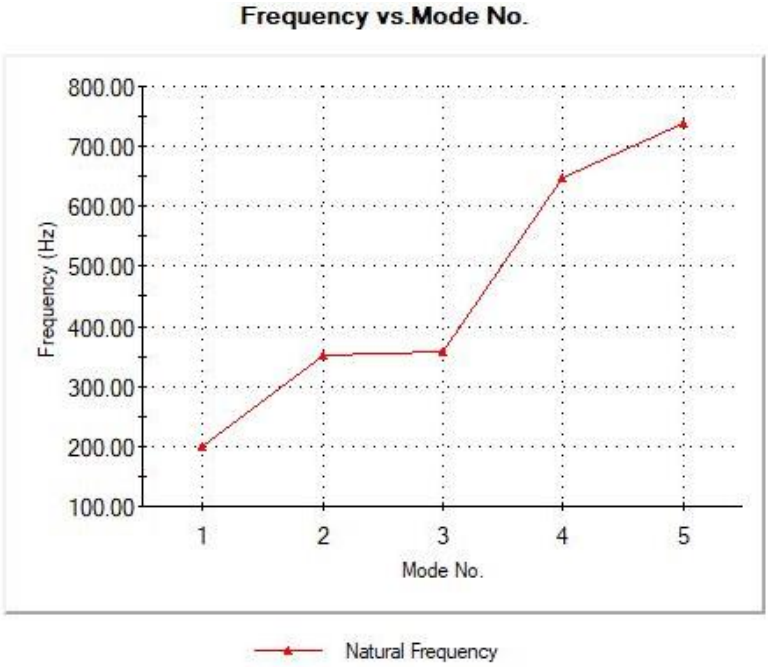

Fig. 7. Graph of spring eigenfrequency simulation results front leaf

Table 3
Spring eigenfrequency simulation results front leaf

Frequency Number	Rad/sec	Hertz	Seconds
1	1,254.6	199.67	0.0050083
2	2,206.6	351.18	0.0028475
3	2,242.5	356.91	0.0028018
4	4,075.1	648.57	0.0015419
5	4,645.9	739.42	0.0013524

Based on the results of the vibration tests carried out, it is known that the frequency that occurs is 4.27 Hz, while the simulation results show that the frequency of the leaf springs is 199.67 Hz, 351, 18 Hz, 356, 91 Hz, 648, 57 Hz, and 7 39.42 Hz. This indicates that no destructive resonance will occur in the front leaf springs.

3.3 Calculation Back Eigenfrequency Leafspring Simulation

After measuring the frequency that occurs in the vehicle by conducting vibration testing, an eigenfrequency simulation is carried out. If the frequency value that occurs is the same as the frequency value in the eigenfrequency simulation (natural frequency), a resonance will occur which will damage the leaf spring. Eigenfrequency simulation is carried out using 5 types of forms (modes) eigenfrequency.

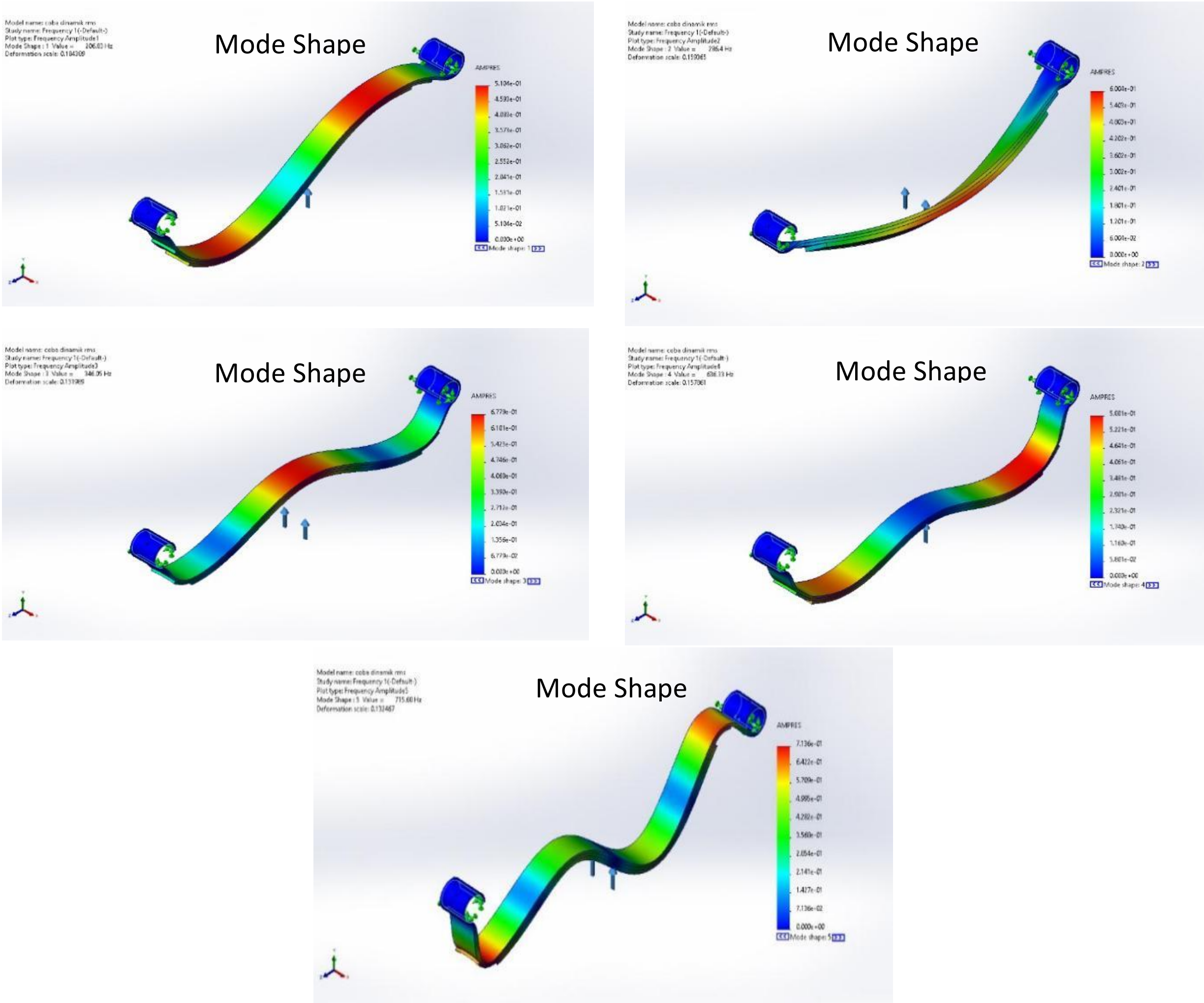

Fig. 8. Spring eigenfrequency simulation back leaf

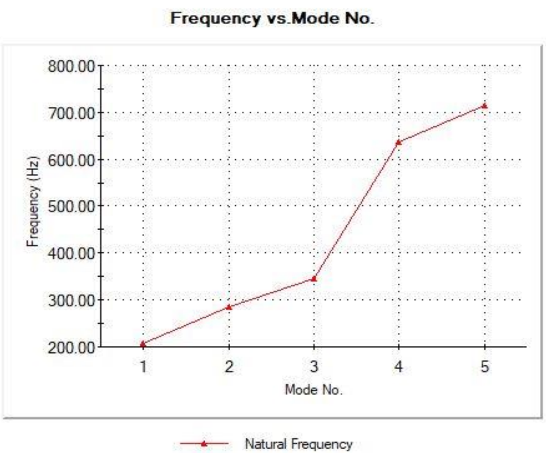

Fig. 9. Graph of spring eigenfrequency simulation results back leaf

Table 4
Spring eigenfrequency simulation results back leaf

Frequency number	Rad/sec	Hertz	Seconds
1	1,299.5	206.83	0.004835
2	1,799.5	286.4	0.0034916
3	2,174.3	346.05	0.0028897
4	3,998.2	636.33	0.0015715
5	4,496.7	715.68	0.0013973

Based on the results of vibration testing conducted, it is known that the frequency that occurs is 4.27 Hz, while the simulation results show that the frequency of the leaf springs is 20 6, 83 Hz, 286.4 Hz, 34 6.05 Hz, 636, 33 Hz, and 71 5.68 Hz. This indicates that no destructive resonance will occur in the front leaf springs.

To evaluate the dynamic conditions of a component or system efficiently, the vibration mode analysis uses the properties of the eigenvalues and eigenvectors. By using Solidworks, capital analysis can be calculated through numerical simulations. This numerical simulation was carried out to identify the personal frequency and mode shape of the leaf springs.

Because the leaf spring is a continuous system it can have infinite mode forms, but in this study only consider the first 5 mode forms. Table 4 the results of the modal analysis performed using Solidworks for the first mode to the fifth mode are shown. The result of the value of the natural frequency of the spring leaves for the initial mode to the next mode, namely 206.83 Hz, 286.40 Hz, 346.05 Hz, 636.33 Hz and 715.68 Hz.

In the rear leaf spring, there is a percentage increase between the second and third vibration modes, here it has a small increase by calculating:

$$\Delta_{23} = \frac{\omega_{3-}\ \omega_2}{\omega_2}\ x\ 100\% = \frac{346{,}05 - 286{,}40}{286{,}40}\ x\ 100\% = 20{,}82\%$$

While on the front leaf spring occurs:

$$\Delta_{23} = \frac{\omega_{3-}\ \omega_2}{\omega_2}\ x\ 100\% = \frac{356.91 - 351{,}18}{351.18}\ x\ 100\% = 1{,}63\%$$

For the case of the rear leaf spring and the natural frequency value of each vibration mode varies, will produce a different reaction. The magnitude of the frequency can be caused by the influence of material, position, defects, and other factors causing an increase in natural frequency, an increase in frequency of 290.28 Hz, in the third to fourth order vibration mode. Each material has a different mode and more than one natural frequency. The smallest increase occurred between the second and third vibration modes of 20.82%.

The magnitude of the frequency can be caused by the influence of material, position, defects, and other factors causing an increase in natural frequency, an increase in frequency of 289.66 Hz, in the third to fourth order vibration mode. Each substance has a different mode and more than one natural frequency. The smallest increase occurred between the second and third vibration mode by 1.63%. This indicates that no destructive resonance will occur in the front leaf springs.

Eigenfrequency analysis of railway vehicle leaf spring suspension using finite element method is a reference that must be taken into account when selecting a leaf spring design to prevent failure. Analysis and monitoring of vibration conditions on engineering systems and components will also benefit from understanding the vibration patterns in a given design. Conditions and forms of vibration mode and frequency can be used as a reference point for further studies in the analysis of transient and harmonic dynamics which form the basis of vibration analysis.

4. Conclusions

Each material has a different vibration mode and more than one natural frequency . By knowing the natural frequency that occurs in this spring, it is very important to prevent damage to a system or component (leaf spring). If the vibration frequency is the same as the natural frequency, it will produce vibrations that are strong enough to be harmful to the system or its components.

SolidWorks software, analysis of leaf springs produces the following conclusions:

i. Based on the results of vibration testing conducted, it is known that the frequency that occurs is 4.27 Hz.
ii. Natural frequencies of the first to fifth mode vibrations are 206.83 Hz, 286.40 Hz, 346.05 Hz, 636.33 Hz and 715.68 Hz for the rear leaf springs and front leaf springs are 199.67 Hz, 351.18 Hz, 356.91 Hz, 648.57 Hz and 739.42 Hz.
iii. From the above data it can be concluded that no destructive resonance will occur in the leaf spring.
iv. The front and rear leaf springs to be installed on the railway vehicles are designed in accordance with the design requirements and can be used as a rail vehicle suspension system.

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