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Analysis of Dynamic Vibration Characteristics in Daihatsu Taft Hiline Gtl Transmission with Fea

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ABSTRACT

Transmission is function to move and to change the power from motor, which is used to turn machine spindle as well as to do feeding movement. The vibration level which occurred in transmission is very important so that a failure does not occur. The purpose of this research is to know vibration phenomenon and vibration mode which occurred to transmission. Material and boundary condition which is used influenced natural frequency and occurred vibration mode. Method which will be used in this vibration analysis is by using modal analysis based on FEA. Software is used in building the CAD shape and FEA process. Numeric model characterized stiffness structure matrix is built to investigate transmission vibration. The results obtained in this research is the natural frequency of neutral gear (1,109.1–1,780.2) Hz, 1st gear (1,173.2–1,795.6) Hz, 2nd gear (1,107.8-1,804.4) Hz, 3th gear (1,206.2–1,805.3) Hz, 4th gear (1,156.3 to 1,804.5) Hz, 5th gear (1,099.3–1,738) Hz, and reverse gear (1,171.6–1,870) Hz. In this research resulted that the smallest natural frequency occurred at the first mode 5th gear is 1,099.3 Hz, While the biggest natural frequency occurred at the eighth mode reverse gear is 1,870 Hz. This matter because contact relation which occured at 5th gear is minim so that the mass of the gear is lighter, while at the reverse gear thas three related wheel gears so that the masses are heavier and produce natural frequencies greater.

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1. INTRODUCTION

The gearbox is a component of a machine in the form of a housing for gears(Muhammad, 2020). This component must have the right construction in order to place the gear shafts on the correct axes so that the gears can rotate properly with as little friction as possible.(Ikhsan et al., 2018). In transmission, power is transmitted in the following order:(Maisyarah, 2019): engine – clutch – gearbox – prop shaft – differential – half shafts – hubs & tires. Vibration in the transmission system is a major problem, where excessive vibration in the transmission can cause failure of the shaft, bearings and gears(Siahaan & Riza, n.d.). Reducing vibration is the main goal of the car industry(Priyono, n.d.).

The whirring and rattling sound caused by the vehicle's transmission in good condition(Iktia & Prabaswara, 2021)torsional vibrations caused by the vibration parts loosening the transmission components(Z Furqon & Pramono, 2021)move back and forth in distance when unloaded(Ruswanto et al., 2011). The cause of the heavy vibration is the resonance caused by the lower frequency derivative of the transmission housing. Besides having to have the right construction(Djatmiko, 2016), there are several criteria that must be met by the components in order to reduce the vibrations that arise due to rotation and friction between the wheels(Putra, 2019)teeth i.e. resistant to the abrasiveness of fluids, and these components must be rigid (Faris, 2020). The vibration factor in a machining process is a very calculated factor in order to maintain the condition of a working machine so that it does not fail (Winarsunu, 2008). Not all vibration events can be identified through experimental studies(Sayekti, 2012), then a vibration simulation is carried out to see the vibration events that occur with different output parameters (Amania et al., 2020). Previous researchers conducted a vibration analysis on the transmission house using the modal analysis method based on FEA (Kalmai, 2016). After analyzing the researchers found that the specified material and boundary conditions affect the natural frequency and mode (Ilham et al., 2021) vibrations that occur. Modal analysis is appropriate to use as an analysis of the vibrations generated from a structure (Soumokil, 2020). The method that will be used in this transmission vibration analysis is to use modal analysis based on FEA (Napitupulu et al., 2021). The targeted result of this research is to be able to identify the vibration characteristics of the vehicle transmission to obtain a stable transmission construction design by simulating the finite element method (Kaleg et al., n.d.).

The objectives of the vibration research on the transmission are: (1) To be able to determine the vibration pattern that occurs in the transmission when the transmission is operated by simulation analysis. (2) To determine the highest vibration in the transmission chamber. (3) To determine the vibration mode that occurs in the transmission. (4) To determine the difference between the results of the simulation and experimental analysis.

The benefits of the research are as follows: (1) From an academic aspect, this research is related to the courses of Mechanical Element Design I & II, Physical Metal Science, Finite Element Method, and Condition Based Maintenance, so that by doing this research can add insight and develop patterns Think about the utilization of transmission materials and the design of a low-vibration transmission system. (2) In practical aspects, this research is expected to be applied to assist the maintenance of the transmission system. (3) Can find out what factors affect the failure of vibration in the transmission system.

2. RESEARCH METHOD

To observe and predict the vibrations that occur in the transmission, it is done by building numerical rules that will simulate the natural frequency and vibration modes that occur (Napitupulu et al., 2021). In this study, the two rules will be reviewed to obtain comfortable vibration characteristics when driving. For this reason, the first step that needs to be done is to identify the design parameters of the vibration object to be studied (Naibaho, 2018).

2.1 Parameter Analysis Design (Design Of Analysis)

In designing parameters, the main thing to do is to identify input (input) and output (results) parameters as well as design parameters that control the correlation between input and output parameters (Harsoyo, 2010). The process of the phenomenon of this vibration is when the transmission works there is a rotating shaft and also the gears that touch each other so that it can cause vibration (Diaz, 2020). Material selection is also a determining factor in the occurrence of vibration (Saputra, 2021). Therefore, a vibration simulation is carried out in the form of a modal analysis to determine the vibration and vibration modes that occur and also critical points that can cause high vibrations (Dirgantara, N.D.). Failures in the form of high vibrations can occur due to several things, namely the fabrication process that is not up to standard, lack of maintenance, and finally due to daily use that does not comply with procedures (Satryawan, 2016).

The input parameters used are modulus of elasticity, poisson ratio, density of the material and applied to zero displacement boundary conditions (Rofiq et al., 2019). The applied load is automatically controlled by the software program (Patta & Iskandar, 2019). So, the output parameters are natural frequency, vibration mode, and also the deformation that occurs in each mode. For a more concise, research design diagram can be seen in Figure 3.1 (Mahardika, 2022).

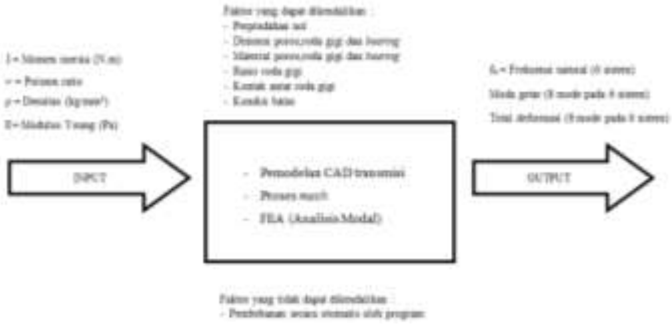

Figure 1. Analysis Design Diagram

2.1.1 Components And Functions

The table of components and functions describes in detail which part of the research is focused on for review, this includes what components are being studied, the function of the components in the system, changes in physical phenomena experienced by the components, the parameters reviewed in the components as well as establishing the empirical formula used in discussing parameter changes experienced by components (Hermawan, 2019).The components that will be discussed only cover the transmission part because the transmission occurs rotation and contact between the gears so that it can give birth to vibrations (Ringan, N.D.). The components in the gearbox are a research reference because there are complex components in the gearbox and friction between the gears (Pudjorahardjo et al., 2003). The natural frequency and the vibration mode that occurs are used as a measure of vibration in the transmission. The difference in results between each system is due to the difference in contacts when changing the transmission (Sihombing, 2021). Table 3.1 shows the components and functions studied.

Table 1. Components And Functions

Komponen utama yang diteliti	Fungsi komponen	Fenomena perubahan fisik	Rumus empirik yang digunakan	Parameter yang diukur
Transmisi	Sebagai pemindah tenaga dari mesin menjadi gerak	Terjadi bentuk getaran dan deformasi pada komponen	$\left(\frac{1}{\sum_{n=1}^{5} I_n}\sum_{n=1}^{6}\theta_n + \frac{1}{\sum_{n=1}^{10} I_n}\sum_{n=1}^{10}\varphi_n\right) + \left(\frac{1}{\sum_{n=1}^{5} k_n}\sum_{n=1}^{6}\theta_n + \frac{1}{\sum_{n=1}^{5} k_n}\sum_{n=1}^{5}\varphi_n\right) = 0$	Frekuensi natural, Moda getar dan Total deformasi

2.1.2 Measurement Data Table

This table contains the items/parameters that will be investigated in the research and the results that will be obtained in the experiment. This table is a summary of what parameters are used or studied from the simulation.

Table 2. Measurement Data Table

Parameter Input				Parameter output		Parameter desain
Momen inersia (I)	Densitas (ρ)	*Poisson ratio* (υ)	Modulus elastisitas (E)	Frekuensi natural (f_n)	Total deformasi	Mode getar
..(N.m)	..(Kg/m^3)		..(Pa)	..(Hz)	..(mm)	

2.2 Testing Stage

There are several stages that need to be considered in the test, namely as follows: (1) Making the transmission CAD (Bahari & Hamzah, 2017). (2) Enter the material type of the transmission. (3) Perform mesh processing on all transmission components (Saputro & Darmawan, 2020). (4) Checking the mesh on all transmission components, if they are not suitable, the mesh process is carried out again (Wahyudi, 2022). (5) Laying of constraint points. (6) Testing is carried out. (7) Tested 8 times (Permana et al., 2017). (8) The test results are recorded 8 times(Pratasik et al., 2019). For more concise testing procedures performed can be seen through the flow chart in Figure 3.4.

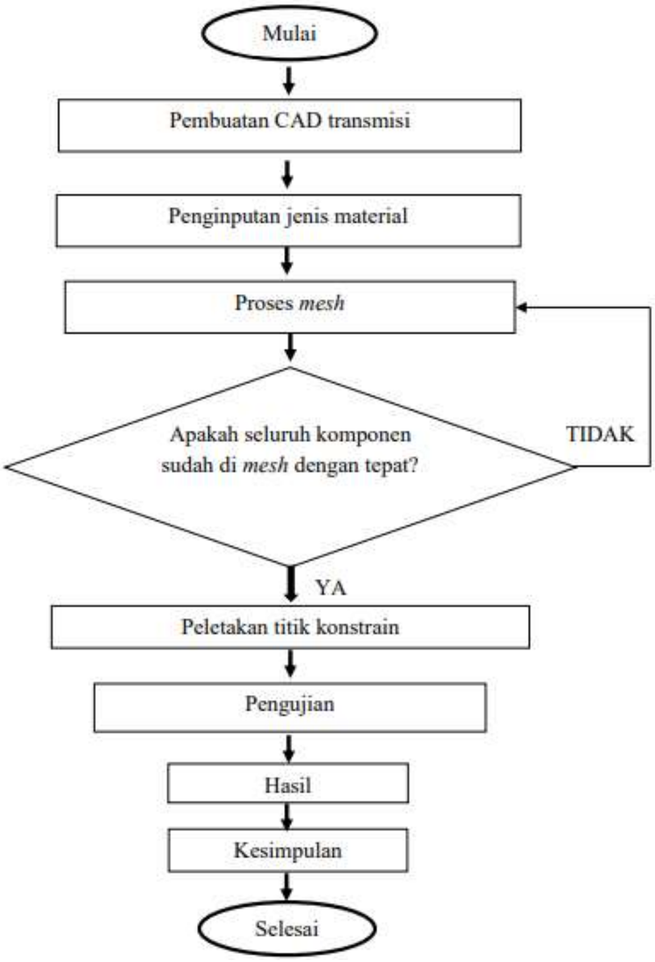

Figure 2. Test Flowchart

3. RESULTS AND DISCUSSIONS

3.1 Simulation Results

At a given load analysis modal is set automatically from the program, by setting the boundary conditions.

3.1.1 On Neutral Gear

In neutral gear can be seen the type of vibration and the natural frequency that occurs is (1.109.1 – 1.780) Hz. It can be seen in the pictures of each mode that occurs when the gear position is neutral

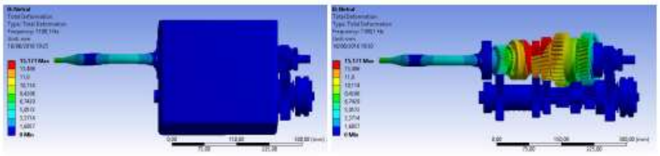

Figure 3. Mode 1 Gear N (F1 = 1109.1 Hz)

It can be seen in Figure 4.4 that the first mode of the neutral gear occurs with a natural frequency of 1,109.1 Hz. Vibration mode that occurs in the first mode is axial vibration deflection on the input shaft. Where the largest deformation occurs in the center of the transmission and causes resonance vibrations to propagate to the input shaft. Vibration mode that occurs like this can cause misalignment of the shaft when working.

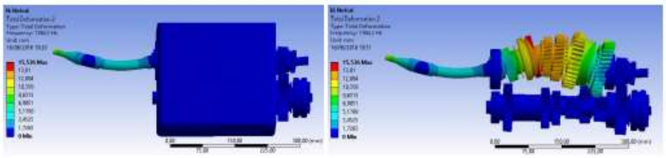

Figure 4. Mode 2 gear N (f2 = 1,168.3 Hz)

Figure 4.5 is the second mode of the neutral gear. It can be seen that there is a natural frequency of 1,168.3 Hz. The vibration mode that occurs in the second mode is the deflection axial vibration. The vibrations that occur cause resonance on the input shaft. Vibration mode that occurs like this can cause misalignment of the shaft when working.

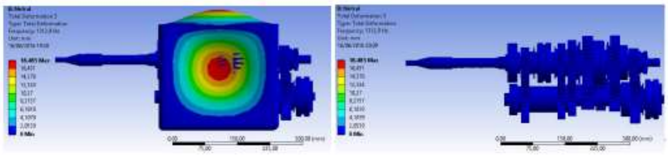

Figure 5. Mode 3 gear N (f3 = 1,312.9 Hz)

Figure 4.6 is the third mode of the neutral gear. It can be seen that there is a natural frequency of 1,312,9 Hz. The vibration mode that occurs is vibration in the form of a deflection in the casing. The vibrations that occur can cause an impact load to occur between the casing and the transmission inside

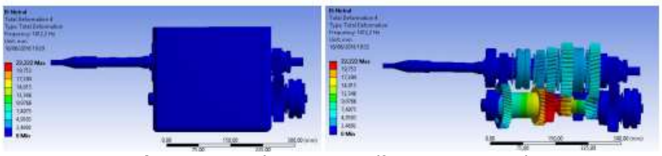

Figure 6. Mode 4 gear N (f4 = 1,412,2 Hz)

Figure 4.7 is the fourth mode of the neutral gear. It can be seen that there is a natural frequency of 1,412,2 Hz. The vibration mode that occurs is the axial vibration of the deflection on the output shaft and the torsional vibration of the system occurs. The greatest deformation occurs in the center of the output shaft and also resonance can cause vibration and shaft misalignment.

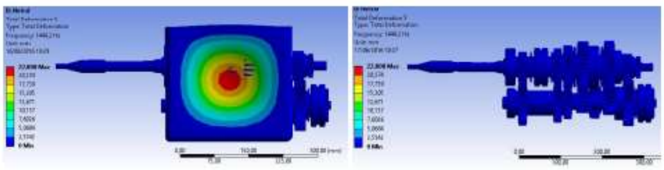

Figure 7. Mode 5 gear N (f5 = 1,442.2 Hz)

In figure 4.8 is the fifth mode of the neutral gear. It can be seen that the natural frequency is 1,442.2 Hz. The vibration mode that occurs is vibration in the form of a deflection in the casing. The vibrations that occur can cause an impact load to occur between the casing and the transmission inside.

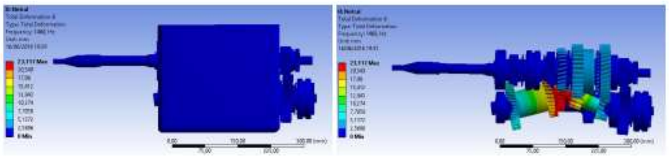

Figure 8. Mode 6 gear N (f6 = 1,460 Hz)

In figure 4.9 is the sixth mode of the neutral gear. It can be seen that there is a natural frequency of 1,460 Hz. The vibration mode that occurs is axial vibration, deflection on the output shaft and minimal torsional vibration in the system. Vibration that occurs can result in misalignment of the shaft.

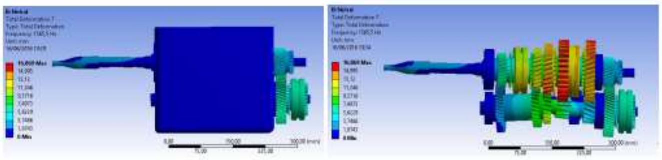

Figure 9. Mode 7 gear N (f7 = 1,565.5 Hz)

In figure 4.10 is the seventh mode of the neutral gear. It can be seen that there is a natural frequency of 1565.5 Hz. The vibration modes that occur are deflection and torsional axial vibrations in the system. From the vibration mode that occurs, it shows that the vibration response occurs to all parts of the transmission. Which can cause loose gears or excessive contact between the gears

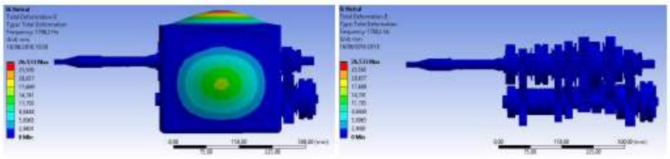

Figure 10. Mode 8 gear N (f8 = 1,780.2 Hz)

Figure 4.11 is the eighth mode of the neutral gear. The vibration mode that occurs is vibration in the form of a deflection in the casing. It can be seen that there is a natural frequency of 1,780.2 Hz. The vibrations that occur can cause an impact load to occur between the casing and the transmission inside.

3.2 Study of Differences in Experimental Natural Frequency Results with Simulation

A study was conducted on the comparison of experimental and simulation results in order to see the differences in the results obtained. The method used to be able to relate the experimental results to the simulation is by using the ANOVA (analysis of variance) regression analysis method. The first step is to find the natural frequency in each direction and then take the average, then compare it with the simulation. The dependent variable is the simulated natural frequency, while the independent variable is the velocity amplitude in each direction. The results of the comparison and percent error of natural frequencies can be seen in tables 4.13 – 4.20.

3.2.1 In Neutral (Normal) Gear

Table 4.13 shows the comparison of experimental results and simulation of neutral gear.

Table 3. Comparison of Experimental Frequency Results and Neutral Gear Simulation

RPM	Eksperimental					Simulasi	Persen ralat (%)
	Aksial		Vertikal		Rata - rata		
	Velocity amplitudo (mm/s)	Frekuensi natural (Hz)	*Velocity* amplitudo (mm/s)	Frekuensi natural (Hz)	Frekuensi natural (Hz)	Frekuensi natural (Hz)	
600	3,650	951,2	3,604	1.321,4	1.136,3	1.138,7	0,21
1000	3,747	1.371,6	3,569	1.219,4	1.295,5	1.362,5	4,91
1500	3,784	1.352,5	3,657	1.475,7	1.414,1	1.452,1	2,61
2000	3,760	1.411,8	3,703	1.609,6	1.510,7	1.672,8	9,69

From table 4.13 it can be seen the percent error that occurs at each engine speed and in Figure 4.71 shows a graph of the results of the comparison between simulation and experimental frequencies.

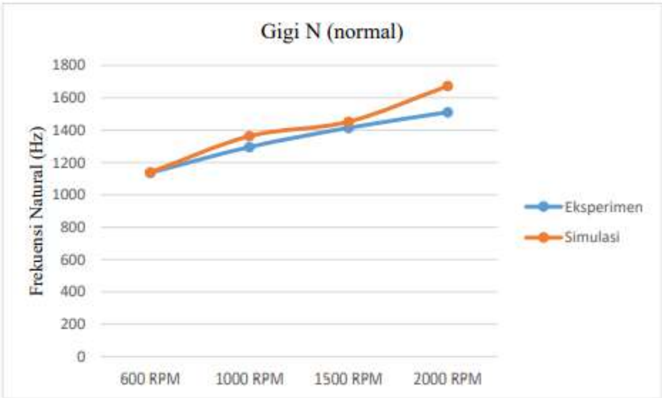

Figure 11. Graph of Comparison of Results Tooth Frequency N (Normal)

From Figure 4.71, it can be seen that at 1,000 RPM, 1500 RPM and 2,000 RPM the frequency that occurs in the experiment is smaller than the simulation results. Because there are several factors in the formulation of the resulting formula.

3.2.2 In Fourth Gear (Broken)

Damage drawings and natural frequency table are attached in section 4.5.8. By setting the dependent variable is the natural frequency of the simulation, while the independent variable is the velocity amplitude of each direction. Then the formula to get the natural frequency for tooth 4 (damaged) is

$$Y = -3{,}360{,}399 + 1{,}139{,}1222\ XA \quad (1)$$

$$Y = -5{,}756{,}576 + 1{,}780{,}9832\ Xv \quad (2)$$

Where :

Y = Natural frequency (experimental)

XA = Velocity axial amplitude

XV = Velocity vertical amplitude

The experimental amplitude velocity data is taken from the vibration experimental thesis report in table 4.5 (Wijaya, 2016). The results of the comparison and percent error of natural frequencies can be seen in table 4.20.

Table 4. Comparison of Experimental Frequency Results and Simulation of Fourth Gear (Broken)

RPM	Eksperimental					Simulasi	Persen ralat (%)
	Aksial		Vertikal		Rata - rata		
	Velocity amplitudo (mm/s)	Frekuensi natural (Hz)	*Velocity* amplitudo (mm/s)	Frekuensi natural (Hz)	Frekuensi natural (Hz)	Frekuensi natural (Hz)	
1.000	4,133	1.347,6	3,988	1.345,9	1.459,7	1.398,6	3,71
1.500	4,502	1.567,8	4,222	1.697,2	1.632,5	1.580,35	3,29
2.000	4,640	1.925,3	4,317	1.932,4	2.118,3	2.061,65	6,44

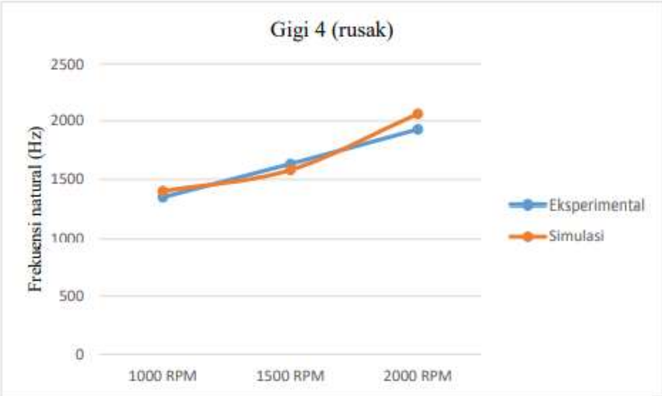

Figure 12. Comparison Graph of Frequency Results of Tooth 4 (Broken)

In Figure 4.79 there are differences between 1,500 and 2,000 RPM due to several factors when formulating the formula.

3.3 Analysis of the Difference between Experimental Results and Simulations

After conducting the study, it was seen that the results were not too much different from the results obtained during the experiment. However, in some parts there are still differences due to several factors in the formulation. In the formulation, the inputted data determines the results achieved. The factors that influence the results are R Square, F, and the significance of F.

4. CONCLUSION

Based on the simulation results from the analysis, conclusions can be drawn from the results of this study, namely: (1) In the simulation, the natural frequency is generated at tooth N (1,109.1 – 1,780.2) Hz, gear 1 (1,173.2 – 1,795,6) Hz, gear 2 (1,107.8 – 1,804.4) Hz, gear 3 (1,206.2 – 1,805.3) Hz, gear 4 (1,156.3 – 1,804.5) Hz, gear 5 (1,099.3 – 1,738) Hz, and gear R (1,171.6 – 1,870) Hz. (2) The highest vibration occurs in the reverse gear in the range of 1,171.6 Hz – 1,870 Hz. Due to the reverse gear there is more contact between the teeth when doing the reverse position so that the mass of the gear becomes heavier. (3) The vibration mode that occurs in the casing is in the form of a deflection vibration, in the transmission there is an axial deflection and torsional vibration. (4) After doing the simulation, The results obtained that the resultant velocity amplitude and natural frequency tend to be higher than experimental because the design conditions of the transmission are in ideal conditions. Where the resultant experimental velocity amplitude is 2,000 RPM in neutral 5,277 mm/s; first gear 5.313 mm/s; second gear 5.312 mm/s; third gear 5.3 mm/s; fourth gear 5.27 mm/s; fifth gear 5.272 mm/s and reverse gear 5.3 mm/s. While the simulation results on the neutral gear 5.29 mm/s; first gear 5.321 mm/s; second gear

5.314 mm/s; third gear 5,306 mm/s; fourth gear 5.277 mm/s; fifth gear 5.283 mm/s and reverse gear 5.309 mm/s. On the results of the experimental natural frequency of 2,000 RPM in neutral 1510.7 Hz; first gear 1,658.8 Hz; second gear 1702.4 Hz; third gear 1,721.1 Hz; fourth gear 1737.3 Hz; fifth gear 1,530.6 Hz and reverse gear 1,795.8 Hz. While the simulation results for neutral gear are 1,672.8 Hz; first gear 1,787.4 Hz; second gear 1,803.8 Hz; third gear 1803.85 Hz; fourth gear 1,803.5 Hz; fifth gear 1,649.4 Hz and reverse gear 1,842 Hz.

Based on the simulation results, the suggestions that can be given from the researchers are as follows: (1) Reduce the size of the mesh so that the results to be achieved are more accurate. (2) It is better to do analysis with dynamic simulation in order to get more like the real situation. (3) It is advisable to add lubrication in the simulation as well. (4) For further research, experimental data from transmission should be carried out experimentally using a test rig.

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