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Analysis of the Gear Ratio Replacement Effect on Speed in Mercedes Units at PT. XXX

[1]Shofwan Bahar, [2]*Eflita Yohana, [3]Jonathan Pulung Kudadiri, [4]Tony Suryo Utomo

[1,2,4]Department of Mechanical Engineering, Diponegoro University, Jl. Prof. Sudarto No. 13, Tembalang, Kec. Tembalang, Semarang, Indonesia

[3]Service Dept Production, PT XXX, Indonesia

*Corresponding Author's E-mail: efnan2003@gmail.com

***Abstract* - The existing gear ratio on vehicles has several weaknesses, one of them is speed limitation. The purpose of this study aims to examine the effect of gear ratio to speed on vehicles. The vehicle's gear ratio will be changed to produce speeds exceeding the existing speed of Mercedes units. This unit is used as a fire truck at the airport. To achieve this, an analytical method with several equations is used. The Allison 4000 series is the most suitable transmission for the unit based on the speed output produced. The results of the analysis showed a significant increase in the maximum speed, from 133.27 km/h to 162.39 km/h, there was an increase of 21.85%.**

Keywords: Transmission System, Gear Ratio, Speed.

I. INTRODUCTION

Fire fighting units are required to be able to move quickly in dealing with various emergency situations. There are several factors that affect the speed or performance of a vehicle, including the engine, transmission, clutch, wheel radius, etc..[1]. Transmission is a part of a motor vehicle that plays an important role in distributing power from the engine rotation to the vehicle's wheels by passing through several components such as gears and differentials.[2]

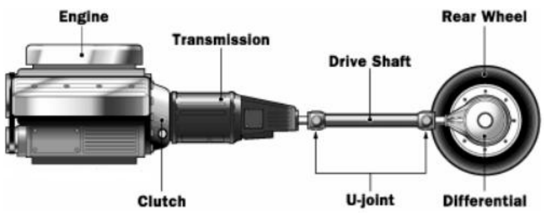

Figure 1.1: Transmission System [3]

In Figure 1.1 there is a drive shaft with a function to transfer power from the transmission to the differential which will distinguish the rotation of the left and right wheels so that the vehicle can turn properly without causing slippage i on both tires. In addition, differential also functions to change the rotary movement of the drive shaft into a forward or backward movement on the wheel. [4]

Sahari, *et al.* conducted a study to redesign the drive ratio to improve the performance of the PROTON Waja vehicle which has been modified by using a CNGDI (Compressed Natural Gas Direct Injection). The study resulted in a recommendation for the use of the drive ratio in the first gear, second gear, third gear, fourth gear, fifth gear and final drive gear of 3.58 respectively; 1,95; 1.34; 0.98; 0,8; and 4.33. The drive ratio from first gear to fourth or fifth gear is in principle getting smaller. Each ratio value at each transmission gear level depends on the type and specifications of the vehicle [5].

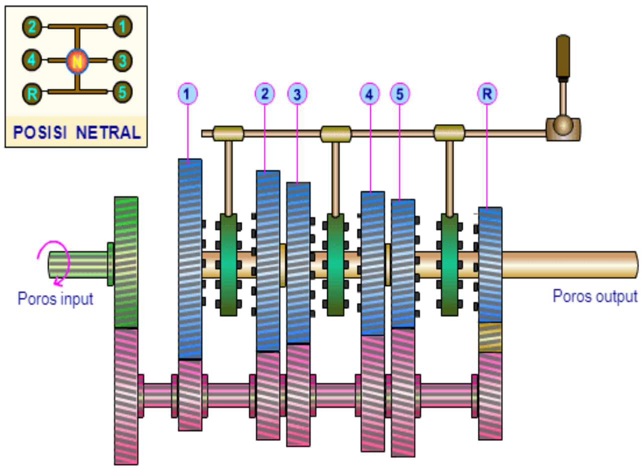

Figure 1.2: Overdrive and under drive conditions [6]

Figure 1.2 shows the transmission conditions that can affect the speed of a vehicle, namely under drive and overdrive conditions. Under drive condition is a condition where the radius of the main drive gear is smaller than the output gear. This condition is similar at the lowest gear or 1st gear. To change the ratio, the sleeve (dark green) will move axially towards the desired gear. Then the sleeve will be connected with the gear, then the gear will rotate the output shaft. This happens until the highest gear, thus there is a reduction in the gear radius in the event of a gear shift from one to two. This goes on until the radius on the input gear reaches its maximum, while on the output gear; the radius reaches the minimum value. This condition is referred as overdrive. [7]

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Figure 1.3: Mercedes Arocs 2551 Unit [8]

Figure 1.3 shows a truck unit used as a fire truck at the airport. To support the tasks of the fire department, this unit will have its gear ratio changed to produce speeds that exceed the existing speed. The purpose of this writing is to determine the transmission correctly so that the maximum speed exceeds the existing speed.

II. METHODS

2.1 Transmission Determination

The data needed to determine the transmission on the unit are the vehicle unit specifications and the automatic transmission specifications. Vehicle unit specification data in the form of engine output, gear ratio (1st), final gear ratio, and tire diameter. For automatic transmission specifications, data is required in the form of maximum power, gear ratio, and stall torque ratio.

2.2 Output Analysis

The performance analysis of the vehicle unit to be changed gear ratio is based on the following parameters, such as

1. Engine Power

Combustion in the engine will produce rotation on the shaft. The shafts also rotate and produce torque, power, and speed. Equation 1 shows the relationship between power, torque, and angular velocity [9].

$$\tau = \frac{BHP}{\omega} \quad (1)$$

Description:

BHP = Power Output (HP)
ω = Angular Velocity (rad/sec)
τ = Torsion (N.m)

In order to get angular velocity

$$\omega = \frac{2.\pi.n}{60} \quad (2)$$

2. Gear Ratio

The relationship between input and output gear ratios is [10]

$$m_G = \frac{N_G}{N_P} \quad (3)$$

Description:

m_G = Gear Ratio
N_G = number of teeth driven on gears
N_P = number of teeth drive on gears

Connected by velocity of gear (rpm)

$$\frac{n_P}{n_G} = \frac{N_G}{N_P} \quad (4)$$

Description:

n_P = Drive gear speed
n_G = Driven gear speed

The relationship of gear ratio to rotational speed

$$m_G = \frac{N_G}{N_P} = \frac{n_P}{n_G} \quad (5)$$

3. Rotation passed towards the transmission

The speed that flows from the engine to the transmission.

$$\text{Maximal Output Engine(rpm)} = \text{Input Transmission(rpm)} \quad (6)$$

From transmission to differential

$$\text{Output Transmission(rpm)} = \frac{\text{Input Transmission (rpm)}}{\text{Gear Ratio}} \quad (7)$$

The rotation produced by the Output Transmission will be the same as the rotation on the drive shaft considering that the 2 components are directly connected without any connecting components such as gears. From the drive shaft, the rotation will be passed towards the differential.

The relationship between differential, drive shaft, and Final Gear Ratio is shown in Equation 8

Output Differential(rpm)

$$= \frac{\text{Output drive shaft (rpm)}}{\text{Final Gear Ratio}} = \frac{\text{Output Transmission (rpm)}}{\text{Final Gear Ratio}} \quad (8)$$

The rotation of the differential is passed towards the axle and towards the tyres.

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4. Speed resulting drom tire rotation

To find out the resulting velocity, the formula for the velocity of a regular straight motion is used, expressed by the equation 9

$$v = \omega r \qquad (9)$$

Description:

v = Velocity (m/s)
ω = Angular Velocity (rad/s)
r = Radius (Seconds)

2.3 Determine the type of transmission on the vehicle unit

In this study, changes were made to the transmission gear ratio for the Mercedes unit which will be used as a fire fighting vehicle at the airport. The specification of the vehicle unit is a determining factor in choosing the type of transmission. This unit has an engine output of 510 PS/2500 Nm, a first gear ratio (1st) of 11.64 and a tire specification of 14.00R 20 with a diameter of 1,270 mm. There are several types of transmissions for this unit, including 3000 series transmission and 4000 series transmission. Table 1.1 shows the existing specifications on the transmission unit [11].

Table 1.1: Existing Transmission Specification

Power Transmission	
Clutch	Double-disc clutch
Transmission	G 330-12/11.63-0.77
Transfer case	VG 2800-3W/1.45-1.04, permanent
Final gear ratio	Axle ratio i = 4.833

Table 1.2 contains the specification data of gear ratio and stall torque on available automatic transmissions that will be used, including the Allison 3000 series and 4000 series

Table 1.2: Available Allison 3000 and 4000 Series Automatic Transmission Specifications

Seri	**Torque Converter**		**Mechanical Ratio**	
	Model	**Stall Torque Ratio**	**Range**	**Gear Ratio**
Seri 3000	TC-411	2,71	1st	3,49 : 1
	TC-413	2,44	2nd	1,86 : 1
	TC-415	2,35	3rd	1,41 : 1
	TC-417	2,20	4th	1,00 : 1
	TC-418	1,98	5th	0,75 : 1
	TC-419	2,02	6th	0,65 : 1
	TC-421	1,77	Reverse	-5,03: 1
Seri 4000	TC- 521	2,42	1st	3,51 : 1
	TC - 531	2,34	2nd	1,91 : 1
	TC – 541	1,9	3rd	1,43 : 1
	TC – 551	1,79	4th	1,00 : 1
	TC - 561	1,58	5th	0,74 : 1
			6th	0,64 : 1
			Reverse	-4,8 : 1

Based on the technical data and specifications of Mercedes units, the determination of the transmission is carried out with several limitations, including:

1. The gear ratio replacement is a transmission change considering the gear ratio on the MERCEDES unit.
2. The need that MERCEDES unit users desired is a higher maximum speed compared to the existing speed.
3. The calculation of the maximum speed is based on the rotational speed that is sourced from the engine and channeled towards the wheels.
4. The speed calculation is based on the assumption that the MERCEDES unit is in a no load condition.

The vehicle unit that will be replaced with a gear ratio has a maximum power of up to 510 ps/2100rpm. The rotational speed passed from the engine to the tire can be calculated using equation 6 to 8. It is assumed that the vehicle reaches maximum speed at the time the engine produces a maximum power of 2100 rpm. Equation 6 shows that the rotation at the transmission input is the same as the rotation at the engine so that the transmission input value obtained using equation 6 is 2100 rpm.

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$$\text{Maximal Output Engine(rpm)} = \text{Input Transmission(rpm)} = 2100\ \text{Rpm}$$

Next, the rotation at the transmission input is passed towards the transmission output. To obtain the transmission output value, equation 7 is used, where the transmission input will be divided by the gear ratio at the time of reaching the highest rev of 0.77; 0.64; and 0.65. The value of 0.77 is obtained from Table 1.1, while 0.64 and 0.65 are from Table 1.2. A score of 2,727.27 was obtained; 3,281.25 and Rpm3.230,76.

$$\text{Output Transmission(rpm)} = \frac{2100\ \text{Rpm}}{0{,}77} = 2.727{,}27\text{Rpm (Existing Transmission)}$$

$$\text{Output Transmission(rpm)} = \frac{2100\ \text{Rpm}}{0{,}65} = 3.230{,}76\ \text{Rpm (3000 Series Transmission)}$$

$$\text{Output Transmission(rpm)} = \frac{2100\ \text{Rpm}}{0{,}64} = 3.281{,}25\ \text{Rpm (4000 Series Transmission)}$$

The transmission output will rotate the drive shaft and be passed towards the differential. Using equation 8, the rev value is obtained at the differential, where the transmission output value is divided by the final gear ratio of 4.833 which is in the existing transmission (obtained from Table 1.1) and the value is obtained at 564.3; 678.87; and 668.47 Rpm.

$$\text{Output Differential(rpm)} = \frac{2.727{,}27\ \text{Rpm}}{4{,}833} = 564{,}30\ \text{Rpm (Existing Transmission)}$$

$$\text{Output Differential(rpm)} = \frac{3.230{,}76\ \text{Rpm}}{4{,}833} = 668{,}47\ \text{Rpm (3000 Series Transmission)}$$

$$\text{Output Differential(rpm)} = \frac{3.281{,}25\ \text{Rpm}}{4{,}833} = 678{,}87\ \text{Rpm (4000 Series Transmission)}$$

The rotation at the differential is equal to the tire rotation on the unit so that by using equation 9 the maximum speed will be obtained by assuming the distance traveled is as many revolutions as the differential .The rotation of the differential will be converted to angular velocity in order to obtain the translation speed. After conversion, the angular speed will be multiplied by the radius on the tyre by 0.635 m. A speed of 37.48 m/s was obtained; 45.11 m/s; and 44.39 m/s.

$$v = \omega\, r = 564\ \text{rpm}\left(\frac{2\pi}{60}\right)\left[\left(\frac{1270\text{mm}}{2}\right)\left(\frac{1}{1000}\right)\right]$$

$$= 37{,}48\frac{\text{m}}{\text{s}} = 135{,}3\ \text{km/h(Existing Transmission)}$$

$$v = \omega\, r = 668\ \text{rpm}\left(\frac{2\pi}{60}\right)\left[\left(\frac{1270\text{mm}}{2}\right)\left(\frac{1}{1000}\right)\right]$$

$$= 44{,}39\frac{\text{m}}{\text{s}} = 159{,}8\frac{\text{km}}{\text{h}}\ \text{(3000 series Transmission)}$$

III. RESULT AND DISCUSSION

The following is the result of calculating the maximum speed of the vehicle unit whose gear ratio has been replaced by the Allison 3000 and 4000 series transmissions

Table 1.3: Before and After Speed Comparison Table

Equ	Description	Existing	3000 Series	4000 Series
6	Input Transmisi (rpm)	2100	2100	2100
7	Output Tranmsisi (rpm)	2.727 rpm	3.230 rpm	3.281 rpm
8	Output differensial	564 rpm	668,47 rpm	678,87 rpm
9	Kecepatan maksimal (m/s)	37,48 m/s	44,39 m/s	45,11 m/s
9	Kecepatan maksimal (km/h)	135,3 km/h	159,8 km/h	162.39 km/h

Based on Table 1.3, the maximum speed on a vehicle unit changes after the gear ratio is replaced. By using the 3000 series transmission there was an increase of 19.9%, while in the 4000 series transmission there was an increase of 21.85%.

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In a previous study with a similar case, where a bus ratio gear was replaced to get a higher maximum speed. There are 2 transmission plans that will replace the existing transmission; the two plans are analyzed to get a comparison of output speeds. The first transmission has a range ratio gear ratio of 11.85 – 0.86, while the second transmission has a range of 10.14 – 0.71. The final result shows that the chosen transmission is the second transmission because it produces a greater speed, which is 117 km/h compared to the first transmission of 116 km/h.[12]

IV. CONCLUSION

Table 1.3 shows the 4000 series transmission resulting in an increase of 21.85% and the speed changes to 162.39km/h. It is larger than the 3000 series which produces a change of 19.9% with a speed of 159.8 km/h. Therefore, the 4000 series transmission was chosen because there is a higher increase compared to the 3000 series transmission.

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