Energy Sensitivity Analysis by Lightning for a Transmission of Commercial Vehicles

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Abstract: - Dynamic performance of transmission has a substantial effect on dynamic performance and fuel efficiency of vehicles, and is directly related to mass inertia moment of the transmission rotor. Rotors of light mass require a small amount of kinetic energy from vehicles that repeat acceleration and deceleration, which increases fuel efficiency as a result.
In this study, equivalent inertia moments at different speeds were calculated by simplifying the transmission system, and, by using the kinetic energy equation related to rotational motion and translational motion of vehicles, required kinetic energy of each speed was calculated. Also, the probability of using different speeds to achieve a target distance was applied as weight in order to calculate the amount of kinetic energy required to achieve the target distance. Assuming that the rotor inside the transmission maintains its function while the mass was minimized, in this study, the relative effect of lightning the rotor was compared to the effect of lightning the sprung mass with regards to kinetic energy.

Key-Words: Kinetic energy, Sensitivity analysis, Transmission gear, Equivalent inertia moment, Effect of mass reduction

1 Introduction

As regulations related to fuel efficiency become stricter each year, relevant research is being actively conducted in order to improve fuel efficiency and dynamic performance of vehicles.

Dynamic performance of transmission has a substantial effect on dynamic performance and fuel efficiency of a vehicles, and is directly related to mass inertia moment of the transmission rotor. Rotors of light mass require a small amount of kinetic energy from vehicles that repeat acceleration and deceleration, which increases fuel efficiency as a result.

In this study, equivalent inertia moments at different speeds were calculated by simplifying the transmission system, and, by using the kinetic energy equation related to rotational motion and translational motion of vehicles, required kinetic energy of each speed was calculated. Also, the probability of using different speeds to achieve a target distance was applied as weight in order to calculate the amount of kinetic energy required to achieve the target distance. Assuming that the rotor inside the transmission maintains its function while the mass was minimized, in this study, the relative effect of lightning the rotor was compared to the effect of lightning the sprung mass with regards to kinetic energy.

2 Analysis of Planetary Gear Characteristics

2.1 Equivalent inertia moment of planetary gear

In this study, the planetary gear refers to a major component attached to the rear of transmission that enables multistage transmission, and the driving mechanism changes depending on whether a ring gear in the planetary gear system is fixed or not. In the 1st speed to the 6th speed gear and reverse gear, the planetary gear generates the reduction gear ratio, while in the 7th speed to the 12th speed gear, the ring gear s fixed and, therefore, reduction gear ratio is not generated.

2.1.1 the 1st speed to the 6th speed and the reverse gear

Fig. 1 s hows a free body diagram and simple modeling for the planetary gear system for the 1st speed to the 6th speed. Below, subscript R denotes the ring gear, P planetary gear, S sun gear, d differential gear, and eq equivalence. Here, n_R refers to the number of teeth of ring gear, and k the amount of addendum modification.

By using the planetary gear ratio, the equation (1) is satisfied.

$$n_R = n_s + 2n_p + (2k_s + 4k_p - k_R) \qquad (1)$$

The following equation is satisfied as, according to the diameter conditions of the planetary gear, the rotation speed at contact points A and B of the two gears must be the same.

$$(n_s + 2k_s)\omega_s = (n_s + 2k_s + n_p + 2k_p)\omega_d - (n_p + 2k_p)\omega_p \qquad (\text{at } A) \qquad (2)$$

$$0 = (n_s + 2k_s + n_p + 2k_p)\omega_d + (n_p + 2k_p)\omega_p \qquad (\text{at } B) \qquad (3)$$

Here, ω_s denotes angular velocity of the sun gear.

By using the kinetic energy equation, the equation (4) is satisfied.

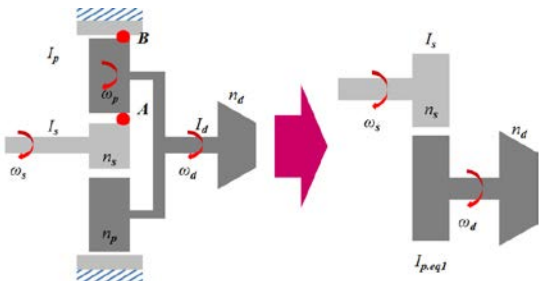

Fig. 1 Free body diagram of planetary gear system when the 1st speed to the 6th speed and the reverse speed

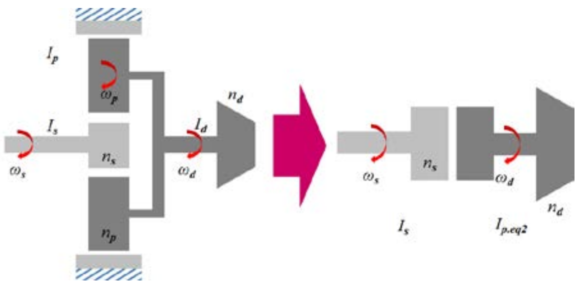

Fig. 2 Free body diagram of planetary gear system when the 7th speed to the 12th speed

$$I_{P.eq1} = I_d + m_P r^2 + I_P\left(1 + \frac{(n_s+2k_s+n_p+2k_p)^2}{(n_P+2k_p)^2}\right) \qquad (4)$$

Here, $I_{P.eq1}$ denotes the equivalent mass inertia moment of the planetary gear system when there is reduction gear ratio.

2.1.2 the 7th speed to the 12 th speed

Fig. 2 shows a free body diagram and simple modeling for the planetary gear system for the 7th speed to the 12th speed.

By using the kinetic energy equation, the following equation (5) is created, with ω_s=$k\omega_d$ and k=1.

$$I_{P.eq2} = I_P + m_P r^2 + I_d + I_R \qquad (5)$$

Here, $I_{P.eq2}$ denotes the equivalent mass inertia moment of the planetary gear system when there is no reduction gear ratio.

3 Analysis of Transmission Characteristics

3.1 Transmission

Fig. 3 s hows simple configuration of the transmission system. Below, E denotes an engine that includes the input shaft and two gears, m the main shaft of the transmission, c the counter shaft, and rev the reverse gear, while M refers to the mass of the car and R the dynamic load radius of the tire.

From the viewpoint of the final output shaft, the equation (6) below calculates the 1st speed to the 6th speed and the reverse gear, while the equation (7) calculates the equivalent inertia moment for the 7th speed to the 12th speed. Here, i and j refers to the i th and j th gear speed, and, in the equation, the gear ratio changes according to the power pathway of the relevant gear speed

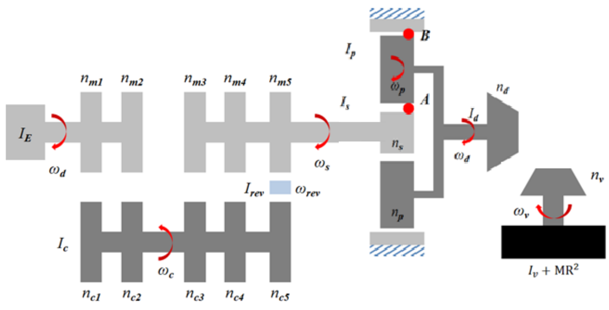

Fig. 3 The diagram of multistep transmission

$$I_{V.eqi} = I_V + MR^2 + I_{P.eq1}(\frac{n_V}{n_d})^2 + I_m(k\cdot\frac{n_V}{n_d})^2$$
$$+I_c(\frac{n_{mi}}{n_{ci}}\cdot k\cdot\frac{n_v}{n_d})^2 + I_B(\frac{n_{ci}}{n_{mi}}\cdot\frac{n_{mi}}{n_{ci}}\cdot k\cdot\frac{n_V}{n_d})^2$$
$$+I_{rev}(\frac{n_{cj}}{n_{rev}}\cdot\frac{n_{mi}}{n_{ci}}\cdot\frac{n_V}{n_d})^2 \quad (i=1,2,\ldots,6, rev) \quad (6)$$

$$I_{V.eqj} = I_V + MR^2 + (I_m + I_{P.eq2})(\frac{n_V}{n_d})^2$$
$$+I_c(\frac{n_{mj}}{n_{cj}}\cdot\frac{n_V}{n_d})^2 + I_B(\frac{n_{cj}}{n_{mj}}\cdot\frac{n_{mj}}{n_{cj}}\cdot\frac{n_V}{n_d})^2$$
$$+I_{rev}(\frac{n_{cj}}{n_{rev}}\cdot\frac{n_{mj}}{n_{cj}}\cdot\frac{n_V}{n_d})^2 \quad (j=7,8,\ldots,12) \quad (7)$$

3.2 Weight energy according to gear speed based on the Probability of usage

By substituting the equivalent inertia moment calculated by using equation (6) and (7) in equation (8), the total energy for different gear speeds can be calculated. V_i denotes the car velocity at different speeds, and r_{dyn} the dynamic radius of the tire.

$$\sum E = \frac{1}{2} I_{eqi}\cdot\frac{V_i}{r_{dyn}} \quad (8)$$

Although the entire energy was calculated by using equation (8), this is applicable when all speeds were used equally. In actual cars, as shown in Table 1, different probabilities of usage are set for different gears. In this study, as in equation (9), the probability of usage (p_i) was applied as weight in order to calculate the energy required for achieving the target distance more accurately. Table 2 shows the result.

$$E_{total} = \sum E\cdot p_i \quad (9)$$

4 Lightning Effect

In order to test the effect on the lightning of the rotor inside the transmission, it was assumed that the function of the internal rotor is maintained while the mass was minimized. The minimized mass is equivalent to one percent of the empty vehicle weight.

In order to compare the lightning effect, the same mass reduction was applied to the sprung mass as well. Table 3 shows the result.

Table 1 Probability of the speed

speed	probability [%]
1st	0.05
2nd	0.08
3rd	0.17
4th	0.30
5th	0.70
6th	1.80
7th	2.60
8th	4.00
9th	7.00
10th	12.00
11th	24.00
12th	47.00
rev-hi	0.15
rev-low	0.15
Total	100

Table 2 Required energy for original mass

step	energy with probability [J]
E_1	5
E_2	13
E_3	44
E_4	130
E_5	484
E_6	2,055
E_7	5,121
E_8	13,008
E_9	37,852
E_{10}	107,256
E_{11}	344,324
E_{12}	1,114,024
E_{rev-hi}	17
$E_{rev-low}$	28
Total	1,624,361

Table 3 Compare the required energy with the T/M internal mass and sprung mass

step	energy with probability [J]	
	lightning of T/M internal mass	lightning of sprung mass
E_1	5	5
E_2	13	13
E_3	44	44
E_4	127	128
E_5	477	479
E_6	2,026	2,036
E_7	5,066	5,071
E_8	12,872	12,881
E_9	37,470	37,487
E_{10}	106,185	106,223
E_{11}	340,914	341,007
E_{12}	1,102,991	1,103,191
$E_{rev\text{-}hi}$	16	17
$E_{rev\text{-}low}$	27	27
Total	1,608,232	1,608,610
	0.99%	0.96%

5 Conclusion

This study demonstrated the effect of mass reduction of the rotor and simple mass reduction on the kinetic energy required to achieve the target distance.

When compared with the conventional transmission model, the rotor mass model showed 0.99% of reduction effect. And the simple mass reduction showed 0.96% of the effect.

Even though the same mass was reduced, because of the effect of the rotor on the gear ratio, the effect of mass reduction by the rotor was larger than the effect of simple mass reduction.

Although the numerical effect is small, considering the nature of commercial vehicles in which the body weight takes up a large proportion, it makes considerable contribution to the dynamic performance of transmissions.

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