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An Experimental Study of the Effects of Temperature and Acceleration on Gear Rattle Noise

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Abstract

This study aimed to experimentally investigate the effects of temperature and acceleration on gear rattle noise in an automotive transmission. For this aim, gear rattle noise was measured at different temperatures depending on the acceleration of the gear motion. Thus, gear rattle noise variations were presented for each speed of the gearbox at different temperature conditions. The gear rattle noise calculated by empirical formulas and the experimentally obtained gear rattle noise were compared for each speed of the gearbox. It was observed that gear rattle noise increases with the acceleration of the gear motion. Furthermore, increasing the temperature causes an increase in gear rattle noise. By accurately estimating the temperature effect on gear rattle noise and by selecting an appropriate lubricant, it is possible to reduce rattle noise in the gearbox in an automotive transmission.

Keywords: Automotive transmission, rattle noise, temperature, acceleration.

1. Introduction

Gears are widely used in automotive transmission technology, and the gear noise level is one of the comfort factors for the automotive industry. For this reason, reducing the gear noise level is an important aim for gear manufacturers and gear designers.

The effects of temperature and acceleration on gear rattle noise are research subjects of engineers in the gear industry and automotive industry.

Gear noise in an automotive transmission is classified as **rattle noise, clattering noise,** and **whine noise** in the literature. Gearwheel and gearshift component vibrations cause noise in an automotive transmission. The cause of noise is the impact of the vibrating components. **Rattle noise** occurs in a transmission when it is in a neutral position. **Clattering noise** occurs during the motion of a transmission. **Whine noise** occurs due to rolling contact under the load of the transmission [1].

The classification of gear noise in automotive transmission, such as rattle noise, clattering noise and whine noise, is shown in Figure 1.

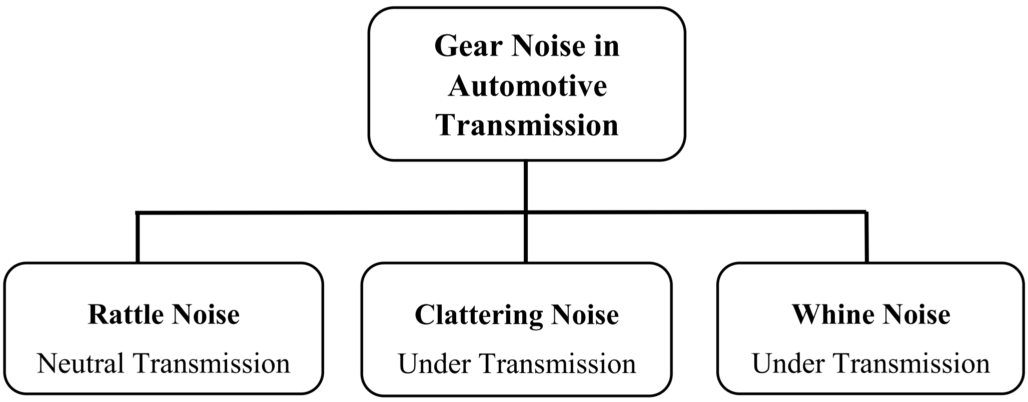

Figure 1 Classification of gear noise

In the literature, studies on rattle noise have focused on *geometric parameters, operational parameters* and *tribological parameters.*

Optimization of geometrical parameters under constraints can reduce rattle noise by satisfying the required safety.

By focusing on geometrical parameter optimization, an empirical rattle noise formula is used as an objective function under stress constraints. It is concluded that by optimising the gearbox geometrical parameters, such as the module, number of teeth, and backlash, it is possible to reduce rattle noise in an automotive transmission [2].

By considering torsional vibration model-based optimization, a torsional model is used as an objective function under stress constraints. It is concluded that by optimising the gearbox geometrical parameters, it is possible to reduce both vibration and rattle noise in an automotive transmission [3].

By minimising the transmission error in an automotive transmission gearbox, geometrical parameters are optimised. It is concluded that minimising the transmission error results in reducing rattle noise in the gearbox [4]

Operational parameters are required to utilise the gearbox in automotive transmission.

By considering operational parameters, the angular acceleration and rattle noise relation is investigated. It is observed that an increase in angular acceleration results in an increase in rattle noise [2].

Optimising tribological parameters can reduce rattle noise by satisfying the required lifetime safety.

By experimental study, the influence of tribological and geometrical parameters on the lubrication conditions and noise of gear transmission is investigated. It is concluded that the tribological parameters have only a small influence on whine noise but strongly determine the lubrication conditions and, therefore, the lifetime and efficiency of the transmission [5].

An experimental study on transmission rattle noise with particular regard to lubricating oil is presented. It is concluded that a hydrodynamic lubrication film formation between gear teeth cause to reduce the rattle noise in automotive transmissions [7].

This study aimed to experimentally investigate temperature and acceleration effects on gear rattle noise in an automotive transmission. For this aim, gear rattle noise is measured at different temperatures depending on the acceleration of gear motion. The gear rattle noise is calculated with empirical formulas and compared to experimentally obtained gear rattle noise for each investigated gearbox speed.

2. Calculation of Gear Rattle Noise

A five-speed gearbox for automotive transmission is the studied automotive transmission gearbox in the following work. The five-speed gearbox for automotive transmission is shown in Figure 1 and Figure 2.

The gearbox gear rattle noise is calculated by using empirical formulas as follows [2-4]:

The rattle noise level of a complete automotive transmission is calculated as follows:

$$L_{pComp} = 10\log\sum_{i=1}^{n}\left(10^{0,1L_{p,i}}\right) \tag{1}$$

The rattle noise L_p is calculated by correlating the computed noise value and the measured noise level:

$$L_p = 10\log(kI_m + 10^{0,1L_{basic}}) \tag{2}$$

where k is the calibration factor [-] and I_m is the average impact intensity [N]. The average impact intensity I_m is written as follows:

$$I_m = m_2\hat{\dot{\omega}}_1 r_{b1} C_{\mathrm{Im}} \tag{3}$$

where m_2 is a loose part [kg], $\hat{\dot{\omega}}_1$ is the angular acceleration [rad/s^2], r_{b1} is the pitch circle radius [mm] and C_{Im} is the related average impact intensity [-]. The average impact intensity, C_{Im}, is written as follows:

$$C_{\mathrm{Im}} = \sqrt{C_{sv}} \left(1{,}462 - \frac{0{,}714 C_{fa} C_{sa}}{-0{,}016 C_{fa} + 0{,}12 C_{sv}} \right) \tag{4}$$

where C_{sv} is the nondimensional circumferential backlash [-]. The nondimensional circumferential backlash C_{sv} [-] is defined as follows:

$$C_{sv} = \frac{s_v \omega_{an}^2}{r_{b1} \hat{\dot{\omega}}_1} \tag{5}$$

where s_v is backlash [mm], ω_{an} is the excitation frequency [rad/s] and C_{sa} is the nondimensional axial clearance [-]. The nondimensional axial clearance C_{sa} [-] is defined as follows:

$$C_{sa} = \frac{s_a \omega_{an}^2 \tan\beta}{r_{b1} \hat{\dot{\omega}}_1} \tag{6}$$

where s_a is the axial clearance [mm], β is the helix angle [°], C_{fa} is the related axial friction force [-] and L_{basic} is the basic noise level [dB].

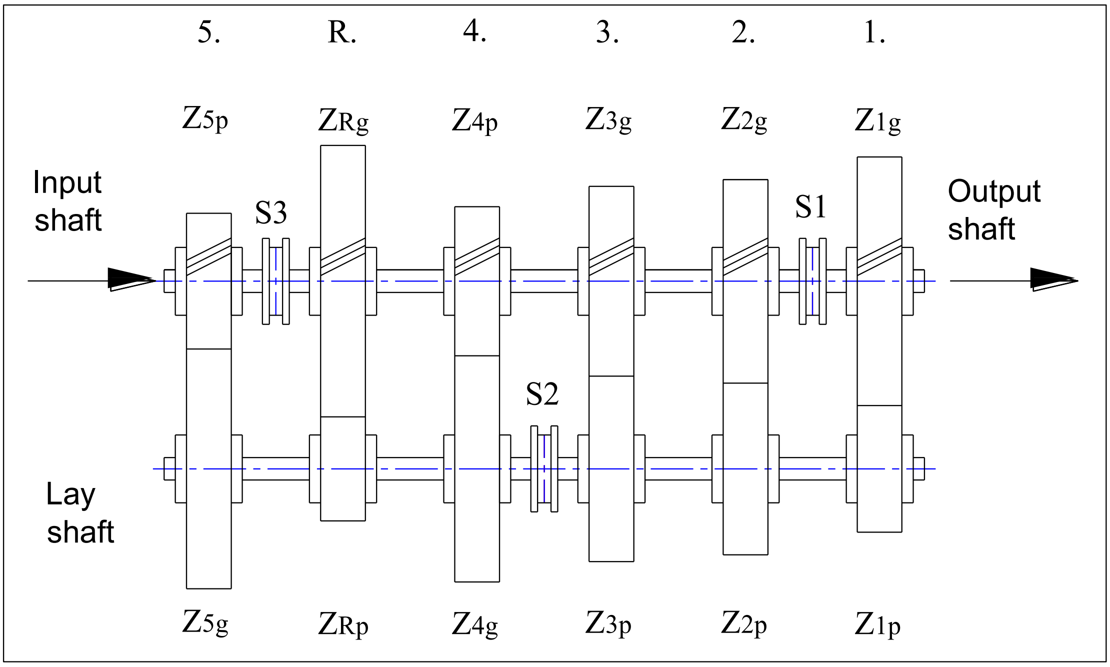

Figure 1 Five-speed gearbox for automotive transmission.

Figure 2 Photograph of the five-speed gearbox for automotive transmission.

3. Numerical Study

The calculated rattle noise values for different accelerations of the five-speed transmission are presented for each speed.

3.1 Calculated Gear Rattle Noises

The rattle noises for this five-speed transmission are calculated and simulated for various angular accelerations.

For the geometrical operational parameters of the rattle noise calculation, module m is assumed to be between 2 [mm] and 2,5 [mm], the number of teeth z is assumed to be between 14 [-] and 34 [-], the helix angle β is assumed to be 30 [°C], the backlash s_v is 0,1 [mm], and the axial clearance s_a is 0,3 [mm]. The excitation frequency ω_{an} is 220 [rad/s].

The calculated rattle noise for the 1st speed is shown in Figure 3. The maximum rattle noise for the 1st speed reaches 84,73 [dB].

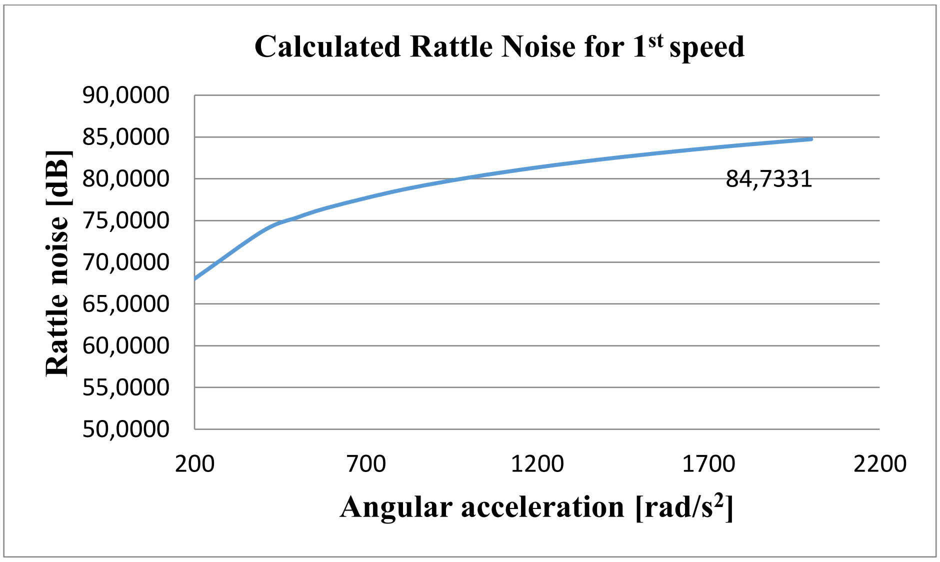

Figure 3 Calculated rattle noise for the 1st speed

The calculated rattle noise for the 2nd speed is shown in Figure 4. The maximum rattle noise for the 2nd speed reaches 83,18 [dB].

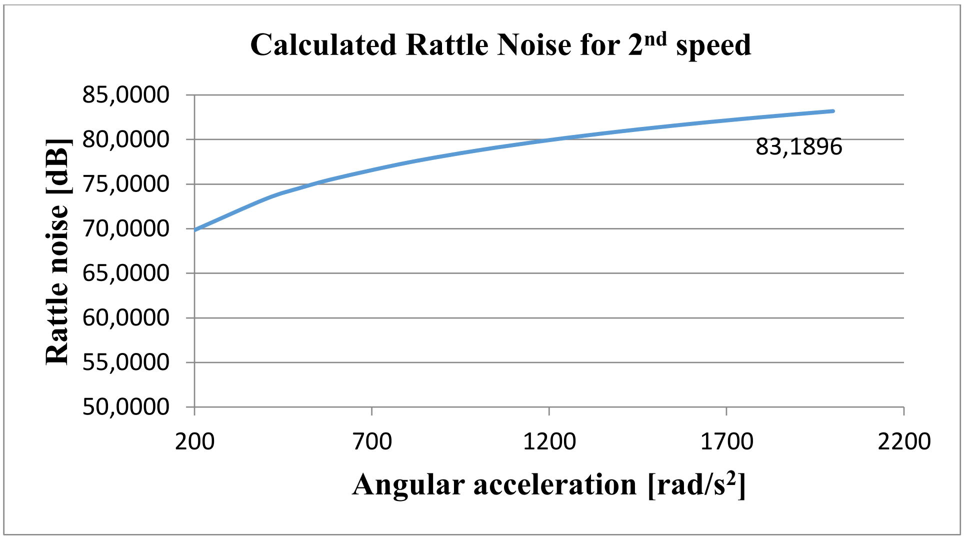

Figure 4 Calculated rattle noise for the 2nd speed

The calculated rattle noise for the 3rd speed is shown in Figure 5. The maximum rattle noise for the 3rd speed reaches 93,38 [dB].

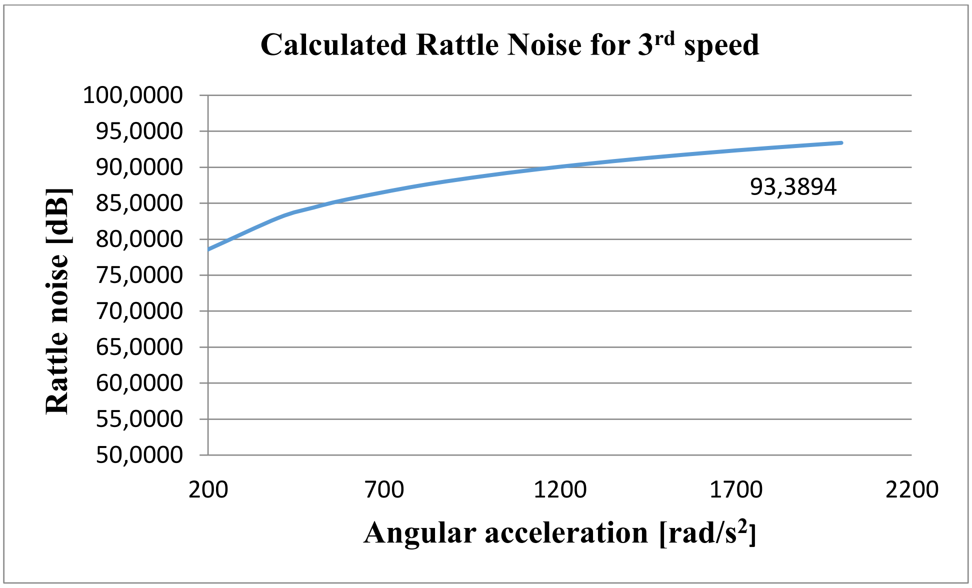

Figure 5 Calculated rattle noise for the 3rd speed

The calculated rattle noise for the 4th speed is shown in Figure 6. The maximum rattle noise for the 4th speed reaches 93,10 [dB].

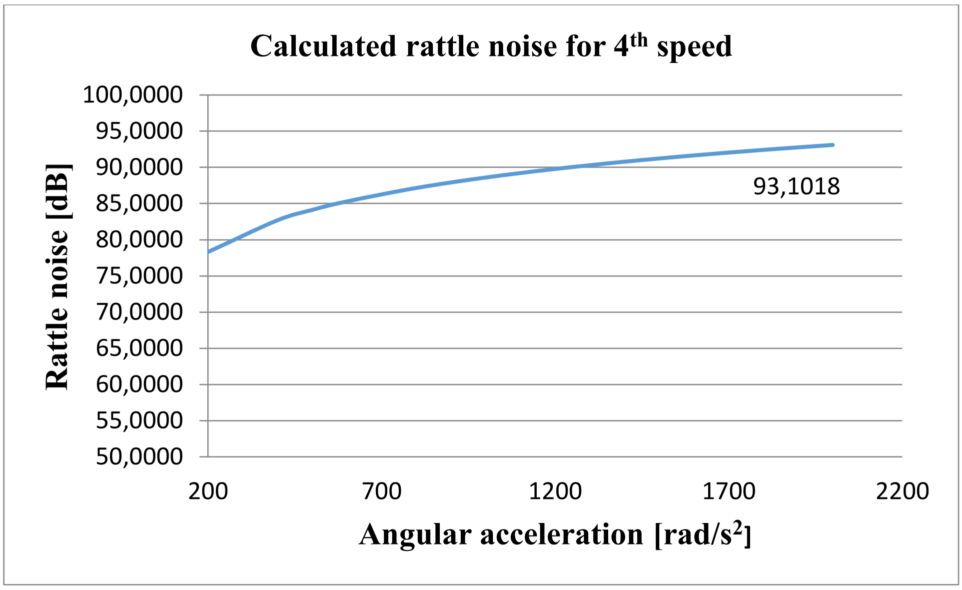

Figure 6 Calculated rattle noise for the 4th speed

The calculated rattle noise for the 5th speed is shown in Figure 7. The maximum rattle noise for the 5th speed reaches 82,34 [dB].

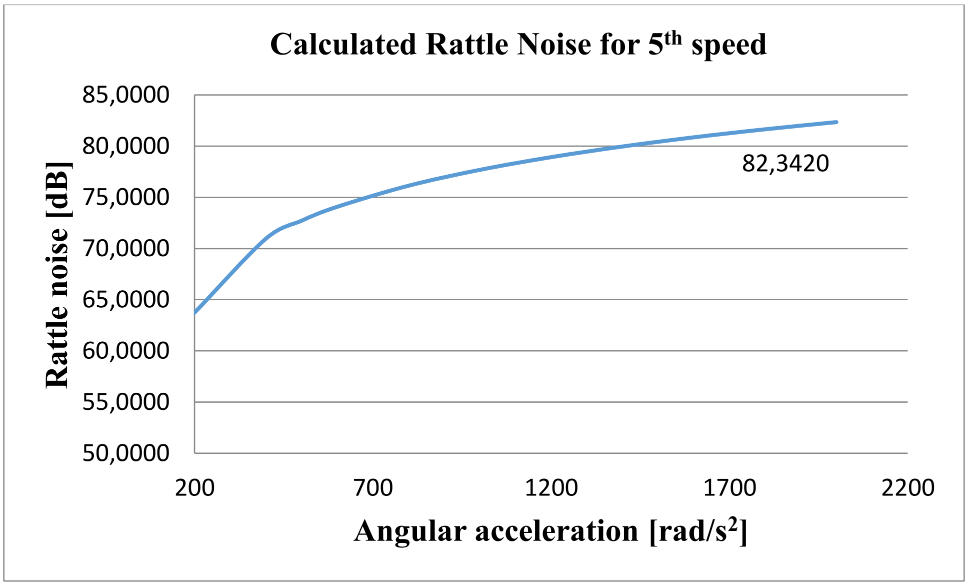

Figure 7 Calculated rattle noise for the 5th speed

4. Experimental Study

The rattle noise test bench of the *Institute for Machine Elements (IMA)* was specially designed and developed to investigate loose part noises from vehicle transmissions [6]. Gear rattle noises are measured by using a rattle noise test bench, as shown in Figure 8.

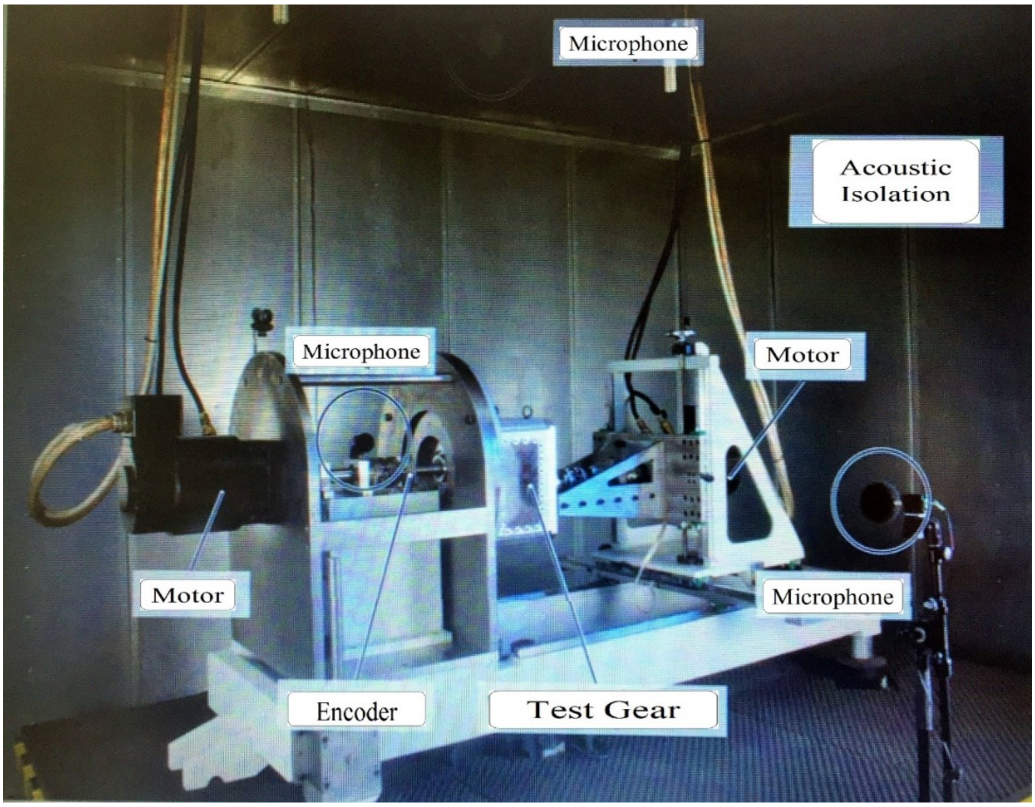

Figure 8 Rattle noise test bench [6]

The input shaft shows an average speed of 900 [m^{-1}] in all the tests. The tribological parameter assumed a mineral oil with a viscosity of η=9,47 [mPas]. The oil sump temperature was 80 [°C].

4.1 Measured Gear Rattle Noises

Gear rattle noises were measured at different temperatures, namely, 25 [°C] and 80 [°C]. Experimentally obtained gear rattle noise at different temperatures and accelerations are presented for each speed of the gearbox.

The relationship between the measured rattle noise and the acceleration and the 1st speed is shown in Figure 9 for each temperature. The maximum rattle noise value at 25 [°C] reaches 73,83 [dB], while the maximum rattle noise value at 80 [°C] reaches 76,30 [dB] for the 1st speed.

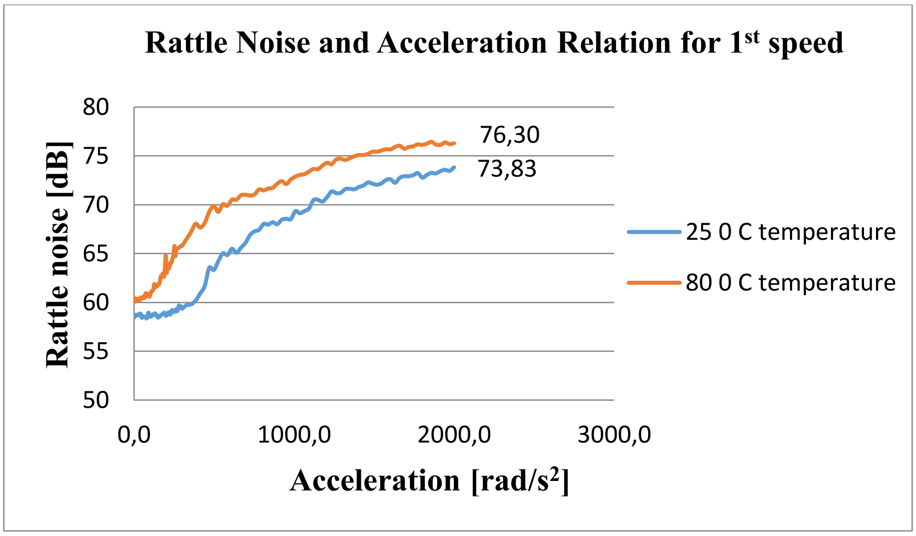

Figure 9 Rattle noise and acceleration relation for the 1st speed

The relationship between the measured rattle noise and acceleration for the 2nd speed is shown in Figure 10 for each temperature. The maximum rattle noise at 25 [°C] reaches 74,57 [dB], while the maximum rattle noise at 80 [°C] reaches 76,95 [dB] for the 2nd speed.

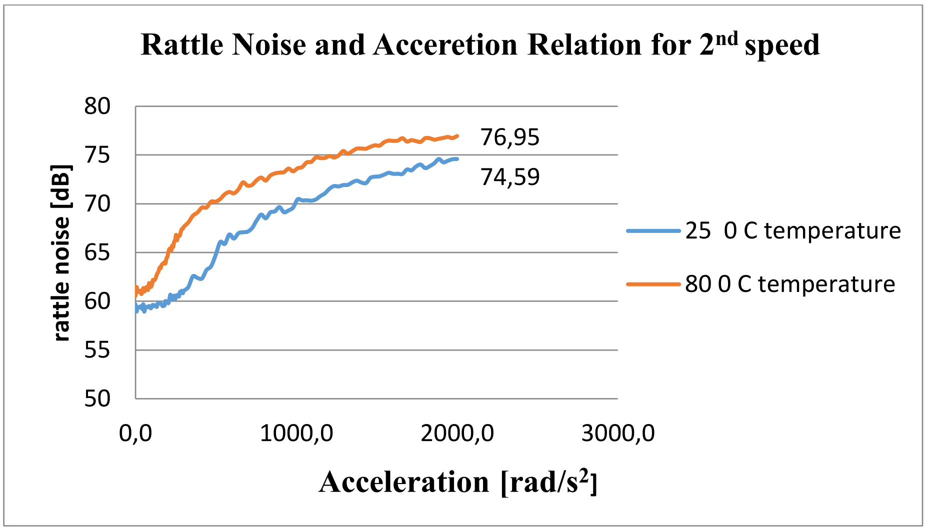

Figure 10 Rattle noise and acceleration relation for the 2nd speed

The relationship between the measured rattle noise and acceleration for the 3rd speed is shown in Figure 11 for each temperature. The maximum rattle noise at 25 [°C] reaches 75,23 [dB], while the maximum rattle noise at 80 [°C] reaches 77,79 [°C] for the 3rd speed.

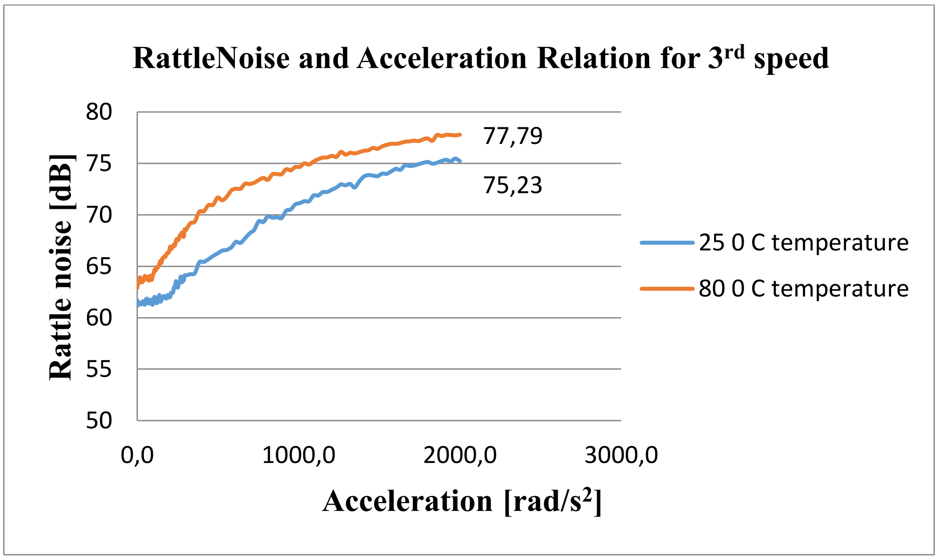

Figure 11 Rattle noise and acceleration relation for the 3rd speed

The relationship between the measured rattle noise and acceleration for the 4th speed is shown in Figure 12 for each temperature. The maximum rattle noise at 25 [°C] reaches 76,76 [dB], while the maximum rattle noise at 80 [°C] reaches 78,67 [dB] at the 4th speed.

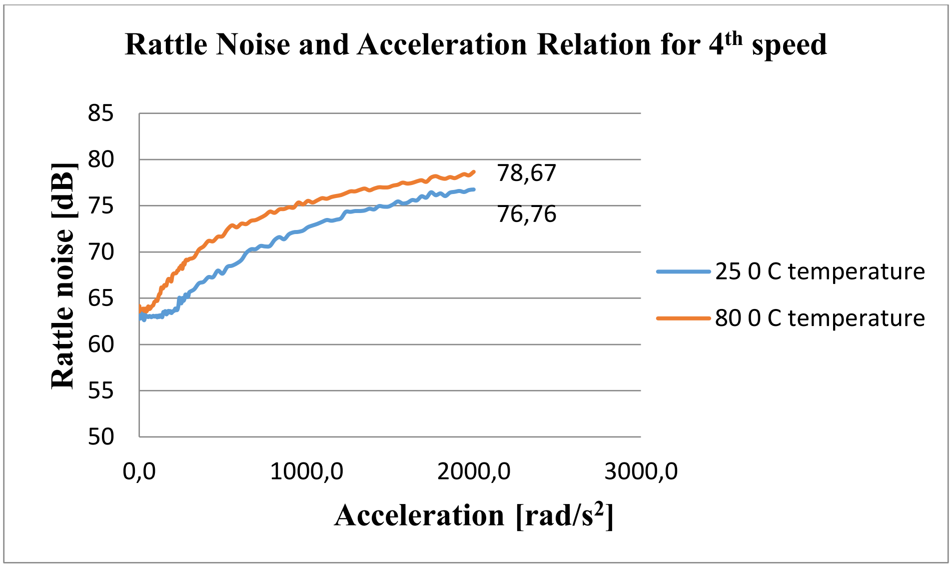

Figure 12 Rattle noise and acceleration relation for the 4th speed

The relationship between the measured rattle noise and acceleration for the 5th speed is shown in Figure 13 for each temperature. The maximum rattle noise at 25 [°C] reaches 74,83 [dB], while the maximum rattle noise at 80 [°C] reaches 73,91 [dB] for the 5th speed.

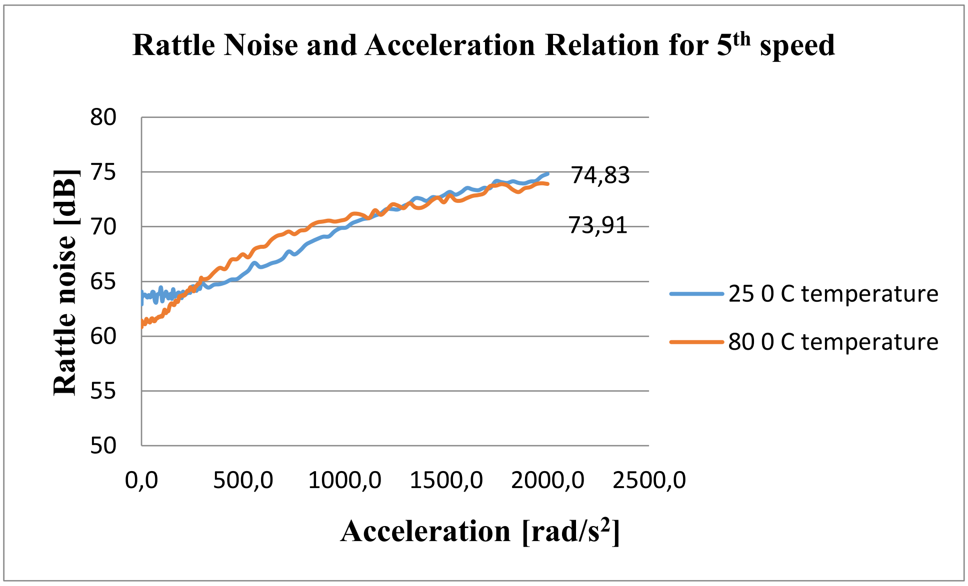

Figure 13 Rattle noise and acceleration relation for the 5th speed

5. Results and Discussion

A comparison of the calculated and measured rattle noise results for the five-speed gearboxes is presented in Table 1.

Table 1 Comparison of the calculated and measured rattle noise results

Rattle noise Lp [dB]	1st speed	2nd speed	3rd speed	4th speed	5th speed
Calculated rattle noise	84,73	83,18	93,38	93,10	82,34
Measured rattle noise at 25 [°C]	73,83	74,59	75,23	76,76	73,91
Measured rattle noise at 80 [°C]	76,30	76,95	77,79	78,67	74,83

A comparison of the calculated and measured rattle noise results for the 1st speed is shown in Figure 14.

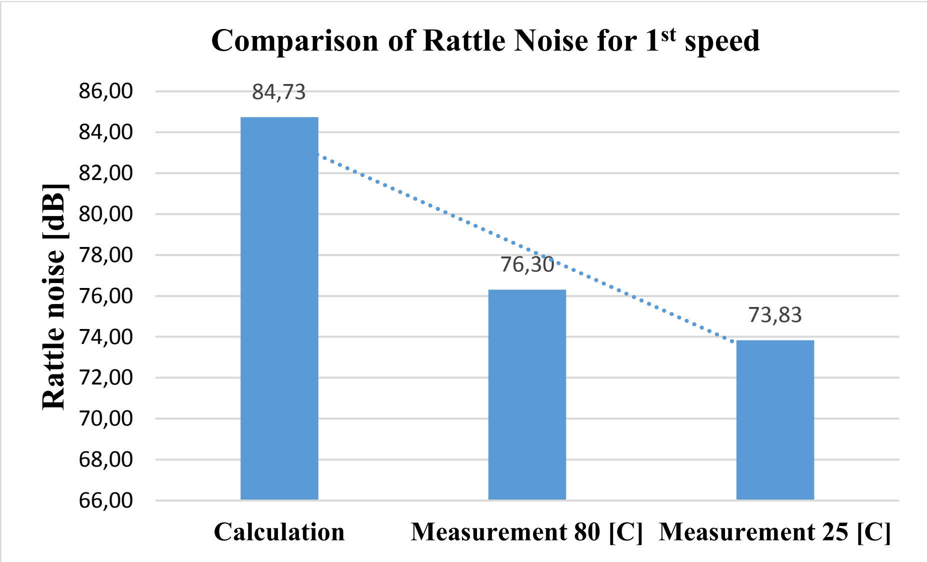

Figure 14 Comparison of rattle noise for the 1st speed

A comparison of the calculated and measured rattle noise results for the 2nd speed is shown in Figure 15.

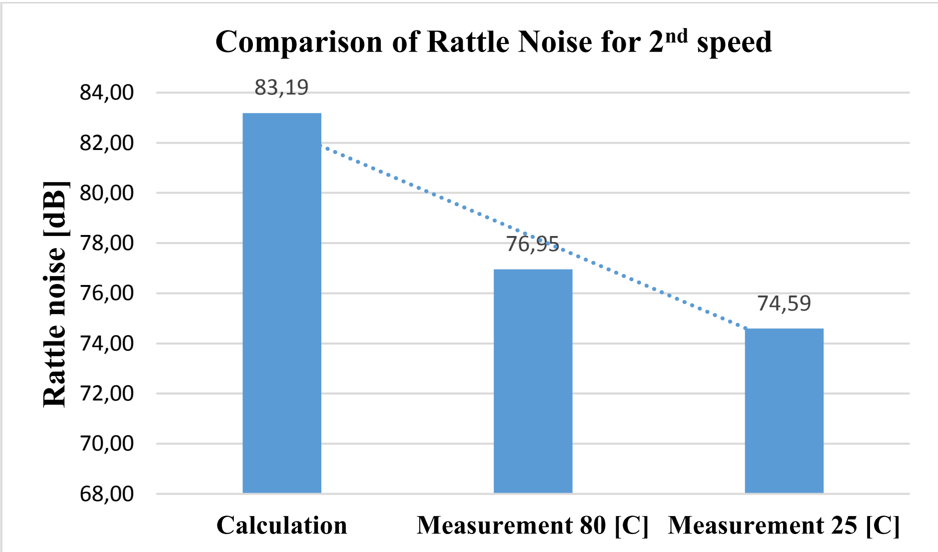

Figure 15 Comparison of rattle noise for the 2nd speed

A comparison of the calculated and measured rattle noise results for the 3rd speed is shown in Figure 16.

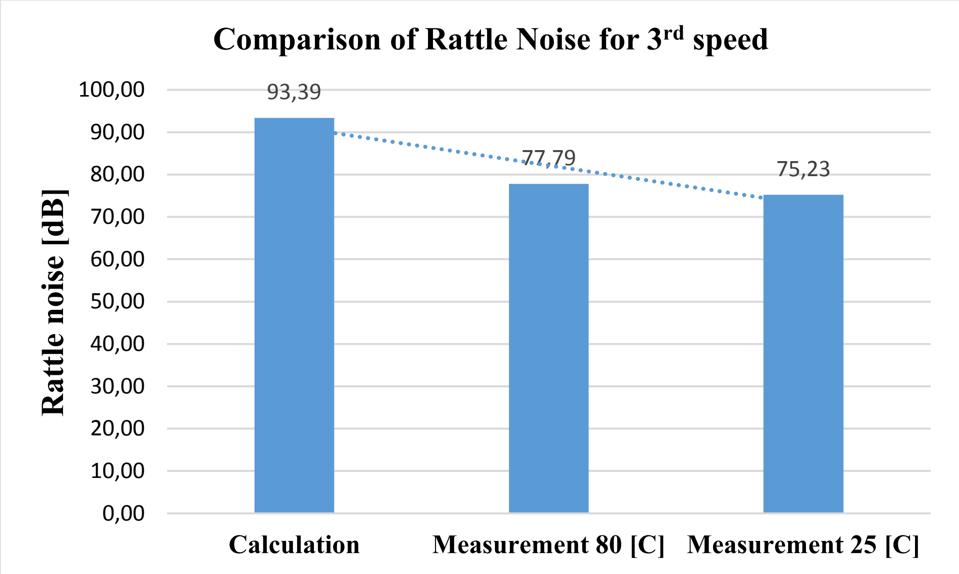

Figure 16 Comparison of rattle noise for the 3rd speed

A comparison of the calculated and measured rattle noise results for the 4th speed is shown in Figure 17.

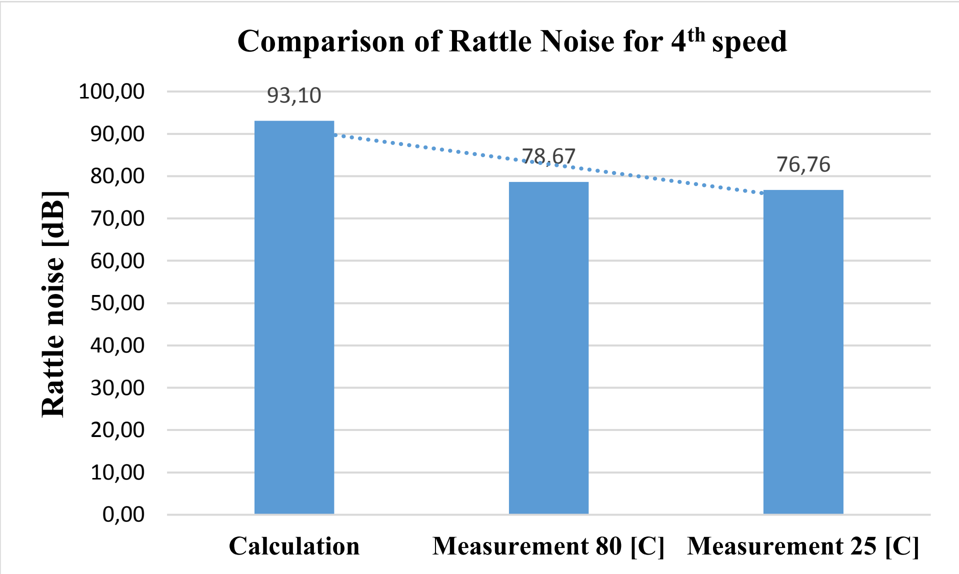

Figure 17 Comparison of rattle noise for the 4th speed

A comparison of the calculated and measured rattle noise results for the 5th speed is shown in Figure 18.

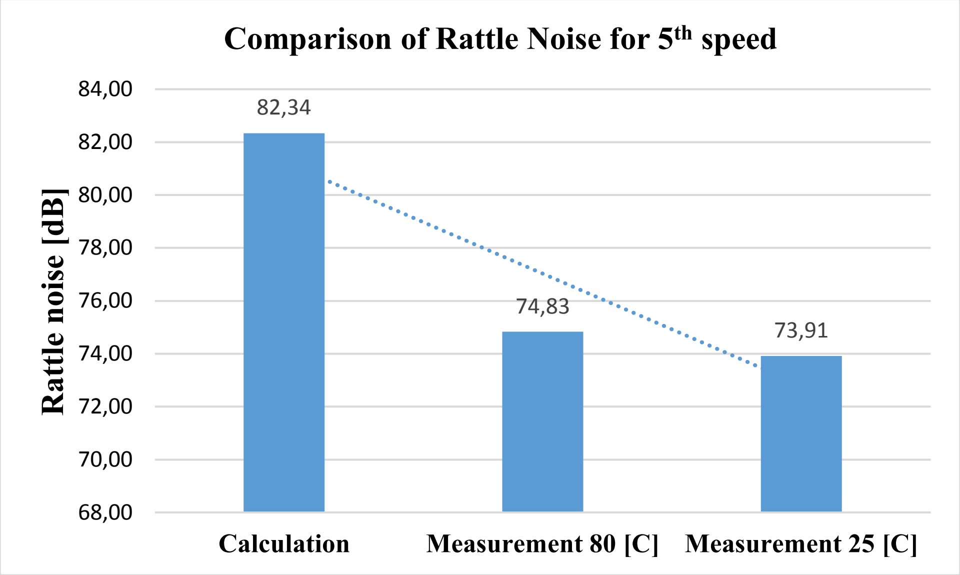

Figure 18 Comparison of rattle noise for the 5th speed

6. Conclusions

The effects of temperature and acceleration on gear rattle noise in an automotive transmission gearbox are experimentally investigated. Gear rattle noise is measured at different temperatures depending on the acceleration of gear motion. The following conclusions are obtained:

i. Increasing the angular acceleration results in an increasing rattle noise for each speed of the five-speed gearbox transmission.
ii. Increasing the temperature results in an increasing rattle noise for each speed of the five-speed gearbox transmission.
iii. Increasing the angular acceleration results in oil throw-out from the gap and an increasing temperature.
iv. Increasing the temperature results in a decreasing viscosity and loss of lubricant between the meshing gear surfaces.

By selecting an appropriate lubricant, it is possible to reduce rattle noise in the gearbox in an automotive transmission. Appropriate lubricants not only reduce rattle noise but also reduce surface failures such as wear and scuffing.

The rattle noise level of gears will be statistically investigated by the author in a future study to determine the reliability level of the gear rattle behaviour.

Acknowledgement

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