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# *Analysis and Solution of Gear Knock of Manual Transmission*

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***Keywords:*** Manual Transmission, Gear Knock, Noise, Angular Acceleration

***Abstract:*** Manual transmission gear knocking is a common transmission noise. It is the noise generated by the continuous impact of the non-working tooth surfaces of the active tooth and the passive tooth of the gearbox hollow sleeve gear under the excitation of the engine torque vibration. Gear knocking noise is an obvious broadband noise characteristic in the cab, which cannot be effectively eliminated by optimizing the acoustic package of the vehicle alone. The common solution in engineering is to reduce the clearance of the gear pair and reduce the speed fluctuation and torque vibration at the input end of the transmission to eliminate the knocking noise. This paper takes a manual transmission gear knocking problem in the actual production process as an example, starts from the mechanism of gear knocking, analyses the transmission gear knocking noise, analyses the transmission gear knocking problem through noise testing, engine torsional vibration testing and driver and passenger subjective evaluation, and verifies the improvement measures through experiments. Finally determine the solution for the gear knocking noise.

## 1. Introduction

Manual transmission is a kind of mechanical structure, which can realize the shift of transmission gear. It is composed of gear, shaft, bearing, synchronizer, gear selection mechanism, etc. Manual transmission in the working process is easy to produce more obvious noise, the reason is that its working environment is relatively harsh. According to the different production principles, the noise of manual transmission can be divided into four categories: gear whistling, gear knocking abnormal noise, bearing noise, synchronizer combined noise. In this paper, experiments are carried out based on a manual transmission, and the improvement measures are verified through noise test, engine torsional vibration test and subjective evaluation of drivers and passengers, and the solution of gear knocking noise is finally finalized.

## 2. Mechanism of Transmission Gear Knocking

Transmission gear knocking is an impact phenomenon that occurs between non-loaded meshing gears. When the transmission gear is working, the non-loaded gear will produce gear knocking noise in the rotation direction [1]. The main cause of transmission gear knocking noise is the obvious torque fluctuation in the process of engine - clutch - transmission torque transmission. Due to the limited vibration damping capacity of the clutch, the torque transmitted by the engine to the input shaft of the transmission after vibration damping through the clutch still has obvious torque fluctuations, resulting in irregular reciprocating knocking noise generated by non-working components inside the transmission within the allowed working gap, and then transmitted to the car through transmission suspension and other paths [2-3].The root cause is that the engine output torque caused by engine combustion and unbalanced inertial force presents periodic changes, so that the engine output speed shows a certain fluctuation, as shown in Figurer 1.Therefore, gear knocking noise is a noise phenomenon caused by engine torsional vibration of transmission non-load gears knocking each other and transmitted to the car through the associated structure and air radiation path [1].

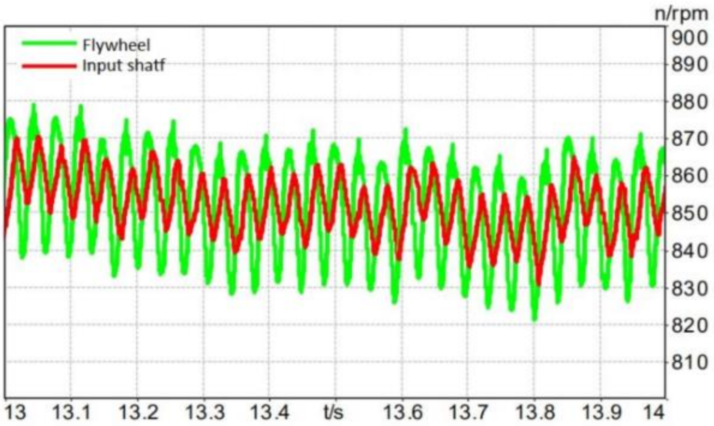


Figure 1: Speed fluctuation of the engine flywheel

## 3. Noise Analysis of Transmission Gear Knocking

Transmission noise sources mainly come from transmission gear meshing, bearing high-speed rotation, synchronizer combination and body vibration, etc., mainly including load gear meshing noise, and empty sleeve gear knocking noise. Gear knocking will produce a wide frequency band, gear knocking noise frequency is higher, the driver and passenger ear is often more sensitive to this noise, so eliminating transmission gear knocking noise has an important contribution to improving the vehicle NVH level [4].

## 4. Transmission Gear Knock Common Solution

1) Reduce the side clearance of gear pair teeth. It cannot be reduced indefinitely, otherwise after the load heats up, the gear tooth thermal expansion, the gear pair backlash disappears, and the gear teeth are damaged by squeezing each other [5].

2) Optimize the vibration reduction characteristics of the clutch, such as adjusting the main vibration reduction stiffness of the clutch, adjusting the pre-vibration reduction stiffness of the clutch, etc.

3) Increase the moment of inertia of the flywheel or gear pair. Increasing inertia can reduce torque/speed fluctuations.The increase of flywheel inertia is limited by space, fuel consumption and cost.

4) Match the dual mass flywheel. The effect is better, but compared with ordinary flywheels, the cost rises higher.

5) The mechanical transmission path is blocked. Suspension, shift cable, etc.

6) Acoustic package optimization.

## 5. Analysis and Solution of Gear Knocking Noise of a Three-Axis Manual Transmission

In the whole vehicle test process of a three-axis manual transmission, the noise of transmission gear knocking occurs, and the failure rate is 75%.The specific condition of finding the problem is: in the idle state (open the air conditioning and headlights) in the cab to hear "dadada" continuous, regular, high frequency abnormal sound, the abnormal sound is not large, but the sound frequency is higher, sitting in the cab can be obviously heard. After turning off the headlights, the abnormal sound is slightly weakened, and then the abnormal sound is significantly weakened after turning off the air conditioning. After stepping on the clutch pedal, the "dadada" abnormal sound is eliminated. After releasing the clutch pedal, the "tap, tap" abnormal sound is repeated. From this, it can be judged that the abnormal sound comes from inside the transmission and is the abnormal sound of the empty sleeve gear knocking inside the transmission. For this reason, the vehicle interior noise test and engine torsional vibration test were carried out respectively under idle conditions with load and without load. The results of vehicle interior noise test are shown in Figure 2, Figure 3 and Table 1, and the results of engine [6].

Torsional vibration test are shown in Figure 4, Figure 5 and Table 2.

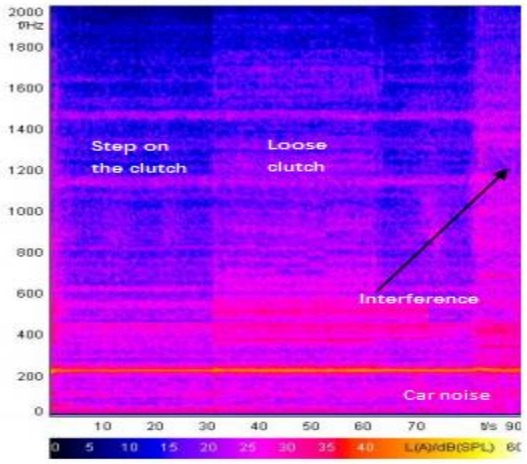


Figure 2: Spectrum diagram of noise of hot car without load

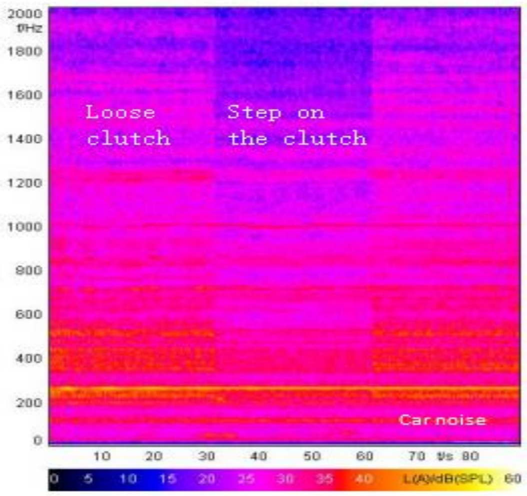


Figure 3: Spectrum diagram of load noise of hot vehicle

Table 1: Noise test values

| Test sample | Working condition | Sound pressure level (dB) | Difference value (dB) |
|---|---|---|---|
| Original vehicle + abnormal sound transmission | Loose clutch without load (off air conditioning and headlights) | 48. 9 | 1. 8 |
| | No load (off air conditioning and headlights) step on clutch | 47. 1 | |
| | Loose clutch with load (open air conditioning and headlights) | 54. 9 | 2.1 |
| | With load (air conditioning and headlights) step on clutch | 52. 8 | |

Summary: The sound pressure level of the right ear of the whole owner is less than 60dB under load and no load conditions, and the difference of the sound pressure level of stepping and loosening is less than 3dB, which is in line with the experimental expectation.

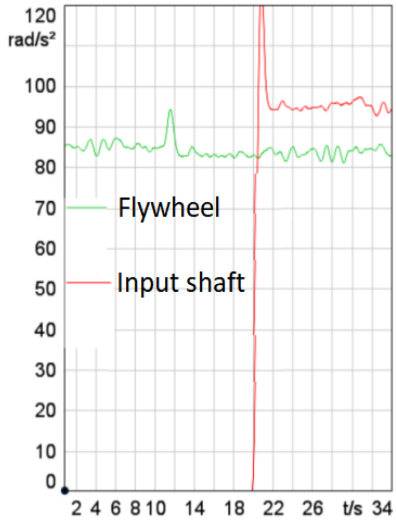


Figure 4: Test of angular acceleration of hot car without load

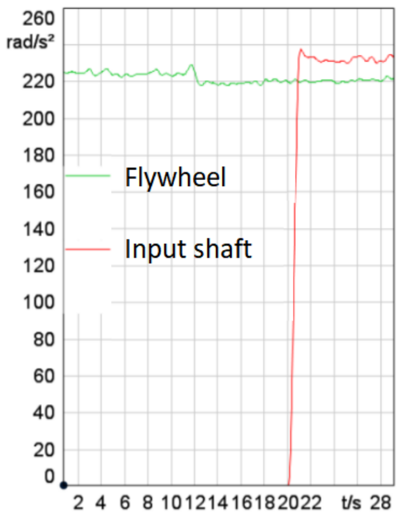


Figure 5: Angular acceleration test of hot car with load

Summary: The ignition order angular acceleration of the input shaft of the sample transmission without load condition is lower than 125rad/s^2, which is in line with the experimental expectation. The minimum ignition order angular acceleration of the input shaft of the sample transmission under load conditions is 231rad/s^2, greater than 125rad/s^2, which is not in line with the experimental expectation.

Table 2: Idle torsional vibration level a hot car speed fluctuation

| Test sample | Working condition | Fluctuation of speed | Rpm |
|---|---|---|---|
| Original vehicle + abnormal sound transmission | No load (off air conditioning and headlights) | Flywheel speed fluctuation | 44. 47 |
| | | Transmission input shaft speed fluctuation | 48. 41 |
| | With load (off air conditioning and headlights) | Flywheel speed fluctuation | 55. 45 |
| | | Transmission input shaft speed fluctuation | 67. 47 |

Summary: The speed fluctuation of the input shaft of the sample transmission without load condition is higher than 40rpm, which is not in line with the experimental expectation. The speed fluctuation of the input shaft of the sample transmission with load condition is 67.47rpm, which is not in line with the experimental expectation.

Noise evaluation criteria: the noise pressure level of the main cab inside the car is ≤60dB(A), and the difference between the noise pressure level of the loose and stepped clutch is ≤3dB(A), which can meet the experimental expectations; Otherwise, it does not meet the experimental expectations. Torsional vibration evaluation criteria: The second-order angular acceleration of the transmission input shaft <125rad/2 and the speed fluctuation <40rpm can meet the experimental expectations; otherwise it does not meet the experimental expectations.

According to the results of the internal noise test and engine torsional vibration test, it can be further confirmed that the abnormal sound is the sound of the transmission gear knocking. Common control measures according to the transmission gear knock mentioned earlier. First of all, the measures to reduce the side clearance of transmission gear were verified, and 10 transmission samples were assembled on the vehicle for testing and subjective evaluation. The adjustment data of tooth side clearance are shown in Table 3, the noise test results of one vehicle are shown in Figurer 6, Figurer 7 and Table 4, and the scheme evaluation conclusions are shown in Table 5.

Table 3: Adjustment data of tooth side clearance

| Gears | Minimum backlash before adjustment | Minimum adjusted backlash | Maximum backlash before adjustment | Adjusted maximum backlash |
|---|---|---|---|---|
| I | 0.043 | 0.025 | 0.182 | 0.161 |
| II | 0.046 | 0.027 | 0.168 | 0.149 |
| III | 0.045 | 0.027 | 0.166 | 0.147 |
| IV | 0.042 | 0.027 | 0.163 | 0.145 |
| V | 0.042 | 0.036 | 0.160 | 0.149 |
| Reverse gear drive teeth | 0.050 | 0.035 | 0.200 | 0.170 |
| Reverse driven teeth | 0.052 | 0.038 | 0.200 | 0.140 |

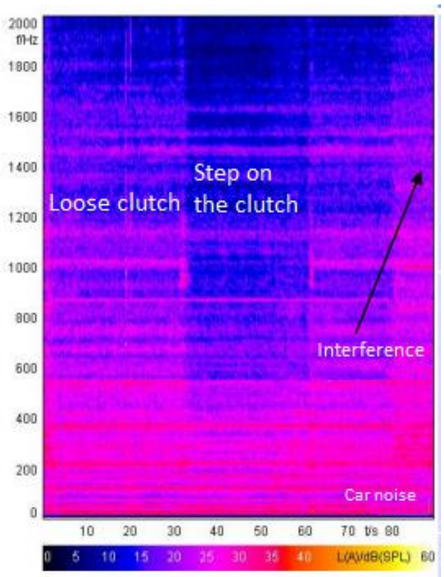


Figure 6: Spectrum diagram of noise of hot car without load

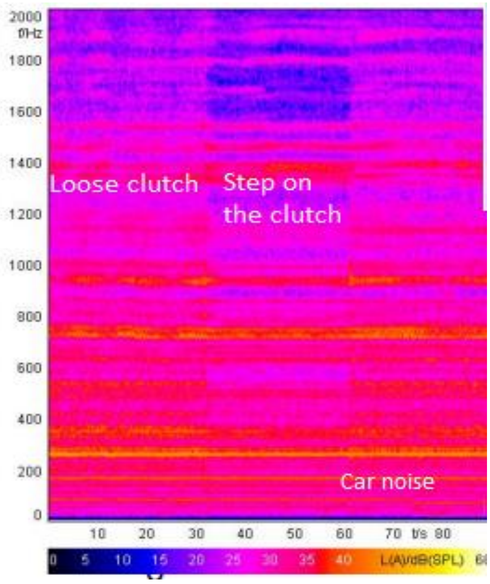


Figure 7: Spectrum diagram of load noise of hot vehicle

Table 4: Noise test values

| Test sample | Working condition | Sound pressure level (dB) | Difference value (dB) |
|---|---|---|---|
| Original vehicle + abnormal sound transmission | Loose clutch without load (off air conditioning and headlights) | 48. 9 | 0.9 |
| | No load (off air conditioning and headlights) step on clutch | 47. 1 | |
| | Loose clutch with load (open air conditioning and headlights) | 54. 9 | 1.1 |
| | With load (air conditioning and headlights) step on clutch | 52. 8 | |

Table 5: Subjective evaluation conclusions

| Transmission number | Review conclusion | Transmission number | Review conclusion |
|---|---|---|---|
| 1# | OK | 6# | NOK |
| 2# | OK | 7# | OK |
| 3# | Boundary state | 8# | OK |
| 4# | OK | 9# | NOK |
| 5# | OK | 10# | OK |

Summary: After adjusting the gear clearance of the transmission, the noise improvement in the cab under idle conditions was detailed. 10 vehicles were subjectively evaluated, 7 of which were in the expected state of the experiment, 1 was in the critical state, and 2 were not in the expected state of the experiment. The improvement measures to reduce the gear clearance of the transmission were effective, and the failure rate was significantly reduced.

Since the problem has not been completely solved, the verification of the second scheme is carried out - optimizing the vibration reduction characteristics of the clutch. The two samples that reduce the main vibration damping stiffness of the clutch are assembled on the two vehicles that are assessed as not meeting the experimental expectations. The noise test results are shown in Figure 8 and Figure 9, the engine torsional vibration test results are shown in Figure 10 and Figure 11, and the test data and evaluation conclusions are shown in Table 6.

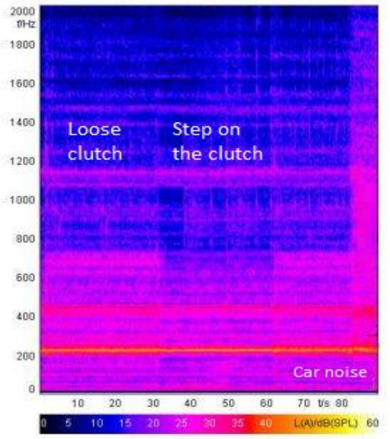


Figure 8: Spectrum diagram of noise of hot car without load

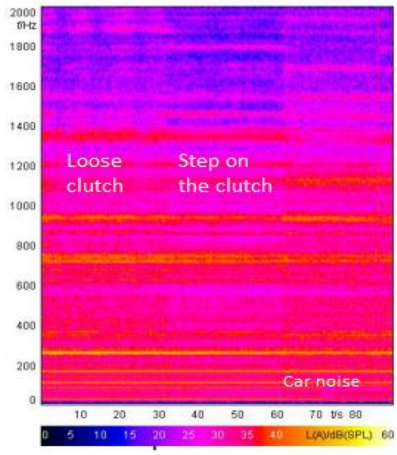


Figure 9: Spectrum diagram of load noise of hot vehicle

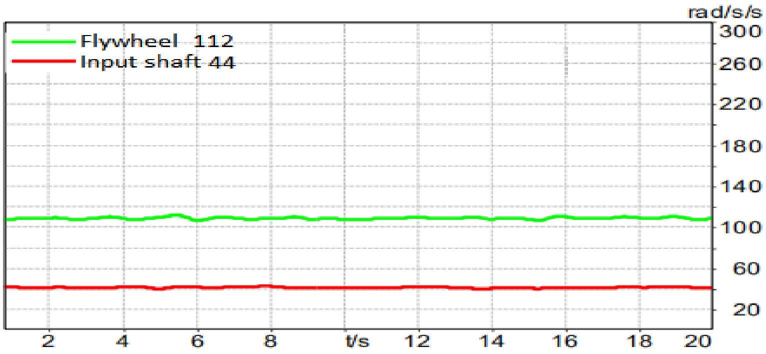

Figure 10: Test of angular acceleration of hot car without load

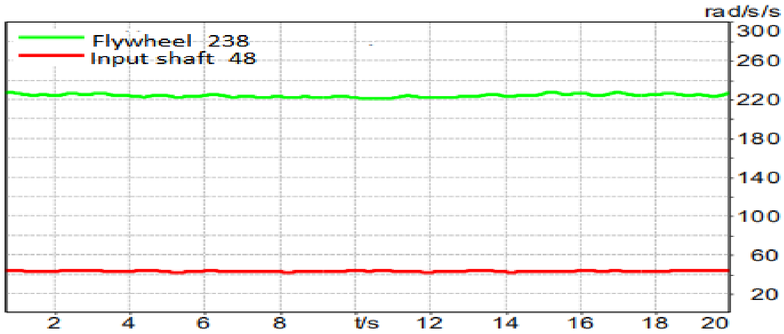

Figure 11: Angular acceleration test of hot car with load

Table 6: Test data and evaluation conclusions

| Clutch reduction main damping stiffness sample (stiffness reduced from 17Nm/ °to 13Nm/ °) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| No | Working condition | Loose clutch main driving sound pressure level(dB) | Loose clutch main driving sound pressure level (dB) | Sound pressure level difference (dB) | Flywheel second order angular acceleration (rad/s2) | Input axis second order angular acceleration (rad/s2) | Clutch vibration isolation rate | Review conclusion |
| 1# | No load | 44. 3 | 43. 7 | 0. 6 | 112 | 44 | About 60% | OK |
| | Bringing onto load | 49. 6 | 48. 8 | 0.8 | 238 | 48 | About 80% | |
| 2# | No load | 44. 5 | 43.8 | 0.7 | 115 | 45 | About 60% | OK |
| | Bringing onto load | 49. 9 | 49. 5 | 0. 4 | 242 | 50 | About 80% | |

Summary: The sound pressure level of the right ear of the whole owner is less than 60dB under load and no load conditions, and the difference of the sound pressure level of stepping and loosening is less than 3dB, which is in line with the experimental expectation. The order angular acceleration of the input shaft of the sample transmission is lower than 125rad/s^2, which is in accordance with the experimental expectation. The vibration isolation rate of the clutch is 60% under the working condition of the hot car without load, and the vibration isolation rate of the clutch reaches 80% under the working condition of the hot car with load. There is no obvious gear knocking noise inside and outside the subjective feeling, which is in line with the experimental expectation.

In order to further verify the effectiveness of the measures, 20 vehicles were assembled to reduce the side clearance of transmission gear and adjust the main vibration damping stiffness of the clutch for subjective evaluation, and 20 vehicles were in line with the experimental expectations. In this case, the two improvement measures of reducing the transmission gear tooth side clearance and adjusting the main vibration damping stiffness of the clutch have a remarkable effect on the improvement of the transmission gear knocking noise.

## 6. Conclusions

This paper analyzes the transmission gear knocking problem found in the development of manual transmission, expounds the mechanism of transmission gear knocking problem, and implements two measures to solve the problem: 1.Reduce the side clearance of gear pair;2. Optimize the vibration reduction characteristics of the clutch. The effectiveness of the measures is verified by noise test, engine torsional vibration test and subjective evaluation of drivers and passengers. Finally, the problem of transmission gear knocking is solved, and it is hoped that it will be helpful to the later people in the transmission design and the analysis and solution of the problem of gear knocking.

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