

Oil leakage analysis of damper in multichannel cab assembly road simulation test

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Abstract. This paper solved the damper oil leakage problem of seven-channel fatigue test of a heavy vehicle cab and it analyzed the relationship between spring damper characteristics parameters and the thermal production and calculated the spring damper heat-producing power. Through the analysis, calculation and comparison of different types of automobiles, it concluded the damper average heating-producing power in seven-channel fatigue test and the basic relationship between highest temperature and damper oil leakage, providing analysis solution for damper oil leakage problems in the fatigue test.

Keywords: Damper oil leakage, characteristic parameters, thermal balance, velocity spectrum.

1. Background

In recent years, indoor simulation test has been widely applied to fatigue and durability evaluation of vehicle, assembly, components, and its essence is the test road spectrum signal acquisition of the vehicle then through signal processing, reproducing the actual road vibration response of vehicles driving on the real roads on the bench, so as to shorten the development cycle of automobile verification and validation, and improve enterprises competitiveness. [1] Because it filters out the non-characteristic road signals such as on the connection roads during signal processing, the vibration intensity of the bench is far greater than that of the road test, causing the sharp growth of heat output of the shock absorber, and the heat dissipation requirement of the shock absorber is much higher than that of the real vehicle, otherwise, it will cause the shock absorber failure and affect the test process. In this context, the cab is a heavy truck cab, the four-point air spring damper configuration was found serious leakage phenomenon until 40 hours' test and its front spiral spring, rear air spring damper configuration was found oil leakage until 53 hours' test.

2. Reason of Damper Oil Leakage

It can be seen from the oil leaking damper that the oil leaking site is the on oil seal, the material of which is NBR (Ding Jing rubber), and the use temperature of NBR is -35°C to 100°C , and it can work for a short time (less than 2 hours) when its working temperature is over 120. When the working temperature of the shock absorber exceeds the use temperature of the NBR material, it will lead to the



thermal aging of the oil seal, and property decrease of its elasticity and sealing which lead to the leakage of the oil from the oil seal. At the same time, the higher the temperature, the higher the oil pressure inside the shock absorber, the more the risk of oil leakage. During the test, the heat output of the shock absorber is greater than the heat dissipation due to its continuous working in a long time, and the temperature continues to rise until the heat dissipation is equal to the heat production, and the shock absorber temperature is in a dynamic balance. From the shock absorber temperature test, it can obtain that the temperature of the oil-leaking shock absorber is over 100 degrees.

The temperature increase of the damper mainly comes from the friction heat generation. The friction in the motion of the damper mainly comes from the following aspects: (1) the friction between the piston and the piston ring with the inner cylinder; (2) the friction from the oil fluid flowing through various valves in the damper and (3) the friction between the piston rod and the oil seal. [3] In the unit time, the greater the stroke of the shock absorber, the more heat produced by the friction, the faster the shock absorber temperature rise, that is, the greater the velocity V of the shock absorber, the more heat production and the faster the increase of the shock absorber temperature. The rise of shock absorber temperature is closely related to the velocity V of shock absorber.

In order to get the velocity spectrum of the shock absorber during the test of the seven channel platform, the displacement spectrum of the shock absorber in the bench test should be collected first, and the velocity spectrum of the shock absorber can be obtained through the formula $V=dS/dt$. Figure 1 shows the displacement spectrum of the left front (black) and the left behind (red) shock absorber, and Figure 2 is the velocity spectrum of the left front (black) and the rear left (red) shock absorber. It can be seen from the velocity spectrum of Figure 2 that the speed of the front suspension damper is larger than the rear suspension damper. The speed root mean square (RMS) of the front and back suspension damper is 188.4mm/s and 158.3mm/s respectively. The speed root mean square of the front suspension damper is greater than the rear suspension about 20%, so the heat output of the front suspension damper is greater than the rear suspension damper. Under the same air cooling condition, temperature of the front suspension damper is higher and the risk of oil leakage is more likely. The following shock absorber temperature measurement test also confirmed this point, the front suspension shock absorber temperature is higher than that of the rear suspension. Meanwhile, the velocity spectrum of the left and right shock absorbers is analyzed. The velocity spectrum of the absorber is shown in Figure 3, which is left front (black) and right front (red). There is no obvious difference in the velocity spectrum of the left and right damper from the diagram, the root mean square (RMS) of the left and right damper is 188.4mm/s and 196.7mm/s, the right damper is about 5% larger than the left shock absorber, so under the same air cooling condition, the temperature of the right damper is slightly higher than that of the left shock absorber, which will lead to the serious leakage of the damper on the right.

In the same way, the air cooling condition of the left and right damper is compared. The power of the cooling fan used by the left and right damper is the same, but the position of the outlet of the air vent will have a great influence on the heat dissipation of the damper, and the problem of the difference between the left and right damper cannot exclude the factor of the air outlet position.

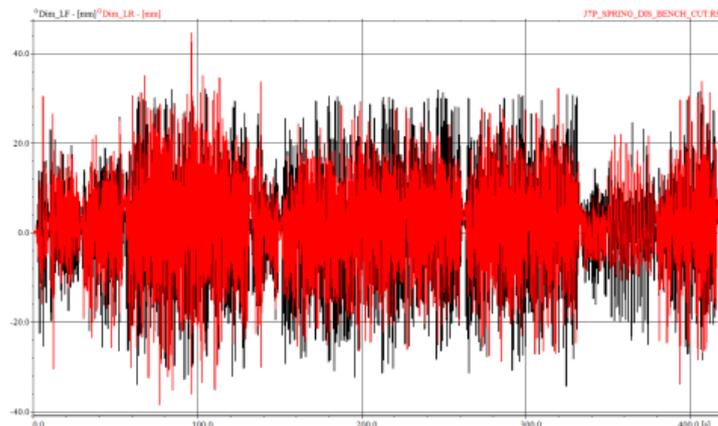


Figure 1. Left front (black) and left rear (red) shock absorber displacement spectrum

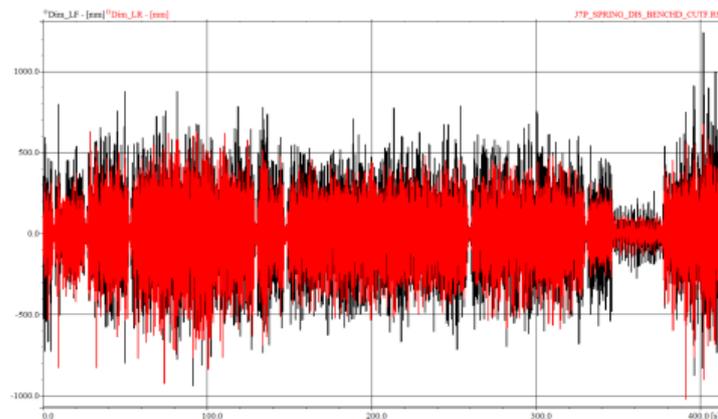


Figure 2. Left front (black) and left rear (red) shock absorber velocity spectrum

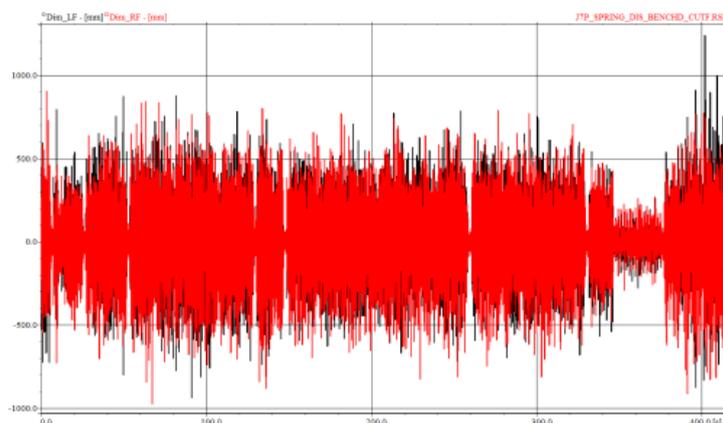


Figure 3. Left front (black) and right front (red) shock absorber velocity spectrum

3. Characteristics Parameters Analysis of Damper Heat Production

Under the same condition of heat dissipation, the temperature rise of damper is related to the amount of damper heat output Q in the unit time and the amount of damper heat output Q is equal to the work W done at the same time t , so the average thermal power of damper heat output can be obtained as follows [4]:

It is assumed that there is a linear relationship between shock absorber damping force F and the velocity V and there are the following basic formulas:

$$W = P \cdot t \quad (1)$$

$$P = F \cdot V \quad (2)$$

$$F = C \cdot V \quad (3)$$

$$C = \xi \cdot C_0 \quad (4)$$

$$C_0 = 2m\omega \quad (5)$$

$$\omega = \sqrt{\frac{K}{m}} \quad (6)$$

In the formulas, W is the heat output, P is the heat output power, F is the damping force, V is the velocity of shock absorber, C_0 is the critical damping coefficient, ξ is the damping ratio, m is single loaded mass of cab, ω is the natural frequency of spring damper and K is the spring stiffness.

Through the basic formulas above, it can get the formula for calculating the instantaneous power P of the shock absorber as follows:

$$P = 2\xi \cdot V^2 \cdot \sqrt{m \cdot K} \quad (7)$$

The work done of shock absorber can be calculated as follows:

$$W = \int_0^T P(t)dt = 2\xi \cdot \sqrt{m \cdot K} \int_0^T V^2(t)dt = 2\xi \cdot \sqrt{m \cdot K} \cdot \sum_{i=1}^n V_i^2 \cdot \frac{T}{n} = 2\xi \cdot \sqrt{m \cdot K} \cdot \frac{T}{n} \cdot \sum_{i=1}^n V_i^2 \quad (8)$$

The average power \bar{P} of shock absorber work can be calculated as:

$$\bar{P} = \frac{W}{T} = 2\xi \cdot \sqrt{m \cdot K} \cdot \frac{1}{n} \cdot \sum_{i=1}^n V_i^2 \quad (9)$$

The root mean square of damper velocity is obtained through the following formula:

$$V_{RMS} = \sqrt{\frac{V_1^2 + V_2^2 + \dots + V_n^2}{n}} = \sqrt{\frac{\sum_{i=1}^n V_i^2}{n}} \quad (10)$$

Therefore, the relationship between average power \bar{P} of shock absorber work and the root mean square of velocity V_{RMS} is as follows:

$$\bar{P} = 2\xi \cdot V_{RMS}^2 \cdot \sqrt{m \cdot K}$$

From the analytical expression of the average power \bar{P} , it can be seen that the average power \bar{P} is proportional to the shock absorber damping ratio ξ and is proportional to the square of the root mean square of damper velocity V_{RMS} and is also proportional to the rooting of the product of cab single mass m and the spring stiffness K .

Table 1. Characteristic parameters related to cab and the shock absorber

| | Mass distribution | Stiffness | Compression damping ratio | Tension damping ratio | Average damping ratio |
|---------------------------------|-------------------|-----------|---------------------------|-----------------------|-----------------------|
| Front suspension(CALM) | 326kg | 22(N/mm) | 0.35 | 1 | 0.725 |
| Front suspension(spiral spring) | | 57(N/mm) | 0.35 | 1 | 0.725 |
| Rear suspension(CALM) | 259kg | 17(N/mm) | 0.35 | 1 | 0.725 |

Notes: CALM-Cabin Air leveling Module

It is driven by iterative equivalent road with different types of vehicles and the displacement signal of the shock absorber is collected as the original analysis signal to get the velocity spectrum of the shock absorber. The velocity average root value (RMS) of a test field with one circle reliability road is obtained.

Table 2. Root mean square (RMS) of damper velocity

| Drive road spectrum | Root mean square (RMS) of damper velocity | | | |
|---|---|-------------|-----------|------------|
| | Left Front | Right Front | Left Rear | Right Rear |
| Vehicle type1 (Four_ CALM) | 188.4 | 196.7 | 158.3 | 160.1 |
| Vehicle type1 (Front_ Coil_ Rear_ CALM) | 191 | 190 | 172.8 | 174.1 |
| Vehicle type2 (Front_ Coil_ Rear_ CALM) | 160 | 145.7 | 165.7 | 163.9 |

4. Average Power Ratio Calculation of Front and Rear Shock Absorber

4.1. Shock absorber average power ratio calculation with same type of vehicle

Next, the vehicle type1 and type2 are used to iterate equivalent road and the before and after absorber average power ratio are calculated with each equivalent road respectively.

4.1.1 Driven by the iterative equivalent road with vehicle type1 (Four_ CALM). Taking the left front and left rear shock absorbers as the calculation objectives, and the front and rear damping ratio are marked as ξ_f and ξ_r respectively and the single mass are recorded as m_f and m_r the spring stiffness are K_f and K_r and the root mean square of absorber velocity are marked as V_{RMS_f} and V_{RMS_r} , so the power ratio is calculated as follows:

$$\frac{\bar{P}_f}{\bar{P}_r} = \frac{\xi_f \cdot V_{RMS_f}^2 \cdot \sqrt{m_f \cdot K_f}}{\xi_r \cdot V_{RMS_r}^2 \cdot \sqrt{m_r \cdot K_r}} = \frac{0.725 \cdot 188.4 \cdot 188.4}{0.725 \cdot 158.3 \cdot 158.3} * \sqrt{\frac{326 \cdot 22}{259 \cdot 17}} = 1.81 \quad (11)$$

4.1.2 Driven by the iterative equivalent road with vehicle type1 (Front_ Coil_ Rear_ CALM). Taking the left front and left rear shock absorbers as the calculation objectives, and the front and rear damping ratio are marked as ξ_f and ξ_r respectively and the single mass are recorded as m_f and m_r the spring stiffness are K_f and K_r and the root mean square of absorber velocity are marked as V_{RMS_f} and V_{RMS_r} , so the power ratio is calculated as follows:

$$\frac{\bar{P}_f}{\bar{P}_r} = \frac{\xi_f \cdot V_{RMS_f}^2 \cdot \sqrt{m_f \cdot K_f}}{\xi_r \cdot V_{RMS_r}^2 \cdot \sqrt{m_r \cdot K_r}} = \frac{0.725 \cdot 191 \cdot 191}{0.725 \cdot 172.8 \cdot 172.8} * \sqrt{\frac{326 \cdot 57}{259 \cdot 17}} = 2.51 \quad (12)$$

4.1.3 *Driven by the iterative equivalent road with vehicle type2 (Front_Coil_Rear_CALM)*. Taking the left front and left rear shock absorbers as the calculation objectives, and the front and rear damping ratio are marked as ξ_f and ξ_r respectively and the single mass are recorded as m_f and m_r the spring stiffness are K_f and K_r and the root mean square of absorber velocity are marked as V_{RMS_f} and V_{RMS_r} , so the power ratio is calculated as follows:

$$\frac{\bar{P}_f}{\bar{P}_r} = \frac{\xi_f \cdot V_{RMS_f}^2 \cdot \sqrt{m_f \cdot K_f}}{\xi_r \cdot V_{RMS_r}^2 \cdot \sqrt{m_r \cdot K_r}} = \frac{0.725 \cdot 160 \cdot 160}{0.725 \cdot 165.7 \cdot 165.7} * \sqrt{\frac{326 \cdot 57}{259 \cdot 17}} = 1.91 \quad (13)$$

It can be seen from the calculation results that the average power of the front suspension damper is about 2 times that of the rear suspension shock absorber. The front suspension damper has high heat production power, more heat output, quick temperature rising, and high temperature of the balance point between heat production and heat dissipation. If it exceeds the maximum working temperature of the damper, the oil leakage problem is easy to appear. However, the rear suspension shock absorber has low heating power and small heat output, and the temperature is always below the highest working temperature of the shock absorber, so the risk of oil leakage is greatly reduced.

4.2. Shock absorber average power ratio calculation with different type of vehicle

Next, the vehicle type1 and type2 are used to iterate equivalent road and the before and after absorber average power ratio are calculated with each equivalent road respectively.

4.2.1 *Average power ratio calculation of front suspension shock absorber*. Taking the left front shock absorbers as the calculation objective, and the damping ratio of vehicle type1 and type2 are marked as ξ_{v1} and ξ_{v2} respectively and the single mass are recorded as m_{v1} and m_{v2} the spring stiffness are K_{v1} and K_{v2} and the root mean square of absorber velocity are marked as $V_{RMS_{v1}}$ and $V_{RMS_{v2}}$, so the power ratio is calculated as follows:

$$\frac{\bar{P}_{v1}}{\bar{P}_{v2}} = \frac{\xi_{v1} \cdot V_{RMS_{v1}}^2 \cdot \sqrt{m_{v1} \cdot K_{v1}}}{\xi_{v2} \cdot V_{RMS_{v2}}^2 \cdot \sqrt{m_{v2} \cdot K_{v2}}} = \frac{0.725 * 191 * 191}{0.725 * 160 * 160} * \sqrt{\frac{326 * 57}{326 * 57}} = 1.425$$

4.2.2 *Average power ratio calculation of rear suspension shock absorber*. Taking the left rear shock absorbers as the calculation objective, and the damping ratio of vehicle type1 and type2 are marked as ξ_{v1} and ξ_{v2} respectively and the single mass are recorded as m_{v1} and m_{v2} the spring stiffness are K_{v1} and K_{v2} and the root mean square of absorber velocity are marked as $V_{RMS_{v1}}$ and $V_{RMS_{v2}}$, so the power ratio is calculated as follows:

$$\frac{\bar{P}_{v1}}{\bar{P}_{v2}} = \frac{\xi_{v1} \cdot V_{RMS_{v1}}^2 \cdot \sqrt{m_{v1} \cdot K_{v1}}}{\xi_{v2} \cdot V_{RMS_{v2}}^2 \cdot \sqrt{m_{v2} \cdot K_{v2}}} = \frac{0.725 * 172.8 * 172.8}{0.725 * 165.7 * 165.7} * \sqrt{\frac{259 * 17}{259 * 17}} = 1.09$$

From the calculated results, it can be seen that the average power of front suspension shock absorber taking vehicle type1 as the iterative equivalent road drive, 1.425 times that of taking vehicle type2 as the iterative equivalent road drive, which has higher heat output power and more heat output and the higher temperature when comes to the balance between heat production and dissipation, so it is easily to appear the problem of oil leakage. Taking the different equivalent road drive has no influence for the rear suspension shock absorber, which has almost same heat output power with no occurrence of oil leakage.

Table 3. Heat output power and balance temperature record list of front and rear suspension shock absorber with different iterative equivalent road drive

| Drive spectrum | Heat output power(W)/(Temperature(° C)(oil leakage× Normal√) | | | |
|--|--|-------------|------------|------------|
| | Left Front | Right Front | Left Rear | Right Rear |
| Vehicle Type1 (Four_ CALM) | 69(70)(√) | 75(100) (×) | 38(37)(√) | 39(47)(√) |
| Vehicle Type1 (Front_ Coil_ Rear_ CALM) | 114(84)(√) | 113(80) (×) | 45(63)(√) | 46(60)(√) |
| Vehicle Type2 (Front_ Coil_ Rear_ CALM) | 80(65) (√) | 66(60) (√) | 42(60) (√) | 41(55) (√) |

5. Conclusion and Suggestions

In the future, before the bench test, the displacement spectrum of four point spring damper should be collected first, the root mean square V_{RMS} of the shock absorber should be calculated, and the calculation formula $\bar{P} = 2\xi \cdot V_{RMS}^2 \cdot \sqrt{m \cdot K}$ is used to calculate the average heat output power \bar{P} of the shock absorber, and the temperature of the damper is monitored (more than 2 hours of continuous work) at the same time, and the maximum temperature T_{max} when the shock absorber works can be recorded. Because the air spring (CALM) damper and the spiral spring damper have different heat dissipation abilities, so the standard of oil leakage will be different. At the same time, it should be noted that when the oil leakage standard is established, the average heat output power of the damper is \bar{P} should be considered first, and the second is the damper maximum temperature T_{max} . If the cooling condition is normal, the two parameters should have a positive correlation. And if the \bar{P} power is low while the T_{max} is higher, the cooling condition may be abnormal. It is necessary to check whether the fan outlet deviates from the shock absorber.

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