Experiments on the damping characteristics of a high-speed train hydraulic damper under low-temperature conditions

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Abstract. Aiming at studying the low-temperature damping characteristics of hydraulic damper, experimental research in the temperature range of -50°C~+30°C was carried out to test the dynamic damping characteristics of a Chinese CRH high-speed train hydraulic yaw damper. Research results show that damping characteristics of the hydraulic damper will vary significantly at low temperature conditions when compared with that at normal temperatures, in general cases, the Force-displacement (F-s) curves are distorted and the damping forces are in abnormal levels; at very low temperatures, when the excitation speed is increasing, more severe empty strokes will occur during the damper compressions, so the absorption works of the damper will decrease significantly in these cases; in addition, dynamic stiffness of the damper will increase with the decreasing of temperatures, but in the compression stroke with large excitation speed, the dynamic stiffness at very low temperature conditions will drop sharply due to empty strokes. The results obtained in this study are significant for reference to improve the environment adaptability of high-speed rail hydraulic dampers and dynamics of the train operating under extreme cold weather conditions.

1. Introduction

Key components such as the hydraulic dampers [1, 2] of modern high-speed train systems are required to operate in extreme environments, thus, it is significant to conduct basic research on dynamic performance of the components under low temperature conditions.

Previous works concerning damper research were almost conducted under ambient [3, 4] temperature conditions, or the damping characteristics under thermal conditions are more likely to be addressed. Ramos et al. [5] and Alonso et al. [6] both performed theoretical modelling and experimental validation of thermal models for automotive twin-tube shock absorbers, Chen et al. [7] built a dissipative heating model of hydraulic damper considering the stochastic uncertainties in their geometric parameters, Wang et al. [8] and Wu [9] studied the thermal effect of oil temperature rise on the damping characteristics of a railway hydraulic dampers.

In this study, experimental research in the temperature range of -50°C~+30°C was carried out to test the dynamic damping characteristics of a Chinese CRH high-speed train hydraulic yaw damper. Research results show that damping characteristics of the hydraulic damper will vary significantly at...
low temperature conditions when compared with that at normal room temperatures, in general cases, the Force-displacement \((F-s)\) curves are distorted and the damping forces are in abnormal levels; at very low temperatures, when the excitation speed is increasing, more severe empty strokes will occur during the damper compressions, so the absorption works of the damper will decrease significantly in these cases; in addition, dynamic stiffness of the damper will increase with the decreasing of temperatures, but in the compression stroke with large excitation speed, the dynamic stiffness at very low temperature conditions will drop sharply due to empty strokes.

2. Experiments under low temperature conditions

2.1 Dynamic damping characteristics of a hydraulic damper

Figure 1 illustrates the testing model of a hydraulic damper and the main dynamic performance indices in \(F-s\) curve of the damper. The testing model shown by Figure 1(a) is based on the Maxwell model [3], it includes a damping element and a spring element, the damping force is acquired by a load sensor and the displacement is acquired by a displacement sensor which are attached with the actuator. Figure 1(b) shows the calculation approach of main indices from the obtained \(F-s\) curve.

![Figure 1](image)

**Figure 1.** (a) The testing model of a hydraulic damper and (b) the dynamic performance indices in the Force-displacement \((F-s)\) curve.

The dynamic damping coefficient \(C\) of a hydraulic damper can be formulated by:

\[
C = \frac{\left(F_{\text{emax}} + F_{\text{cmax}}\right)}{2} \times \text{sin} \phi
\]

where \(\omega\) is the circular frequency of excitation, \(\phi\) is the phase angle of the damper, \(F_{\text{emax}}\) and \(F_{\text{cmax}}\) are the maximum damping forces in the extension stroke and the compression stroke, respectively, \(S_{1\text{max}}\) is the amplitude of excitation; the phase angle of the damper can be given by:

\[
\phi = \arcsin \frac{S_{\text{max}}}{S_{1\text{max}}}
\]

where \(S_{\text{max}}\) is the amplitude of damper piston. Thus, the dynamic stiffness \(K\) of the damper is formulated by:

\[
K = G\omega \tan \phi = \varphi fC \tan \phi
\]

In addition, the energy dissipation \(W\) of the damper during a cycle of excitation can be given by

\[
W = A = \int_0^{\phi} S_{1}(t) dF(t) = \pi G\omega S_{\text{max}}^2 = \varphi^2 fC S_{\text{max}}^2
\]

where \(A\) is the area enclosed by \(F-s\) curve of the damper.
2.2 Experiments
Experiments are conducted on the dynamic damping characteristics of a Chinese CRH high-speed train yaw damper in the temperature range of -50°C~+30°C. Figure 2 shows the used industrial cryostat and test rig in the experiments.

![Figure 2. Experiments on the damping characteristics of a high-speed train hydraulic damper under low temperature conditions: (a) industrial cryostat used for damper preparation and (b) the damper is being tested at -50°C.](image)

Before any experiment, the sample damper is prepared and put into the industrial cryostat for at least 24 hours [2, 10] after the experimental temperature is reached, and then the experiment can be performed.

3. Temperature effects on damping characteristics
3.1 The F-s performance
Figure 3 demonstrates the F-s damping characteristics of the damper when it is excited at various excitation speeds, Figure 3(a) is obtained at +30°C and Figure 3(a) is obtained at -50°C conditions.

![Figure 3. The F-s damping characteristics at various excitation speeds at (a) +30°C and (b) -50°C conditions. (Fluid: TITAN SAF 5045 EU 137)](image)

Figure 3(a) shows that in ambient temperature conditions F-s curves are full and the damping forces are in normal levels, however, at the temperature of -50°C, as shown by Figure 3(b), the F-s curves are distorted and the damping forces are in abnormal levels: when $v_{\text{max}}=0.01 \text{ m/s}$, the maximum damping force at -50°C almost increases by 50% when compared with that at 30°C; in addition, when the
excitation speed is increasing, e.g., at \( v_{\text{max}} = 0.2 \) m/s and 0.3 m/s, more severe empty strokes occur during the damper compressions, so this indicates that absorption works of the damper will decrease significantly in these cases.

The reason why empty stroke occurs is that, at very low temperature conditions, viscosity of the fluid increases significantly, so the fluids almost become sticky fluids which are difficult to pass through the orifices, when the excitation speed is high, the fluids almost have no time to response and pass by, thus, empty stroke occurs.

3.2 The main indices of the damper

Figure 4 shows the main performance indices of the hydraulic damper at various temperature conditions. Figure 4(a) shows that when the excitation speed is low, such as that at \( v_{\text{max}} = 0.01 \) m/s and 0.03 m/s, the absorption work will increase with the decreasing of temperatures, however, when the excitation speed is high, such as that above \( v_{\text{max}} = 0.2 \) m/s, the absorption work will remain constant in the range of \(-30^\circ\text{C} \sim +30^\circ\text{C}\), but will decrease sharply with the decreasing of temperatures. The sharp decreasing of absorption works in the range of \(-50^\circ\text{C} \sim -30^\circ\text{C}\) indicates that, at very low temperature conditions, severe empty strokes will occur during the damper compressions.

![Figure 4](image)

**Figure 4.** Absorption work (a) and dynamic stiffness (b) of the hydraulic damper at various temperature conditions.

Figure 4(b) shows that dynamic stiffness of the damper will increase with the decreasing of temperatures, however, in the compression stroke with large excitation speed, such as that at \( v_{\text{max}} = 0.3 \) m/s, the dynamic stiffness at very low temperature conditions will drop sharply due to empty strokes.

4. Conclusions

(1) Damping characteristics of a hydraulic damper will vary significantly at low temperature conditions when compared with that at normal room temperatures, in general cases, the \( F-s \) curves are distorted and the damping forces are in abnormal levels.

(2) At very low temperatures, when the excitation speed is increasing, more severe empty strokes will occur during the damper compressions, so this indicates that absorption works of the damper will decrease significantly in these cases.

(3) Dynamic stiffness of the damper will increase with the decreasing of temperatures, but in the compression stroke with large excitation speed, the dynamic stiffness at very low temperature conditions will drop sharply due to empty strokes.

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