Wear Mechanism and Failure Analysis of A High-speed Train Hydraulic Damper Using CFD Approach

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Abstract. To evaluate wear-induced hydraulic damper failures, wear mechanism of a Chinese CRH train hydraulic damper by invaded dust and sand particles under vibration conditions is firstly analysed. CFD modelling of the working chamber of the damper is then carried out and fluid dynamics analysis of the damper under different vibration speed input conditions is performed. The CFD results demonstrate that under wear conditions both the fluid discharge speed and produced pressure would drop significantly, the maximum fluid discharge speed and pressure are far smaller than that under non-wear conditions, the damping force would have a maximum decrease of 62.3%. The wear mechanism, CFD model established and analysis results obtained in this study can be used for further railway hydraulic damper evaluation and optimal designs.

1. Introduction
Hydraulic dampers [1-2] are key components for running stability and ride comfort of modern railway vehicle systems. However, as shown by Figure 1, hydraulic dampers are commonly subject to premature failure due to wear and fluid leakage.

Figure 1. Wear and fluid leakage failure of a high-speed train hydraulic damper.

In previous works, service failure of an automobile shock absorber [3] with welding imperfections was investigated, the result indicated that poor positioning of the items to be joined and prior contamination of the surfaces to be welded would lead to premature failures of the damper attachment. The fretting fatigue failure and crack under cyclic loading of the shim valve of an automotive shock absorber [4] was
Zheng [5] found that the main cause of sealing failure is due to vibration with high frequency and low amplitude. Wang et al [6] built fluid leakage mathematic model to illustrate the effect of fluid leakage on damping characteristics. Shams et al [7] used a coupled Computational Fluid Dynamics (CFD) and Finite Element Analysis (FEA) approach in predicting and evaluating the performance of an automotive shock absorber. Ding et al [8] also used CFD method in simulating the working flow filed of a train damper. Therefore, research work on wear mechanism and failure analysis of railway hydraulic damper shows limited.

In this study, wear mechanism of the rod and seal of a Chinese CRH train hydraulic damper by invaded dust particles under vibration conditions is firstly analysed, then CFD modelling of working chamber of the damper is carried out and fluid dynamics analysis of the damper under different vibration speed input conditions are performed, the results uncover the wear and fluid leakage induced failure mechanism of railway hydraulic damper. The analysis approach and CFD model established can be used further railway hydraulic damper evaluation and optimal designs.

### 2. Wear mechanism and CFD-based failure analysis

The feature of railway vehicle vibration is high frequency and low amplitude, especially that for the high-speed train, in addition, the working environment of the hydraulic damper (on the bogie) is severe, i.e., dust and sand usually with high wind, and the ambient temperature is very low or high. Therefore, dust and sand are readily to invade into the gap between the rod and the guide seat when the damper is vibrating with high frequencies, as illustrated in Figure 2, because the dust and sand are very hard particles despite of being tiny, both of the rod surface and the seal would be cut and worn by the particles, which would cause fluid leakage and fading of damping capability. If the cut and wear have accumulated to exceed a wear allowance, the damping force would be very small or even zero, in other words, the damper is in failure, just likes the sample in Figure 1.

![Figure 2. Wear mechanism of the rod and seal of a hydraulic damper by invaded dust particles under vibration conditions.](image)

To analysis and evaluate wear induced damper failure, 3D modelling of the piston and inner tube of a Chinese CRH train damper has been firstly performed using the software Solidworks, then the 3D model is imported into Fluent software to mesh, as demonstrated by Figure 3, the CFD model is meshed by hexahedron element [9], and has totally 59,496 elements.

The flow status in the working chamber can be judged by Reynold number $R_e$

$$R_e = \frac{Vd}{\nu}$$  \hspace{1cm} (1)

where $V$ is mean velocity of the flow, $d$ is diameter of the pipe or orifice, $\nu$ is the kinematic viscosity of the fluid. The flow discharged from the piston valve can be formulated by

$$Q_e = \frac{\pi}{4} D^2 V, \quad Q_e = \frac{\pi}{4} (D^2 - d_t^2) V$$  \hspace{1cm} (2)
where $Q_c$ and $Q_e$ are respectively flows of the compression stroke and extension stroke, $D$ and $d_r$ are respectively diameters of the piston and rod.

Fluid dynamics of the damper are analysed in Fluent environment, as an example, the pressure fields and velocity fields in the working chamber of the hydraulic damper are respectively shown in Figures 4 and 5, the simulation is performed at extension stroke and piston speed=0.1 m/s.

![Figure 3](image3.png)

**Figure 3.** (a) 3D modelling and (b) CFD modelling with 59,496 hexahedron elements of the working chamber of a Chinese CRH train hydraulic damper.

![Figure 4](image4.png)

**Figure 4.** Pressure fields in the working chamber of the hydraulic damper (extension stroke with piston speed=0.1m/s).
Figure 4 demonstrates that under wear conditions, the produced pressure drops significantly, the maximum pressure is only 4.22e5 Pa, which is far less than that under non-wear conditions. Figure 5 also demonstrates that the fluid discharge speed decreases significantly due to wear and fluid leakage, the maximum speed is only 0.959 m/s, which is far small than that under non-wear conditions.

![Velocity field at X cross-section (non-wear)](image1)

(a) Velocity field at X cross-section (non-wear)

![Velocity field at Y cross-section (non-wear)](image2)

(b) Velocity field at Y cross-section (non-wear)

![Velocity field at X cross-section (wear)](image3)

(c) Velocity field at X cross-section (wear)

![Velocity field at Y cross-section (wear)](image4)

(d) Velocity field at Y cross-section (wear)

Figure 5. Velocity fields in the working chamber of the hydraulic damper (extension stroke with piston speed=0.1m/s).

Table 1 and Figure 6 both compare the damping forces at non-wear and wear conditions, and illustrate that the damping force would have a drop of 10.7% to 62.3% when the simulation speed increases from 0.01 m/s to 0.1 m/s. According to the European [1] or Chinese Standards [10], when the drop of damping force exceeds ±10~15%, the damper would be regarded as in failure.

| Velocity (m/s) | Damping force (N) (non-wear) | Damping force (N) (wear) | Rate of change |
|---------------|-----------------------------|--------------------------|----------------|
| 0.02          | 745.3                       | 563.8                    | ↓ 24.4%        |
| 0.04          | 1473.4                      | 805.3                    | ↓ 45.3%        |
| 0.06          | 1962.8                      | 934.5                    | ↓ 52.4%        |
| 0.08          | 2664.5                      | 1125.6                   | ↓ 57.8%        |
| 0.1           | 3618.8                      | 1363.5                   | ↓ 62.3%        |
3. Conclusions
(1) Dust and sand are readily to invade into the gap between the rod and the guide seat when the railway hydraulic damper is vibrating with high frequencies, because the dust and sand are very hard, both of the rod surface and the seal would be cut and worn by the particles, which would cause fluid leakage and fading of damping capability.
(2) CFD modelling of working chamber of the damper is carried out and fluid dynamics analysis of the damper under different vibration speed input conditions is performed. The results demonstrate that under wear conditions both the fluid discharge speed and produced pressure drop significantly, the damping force would have a maximum decrease of 62.3%.
(3) The wear mechanism, CFD model established and analysis results obtained in this work can be used for further railway hydraulic damper evaluation and optimal designs.

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