Structural dynamic response of a locomotive hydraulic damper with welding imperfections

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Abstract. Railway vehicle hydraulic dampers are usually subject to premature structural failures, so it is meaningful to investigate the dynamic response of its welded main structure. FEA modelling of the welded rod-and-attachment assembly with imperfections of a Chinese electric locomotive axle-box hydraulic damper is performed, and load spectra of the axle-box hydraulic damper both under nominal and actual in-service conditions are obtained. Structural dynamics response analysis of the welded rod-and-attachment assembly of the damper is then conducted by using the FEA model and load spectra, and demonstrates that all of the maximum dynamic stresses have increased by 40% or so when using the actual in-service load spectra regardless of the weld joint condition, if the weld joint is with imperfection of misalignment of rod and attachment, the maximum dynamic stress has increased by 41.46%. Therefore, railway hydraulic dampers are usually subject to actual in-service load spectra instead of the nominal load spectra used in the design process, if the damper also has got welding imperfections, the damper would be readily subject to premature failures, this is why many current railway vehicle hydraulic dampers are still subject to premature failures despite ‘perfect’ designs. The FEA model, the structural dynamic response analysis approach and results obtained in this work would be instructive in improving damper structure design, welding quality control and inspection.

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, the main welded structure of a locomotive hydraulic damper is usually subject to fatigue and fracture in engineering. Therefore, it is meaningful to understand the structural dynamic response of damper with welding imperfections under actual in-service load conditions.

Many previous researchers have addressed fatigue analyses of welded structures of wheel/rail rolling contact [3] and rail welded joints [4] by using simulated and/or tested loading spectra with Finite Element Analyses (FEA). The rain-flow cycle counting method was often used to obtain load spectra, the variable amplitude loading conditions [5] and weld residual stress [6] were also considered in the fatigue behaviour analysis of steel structures.

Gallardo et al [7] investigated the service failure of an automobile shock absorber with welding imperfections, Reza et al [8] studied the fretting fatigue failure and crack under cyclic loading of the shim valve of an automotive shock absorber, Zheng [9] found that the main cause of sealing failure is
due to vibration with high frequency and low amplitude, Wang et al [10] built fluid leakage mathematic model to illustrate the effect of fluid leakage on damping characteristics. However, research work on structural dynamic response of the railway vehicle hydraulic damper with welding imperfections under actual in-service load conditions shows inadequate.

Figure 1. Fatigue and fracture of the welded structure of a locomotive axle-box hydraulic damper.

In this work, FEA modelling of the welded rod-and-attachment assembly of a Chinese electric locomotive axle-box hydraulic damper is performed, load spectra of the axle-box hydraulic damper both under nominal and actual in-service conditions are simulated, and the corresponding load profiles and its rain-flow cycle counting results of the axle-box hydraulic damper are obtained. Structural dynamics response analysis of the welded rod-and-attachment assembly of the damper is then conducted by using the FEA model and load spectra, and the nature of structural dynamic response and its change of the welded main structure of the locomotive axle-box damper with welding imperfections is uncovered.

2. FEA modelling

2.1. FEA modelling of the main structure with welding imperfections

FEA modelling of the welded rod-and-attachment assembly of a Chinese electric locomotive axle-box hydraulic damper is performed using ANSYS Workbench, as shown in Figure 2, the FEA model has totally 6723 mesh elements with 25882 nodes, the material is No. 20 steel with elastic modulus of 2.07e+5 MPa, yield strength of 254 MPa, tensile strength of 392 MPa and Poisson Ratio of 0.3. Figure 2 also demonstrates the simulation of weld joint with porosity and misalignment of rod and attachment after the welding in the ANSYS Workbench environment.

Figure 2. FEA model of the welded rod-and-attachment assembly with welding imperfections of a Chinese electric locomotive axle-box hydraulic damper.

2.2. Load spectra under actual in-service conditions

Load spectra of the axle-box hydraulic damper under actual in-service conditions are obtained by using the electric locomotive simulation model established in Literature [11], simulation is conducted
when both a conventional axle-box damper model and an actual in-service damper model are respectively incorporated, and the corresponding load profiles and its rain-flow cycle counting results of the axle-box hydraulic damper are obtained, as shown by Figure 3.

Figure 3 compares the nominal load spectra and actual in-service load spectra of the hydraulic damper, the nominal load spectra are obtained by using an ideal normal damper model, while actual in-service load spectra are obtained by using an actual damper model with fitting clearance.

(a) Nominal load profile and its rain-flow cycle counting result (the mean and amplitude damping forces) when an ideal normal damper model is used

(b) Actual in-service load profile and its rain-flow cycle counting result of the damper (simulation conditions: vehicle speed 160 km/h in tangent track, a 1.5 mm fitting clearance of the damper is used in the in-service load simulation)

Figure 3. A comparison of the nominal load spectra and actual in-service load spectra of the damper.

Figure 3 illustrates that the actual in-service load spectra involve many dead-zone-induced impact peaks, the scattering range and rain-flow cycle counts of the mean and amplitude of the damping forces under actual in-service load condition are much stronger than that under nominal load condition. This might be why many current railway hydraulic dampers are still subject to premature failures despite being designed to nominal load cases.

3. Structural dynamic response analysis

Structural dynamics response analysis of the welded rod-and-attachment assembly of the damper is conducted using ANSYS Workbench, as an example, Figures 4 and 5 compare the dynamic stress response fields and profiles of the welded rod-and-attachment assembly of the damper at different conditions, respectively. The two analysis are respectively performed under nominal load and under actual in-service load conditions, and the weld joints are all with porosity imperfection.

Figures 4 and 5 combine to indicate that the dynamic stress amplitudes under actual in-service load condition are much larger than that under nominal load condition, although the latter one has many dead-zones which are caused by the fixing clearance of the damper.

Table 1 summarizes the comparison results of the maximum dynamic stresses respectively under nominal load and under actual in-service load conditions, and demonstrates that all of the maximum dynamic stresses have increased by 40% or so when using the actual in-service load spectra regardless of the weld joint condition, if the weld joint is with imperfection of misalignment of rod and attachment, the maximum dynamic stress has increased by 41.46% when using the actual in-service load spectra instead of using the nominal one.
(a) Under nominal load, weld joint with porosity

(b) Under actual in-service load, weld joint with porosity

**Figure 4.** A comparison of the dynamic stress response fields of the welded rod-and-attachment assembly of the hydraulic damper at different conditions.

(a) Under nominal load, weld joint with porosity

(b) Under actual in-service load, weld joint with porosity

**Figure 5.** A comparison of the dynamic stress response profiles of the welded rod-and-attachment assembly of the hydraulic damper at different conditions.
Therefore, the nature of structural dynamic response and its change of the welded main structure of the locomotive axle-box damper with welding imperfections is uncovered, under real in-service operation situations, the load spectra of the damper are much stronger than that under nominal operation situations, and this would lead to significant increase of the dynamic stress responses, so the axle-box damper is readily subject to premature structural failures.

Table 1. A comparison of the maximum dynamic stresses under nominal load and under actual in-service load conditions.

| Weld joint condition | Load spectra      | The maximum dynamic stress (MPa) | The rate of change |
|----------------------|-------------------|----------------------------------|-------------------|
| Non-imperfection     | Nominal load      | 18.993                           | ↑ 39.31%          |
|                      | Actual in-service load | 26.460                           |                  |
| With porosity        | Nominal load      | 27.515                           | ↑ 39.32%          |
|                      | Actual in-service load | 38.333                           |                  |
| Misalignment         | Nominal load      | 20.495                           | ↑ 41.46%          |
|                      | Actual in-service load | 28.993                           |                  |
| With porosity + Misalignment | Nominal load | 28.531                           | ↑ 40.27%          |
|                      | Actual in-service load | 40.021                           |                  |

4. Conclusions

(1) FEA modelling of the welded rod-and-attachment assembly of a Chinese electric locomotive axle-box hydraulic damper is performed, the obtained FEA model can simulate the weld joint with imperfections, such as weld joint with porosity, misalignment of rod and attachment and its combination.

(2) Actual in-service load spectra of the hydraulic damper involve many dead-zone-induced impact peaks, the scattering range and rain-flow cycle counts of the mean and amplitude of the damping forces under actual in-service load condition are much stronger than that under the nominal load condition. Further dynamic response analyses show that all of the maximum dynamic stresses have increased by 40% or so when using the actual in-service load spectra regardless of the weld joint condition, if the weld joint is with imperfection of misalignment of rod and attachment, the maximum dynamic stress has increased by 41.46%.

(3) Railway hydraulic dampers are usually subject to actual in-service load spectra instead of the nominal load spectra used in the design process, in addition, if the damper also has got welding imperfections, the damper would be readily subject to premature failures. This is why many current railway vehicle hydraulic dampers are still subject to premature failures despite with ‘perfect’ designs.

(4) The FEA model, the structural dynamic response analysis approach and results obtained in this work would be instructive in improving damper structure design, welding quality control and inspection.

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