The Development of Stiffness-Adjustable Anti-yaw Damper

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Abstract. It has been known that the high speed passenger car is likely subjected to the carbody hunting and the bogie instability owing to the different wheel/rail conditions. Carbody hunting always be occurred in low wheel/rail conicity after wheel re-profiling procedure and the bogie hunting can be occurred in the increased wheel/rail conicity in the service. These could impose highly adverse influence on the ride comfort of passengers and wheel/rail safety. A stiffness-adjustable anti-yaw damper integrating a FSS (Frequency Selective Stiffness) valve has thus been developed to enhance the adaptive of vehicle to both the low and high wheel/rail conicity service conditions. The damper laboratory test is undertaken to obtain its characteristic curve, which is further used in the vehicle dynamic model to investigate the influences of stiffness-adjustable anti-yaw damper. To better characterize the influence of the stiffness-adjustable anti-yaw damper, a roller rig test is further performed to compare the FSS yaw damper with other two conventional yaw dampers. The numerical and experimental results suggested that the FSS damper can achieve better adaptive to both low and high wheel/rail conicity with respect to other two conventional yaw dampers. In the low frequency range, the FSS yaw damper can yield relatively low stiffness so as to suppress the car body hunting for the low wheel/rail conicity condition, while it can also provide high stiffness in the high frequency range to improve the bogie stability for the high wheel/rail conicity condition.

Keywords: Stiffness-adjustable anti-yaw damper · Carbody hunting · Bogie instability · Vehicle system dynamics

1 Introduction

It has been reported that the high speed passenger car is likely subjected to the carbody hunting and the bogie instability owing to the different wheel/rail conditions. A low wheel/rail conicity after wheel re-profiling procedure combined with a high stiffness yaw damper could give rise to the carbody hunting thereby affect the ride comfort of

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passenger, while a high wheel/rail conicity incorporating with small stiffness yaw damper could lead to the bogie hunting further affecting the running safety of vehicle. The wheel/rail equivalent conicity varies with the increased vehicle mileages owing to the wheel wear procedure. A set of compatible suspension parameter is thus needed to achieve better vehicle system dynamic performance for both the low and high wheel/rail conicity conditions [1, 2]. This paper developed a stiffness-adjustable anti-yaw damper, referred as the FSS (Frequency Selective Stiffness) damper, to achieve low level stiffness in the low frequency range while the high stiffness in the high frequency range. The FSS damper is characterized by the FSS valve in the piston comparing with other conventional damper, as shown in Fig. 1(a). In the low frequency and short stroke condition, the leakage occurs in the FSS valve and further lead to small stiffness in the yaw damper. In the high frequency and large stroke condition, the FSS damper tends to be a conventional yaw damper thereby the relatively high stiffness. In this paper, the numerical simulation and laboratory tests have thus been performed to characterize the dynamic stiffness and damping of yaw damper and to investigate its influence on the vehicle dynamic performance.

2 Characterization of Stiffness-Adjustable Anti-yaw Damper

The characteristics of hydraulic damper are usually characterized by its static and dynamic properties. The static property of hydraulic damper is defined as a function of damper force and piston velocity, which is usually obtained at low speed range. The dynamic properties in terms of dynamic stiffness and damping are evaluated using the Maxwell model considering different frequencies. Figure 1(b) illustrates the comparison of static properties for three different anti-yaw dampers obtained at the piston speed of 0.15 m/s, where FSS samples are the stiffness adjustable anti-yaw dampers designed by Koni, YD1 samples and YD2 samples are two types of conventional anti-yaw dampers designed by Sachs and widely used in high speed passenger car. The test results show that the stiffness adjustable damper exhibits moderate damper force in the velocity range less than 0.02 m/s comparing to other two conventional dampers, while the stiffness adjustable damper show comparable damper force with the YD2 anti-yaw damper. YD1 anti-yaw damper shows lowest damper force with respect to other two types of dampers. According to the operational experience, a high passenger car equipped with YD1 operating in high wheel/rail conicity condition is usually subjected to high frequency bogie hunting motion owing to the low damping force for increased wheel/rail conicity. YD2 anti-yaw damper, however, usually yields the carbody hunting motion due to the high stiffness for low wheel/rail conicity condition. It is thus expected that the stiffness adjustable damper can combine dynamic properties of those two conventional anti-yaw dampers, and further enhance the dynamic performance of vehicle for both the low and high wheel/rail conicity conditions.

Figure 2(a) and (b) compare the dynamic stiffness and damping of FSS damper with those of other two conventional yaw dampers (YD1 and YD2). It can be seen that the dynamic stiffness of yaw dampers increase with the excitation frequency and show saturation phenomenon near 5 Hz. The FFS damper yields the lowest dynamic stiffness in the frequency range less than 1.3 Hz while moderate dynamic stiffness in the high frequency range with respect to YD1 and YD2. Regarding the dynamic damping, two conventional yaw dampers (YD1 and YD2) exhibit notable peak near 1.5 Hz and 3.5 Hz respectively, owing to dynamic features in the dampers. The FSS damper shows lowest dynamic damping in the frequency range less than 3 Hz compared with other two conventional dampers. With further increased excitation frequency, the FSS damper can provide relatively larger dynamic damping with respect to the YD1 yaw damper.

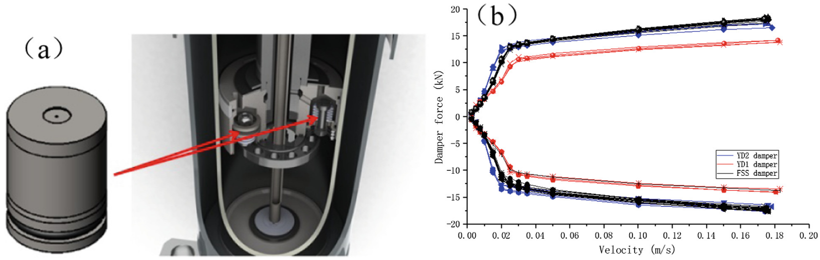

Fig. 1. (a) FSS valve, (b) Static properties of three different yaw dampers.

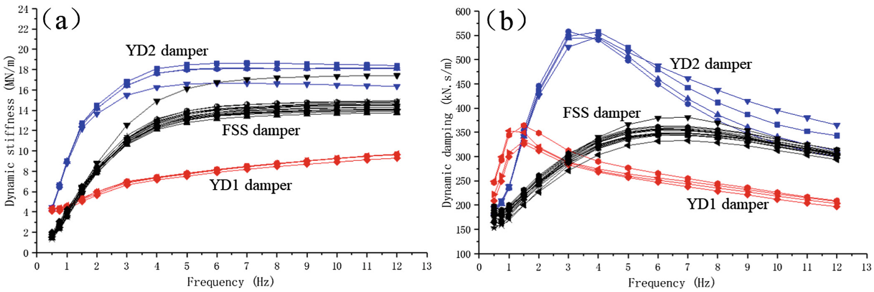

Fig. 2. Dynamic features for three different dampers: (a) dynamic stiffness, (b) dynamic damping.

3 Influences of Stiffness-Adjustable Anti-yaw Damper on the Vehicle System Dynamic Performance

A typical high speed passenger car multi-body dynamic model and the roller rig test are further used to investigate the influences of stiffness-adjustable anti-yaw damper on the vehicle system dynamic. Figure 3 illustrates the multi-body dynamic model of high speed passenger car and the wheelset lateral displacement responses obtained through the roller rig test with low wheel/rail conicity condition. The results show that both the FSS and YD1 yaw dampers yield comparable lateral wheelset displacement responses. Owing to relatively larger dynamic stiffness of the YD2 yaw damper, the vehicle exhibits larger wheelset lateral displacement comparing with other two types of yaw damper. The result suggests that the YD2 anti-yaw damper more likely yields the carbody hunting comparing to two other dampers and the stiffness adjustable damper can mitigate the carbody hunting due to smaller stiffness in the low frequency range.

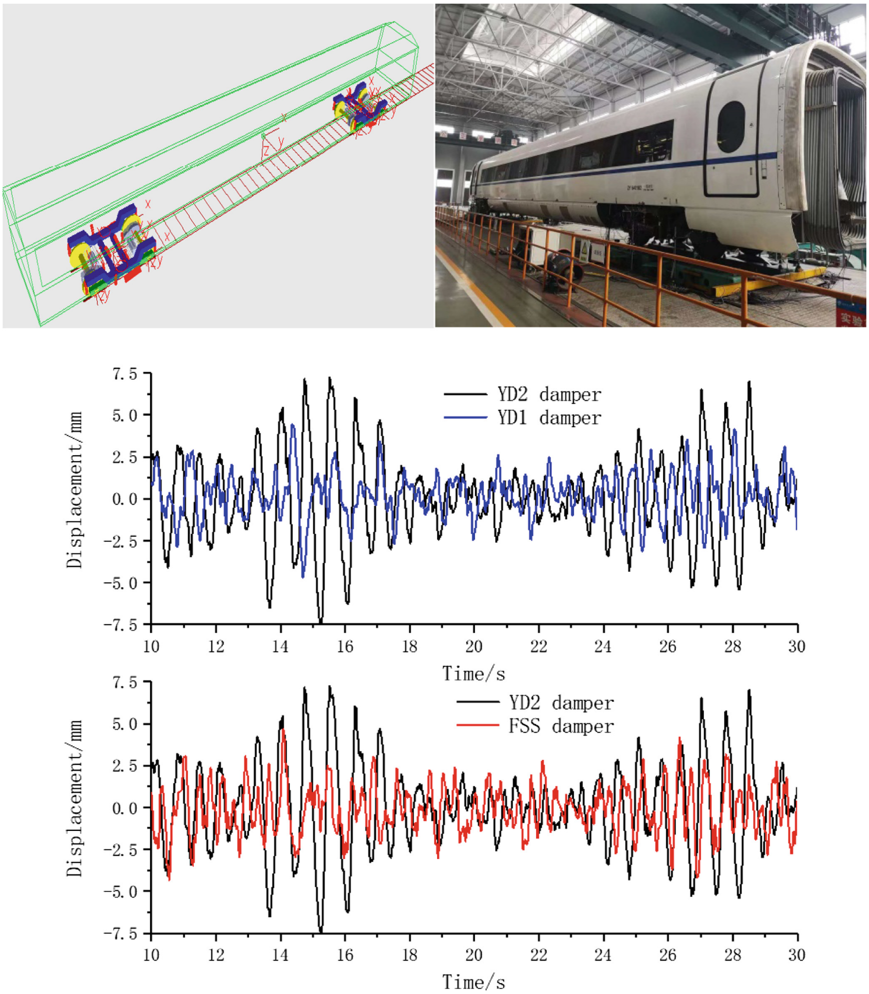

Fig. 3. Multi-body dynamic model of a high speed passenger car and wheelset lateral displacement responses obtained through the roller rig test with low wheel/rail conicity.

4 Conclusions

A stiffness-adjustable anti-yaw damper integrating a FSS (Frequency Selective Stiffness) valve has been developed to enhance the adaptive of vehicle to both the low and high wheel/rail conicity service conditions. The damper laboratory test is undertaken to obtain its characteristic curve, which is further used in the vehicle dynamic model to investigate the influences of stiffness-adjustable anti-yaw damper. To better characterize the influence of the stiffness-adjustable anti-yaw damper, a roller rig test is further performed to compare the FSS yaw damper with other two conventional yaw dampers. The numerical and experimental results suggested that the FSS damper can achieve better adaptive to both low and high wheel/rail conicity with respect to other two conventional yaw dampers. In the low frequency range, the FSS yaw damper can yield relatively low stiffness so as to suppress the car body hunting for the low wheel/rail conicity condition, while it can also provide high stiffness in the high frequency range to improve the bogie stability for the high wheel/rail conicity condition.

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