Investigation on Customer Vehicle Brake-Induced Vibration Phenomenon

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Abstract

This paper presents the findings of study conducted on a heavy commercial truck customer unit. High level vibrations perceived in the complaint customer vehicle’s cabin and its relevant connected parts (steering wheel, throttle pedal etc.) during gentle braking. On subjective customer vehicle evaluation drives it was seen that vibrations only occur during braking not during acceleration when brakes are warm. Thus, the vehicle level objective data is accumulated first to be able to define the operating conditions effects such as brake line pressure fluctuation, gear ratio, engine, compressor, engine/vehicle speed, vehicle geometry on the generated excitation.
All subjective evaluations and objective tests are performed on the smooth asphald public roads having down and up hills in Şekerpınar, Gebze region. The vehicle test data consist of braking at neutral gear downhill with hot and cold brakes, WOT (wide open throttle) acceleration at 5th gear no up/down hills and acceleration down hills by way of inertia at neutral gear (no throttle). Next, the data have been analysed in the respect of wheel rotation speed, engine or compressor excitation, pressure oscillations on vibration frequencies. It was found that braking vibration frequencies and orders are independent from engine or wheel excitation mechanisms and geometrical irregularities (drum & hub assembly run-out, concentricity, imbalance) are purely excited by the interaction of the drum and brake shoe and amplified in the route to the cabin from the second/command front axle. To correlate the disturbing vibration frequency to cabin inside vibrations, frequency response function (FRF) measurements were carried out. The FRF study showed that the resonance vibration peaks are very close to cabin vibration frequency of 33.5 Hz. The resonance peak attenuation is tried out via changing vehicle wheel end geometry.

Key words: Vibration, frequency, excitation, frequency response function, truck

1. Introduction

Brake judder is a forced vibration occurring in different types of vehicles. The frequency of the vibration can be as high as 500 Hz, but usually remains below 100 Hz and often as low as 10-40 Hz. The driver experiences judder as vibrations in the steering wheel, brake pedal and floor [1]. Brake Torque Variation (BTV) is the primary excitation for the vibrations. The mechanical effects generating BTV are linked not only to manufacturing tolerances but also to tribological issues [1]. Brake judder still poses a serious design problem for the brake refinement engineer. It may take the form of cold or hot judder but in both cases it presents itself as a vibration directly related to wheel speed. Cold judder is typically manifested as a low-order vibration, whilst hot judder is typically associated with a higher-order vibration. Both types may be felt by the driver through the brake pedal, steering wheel or vehicle floor pan, with higher ‘drone’ frequencies becoming audible within the cabin. Cold judder tends to be caused by geometry errors arising from off-brake wear. Hot judder is caused due to a short duration but high thermal input to the brake that results in a thermo elastic deformation, and eventual thermo elastic instabilities in the form of hot spots. [2].

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During braking, possible vibration excitation passes through a wide frequency band due to the coupling between the judder frequency and the wheel rotational speed, and thus, resonant frequencies of many vehicle components can be excited. This includes wheel suspension components and the steering column [3].
The two fundamentally different problem approaches, shown in Figure 1. The first is the cause approach which examines how one or more physical effects generate the BTV. The second, the effect approach, studies how the BTV generates judder and how this judder is experienced by the driver [4].

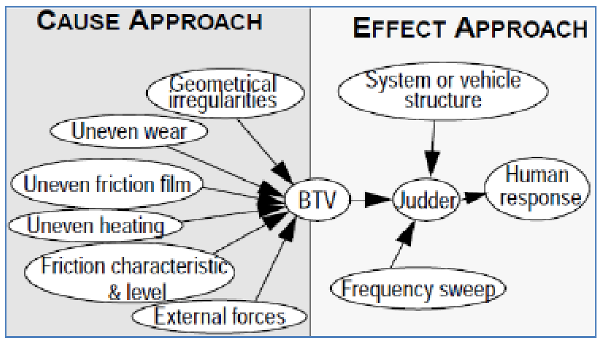

Figure 1. Problem approaches to brake judder.

It is clear the brake NVH is a major issue in terms of cost and vehicle perception. Noise and vibration related to the braking system can generate major reactions from a customer. This is a problem of high priority for the automakers for which considerable money and effort has and will continue to be devoted. judder is the most extreme case. It is not a noise. One does not hear judder because it is too low in frequency. It is sensed as a vibration. [5].
This paper presents subjective and objective investigations on specific brake judder issue. Local customer dissatisfaction and complaints were ignited us to investigate brake judder causes. The subjective evaluations and objective tests are performed on the smooth asphalt public roads having down and up hills in Şekerpınar, Gebze region. For the objective data measurement, data acquisition locations were instrumented with 3D accelerometers, pressure sensors for processing. Since BTV is low frequency mechanism, sensors were placed at attachment nodes between the various suspension elements only. The reason being that, at those frequencies, all mechanical parts are essentially rigid and all deformations take place in the compliant bushings. With the vehicles fully instrumented, data was collected for several runs with varying conditions. These are;

- Braking at neutral gear downhill with hot brakes.
- Braking at neutral gear downhill with cold brakes.
- WOT (wide open throttle) acceleration at 5th gear, no up/down hills.

2. Testing

2.1. Instrumentation

Brake judder issue was performed in the dry, smooth asphalt public roads, having down and up hills in Sekerpınar, Gebze region. The same driver was used at all different testing scenarios. All subjective evaluations and objective tests are performed on four axles truck owning SAC (simplex air cam) drum brake system to correlate axle wheel brake vibration to cabin inside vibrations or sensed brake judder. The exact evaluation route is as shown in Figure 2.

Pressure oscillations were recorded during test in order to see its contribution on the disturbing brake vibration frequencies as well. The pressure sensors were installed on first axle and second axle spring brake actuators as shown in Figure 2.

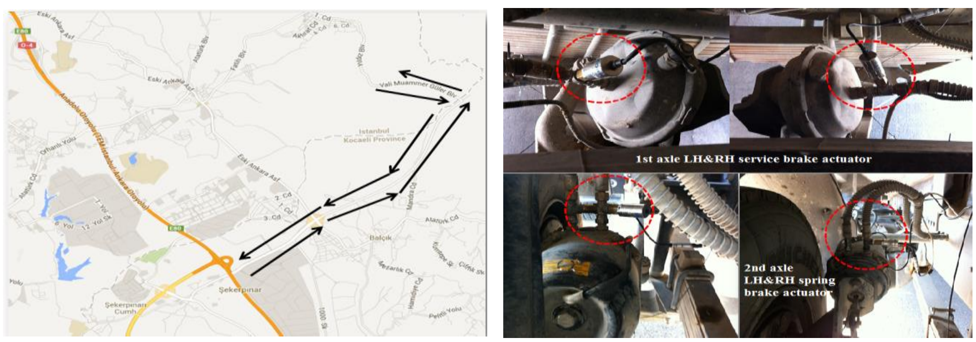

Figure 2. The test evaluation route and pressure sensors installation locations

The vehicle was equipped with three directional accelerometers on right and left of 1^{st} & 2^{nd} axles and in order to correlate the disturbing vibration frequency to cabin inside vibrations one more three directional accelerometer was mounted inside the cabin under heater radiator as shown in figure 3.

Figure 3. Three directional accelerometer locations

2.2. Testing

2.2.1. Braking at neutral gear downhill drive with hot brakes

All brakes are active. Brakes are warmed up after several continuous downhill braking. Figure 4 shows vibration frequencies perceived in the cabin around 33.5 Hz where vibration amplitude starts increasing around vehicle speed of 30 kph. The cabin vibrations frequency has correlation with wheel vibration frequencies in the z-direction due to its dominant effect.

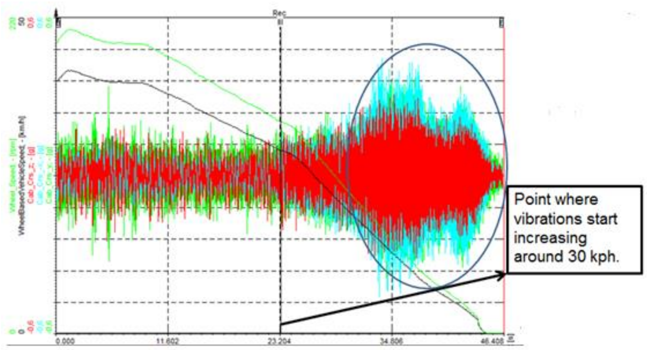

Figure 4. Cabin vibration frequencies in x, y, z directions

Figure 5&6 shows vibration frequencies on 1st & 2nd axles left and right wheels. Surprisingly all have peak frequency around 33.5 Hz.

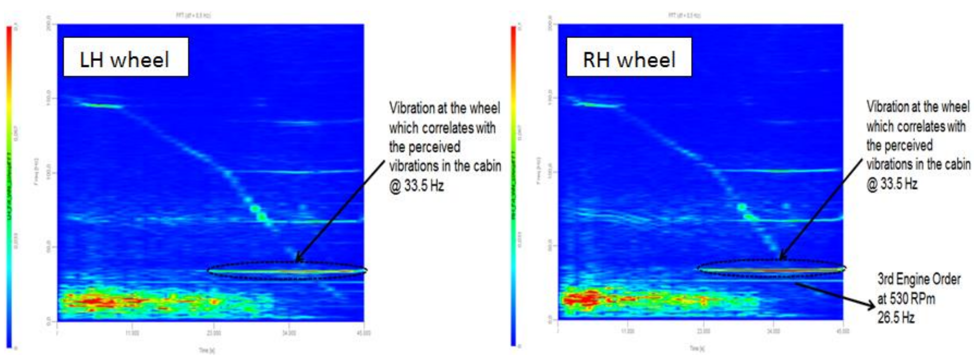

Figure 5. Left & Right Front Wheel (1st Axle) data in the z Direction

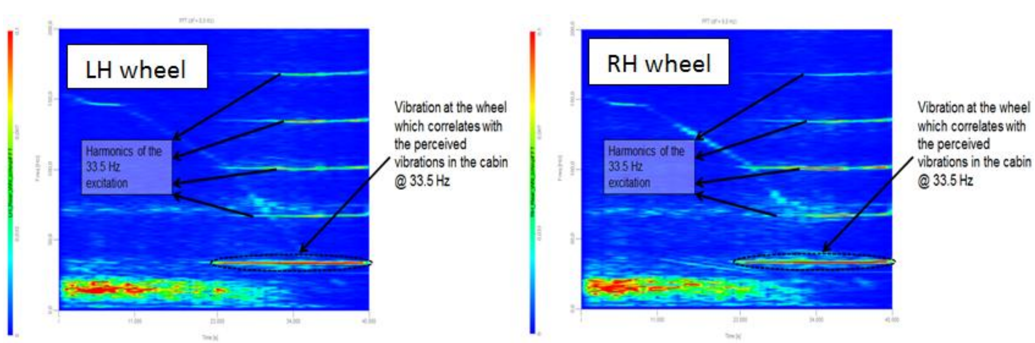

Figure 6. Left & Right 2nd axle wheels data in the z Direction

It is clear from the harmonic analysis that vibration frequency does not decrease with the decreasing wheel speed, therefore is not rotation dependent. Perceived high level vibrations in the cabin, around 33,5Hz totally correlates wheel excitations, very dominant at the 2nd axle wheels both on the LH and RH side. Excitations on the 1st axle wheels are either less compared to 2nd axle; or they are transferred from the excitations of the 2nd axle wheels through chasis.

2.2.2 .Braking at neutral gear downhill with cold brakes.

All brakes are active and cold. The forced vibrations were not recorded in the cabin. No peak vibration frequency is recorded at the 2nd axle wheels during this scenario as well and shows similar behaviour with the cabin frequency measurements as seen in figure7.

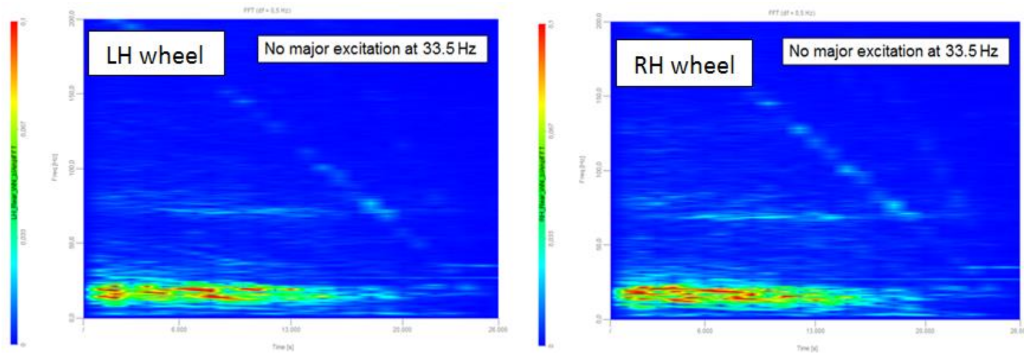

Figure 7. Left & Right Wheel (2nd Axle) z Direction

2.2.3. Wide open throttle acceleration at 5th gear, no up/down hills

No severe vibrations perceived in the cabin during wide open throttle acceleration. No excitation on the left & right wheels (2nd axle) is recorded too. Subjective drives for all measurements were in line with the measured data as seen in figure 8.

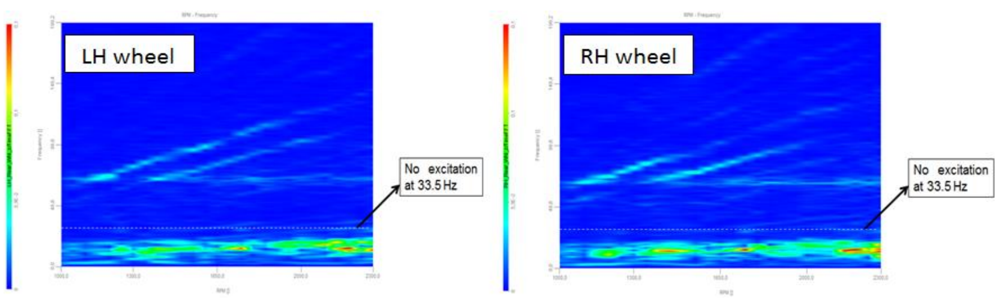

Figure 8. Left & Right Wheel (2nd Axle) data in the z direction

3. Discussion

The test results figure out that the scenario “braking at neutral gear downhill drive with hot brakes” excites the cabin vibrations and the root cause behind the brake judder issue. The next study is to investigate the source of excitation.

1st axle brakes are operating, 2nd axle brakes are cancelled

No major cabin vibrations was perceived throughout the full vehicle speed range and is in line with the wheel vibration measurements as displayed in figure 9, 10, respectively.

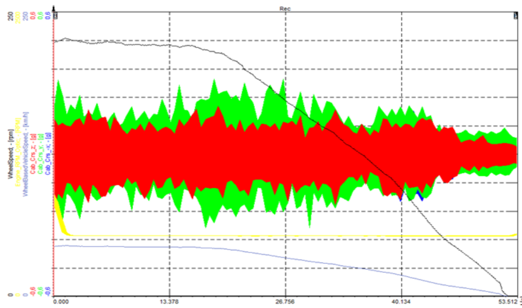

Figure 9. Cabin vibration frequencies in x, y, z direction

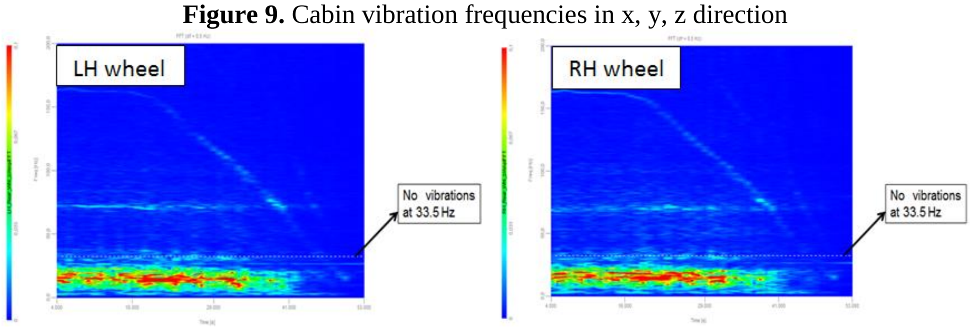

Figure 10. Left & Right Wheel (1nd Axle) data in the z direction

2nd axle brakes are operating, 1st axle brakes are cancelled

Major cabin vibrations were recorded during this testing event as shown below (figure 11).

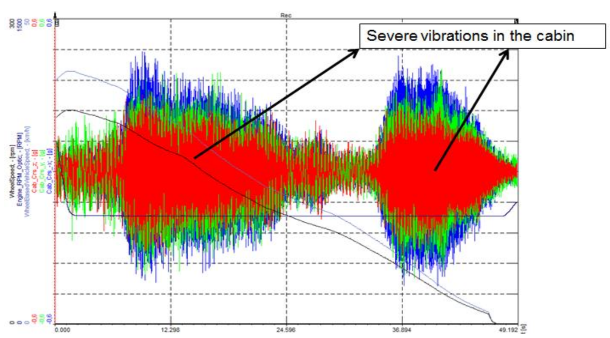

Figure 11. Cabin vibration frequencies in x, y, z direction

The wheel vibration frequencies around 33.5 Hz correlates with the cabin frequency as shown, in figure 12 but there is also a peak frequency around 10Hz that may be excited due to the vehicle suspension & body modal behavior coming from via road inputs or transmitted engine harmonics. It has to be worked to understand the causing mechanism behind.

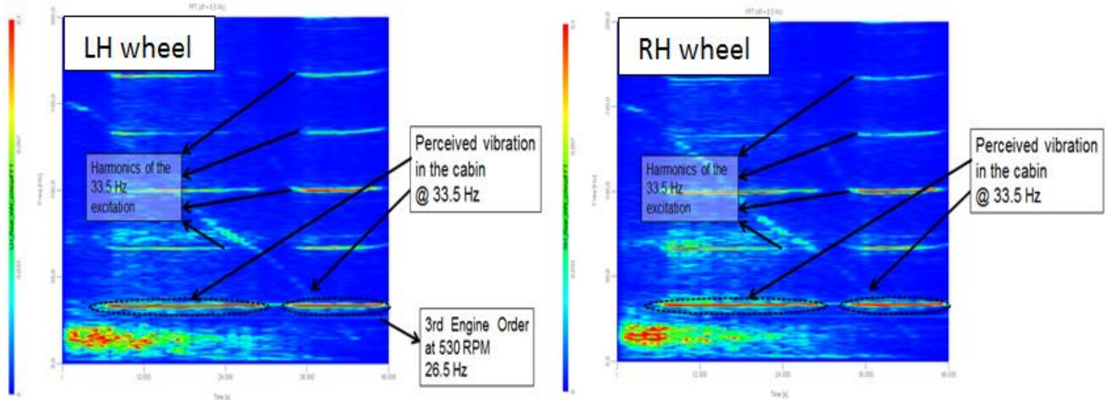

Figure 12. LH&RH Wheel (2nd Axle) z Direction

All brakes are active and 2nd axle spring brake actuators are replaced with service brake actuator

Concerning the brake system point of view the 2nd axle has a difference in that spring brake actuators are assembled instead of service one. Service brake actuators are lighter around 8kg. It was thought that spring brake actuator inertia effect may have a contribution in occurrence of brake vibration excitation. As expected no forced excitation is noticeable at cabin & 2nd axle wheels (figure 13).

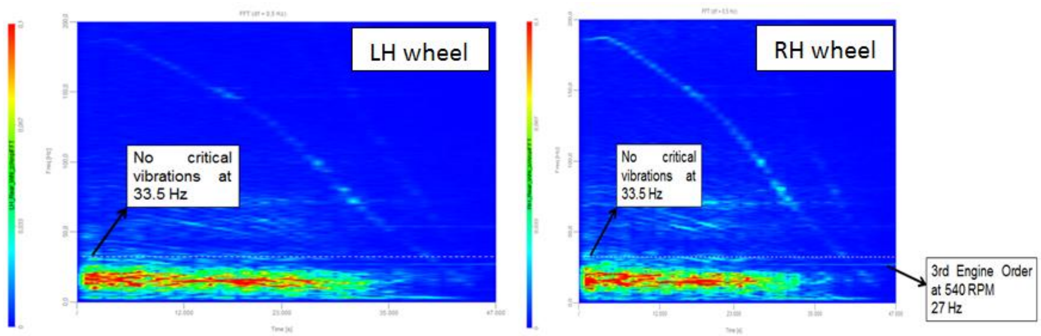

Figure 13. Left & Right Wheel (2nd Axle) dat in the z direction

Frequency Response Function (FRF) measurements were decided to be carried out on the brake actuator brackets to quantify brake actuator difference effect on forced vibrations. Three directional accelerometers were attached to 1st & 2nd axle left & right brake actuator brackets as shown below (figure 14).

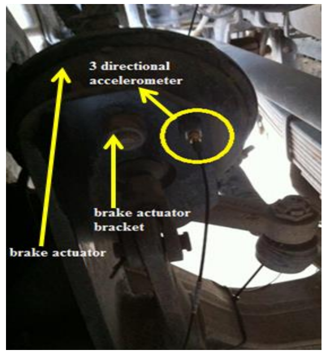

Figure 14. Directional accelerometer on brake actuator bracket

The 1st axle Frequency Response Function (FRF) measurements showed that no severe peak is around 33,5Hz. However, 2nd axle with spring brake actuator have frequency response function result showing predominant peak frequency at around 32,7Hz and 34,6Hz that are very close to cabin vibration frequency of 33,5Hz displayed in figure 15, 16.

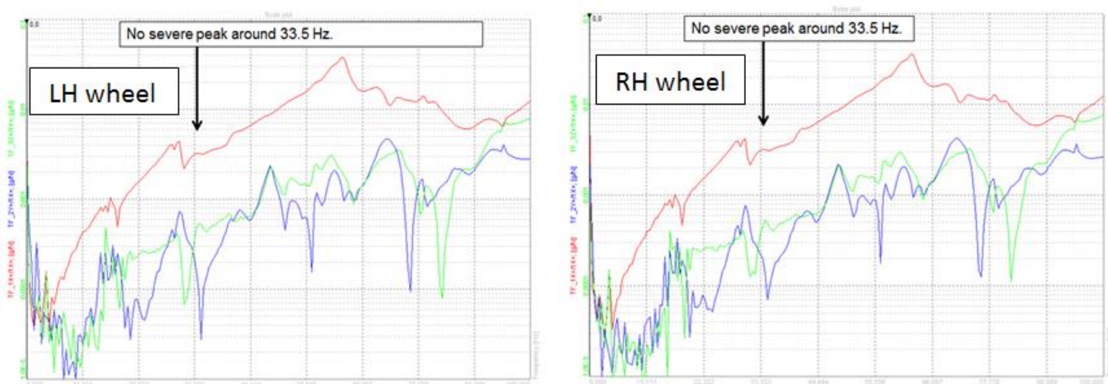

Figure 15. Left & Right Front (1st axle) Bracket FRFs

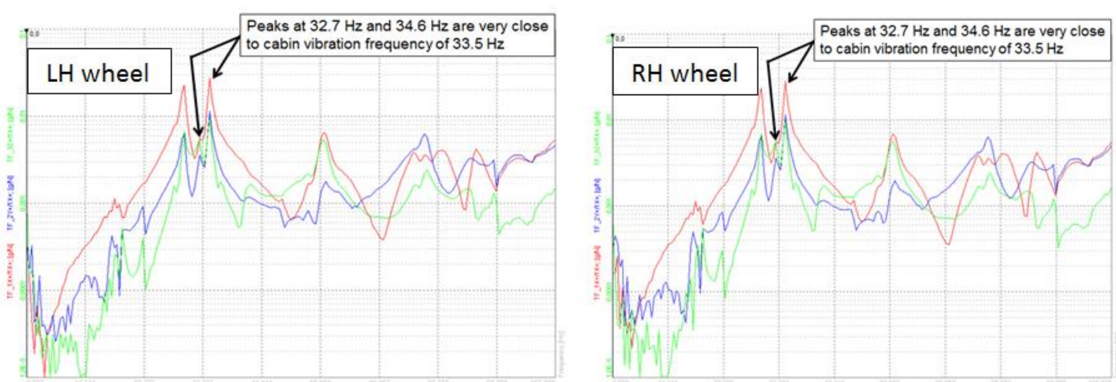

Figure 16. Left & Right (2nd axle) Bracket FRFs

Conclusions

1- Excitation force is generated by the contact of brake shoe and drum when the brakes are warm.

2- No other excitation mechanism such as the engine or compressors has an impact. After the engine has been shut off brake applied and the disturbing brake vibrations still exists.

3- Cabin vibrations via brake activation start increasing around vehicle speed of 30 kph at around 33.5 Hz and are independent from wheel rotation speed.

4- Excitations on the 1st axle wheels are either less compared to 2nd axle; or they are transferred from the excitations of the 2nd axle wheels through chassis.

5- The 1st axle frequency response function (FRF) measurements showed that no severe peak is available around 33,5Hz.

6- 2nd axle frequency response function result showed that the predominant peak frequency at around 32,7Hz and 34,6Hz are very close to cabin vibration frequency of 33,5Hz. The spring brake actuator inertia effect on the occurrence of brake vibration excitation was proven out. The 2nd axle spring type actuators high level displacement is also correlated to that result.

References

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