# Reduction of running noises on light rail vehicles using resilient hybrid wheels

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## Introduction

Aluminium hybrid wheels are enjoying increasing popularity for use in regional public rail transport. Weight savings of up to 70 kg per wheel lead to lower energy consumption in operation and allow higher vehicle load capacities. For operational use, the question of influencing the running noises with the use of hybrid wheels is also important. To this end, in 2019 and 2021 two measuring campaigns were carried out with comparative acoustic measurements at different passing speeds on a track at the depot of the VGF central workshop in Frankfurt. The noise level when passing of a regular "U5" type vehicle with conventional steel tram wheels was compared to that of a "U5" vehicle equipped with aluminium hybrid wheels.

## Resilient hybrid wheel

The wheels on trams and light rail vehicles are generally resilient wheels, i.e. an outer wheel tyre is connected to an inner hub by resilient and damping rubber elements. The suspension provided by the rubber elements allows wheel tyres and hubs to move against each other within narrow limits (a few millimetres), thus compensating for irregularities on the track system.

Whilst the wheel tyre which runs on the rail, is made of steel for reasons of strength, the hub can generally be made of other materials. When it comes to aluminium hybrid wheels, the hub and detachable ring are made of a wrought aluminium alloy.

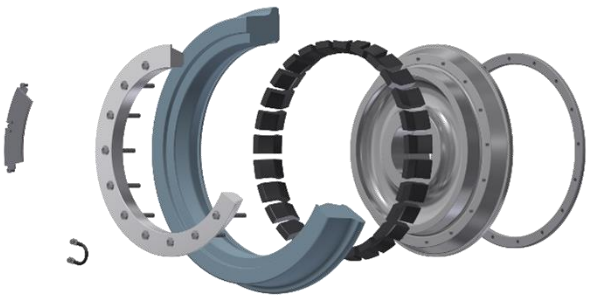

**Figure 1:** Exploded view of a hybrid wheel. With (from left to right) wheel sound absorber, hybrid shunt, aluminium detachable ring with bolts, high-strength steel wheel tyre, rubber block, aluminium hub and high-strength steel counter bearing.

With a design adapted to the material, weight of up to 70 kg can be saved when using an aluminium hub. The lower accelerated mass leads to lower energy consumption in operation and allows a higher vehicle load capacity [1].

Figure 1 shows the schematic layout of the hybrid wheel (type Bo2000) currently in use at VGF, Frankfurt.

The different strength properties of aluminium require a different, more solid hub design (see fig. 2). In particular the web is a much thicker (factor of 3) and shorter design than on steel wheels. This renders the component more rigid and thus makes for lower vibration amplitudes in the acoustic range.

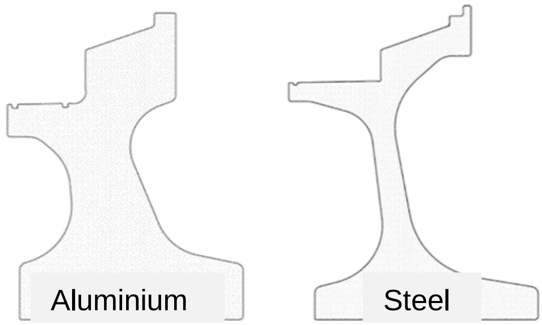


**Figure 2**: Comparison of the contour of an aluminium hub and a steel hub.

FEM calculations also confirm that the aluminium hub deforms less than the steel hub when subjected to the same forces [2].

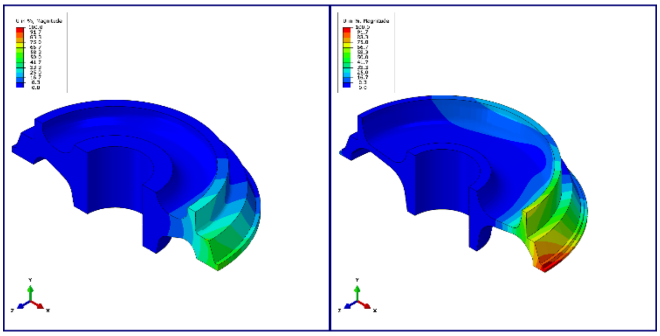

**Figure 3**: FEM calculation of the deformation of an aluminium/steel hub when subjected to the same axial force.

## Wheel sound absorbers

The hybrid wheels are equipped with wheel sound absorbers which are adapted to the wheel and its dynamic properties. They are fastened to the outside of the wheel tyre with bolts.

The wheel sound absorbers have a sandwich structure made of layers of steel and elastomer which allow it to oscillate with the natural frequency of the wheel, thus attenuating tonal noises when travelling in bends (curve squeal). Wheel sound absorbers are adapted geometrically to the shape and the dynamic deformation and acoustically to the natural frequencies of the wheel.

**Figure 3:** Shunts and absorbers installed on the aluminium hybrid wheel [3]

## Vibration measurement on the wheel

The attenuating effect of the absorbers can be demonstrated by measuring the frequency response in the laboratory. To do so, the wheel is placed on the test bench and stimulated axially on the face with an impulse hammer and the acceleration of the wheel vibrations is measured in the same direction. The ratio of the vibration acceleration to the excitation force is shown in relation to frequency.

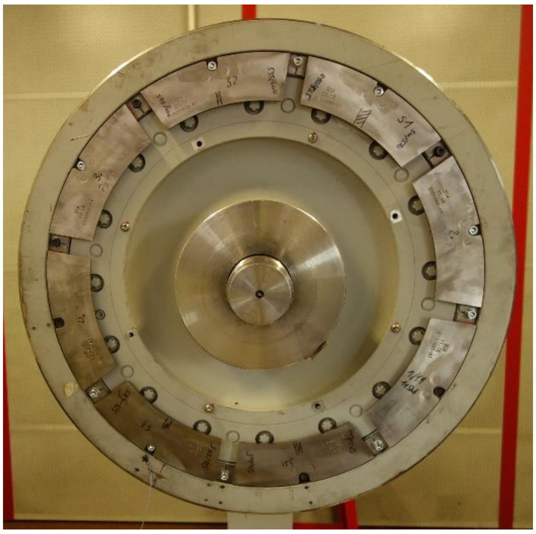

**Figure 4**: Hybrid wheel with wheel sound absorber on the test bench

The following shows the axial frequency response of a wheel with absorbers and a wheel without absorbers.

Axial wheel vibrations are above all responsible for screeching noises in bends whilst radial vibrations determine the running noise when travelling straight ahead. The ratio of vibration acceleration to the excitation force of the impulse hammer in a logarithmic dB scale is shown for a frequency range of up to 5,000 Hz in each case.

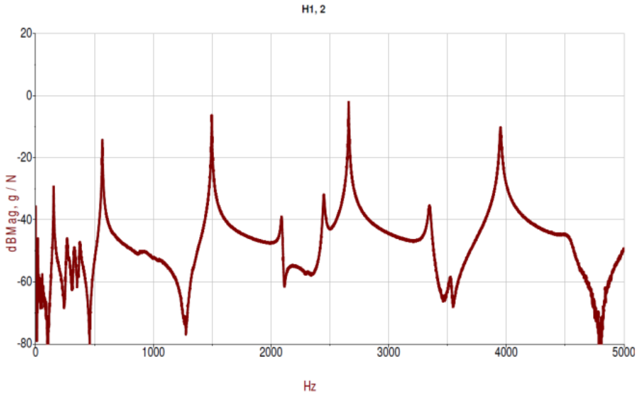


**Figure 5**: Frequency responses, axial/without absorbers

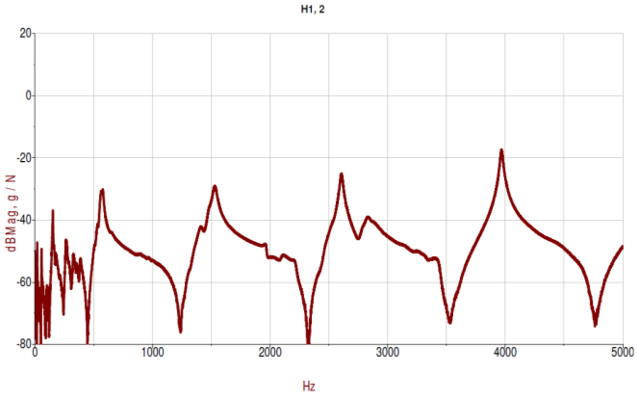


**Figure 6**: Frequency responses, axial/with absorbers

The frequency responses clearly show a lower level of vibrations in the wheels with wheel sound absorbers.

## Operational trial on the U5 light rail vehicle

Vehicles of the U5 series have been deployed in Frankfurt since 2008. They are six-axle high-floor articulated railcars with a length of 25 m.

Since 2018, within the scope of a field trial for series release of the hybrid wheels, an accordingly equipped bi-directional vehicle (no. 694) has been deployed for the VGF's normal passenger service. Part of this operational trial is an acoustic measurement of running noises.


**Figure 7:** U5 light rail vehicle no. 694, Frankfurt

## Acoustic measurements

Acoustic measurements were taken by FCP IBU GmbH in May 2019 [4] and August 2021 [5] on the track system of VGF's central workshop on Heerstraße in Frankfurt. Measurements were taken in the track bend (65 m radius) to the south-east of the factory hall and on the straight section of track to the east of the factory hall. Microphone distance 7.5 m from the middle of the track, 1.2 m above the upper edge of the track, on the inside of the bend.

Alongside vehicle no. 694 which is equipped with hybrid wheels, a series vehicle with normal steel wheels was deployed as a reference in each case.

**Figure 8**: Light rail vehicle at the exit from the south-eastern track bend. Photo by A. Schäfer/FCP IBU

The first measurements were take on 15.05.2019 (track bend) and 16.05.2019 (straight). The bi-directional vehicles no. 694 (hybrid wheels) and no. 663 (steel wheels) – which are identical in design with the exception of the wheels – were deployed, all wheels without wheel sound absorbers.

Tables 1 and 2 show the average sound exposure level SELm in dB(A) as measured over three runs.

**Table 1:** SELm level, track bend (15.05.2019)

| Variant | dB(A) level | | |
|---|---|---|---|
| | 20 km/h | 40 km/h | 55 km/h |
| Aluminium | 91.7 | 92.0 | 92.3 |
| Steel | 94.1 | 94.4 | 94.3 |
| Delta | 2.4 | 2.4 | 2.0 |

**Table 2:** SELm level, straight (16.05.2019)

| Variant | dB(A) level | | |
|---|---|---|---|
| | 20 km/h | 40 km/h | 55 km/h |
| Aluminium | 82.5 | 88.3 | 90.7 |
| Steel | 83.5 | 89.0 | 91.6 |
| Delta | 1.0 | 0.7 | 0.9 |

Further measurements were take on 25.06.2021 (track bend) and 26.08.2021 (straight). The hybrid wheels on vehicle no. 694 have since been equipped with wheel sound absorbers.

The reference vehicle was no. 644 (steel wheels without absorbers).

Tables 3 and 4 show the average sound exposure level SELm in dB(A) as measured over three runs.

**Table 3:** SELm level, track bend (25.08.2021)

| Variant | dB(A) level | | |
|---|---|---|---|
| | 20 km/h | 40 km/h | 55 km/h |
| Aluminium abso. | 90.5 | 91.0 | 91.0 |
| Steel | 91.6 | 92.0 | 92.5 |
| Delta | 1.1 | 1.0 | 1.5 |

**Table 4:** SELm level, straight (26.08.2021)

| Variant | dB(A) level | | |
|---|---|---|---|
| | 20 km/h | 40 km/h | 55 km/h |
| Aluminium abso. | 77.7 | 82.8 | 84.3 |
| Steel | 77.5 | 83.5 | 86.7 |
| Delta | -0.2 | 0.7 | 2.4 |

When it came to noises when travelling in the bend, no screeching which determined the level could be perceived during any of the runs.

The levels of the two measuring campaigns are (in particular on the reference vehicles) clearly different, making a direct comparison impossible in this case. The cause of the differences in level may be related to the locations of the microphones, but also changes in the condition of the track and running surfaces, e.g. due to braking tests.

On each respective day of measurement the levels of the vehicle with hybrid wheels, under otherwise identical framework conditions, were always lower than those of the vehicle with steel wheels. Given that no screeching noises significant to determining the level arose, wheel sound absorbers were not able to provide any benefits.

## Summary/outlook

When using hybrid wheels, acoustic measurements on light rail vehicles when passing by and when travelling in the track bend recorded lower levels than when using conventional steel tram wheels made of steel. The fear that greater vibration amplitudes would arise on lighter components, thus leading to higher acoustic levels, did not prove to be true. In fact, the greater volume of the design of the aluminium components makes for greater component strength and thus leads to lower acoustically effective vibrations.

## Acknowledgement

Warm thanks to the employees of FCP IBU GmbH, Essen for the professional implementation of the acoustic measurements, and to the employees of the Frankfurt transport services for the professional preparation and implementation of the measurement campaigns.

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