COMPARISON OF TWO METHODS OF TRANSFER PATH ANALYSIS APPLIED TO SNOWMOBILE FOR NOISE SOURCE IDENTIFICATION

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1 Introduction

The problems related to snowmobiles noise are important issues for the recreational vehicle industry. When a snowmobile is operating, forces are injected in its rear suspension by the rotating track and will generate vibrations and also possibly acoustic radiation of the drive system (track - suspension - tunnel). To identify the related vibroacoustic transfer paths and main sources, the methodology of TPA (Transfer Path Analysis) and OTPA (Operational Transfer Path Analysis) were used. A comparison between these two methods was reported in [1] for a panel excited by two shakers and one speaker in laboratory conditions. This paper compares these two methods for an industrial case in terms of reconstruction of radiated pressure and transfer path identification.

2 TPA and OTPA

For the TPA, the matrix equations are the following:

$$\begin{cases} \{A\} = [H_1]\{F\} \\ \{P\} = [H_2]\{F\} \end{cases} \quad (1)$$

where F, A and P are vector quantities that represent the injected forces, corresponding accelerations and radiated pressure, respectively. H_1 and H_2 are matrices containing 'acceleration upon force' and 'pressure upon force' transfer functions, respectively (obtained using static measurements). A will be measured in dynamic conditions. To determine F, the matrix H_1 has to be inverted and the SVD (singular values decomposition) will be applied.

For the OTPA, we have the following equations:

$$\begin{cases} \{A\} = [H_1]\ \{F\} \quad (2.1) \\ \{P\} = [H_3]\ \{A\} \quad (2.2) \end{cases}$$

The unknowns are F and H_3. The matrix H_3 is now calculated by taking several operational measurements to obtain a sufficient number of equations to express the radiated pressure at each speed by a linear combination of the measured accelerations [2].

3 Experimental characterization

3.1 Measurements

To perform the measurements, a test workbench (Figure 1) for the drive system was designed. It allows controlling the operating speed of the drive shaft and set the track in realistic rotating conditions. Other sources of noise and vibrations are eliminated since they do not operate (engine, CVT). Realistic load conditions (weight of a driver, …) are achieved by putting the tunnel under constraint using a hydraulic actuator.

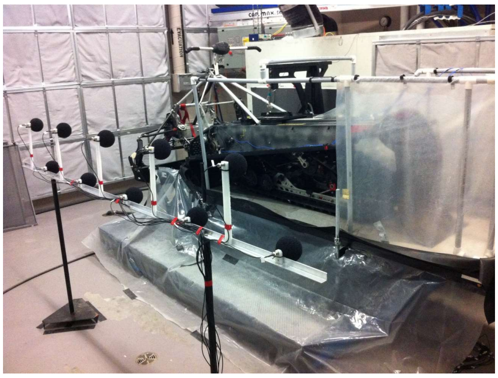

Figure 1 : Test workbench for the measurements.

This study was focused on the noise linked to the excitation corresponding to the engagement of the drive shaft on the track by the sprocket teeth (composed of eight teeth). The corresponding frequency depends on the vehicle speed, and at a given rotational speed (rpm), it equals eight times the rpm divided by 60 (then called order 8).

Twelve 3D accelerometers (named A1-A12) were placed on the suspension, and three target microphones were positioned in the room in front of the suspension (see figure 1). Measurements were made on a 0-2048 Hz frequency range with a 2 Hz frequency resolution (the upper considered frequency is 600 Hz), and separated in two static and dynamic steps.

Static measurements:

1. H_1 transfer functions were determined using impact hammer testing at each accelerometer locations (3D measurements). The size of H_1 is 36x36x1024.
2. H_2 transfer functions were reciprocally determined, using a volume velocity source located at each microphone position. This volume source has low frequency limitations under a frequency of 200 Hz. The size of H_2 is 3x36x1024.

Operational measurements:

3. Operational accelerations and pressures were measured during three consecutive run-ups of the drive system from 20 to 120 km/h (then discretized in 147 speeds). The sizes of A and P are 36x147x1024 and 3x147x1024.

3.2 Assumptions

Since measurements could be made only on one side of the suspension, it was verified by preliminary tests that acceleration levels and frequency contents were similar on

both sides of the suspension so that the problem is considered symmetric. Two important assumptions were also made:
1. For both methods: the transfer functions are independent of the vehicle speed.
2. For OTPA only: the measured sound pressure level can be expressed as a linear combination of the acceleration measurements of each points.

4 Results

For the order 8, results of TPA and OTPA modelling in terms of radiated pressure compared with the measured one are shown in figure 2.

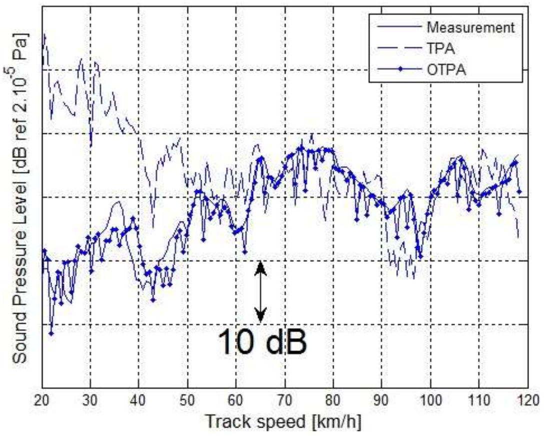

Figure 2 : Comparison of the TPA and OTPA modelling results with a dynamic pressure measurement (order 8).

The reconstruction results are very similar for both methods. However the TPA clearly overestimates the pressure level below a speed of 50 km/h, which is linked to the low frequency limitation of the volume source. This limitation is absent in the case of OTPA which remains valid at all frequencies.

5 Identification of transfer paths

For the TPA, Eq. (1) is used to calculate the contribution (A1 to A12) as following.

$$\{P\} = [H_2][H_1]^{-1}\{A\} \quad (3)$$

For the OTPA, Eq. (2.2) has to be used after having calculated the matrix H_3 using operational data only.
Figure 3 shows the respective contribution in terms of noise level for the 36 considered transfer paths as a function of the track speed. The main transfer paths can be easily identified and ranked in order to target which component should be modified in order to obtain possible reduction of the noise generated by the drive system. Note that in the case of the TPA, main transfer paths are better distinguished.
Four major contributors are easily identified from the results shown in figure 3: A3, A8, A11 and A12. A new experimental test was made for testing the effect of structural modifications at these points. The results showed a significant reduction in the noise of the drive system. This confirms that the two models were able to well identify the main transfer paths and sources of the considered snowmobile rear suspension.

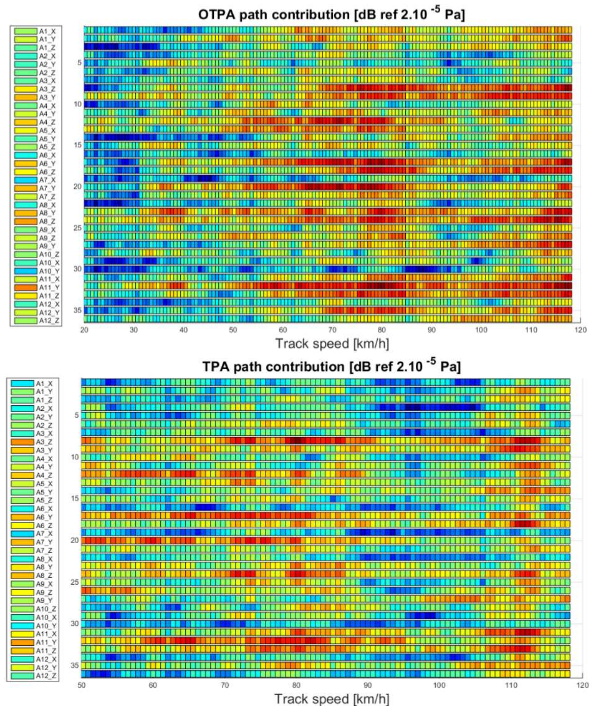

Figure 3 : Contribution of transfer paths in the case of OTPA and TPA, for the order 8 (TPA results are given from 50 km/h, whereas OTPA results start from 20 km/h).

6 Conclusions

The methodologies of TPA and OTPA were applied to the rear suspension of the snowmobile. The OTPA is quicker to implement since measurements of H_2 are no longer needed, and it avoids limitations linked to bandwidth-limited transfer functions (here low frequency limitations of the volume velocity source). However, it relies on a strong hypothesis (pressure is a linear combination…) that can have for consequence overestimations in the matrix H_3 if other sources than those included in the model strongly influence the measured sound pressure level. The TPA generally provides more precise predictions; however both methods provided a satisfactory identification of transfer paths. This was confirmed by noise reduction results obtained with additional tests on a snowmobile including modifications of the identified main paths and noise contributors.

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