Experimentelle Bestimmung von Dispersionseigenschaften einer Leichtbau-Profilplatte

Carsten Hoever[1], Torsten Kohrs, B.A.T. Petersson

[1] *Inst. f. Strömungsmechanik und Technische Akustik, 10587 Berlin, Deutschland, Email: carsten.hoever@tu-berlin.de*

Introduction

Light weight profiles comprising a high static stiffness and low mass are used in many fields of application, e.g. vehicle construction or mechanical engineering. The reduced mass in combination with the often periodic nature of the plates tends to enhance structure-borne sound transmission, propagation and radiation, at least in some frequency bands. For effective noise control efforts it is hence important to have a better understanding of wave propagation in such structures. Due to the high geometrical complexity of the structures not only analytical determination of inherent propagation mechanisms is difficult, but also experimental evaluation. Especially the spatial Fourier transformation easily reaches its limitations. In order to circumnavigate these, parameter estimation and wave speed analysis techniques have been investigated in the last two decades [1, 2, 3].

It is the aim of this study to identify the dispersion characteristics of a typical light weight profile plate (an extruded plate of a train carriage, see Fig. 1). For this the Inhomogeneous Wave Correlation (IWC) method [4] is used. It estimates the wave number content of the signal from calculated or measured velocity fields and comprises a set of promising features, amongst which are wave attenuation estimation, quality-based data weighting, an arbitrary data grid and an estimation algorithm which is comparably easy to implement. For comparison reasons the experimental analysis of the light weight plate is also extended to a transient group speed evaluation of the propagating wave packets by using an algorithm for the continuous wavelet transform (CWT) proposed by Büssow [5]. Apart from the CWT approach the data is also analysed using short-time Fourier transformation (STFT) and pseudo Wigner-Ville distribution (PWVD). Two different techniques for arrival time estimation are used. One determines arrival times of energy maxima while the other uses single frequency correlation to estimate propagation times. Hence, a comparison between different techniques for group speed evaluation is possible. Prior to the measurements all techniques are evaluated using simulated simple infinite bending plates to obtain information regarding feasibility and easiness of measurements and post-processing as well as regarding quality and comparability of attained results.

Figure 1: Light weight profile plate investigated.

Setup

Group speed measurements are conducted for seven angles from 0° to 90° with four measurement positions for each case. For IWC a plate area of $0.75\,\mathrm{m} \times 0.75\,\mathrm{m}$ is divided into a grid of 31×31 irregularly spaced measurement points. In all cases the centre of the plate is the point of origin as well as excitation position. IWC data acquisition is performed using an automated setup involving a positioning unit and a laser vibrometer. Simulations are based on the setup but only involve a simple infinite plate behaviour with face plate properties.

Results

In the simulations the IWC method and all group speed methods provided adequate and comparable results even for noisy signals. Hence, here it is focused on the actual measurements. It has to be distinguished between the actual results and a comparison of the usefulness of the different employed methods. For the sake of brevity, presentation of group speed data is limited to CWT results.

Dispersion Characteristics

IWC results for propagation perpendicular to the profile webs are shown in Fig. 2. Below approximately 300 Hz global behaviour is visible with low wave numbers. For higher frequencies not only typical periodic features like attenuation and propagation zones can be found but also different wave types: Between 1800 Hz and 2200 Hz, 2800 Hz and 3200 Hz and 4700 Hz and 5000 Hz there is a steeper rise of wave numbers than in the interjacent regions, which indicates different wave types. In most frequency regions a periodic spacing of wave sets is visible with a typical wave number periodicity of around $35.5\,\mathrm{m}^{-1}$ below 2800 Hz and approximately $15.5\,\mathrm{m}^{-1}$ above. These numbers roughly match the width of one respectively two of the profile webs. For comparison with CWT data, the extracted wave numbers are converted to group and phase speeds. Exemplary results for the IWC data depicted in Fig. 2 are shown in Fig. 3. Matching of data obtained with the different techniques is limited. In contrast to physical expectation, CWT results often match better with IWC phase than group speeds. Generally all CWT results reveal little useful information about the inherent wave propagation mechanisms in the profile plate. Regarding other measure-

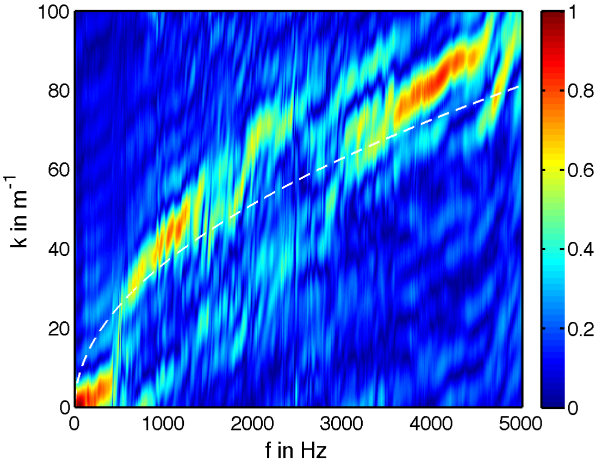

Figure 2: IWC results for propagation perpendicular to the profile webs. (−−) wave number of simple infinite face plate.

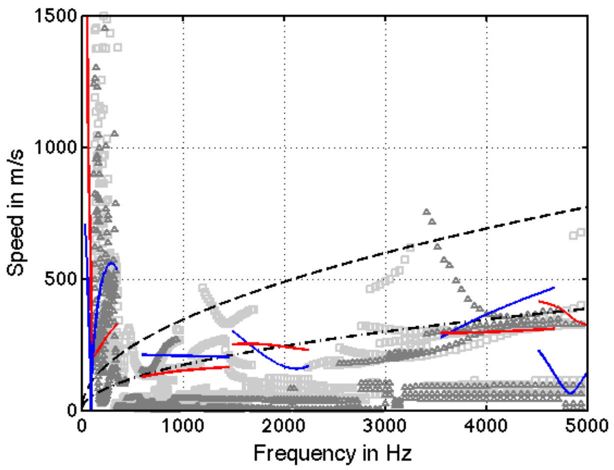

Figure 3: CWT group speeds and speeds converted from IWC wave numbers for propagation perpendicular to the profile webs. (□) correlation method, (△) energy maximum method, (—) IWC group speeds, (—) IWC phase speeds, (− −) theoretical group and (− · −) phase speed for a simple infinite face plate.

ment results, which cannot be shown here, IWC reveals well-defined dispersion characteristics including typical features of wave propagation in periodic structures. For propagation parallel to the inner webs typical plate strip bending wave propagation is visible. For oblique angles wave propagation is limited while approaching propagation perpendicular to the webs results reveal pass and stop bands as well as periodicities in the frequency as well as the wave number domain. A global wave with nearly isotropic behaviour exists for all angles.

Usefulness of the Employed Methods

The IWC method for wave number estimation seems to be a robust and practical approach for the evaluation of dispersion characteristics of complex geometric structures like the one considered here. While the measurement itself is more time-consuming than for the group speed evaluation techniques, the attained data is of higher quality, post-processing effort is minimal and results are more distinct, reliable and easier to interpret physically. In the present implementation group speed evaluation cannot be considered as a reliable process for complex geometries. Especially diversification of results is a large problem. This seems to be caused by multiple reflections at joints and the problem of identification of the first wave front under these conditions. Still the group speed estimation techniques should not be ruled out completely as for simpler conditions like the simple infinite plate simulation results are good. Even though in this study care was taken to optimise results, it is expected that the performance for more complicated setups can possibly be improved by different means, e.g. choice of window function and size for STFT and PWVD, choice of mother wavelet for CWT, limitation of region for energy maxima determination to certain time frames and finer time sampling. Regarding the performance of the IWC, however, it remains doubtful whether a lengthy optimisation of group speed evaluation techniques is reasonable for analysis of dispersion characteristics. Comparing the time-frequency transformation techniques, the CWT seems to be the most promising, albeit the PWVD with a further optimised smoothing window might be worth a second look. STFT seems to be too limited by the combination of the fixed resolution and the uncertainty principle. It is difficult to make a final decision on the two time estimation techniques as the group speed results generally are too uncertain to decide if either of it produces more accurate results. Comparing the obtained time-frequency representations (which seem to be reasonable in most cases) with the estimated group speeds it can be argued that the actual problem in the group speed evaluation lies not in the time-frequency transformation step but rather in the following arrival time estimation step.

Conclusions

The gathered insights into dispersion characteristics of the light weight profile plate can be used for noise and vibration control, e.g. for the placement of vibration sources and connections to receiving structures or placing of damping material. Regarding the comparison of techniques, IWC seems to be an adequate tool for wave number estimation in complex structures. Usefulness of group speed techniques is limited for complex structures.

References

[1] Grosh, K., Williams, E.G.: Complex wave-number decomposition of structural vibrations. Journal of the Acoustical Society of America 93 (1993), 836–848

[2] Halkyard, C.R.: Maximum likelihood estimation of flexural wavenumbers in lightly damped plates. Journal of Sound and Vibration 300 (2007), 217–240

[3] Kim, Y.Y., Kim, E.H.: Effectiveness of the continuous wavelet transform in the analysis of some dispersive elastic waves. Journal of the Acoustical Society of America 110 (2001), 86–94

[4] Berthaut, J., Ichchou, M., Jezequel, L.: K-space identification of apparent structural behaviour. Journal of Sound and Vibration 280 (2005), 1125–1131

[5] Büssow, R.: An algorithm for the continuous Morlet wavelet transform. Mechanical Systems and Signal Processing 21 (2007), 2970–2979