Contact-free Vibration Measurements with Particle Velocity Probes – Part II: Experimental Investigations

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Introduction

This paper reports on contact-free vibration measurements using a particle velocity probe (pu-probe), [1]. The aim is to determine, if it is possible to measure structural oscillations using such a device, [2]. The 3-D probe used in the investigations can be applied to measure both particle velocity (pu) and sound pressure, [3]. One advantage of contact-free vibration measurements is the accuracy in measurement results compared to conventional methods, because it is not necessary to de-tune the structure by the attachment of sensors.

Vibro acoustic test environment

According to the paper "Contact-free Vibration Measurements with Particle Velocity Probes - Part I: Theory", this paper continues with the description of the experimental investigations using a vibro-acoustic test rig. The latter consists of an acoustic cavity (1.495m x 0.95m x 0.2m). Inside this cavity a simply supported beam structure (Aluminum, 0.895m x 0.03m x 0.002m) is used to excite the sound field. A loudspeaker has been used to simulate the effect of background noise (BGN). The measuring equipment given in Tab. 1 has been used.

Table 1: Overview on the measuring equipment

Component	Type
pu-probe	USP-Regular (Microflown)
accelerometer	Bruel&Kjaer Type 4517
loudspeaker	Eighteensound 6ND430
modal analysis hardware	SCADAS mobile, LMS
power amplifier	Bruel&Kjaer Type 2706
audio amplifier	Kenwood KRF-V7020
electro-dynamical exciter	ELAC Standart, Autotune II

Measurement of structural vibration

Behavior of the test rig

To analyze the behavior of the test rig, the natural frequencies have been determined.

Table 2: Resonances of the test rig

	cavity	beam structure
resonance	**f_n [Hz]**	**f_n [Hz]**
1	10.4	134.2
2	21.5	229.0
3	55.2	307.0
4	94.1	352.0
5	138.4	398.0
6	193.2	502.0

The resonances of the beam structure have been detected with a modal analysis system, the resonances of the cavity using the microphone signal of the pu-probe. The latter has been placed in a corner of the cavity. A broadband signal has been used to excite the enclosure via the BGN-loudspeaker. Tab. 2 contains the first six resonances of the uncoupled systems – beam structure and cavity.

Coherence based measurement technique

To be independent of a signal measured with sensors that are directly mounted on the structure, a coherence based approach has been analyzed. At first the acceleration and the normal component of the pu have been measured at a particular position considering broadband structural excitation without BGN. The coherence between these signals is shown in Fig. 1. Three different distances between the pu-probe and beam structure have been examined.

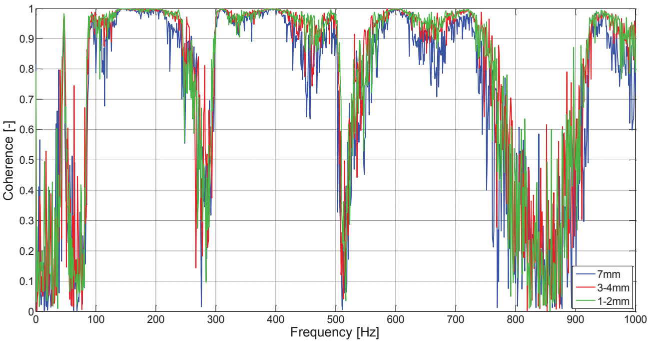

Figure 1: Coherence between signal of accelerometer and normal component of particle velocity without BGN, [1]

Because the measurement has been performed close to the structure, both, normal and tangential component of the pu should be related to the structural vibration. Therefore, the coherence between these signals has been calculated (see Fig. 2).

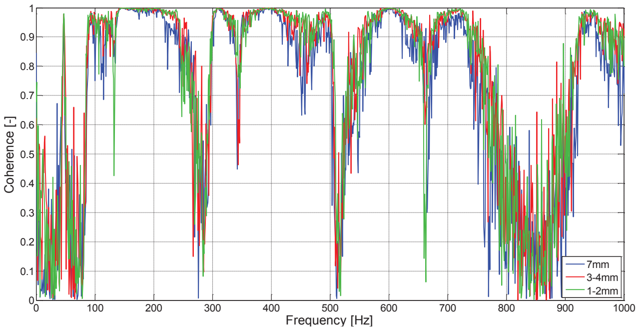

Figure 2: Coherence between normal and tangential component of the particle velocity without BGN, [1]

It can be noticed that the curves shown in Fig. 1 and Fig. 2 are nearly identical.

To quantify the effect of BGN, the measurement has been repeated. For this purpose, the BGN has been adjusted to 82dB sound pressure level (SPL). The results are shown in Fig. 3.

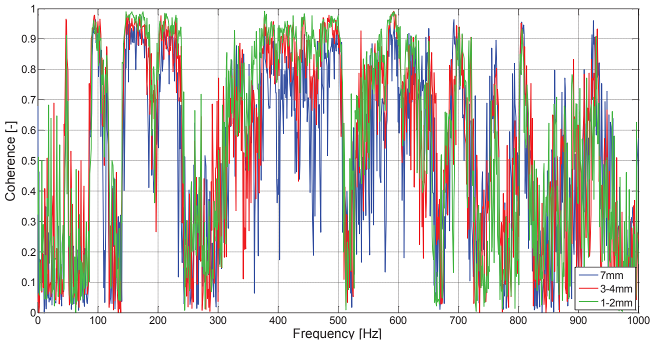

Figure 3: Coherence between normal and tangential component of particle velocity with BGN, [1]

The BGN clearly affects the coherence. The same holds for the distance between probe and structure. This indicates, that the coherence between normal and tangential component of the pu can be used to quantify the effect of BGN.

Signal-to-noise ratio

According to the linear system theory, the signal-to-noise ratio (SNR) can be calculated as follows.

$$\text{SNR} = 10\log_{10}\left(\frac{|H_1(j\omega)|}{|H_2(j\omega)|}\right)^2 + 10\log_{10}\left(\frac{S_{u1u1}(j\omega)}{S_{u2u2}(j\omega)}\right) \qquad [\text{dB}] \quad (1)$$

H_1 is the complex transfer function between the driving signal of the exciter and the normal component of the pu. S_{u1u1} and S_{u2u2} are the auto spectral densities of the electrical voltage which drive the actuators. The first summand represents the effect of the transfer paths on the SNR. The effect of auto spectral densities of the actuator driving signals is represented by the second summand. Fig. 4 shows the measured transfer functions as well as the SNR calculated by Eqn. 1. If the magnitude of H_1 is below the one of H_2, a low SNR can be detected. Thus not all natural frequencies can be observed with the pu-probe, if the SPL caused by the exciter is too low.

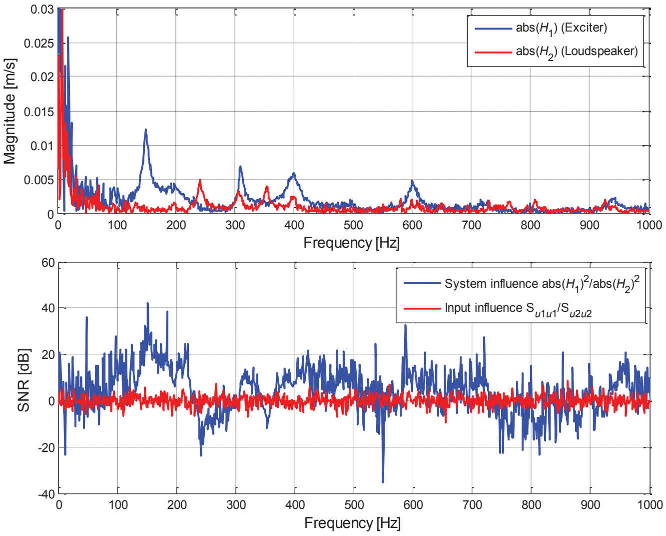

Figure 4: Transfer functions and SNR, [1]

Finally the absolute error has been compared for both signals (acceleration a_s and normal component of pu v_n). Therefore the conversion given in Eqn. 2 has been applied.

$$T_{a_s v_s} = \frac{v_n}{a_s} = \frac{v_n}{j\omega \cdot v_s} = \frac{1}{j\omega}\frac{v_n}{v_s} = \frac{1}{j\omega}T_{v_s v_n} \qquad [\text{m/s}] \quad (2)$$

The absolute error has been calculated using Eqn. 3.

$$\text{error} = 20\log_{10}\left(\left|T_{a_s v_s}\right| \cdot \omega\right) \text{ with } \omega = 2\pi f \qquad [\text{dB}] \quad (3)$$

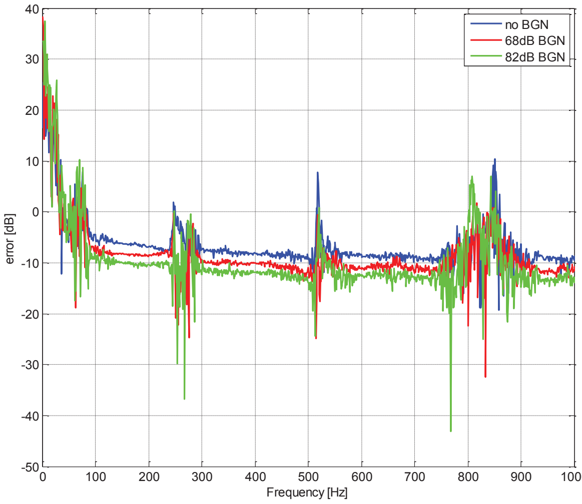

Figure 5: Measurement error with/without BGN, [1]

Without BGN, the loss in signal measured with the Microflown is (for most of the frequencies) -8dB. The error increases when the BGN increases, see Fig. 5.

Conclusion

A coherence based approach has been used to proof that it is not necessary to use structural sensors, such as accelerometers, to measure the structural vibration. Furthermore, the influence of BGN has been examined. Moreover, a method for the qualification of the SNR using the transfer function and the auto spectral density has been analyzed.

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References

[1] Sadra, D.: Contact-free Vibration Measurements with Particle Velocity Probes. Master Thesis, Hamburg University of Applied Sciences, 2013

[2] Kletschkowski, T.: Identification of Structural Parameters based on Acoustic Measurements. AIA-DAGA 2013, Merano, Italy

[3] de Bree, H.-E.: The Microflown – An Particle Velocity sensor. Acoustics Australia (2003), pp 91-94, Vol. 31 No.3