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Vibro-Acoustic Paths and their Impact on Vibro-Acoustic Signal Strength

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Introduction

A signal strength plays an important role e.g. in condition monitoring, where even a small change of dynamic behaviour of the system needs to be captured and analyzed. A weak signal ‘buried’ in noise does not provide an informative value as the strong signal with large signal-to-noise ratio does (i.e. with negligible noise level).

To quantify the strength of the signal transmitted via different transfer paths, the total RMS (root mean square) value of signal is measured and compared. The signal-to-noise ratio is analyzed as well in order to verify, if the signal is capable to carry sufficient informative value as well, or it is noise which is recorded and analyzed [1].

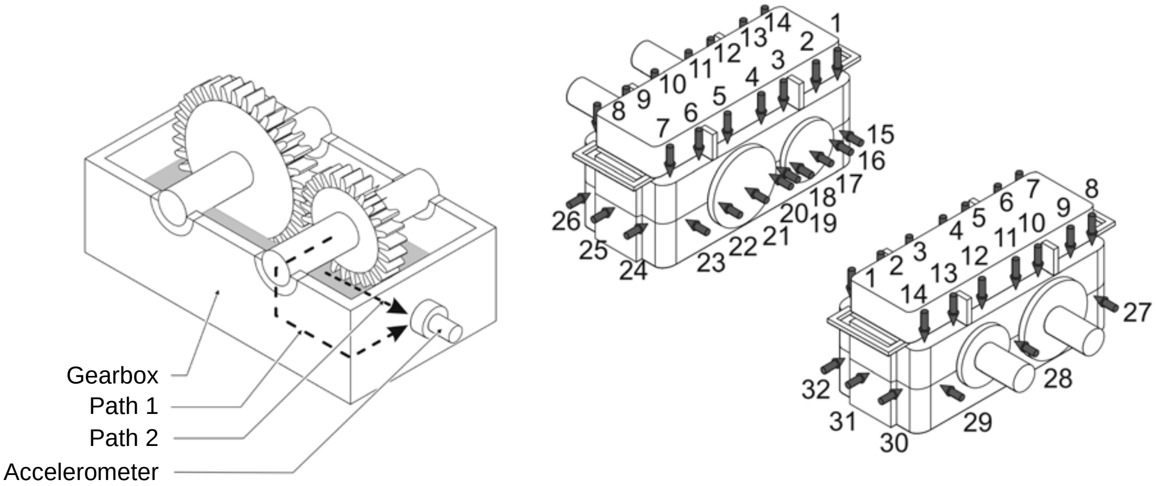
Vibro-acoustic paths

In general, we can distinguish two principal vibro-acoustic paths [2]:

- *Structure-borne path* (Path 1 in Figure 1a) – transmission via structural elements (e.g. frame, casing, shaft, etc.). Because of connections between elements, this path can be full of discontinuities, which can attenuate the signal.
- *Fluid-borne path* (Path 2 in Figure 1a) – transmission via fluid medium (e.g. water, oil, air). In general (especially for heavy fluids), the internal friction of the fluid causes signal attenuation.

In the analysis of the transfer paths, we need to take into account [2],[3]:

- *Material properties* – internal damping of the material or homogeneity can attenuate the signal of interest;
- *Length of the path* – especially in the case of material with higher damping;
- *Discontinuities* – either structural or material. At discontinuities the signal can be transmitted, reflected, or absorbed.



(a) (b)

Figure 1 – (a) Sketch of main vibro-acoustic transfer paths in gearbox; (b) visualization of measurement points location used in experimental analysis of a test gearbox.

Choice of Measurement Location Points

In literature, there have been published general rules to be followed in measurement location choice, applied in vibro-acoustic diagnostics [3], [4]:

- Location where the signal is strongest (in general it means as close to the source as possible to ensure direct path for vibro-acoustic signal transmission);
- Mount the transducer so, that the measuring direction coincides with transducer's sensitivity axis;
- Transducer should not behave as an added-mass (the rule of thumb is, that transducer's mass should be 1/10 of mass of structure, or smaller).

The first rule (location) is analyzed further and demonstrated on experiments.

Experimental Search

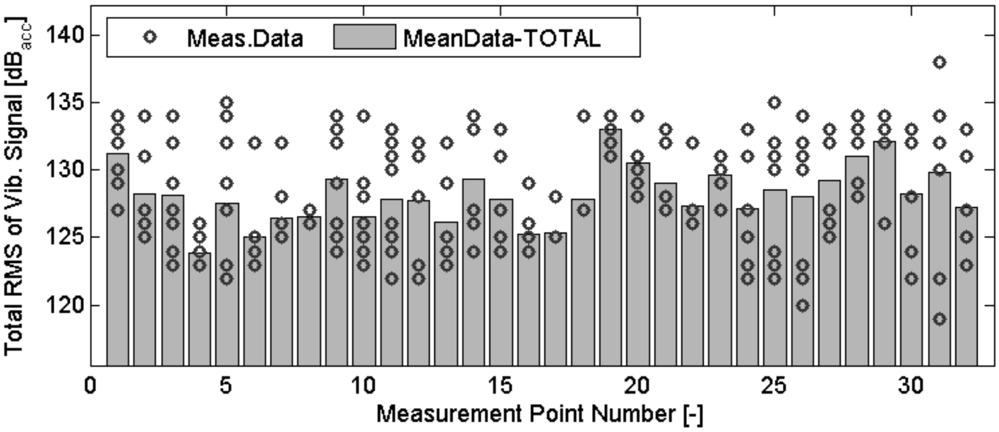
To analyze the influence of vibration transfer paths on signal, acceleration of vibration was measured on the gearbox shown in Figure 1b. A single accelerometer B&K 4514 was attached in one of the points of interest and measured signal was processed using B&K PULSE platform.

The measurements were done on an experimental gearbox used for gear wheel testing (so called FZG test rig). All in all, 32 points were chosen in three directions (axial, horizontal and vertical), in order to map the signal strength on the structure. Points 1-14 were measuring vertical direction, whereas points 15-32 were used to analyze the horizontal and axial direction. All together, 8 measurements of autospectra in every point were done and results were averaged. In order to reduce the noise level, each measurement of autospectra contains 1000 averaged samples.

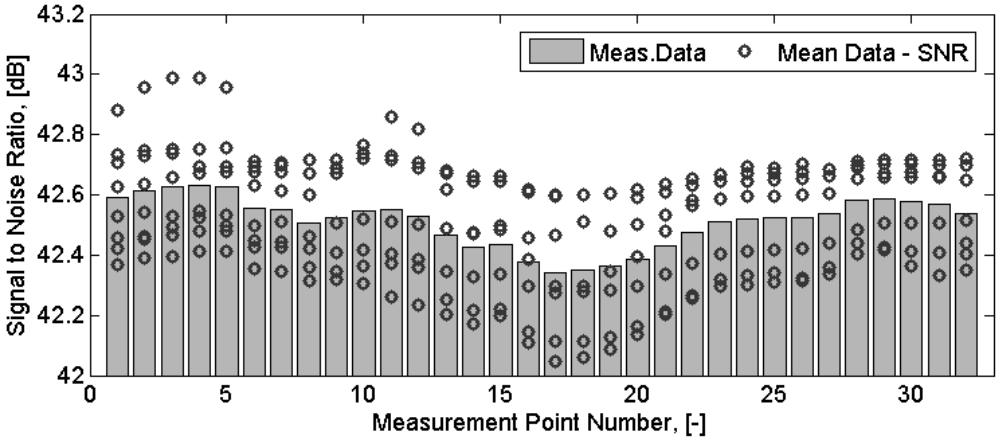
Results and discussion

The power content of the signal, in terms of RMS (root mean square) value, for each measurement point, is presented in Figure 2a.

It can be seen, that the strongest signal (signal with the largest RMS value, $L_{a,max}$ = 133 dB_{acc}) was measured in point 19, which corresponds to the axial measurements between the shafts (Figure 1b). At this point the signal from both shafts is summed up.



(a)



(b)

Figure 2 – (a) Total RMS and (b) Signal-to-Noise Ratio measured at points of interest

It needs to be noticed, that the tooth meshing frequency is a dominant one in measurements of gearboxes. Thus the strongest signal should be measured close to shafts, where the transfer path from the source (meshing gears) is shortest and with least number of discontinuities. Similar result is obtained for point 28, which is located at the other side of gearbox, also between the shafts (Figure 1b). The only discontinuities in these structure-borne transfer paths are between gearwheels, shafts and bearings. On the other hand, the material properties at this path are approximately the same, without significant damping (steel was used).

Larger number of discontinuities and material change contains the path to the aluminium shaft caps (measurements in points 16-18 and 20-22 in Figure 1b). The signal measured in these points is significantly weaker (around L_a = 126 dB$_{acc}$), comparing to one measured in points 19 and 29 ($L_{a,max}$ = 133 dB$_{acc}$) with smaller number of discontinuities and no material change.

The combination of structural and fluid transfer paths is analyzed in points 25 and 31 (L_a = 129 dB$_{acc}$), at the faces of the gearbox, where the signal is not as strong as in point 19, i.e. in the point closest to both shafts. As expected the fluid path does not contribute too much as there are reflections of the signal at boundaries (structural/fluid) and thanks to internal damping, the fluid attenuates the signal as well.

The weakest signal was measured in point 4 ($L_{a,min}$ = 124 dB_{acc}), at the edge of the gearbox with larger structural stiffness.

Another parameter, which determines the 'signal quality', is a signal-to-noise ratio (SNR), defined as a ratio of signal power to error power [1]. It can be defined also in terms of RMS of signal and noise amplitudes [5], which is used in the paper.

As can be seen from Figure 2b, the value of SNR is relatively constant oscillating around 42.5 dB (with variation around 5 dB). Therefore, it can be concluded, that the signal measured in either of 32 points analyzed, is not degraded by excessive noise and their informative value is sufficient. This is also caused thanks to sufficient number of averages of autospectra (used in data post-processing) which helps to suppress successive noise [1].

Conclusions

The analysis of vibro-acoustic transfer paths (length, material change and discontinuities) and their influence on signal strength was presented in the paper. Experimentally, using measurements done at an experimental gearbox, it was shown that the direct path with minimum number of discontinuities and uniform material provides the strongest signal. On the other hand, many discontinuities, material change and large stiffness of the structure attenuate the signal more. Therefore, it is very important to analyze potential measurement points, before doing any long-term measurement, in order to assess in which point the strongest signal can be measured.

Comparing values of signal-to-noise ratio, it was shown, that the information value of the signal is approximately the same. The only difference analyzed was its strength (i.e. amplitudes of significant frequencies, in the case of gearbox vibration harmonics of tooth meshing frequency).

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Resumé

Dráhy vibro-akoustického signálu a ich vplyv na silu signálu. Príspevok sa zaoberá analýzou dráh vibro-akustického signálu. Merania uskutočnené na testovacej prevodovke ukázali potrebu vyhodnotiť kde je signál najsilnejší, aby i minimálna zmena dynamického stavu bola zachytená čím skôr, a tým sa zamedzilo potenciálnym škodám na zariadení. Porovnanie odstupu signálu od šumu ukázalo, že spriemernenie autspektier účinne eliminuje šum, čím sa zabezpečí dostatočná informačná hodnota meraného signálu.

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