Identification of noise sources during press work operations in metal working production

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IDENTIFICATION OF NOISE SOURCES DURING PRESS WORK OPERATIONS IN METAL WORKING PRODUCTION

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SUMMARY.

For reducing the noise radiation level in a metal working production shop it is of vital importance to have a clear impression of the amount of noise which a particular source contributes to the overall sound pressure level. For instance, considering a press-work operation like punching, one should like to distinguish the contribution of the clutch from the contribution of the vibrating press during the punching process.

To this end the article describes a method based on measurements in the frequency domain by means of a Digital Signal Analyzer. From this, the contribution of each suspected source can be derived.

Finally, the paper gives a typical example of the application of the method.

NOMENCLATURE.

B	- Frequency bandwidth
f	- Frequency
$G_{xx}(f)$, $G_{yy}(f)$	- Autopowerspectrum of signals x, y
$G_{xy}(f)$	- Crosspowerspectrum between the signals x and y
H(f)	- Transfer function
$S_x(f)$, $S_y(f)$	- Fourier transform of the signals x, y
T	- Time
$\gamma^2(f)$	- Coherence-function

1 INTRODUCTION

Noise is one of the more serious problems we encounter considering working conditions in a metal working production shop. In 50% of the Dutch firms the sound pressure level is over 80 dB(A). This level is internationally accepted by ISO as the boundary for damage to the human ear [1]. Press work operations are often responsible for these high noise radiation levels.

A lot of research is done to reduce the noise radiation of different kinds of sources, the so-called active reduction [2]. For every single noise source there are some methods available for active reduction, but the problem in applying these methods is to find which source is the most intensive. To combat the noise radiation of a certain machine effectively it is necessary to use an objective method to measure the noise contributed by a suspected source.

There are several ways to develop such a method. In this paper a method is presented based on measurements in the frequency domain. Here each source has its own characteristic "frequency signature", hidden in the total sound pressure spectrum. Use of statistical functions like the coherence function can provide a noise spectrum which represents the contribution of a suspected source. Before this method is explained in detail, some remarks are given about measurements with a Digital Signal Analyzer.

2 RELATIONS FOR A LINEAR SYSTEM IN THE FREQUENCY DOMAIN

In tracing noise sources it is often necessary to use more advanced measurement equipment than the well-known sound pressure level meter with an A-weighting filter. Measurements in the frequency domain are required for more detailed information; nowadays they can easily be performed by a Digital Signal Analyzer.

By an A/D-converter the signal is sampled. A micro-processor is used for the Fourier-transformation based on the Fast Fourier Transform (FFT):

$$S(f) = \int_{-\infty}^{\infty} f(t) e^{-2\pi i f t} dt \quad (2.1)$$

In order to obtain spectra with acceptable random errors it is necessary to average several measurements. Because $S(f)$ contains both amplitude and phase information, averaging becomes very difficult without the aid of an extreme accurate trigger mechanism. In practice it is mostly not $S(f)$ which is measured, but the autopower spectrum $G_{xx}(f)$; representing the power per frequency band without phase-information. In formula:

$$G_{xx}(f) = S_x(f) \cdot \bar{S}_x(f) \quad (2.2)$$

Phase-information is lost by multiplying $S_x(f)$ with its conjugate. The relation between two signals (for instance the input and the output of a system) can be studied by using the cross-power spectrum, defined by:

$$G_{yx}(f) = S_y(f) \cdot \bar{S}_x(f) \quad (2.3)$$

It can be seen from Eq.(2.3) that the phase-relation between the signals is saved. This phase angle of $G_{yx}(f)$ is the difference of the phase angles of S_y and S_x . The cross-power spectrum is often used for observing the common power in two signals. Components with random phase difference are removed by averaging. Often can be said that this power is caused by the same source. However, it is difficult to conclude from the cross-power spectrum which percentage per frequency is radiated from the same source. Therefore the cross-power spectrum is scaled between zero and unity. This so-called coherence-function is calculated according:

$$\gamma^2(f) = \frac{|G_{yx}(f)|^2}{G_{xx}(f) \cdot G_{yy}(f)} \quad (2.4)$$

$\gamma^2=1$ means total coherence, $\gamma^2=0$ means no coherence.

Another application of the cross-power spectrum is in an accurate method of calculating the transfer-function $H(f)$. As said before it is difficult to measure $S_x(f)$ and $S_y(f)$ with acceptable random errors; so use of the Equation

$$H(f) = S_y(f) / S_x(f) \quad (2.5)$$

will often lead to erroneous results. For this reason the transfer-function is always calculated according to:

$$H(f) = G_{yx}(f) / G_{xx}(f) \quad (2.6)$$

The mentioned relations can be represented in a schematic diagram (fig. 2.1).

Fig. 2.1 System relations

Before the mentioned functions can be measured by a Digital Signal Analyzer some important aspects of the measuring method have to be considered. Because the Fourier-transform is performed digitally the signal has to be sampled at time intervals of ΔT seconds. The theorem of Shannon states that the maximum bandwidth in which frequency components can be recognized is limited according:

$$B_{\max} < \frac{1}{2\Delta T} \quad (2.7)$$

The signal components with a frequency out of the actual frequency band cannot be measured properly. It results in a distortion of the spectrum (aliasing). This can be prevented by using an anti-aliasing filter. The output of the filter is fed into the A/D convertor.

Another important aspect is averaging. Because of the random behaviour of the signals it is absolutely necessary to average a number of measurements. An indication of the confidence intervals of the measured estimates is given in table 1.

Apart from aliasing and random errors a third kind of error is likely to occur. It is caused by truncation of the signal at the begin and the end of the measuring time period. A sine which is observed over *infinite* time will result in a Dirac-function. A sine which is truncated by measuring during a finite time - as always happens in practice - will be transformed to a spectrum

which is the convolution of a Dirac-function and the Fourier-transform of a rectangular window. This distortion can be reduced by using other window functions instead of the rectangular function, such as cosine, $(\cosine)^2$, $(\cosine)^4$, Hamming or exponential functions. Generally can be said that windowing reduces the height of the sidelobes, but widens the bandwidth of the mainlobe. (see fig. 2.2)

Fig. 2.2 Windowing

3 THE MEASURING METHOD

In applying these theories to investigate noise radiation during press work operation, a lot of practical problems arise. First of all, a detailed measuring method has to be developed. A set of measurements in an anechoic room was set up to achieve:

- a checking and calibrating of the microphones and other devices,
- a check of the change in results as a function of the microphone's position,
- an impression of the relation between sound and vibrations of the source,
- a method to separate the contributions of different noise sources.

The set-up for these measurements is outlined in fig. 3.1.

Fig. 3.1 Experimental set-up

In an anechoic room two noise sources are installed; the main source is of the impact noise type, the background noise is random. The sound is measured by two microphones. The vibrations of the main source can be measured by means of an accelerometer. The signals are fed to the Signal Analyzer. Measuring the transfer- and the coherence-function between the two microphones pointed out that slight changes in the microphone's position do not effect the measured sound too much as long as the measured frequencies were below 4kHz.

The next series of experiments was meant to evaluate two methods for separating noise signals. The first method is based on two measurements. The

autopowerspectrum of the total sound is measured and recorded. After that, the main source is switched off and the background noise is measured. This autopowerspectrum is subtracted from the first one, thus resulting in the contribution of the main source to the overall level. The second method uses the relationship which exists between the vibrations of the source and its emitted sound. The vibrations are picked-up by means of an accelerometer. The transfer- and the coherence-function between sound and vibrations are calculated, in addition to the auto-powerspectrum of the microphone signal. The coherence-function is equal to unity for frequencies where the recorded vibrations are highly coherent with the sound. When there is no relationship between sound and vibrations the coherence function is zero. So multiplying the total noise auto-power spectrum and the coherence function renders a noise spectrum of the coherent sound. Background noises are eliminated. This spectrum is called the "Coherent output power spectrum" [3]. These two methods are applied to the two sources in the anechoic room (fig. 3.1). The results are drawn in fig. 3.2.

Fig. 3.2 Results of the experiments in the anechoic room

There are slight differences for the lower levels; use of the coherence function method yields mostly lower levels than the subtraction method. However, the main source is not effected by either of the two methods. In the selection procedure of the method to be used the following remarks have to be considered:

- Use of the coherent output power spectrum method enables measurements of sources which can only operate simultaneously. This is of great importance when different noise sources of one machine have to be separated.
- When the coherence-function is calculated between sound and vibrations the coherence can be low when the accelerometer is mounted in a node of a particular mode. Then the vibrations are not measured and the sound produced by that particular mode is filtered out.
- The coherence-function can be low because of the power in a certain frequency band being much lower than the main level. Sound and vibrations may be coherent, but this is not measured because of measurement errors.

In this paper the coherent output power spectrum method is used for finding noise sources of a press.

There are several ways to apply the coherence-function for noise sources. The second signal to the analyzer has to be a good

representation of the suspected source. This signal can be obtained by different methods, for instance:

- from a vibration pick-up, mounted on the suspected source,
- from a second microphone placed near the source,
- from a load cell, mounted between vital parts of the machine.

Which method is best differs from case to case. Some try-out measurements have to be made before the final decision can be taken.

4 CASE STUDY

The outlined measuring technique with the coherence function will be applied to a Raskin R2 press equipped with a punching die set. The aim was to find the contribution of the main sources to the overall sound level. The experimental set-up is outlined in fig 4.1.

Fig. 4.1 Experimental set-up

The total sound is measured by one microphone.

There are three possibilities for the second signal:

- Another microphone can be placed near a suspected source.
- Between the press and the die-set a force transducer was mounted to deliver a force-signal.
- A vibration pick-up can be glued to a suspected source.

The analyzer is externally triggered by a micro-switch controlled by a cam on the excentre axle.

Before signals are measured in the frequency domain it is useful to study them first in the time domain to examine which time-length is of importance to determine the frequency bandwidth. From equation (2.7) the measuring time can be derived from the chosen bandwidth. On one hand, this measuring time has to be long enough to include the complete signal, on the other hand a time which is much too long will introduce random errors. It was found that a bandwidth of 400 Hz was suitable for all the signals in our experiments. In that case the length of the time window is 0.65 s. When the frequency bandwidth is determined, measurements in the frequency domain can be made. We wish to separate the contribution of the clutch and the vibrating press. An accelerometer was mounted to the clutch and to the table of the press. With these signals in addition to the microphone-signal, the coherent output power spectra could be calculated. An example is given in fig. 4.2.

Fig. 4.2 The coherent output power spectrum

Addition of the coherent output power spectra involved renders a spectrum which must be equal to the total noise spectrum. This is a way to check the calculated coherent output power spectra. Errors, as a result from vibrations travelling through the whole machine can be detected by addition of the coherent output power spectra for the different noise sources. A comparison between the measured overall spectrum and the addition of three coherent output power spectra is given in fig. 4.3.

Fig 4.3 Comparison between overall spectrum and coherent output power spectrum

The same procedure was followed using two microphones instead of one microphone and an accelerometer. In that case the second microphone is to be placed close to the suspected source. The coherence-function between the two microphone signals is used to calculate the coherent output power spectrum. It was found that this method was also suitable for detecting noise sources. However, the level of the coherent output power spectra seems mostly too high, because of picking up noise from other sources by the second microphone. For this reason addition of several coherent output power spectra shows often results in a higher level than the measured overall level.

The method with the second signal coming from either an accelerometer or a microphone can be applied in tracing noise sources caused by mechanisms or other construction elements in the press. When the influence of the process is of primary concern, a parameter has to be used which is characteristic for the process, for instance the punching force. A load cell was mounted between the tool and the press. Using this signal,

the coherent output power spectrum was calculated. Sound and punching force appeared to be highly coherent in a frequency band up to 300 Hz.

After the experiments in the anechoic room, several measurements were repeated in the production shop to check whether background noises have negative effects on the procedure. The results of these measurements are shown in the appendix.

About the noise sources on this press one can conclude from these measurements:

- Sounds in the frequency range 125 - 180 Hz are very likely to be produced by the vibrating press when elastic energy is suddenly relieved.
- In the frequency range 180 - 230 Hz the vibrations on both the table and the clutch are coherent with the sound. From these the clutch is the most suspected one because of the peak in the auto-power spectrum of the vibrations.
- Noise in the frequency range 230 - 320 Hz is most coherent with the vibrating press. This is to be expected considering the peak in the auto-power spectrum of the vibrations on the table. This coincides with the main bending mode of the press at approximately 275 Hz.
- In the range 400 - 700 Hz the clutch contributes very little to the overall noise level. Here, the sound is most coherent with the vibrating press.

5 CONCLUSIONS AND RECOMMENDATIONS

To get a picture of the contribution of different noise sources of a machine to the total sound pressure level one can follow the following measurement procedure:

1. Calibration and checking of all measurement devices, such as microphones, accelerometers etc.
2. Care has to be taken with the surroundings of the machine. Reflections can decrease the coherence-function seriously.
3. A number of suspected noise sources is defined. Examples are: clutch, brake, vibration press, mechanisms of the tool, etc.
4. For every source a signal has to be accomplished which is representative for this source. The signal can be taken from a load cell, a vibration pick-up or a second microphone.
5. The measurement time has to be determined by studying the signals in the time domain. Now, also the bandwidth of the frequency domain measurements is determined.
6. The number of averages can be derived from table 1. The accuracy of the measurement is highly dependent of the number of averages. [4].
7. A series of auto-power spectrum measurements is made through the entire frequency range in order to see which range contains the most power.
8. Calculation of the coherent output power spectra. These can be calculated by multiplying the overall noise spectrum by coherence-function. The coherent output power spectrum represents the contribution of that particular source to the total sound level.
9. The coherent output power spectra can be checked by comparing the addition of the several coherent output power spectra with the measured total sound pressure auto-power spectrum.

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Number of averages	coherence function estimate						
	$\gamma^2=.3$	$\gamma^2=.4$	$\gamma^2=.5$	$\gamma^2=.6$	$\gamma^2=.7$	$\gamma^2=.8$	$\gamma^2=.9$
5	.00-.62	.00-.70	.03-.76	.10-.82	.22-.87	.39-.91	.65-.96
10	.03-.55	.09-.63	.17-.70	.28-.77	.42-.83	.58-.89	.77-.95
25	.12-.46	.20-.56	.31-.64	.42-.72	.55-.79	.69-.87	.84-.93
50	.17-.42	.26-.51	.37-.60	.48-.69	.60-.77	.73-.85	.86-.93
100	.21-.39	.31-.48	.41-.58	.52-.67	.63-.75	.75-.84	.87-.92
250	.24-.36	.34-.45	.45-.55	.55-.64	.66-.73	.77-.82	.88-.91

Table 1a. 90% confidence intervals for coherence function estimates.

Number of averages	5	10	25	25	100	250
(G _{estimate} /G) confidence intervals	0.55-2.54	0.64-1.83	0.74-1.43	0.80-1.28	0.85-1.19	0.90-1.11

Table 1b. 90% confidence intervals for power spectra.

APPENDIX

IDENTIFICATION OF NOISE SOURCES