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Systematic design of low noise machinery

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Abstract

The design of low noise machinery does often meet many challenges. The noise sources can be described by an emprical formula developed in-house at the manufacturer. The load carrying structure is a shell of complicated geometry, the cover plates are simple flat plates, and the silencers for the intake and exhaust are designed by a third party software. The task of designing the optimum solution with respect to noise and economy is also a coordination between the different tools involved in the prediction of acoustic characteristics of each component.

A systematic approach and a common base for handling the data in one combined model is a wish of many engineers and developers. One way to systematise the inputs to such a model is to think in terms of an acoustic component model, where all components are described with an as simple as possible and as complicated as necessary approach to the modeling. This way a systhesis of sound powers, transfer functions, radiation behaviour of different tools are combined to one model which has a finite number of simple components.

This paper gives examples of the technique and cases for illustration.

1 Introduction

This paper provides argumentation for using an engineering applicable Acoustic Component Modeling, by using a technique "as simple as possible and as complicated as necessary". The approach emphasizes the importance of making a decision qualifiable model for the design of low noise machiunery, to assist in focusing on the major and possible solutions.

2 Systematic approach

A systematic approach is first used to generate an overview of all acoustic components in a graphical representation. Take an example of the compressed air unit manufacturer who wishes to reduce the noise from his unit, see Figure 1.

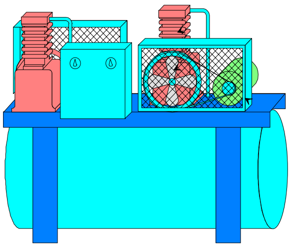

Figure 1. Compressor unit consisting of Compressors, Motors, Ventilators, Frames, Instrument Panel and Reservoir.

An Acoustic Component Model in graphical form for the unit is seen in Figure 2.

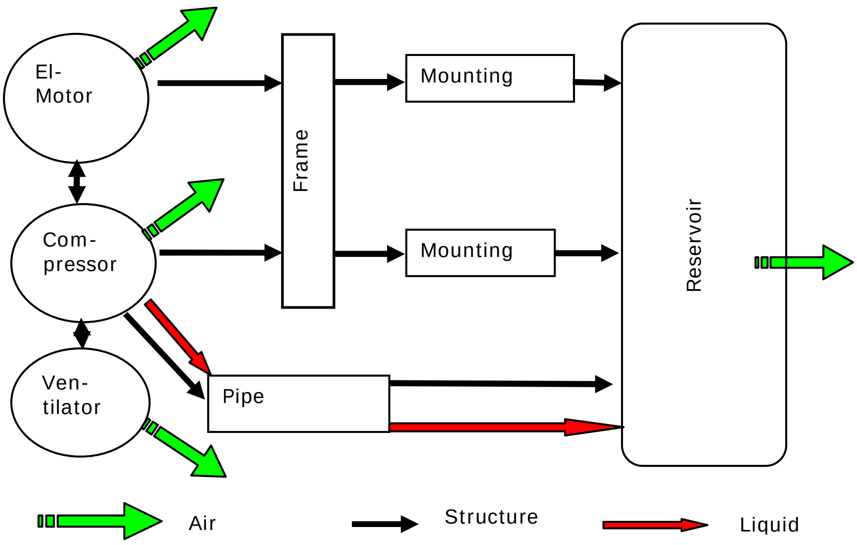

Figure 2. Acoustic Component Model of Compressor unit.

The air borne sound power of the active noise components can normally be required from the manufacturers of the active components. But what is also required for modeling the noise generated in the unit, is the power flow of structure borne and compressed air borne sound. These properties are more often not available, resulting often in a summary of information of the noise sources as in Table 1.

Active noise component	Air Borne Sound Power	Structure borne Sound Power	Compressed air Sound Power
Motor	Yes	NA	NA
Compressor	Yes	NA	NA
Ventilator	Yes	NA	NA

Table 1. Sound Power from active noise components. (NA – not available)

Methods for determination of the air borne sound power are available from standardized measuring methods. Other ways to determine the power flow is to synthesize source strengths by means of the design software used for optimization of the component. This can for instance be design software for electric motors, CFD calculations of flow generated noise, or dynamic force calculations based on first principles. Prerequisite for the application is that data are put in suitable form for the Acoustic Component Modeling.

When it comes to the Passive noise components, several acoustic parameters have an important influence on the total power flow in the machine. The passive components are mounting frames, beam structures, reservoirs, instrument panels etc. The major parameters governing the structure borne power flow for the compressor and the machine structure can be described as in the diagram in Figure 3 a and b.

The detail of the Frame and Reservoir in Figure 3b uses an impedance formulation to describe the parameters influencing the structure borne power flow. Some structures can be described by an elementary case, such as a plate or a beam. Other more complicated structures can be modeled by means of FEM calculations and synthesized in the appropriate form for the use in the Acoustic Component Modeler. Measurements can also be made to generate the necessary data.

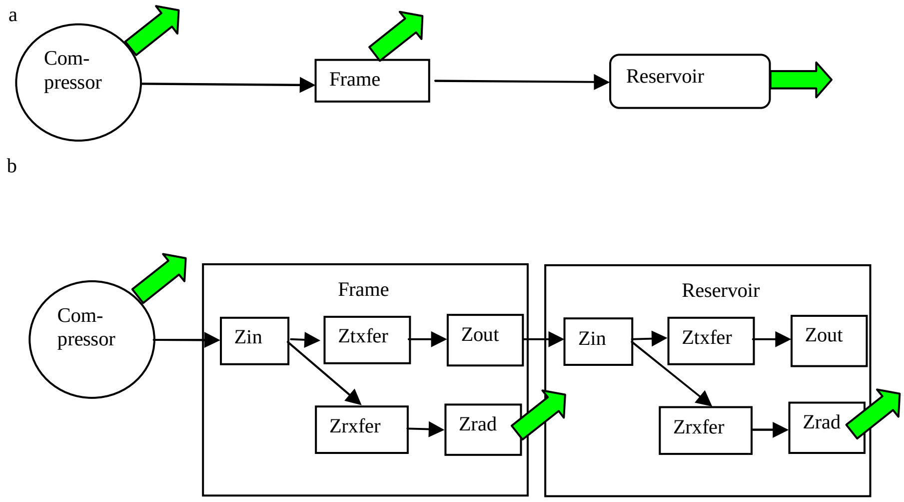

Figure 3. Details of acoustic parameters of the compressor-frame-reservoir detail.

3 Data formats for modeling

The use of Acoustic Component Modeling only makes sense if data for all parameters have the same format. The use of 1/3 octave spectrum data is recommended, since it contains sufficient detail to achieve an overview.

The airborne acoustic data for most machines are available as the Sound Power expressed in dB, and is often available as an octave or third octave band spectrum. There is a series of relevant ISO standards available, 37xx, that describe in detail which method to use for the determination of sound power. It is interesting to note that there are typically three levels of precision described in these standards, with uncertainties ranging from 1 to 5 dB on the total weighted sound power, and larger values in the octave band spectra.

The structure borne sound power and the acoustic impedances for use in an Acoustic Component Model must have the same form as the air borne sound power for a valid representation. The choice of spectral representation can be 1/3 octave band spectra, because the detail is sufficient to discover problems with rotating and pumping frequencies below 1000 Hz.

Third octave bands are “broad band” for many structural dynamics people; their work is often centered on avoiding synchronization of driving frequencies and structural resonances, requiring a fine frequency resolution.

It is however a recommended approach in relation to Acoustic Component Modeling, to determine the structure borne Power Flow as an energy summation of power for all degrees of freedom in third octaves. A Power Flow determination like this will probably have an expected uncertainty comparable to the available air borne sound power values. In this way a consistent expression of the parameters in the model is achieved.

In conclusion it is recommended to use 1/3 octave band representation for Acoustic Component Modeling purposes. This approach is used in the EQUIP+ software for Acoustic Component Modeling produced at TNO in Holland. It contains a graphical modeler and mathematical modeling through Matlab. Some elementary cases are included in the component library, which can be used to further develop Acoustic Component Models for optimization of own products. Since EQUIP+ is programmed in Matlab, its facilities can be integrated with own applications of signal processing and optimization codes.

4 Case: crane noise reduction

A case that shows the use of Acoustic Component Modeling and the engineering aspects of {reduction of noise}/{cost}/{practical implications}.

The questions posed for this noise reduction job were:

- This crane is too noisy
- A noise reduction project has been offered
- How efficient will it be?
- What can be done otherwise?

The crane structure is shown in figure 4. Main dimensions are: Machinehouse 30m above ground, width: 100 m.

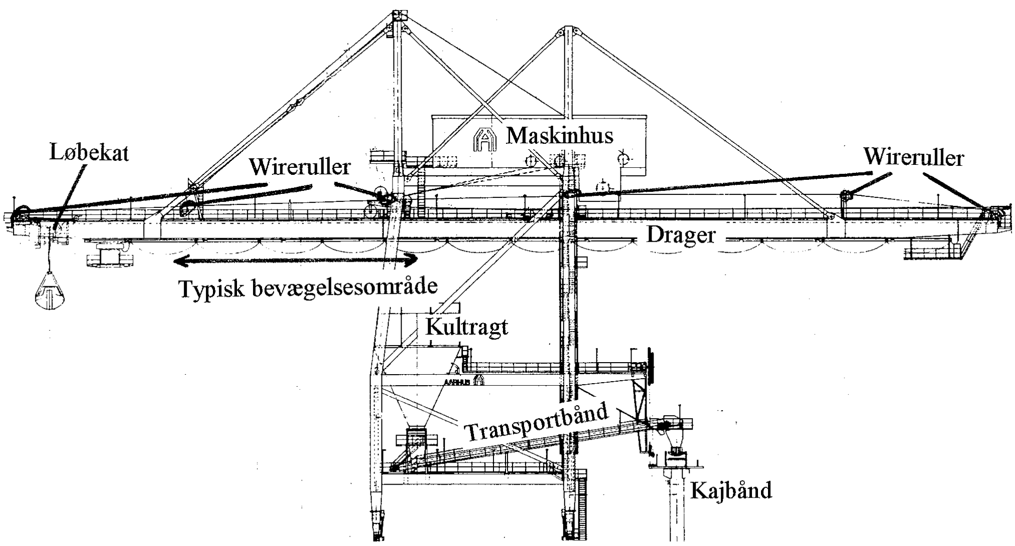

Figure 4. Crane structure.

An Acoustic Component Model for the crane is seen in Figure 5.

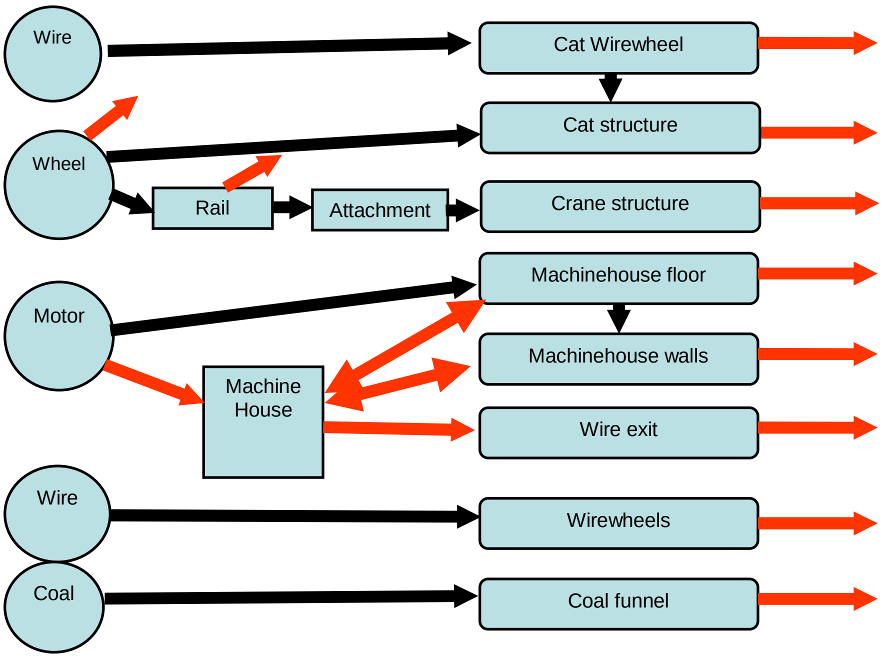

Figure 5. Crane Acoustic Component Model

The air borne sound power measured in operation from the modeled components is seen in Figure 6. The Machinehouse floor dominates due to its excitation by the hydrostatic drives for the wires. They are mounted directly on the steel floor plates.

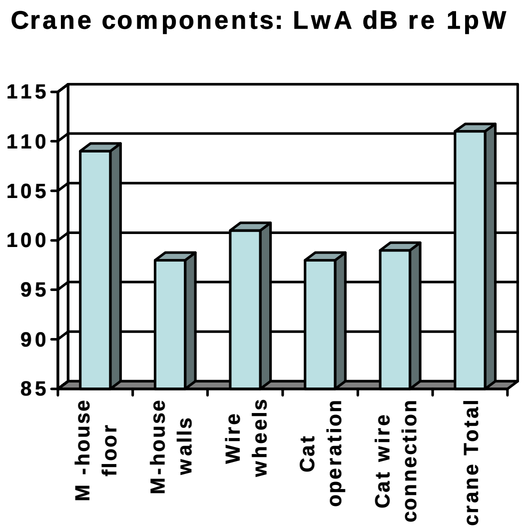

Figure 6. Sound Power of Crane components.

The A-weighted octave band spectra of the Sound Power of the components is seen in Figure 7. The major spectral component is the pumping frequency at 315 Hz.

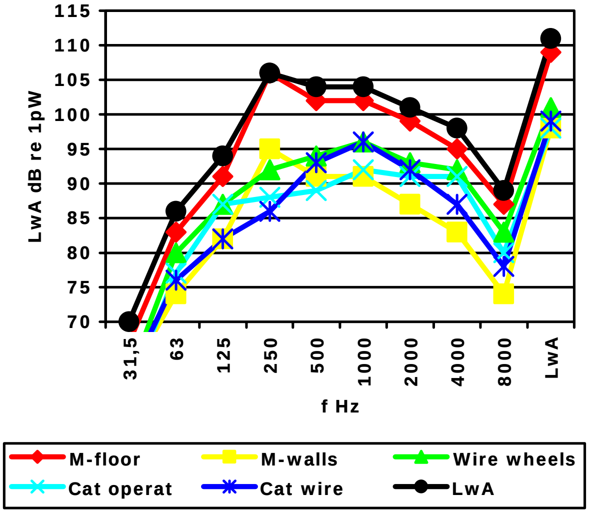

Figure 7. A-weighted Sound Power of components.

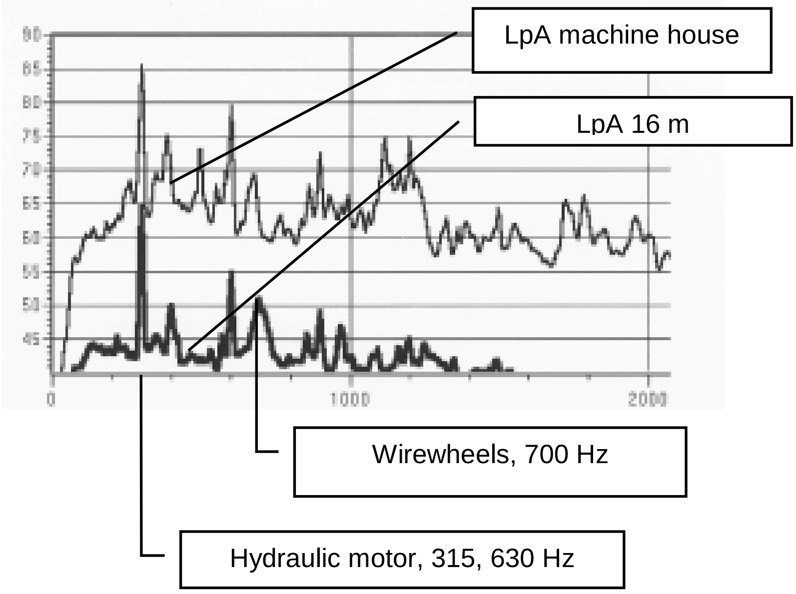

Figure 8. FFT analysis of air borne noise.

The pulsation frequency at 315 Hz and its harmonics are seen clearly in the FFT analysis. Note also the wire/wheel rolling noise excitation at 700 Hz.

Noise reduction proposals for the Crane is seen in figure 9.

Component	**L_{WA}**	**A**	**B**	**C**
M-floor	109	0	10	15
M-walls	98	0	0	10
Cat, connector	99	0	10	10
Cat operation	98	10	0	5
Wire wheels	101	0	0	10
Total	**111**	**0,2**	**5**	**12**

Figure 9. Noise reduction schemes. Numbers in dB.

- The original proposal (A) for reducing the total noise from the crane by refitting of rubber wheels to the cat, would have been a cost of 50.000 euro to reduce the noise by 0,2 dB in total.
- The fitting of a new local encapsulation (B) below the floor and changing the wire connector result in 5 dB total reduction.
- Reducing the noise by 12 dB, (C), requires reduction to all components.

One aspect of this model is that the main sources of noise are structure borne: the hydrostatic gearbox that drives the wire drums giving pulsations in the hydraulic fluid resulting in dynamic forces, and the wires rolling on the wire wheels.

5 Conclusion

The noise reduction applied in this case story is typical for such a structure and project: the dominating radiating surface is encapsulated. According to most design engineers, this is the most economical solution at this stage of design. Changing the structure borne transmission paths to the floor of the machine house would be more efficient to control the noise, but it would lead to re-engineering the function of the crane.

If we had better simulation models that can be used for noise reduction projects like the one just described, it would be possible to make better, more realistic and less expensive noise reduction recommendations. The EQUIP+ software from TNO does fulfill many of these needs, and is a development tool for combining acoustic components in one model.