

## **Technical Acoustics and Noise Control** (lecture notes for self-learning)

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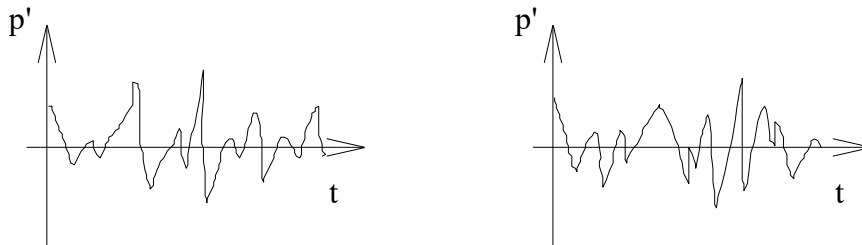
Lecture 7.

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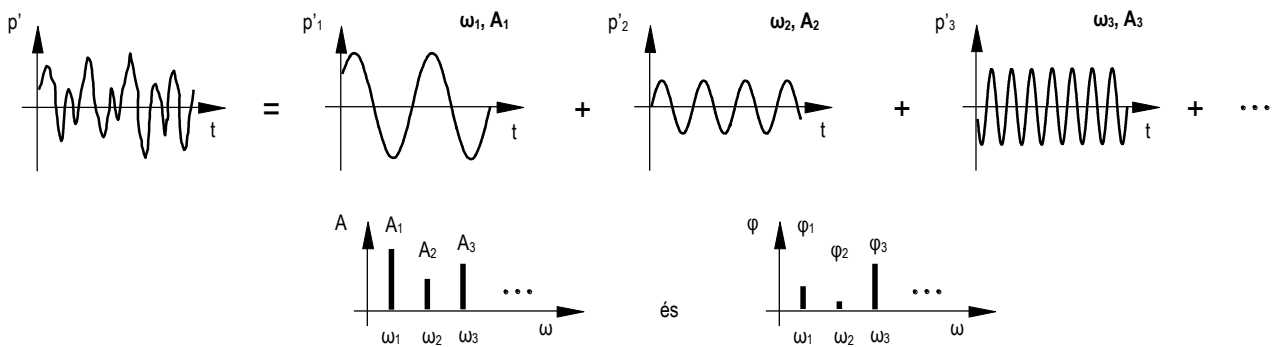
### **7.1. Introduction to harmonic analysis and sound spectra**

First let speak about the motivation, why is important the harmonic analysis and sound spectra in the noise engineering practise. In a sound field, point by point the time history of the acoustic variables include all of the important information. Despite of this, comparing the time functions of absolutely different sound effects, often the shape of the functions are very similar, and we cannot make difference between the sounds, based on their time functions. Left hand side of the drawing we can see sound pressure time variation 30m far from a tracked machine, right hand side we can see similar data, but in a music hall, during the performance of a chamber orchestra. At first sight there is no characteristic difference between the diagrams, but the subjective impressions are really different. In spite of the time function contain a lot important information about the sound field, the direct use in the acoustic engineering problem analysis and design is limited.



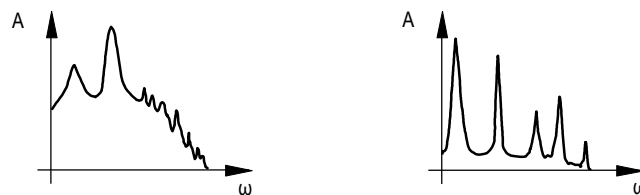
Sound pressure as a function of time 30m far from tracked machine (left) and at a performance of a chamber orchestra (right)

So we need a method that can clear the information hidden in the time function. Important, that the acoustic variables (with periodic or not periodic character) alter around the ambient equilibrium pressure. It looks promising to find simple, mathematic base function, that describes a variation around a mean value. We suspect, that the behaviour of the sound concerning the generation, propagation, decay and sensation of it, will different at long and short cycles. So decomposing the original time function, into different periodic components, the missing information will turn out. There are several periodic function in mathematics, but most of them are problematic (nonanalytic, discontinuous, ...). The sinus and cosine functions satisfies all conditions. Further increase the importance of sinus and cosine functions, the fact, that the natural vibration of finite size flexible structures are harmonic vibrations or the composition of this (described with sine or cosine) and the harmonic vibrations will radiate harmonic waves. Summarising it looks useful to decompose the original time function to different time of period and amplitude harmonic components. The next picture symbolises the graphic decomposition.



The graphic decomposition of the time function to harmonic component

The sinus and cosine are periodic functions, so their time histories contain a lot of redundant information. To rebuild an arbitrary time function it is enough to know the amplitude and initial phase of the needed harmonic components. The frequency amplitude and frequency initial phase functions are called amplitude and phase spectrum of the original time function. In mechanical engineering noise control often it is enough to know the amplitude spectrum, the phase spectrum has more application in the mechanical engineering fault diagnostics.



Sound pressure amplitudes as a function of angular frequency 30m far from a tracked working machine (left) and at a chamber orchestra performance (right)

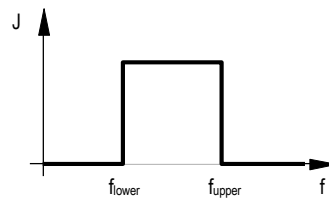
Left hand side on the schematic drawing, the broad band frequency distribution relates to disturbing noise effect. The high amplitude low frequency component is due to periodic exhaust of the diesel engine, the components at upper frequency range belongs to creaking track noise. The right hand side of the picture shows big amplitude discrete frequency component, and low amplitude broad band noise. This can relates to solid or fluid mechanic resonant sound generation. When calculate the ratio of upper and base frequency components, it will turn out that it should be a musical sound.

The harmonic components of an optional periodic time function can calculate with the Fourier-series of the function. The harmonic decomposition of an optional aperiodic time function can calculate with the Fourier-integral. In general case the spectrum of a periodic function will consist of unlimited number discrete frequency components (different frequency values), the non-periodic functions have continuous spectrums.

## **7.2. Harmonic analysis in measurement practise**

Today to determine a spectrum of a time function we will use digital signal processing. The first step of the digital signal processing is the digital sampling. The digital sampling completed by a special electronic unit (called digital data collector) that will measure the electronic signal (e.g. microphone output voltage) rapidly, periodically several time and store the measured values. From the digital sample sequence, the digital spectrum will be available with DFT (Discrete Fourier Transform), or with the fastened version FFT (Fast Fourier Transform) algorithm. Based on DFT, FFT, lot of other signal processing method is known, as STFT (Short Time Fourier Transform), order tracking, and envelop detection, that are wide spread in the mechanical engineering noise and vibration control and fault diagnostics.

Because the application advantages, the harmonic analysis was deeply involved to solve acoustic problems much more before the grow up of the digital signal processing. In this early time the harmonic decomposition was completed by the use a series of a band pass filters. The band pass filter admit the signal (J) only between a given lower and upper frequency.



Theoretic band pass filter frequency characteristic

If we build up a sequence of filter on the complete frequency range of interest, where the upper boarder frequency of the lower band is equal with the lower boarder frequency of the upper band, and switching on the filters following each other, we can scan the complete frequency range and determine a band spectrum. The magnitude of the band with determines the frequency resolution of the spectrum. Based on the relation of upper and lower boarder frequencies, the band pass filter sets can classify as constant absolute and constant relative band width types.

**Constant absolute band width:**  $f_{upper} - f_{lower} = const.$

**Constant relative band width:**  $\frac{f_{upper}}{f_{lower}} = const.$

In the case of constant absolute band width the frequency resolution is optional, but a special value is the 1Hz. At constant relative band width often used resolutions are the octave and the one-third octave bands.

**Frequencies to determine the octave,**

$$f_{oct\ upper} = 2 f_{oct\ lower} \quad f_{oct\ middle} = \sqrt{f_{oct\ lower} f_{oct\ upper}} = \sqrt{2} f_{oct\ lower} = f_{oct\ upper} / \sqrt{2}$$

Standardised octave band middle frequencies: ... 31,5 63 125 250 500 1k 2k 4k 8k 16k ... [Hz].

The advantage of the octave that to cover the complete audible frequency range, only 10 value is enough. The disadvantage is, that mostly in the upper frequency range the resolution is bad. This problem will partly handled by the one-third octave band. **Frequencies to determine the one-third octave,**

$$f_{third\ upper} = \sqrt[3]{2} f_{third\ lower}$$

$$f_{third\ middle} = \sqrt[3]{f_{third\ lower} f_{third\ upper}} = \sqrt[6]{2} f_{third\ lower} = f_{third\ upper} / \sqrt[6]{2}$$

Examples to the standardised one-third octave band middle frequencies: ... 31,5 40 50 63 80 100 125 160 200 ... [Hz].

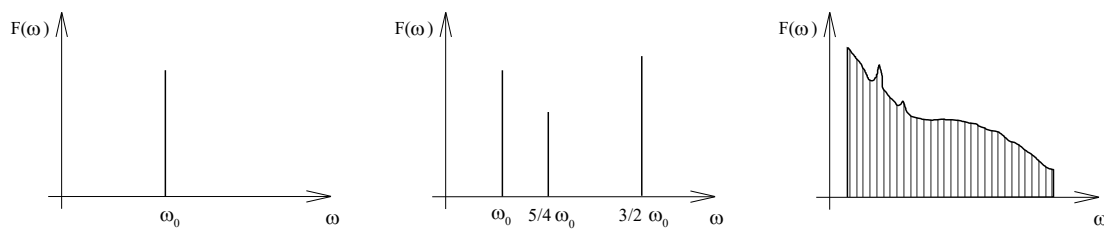
### **7.3. Classifying sound waves using sound spectra**

**Pure tone:** The pure tone is a sound wave, consists of only one  $\omega$  angular frequency harmonic component. The spectrum of the pure tone is one vertical line at  $\omega$  angular frequency.

**Musical sound:** A consonant composition of pure tones is musical sound. The subjective condition of the consonance is the pleasure during the joint sound effect. The mathematic condition of the consonance when

two or more pure tone exist in the same place and same time together is, that ratios of frequencies have to be equal with prescribed values.

**Noise:** A dissonant composition of pure tones is noise. The spectrum of a noise is often continuous.



Sound spectrums: pure tone (left), musical sound (major triad, mid), noise (fan noise, right)

#### **7.4. Pitch and colour of sound**

Pitch and colour are subjective phenomena of sound. Pitch is the subjective sensation of the sound frequency. The colour of a sound depends on the number and structure of the upper frequency components, accompanied to the base frequency. To sense the colour of a sound gives the possibility to distinguish the tone of a clarinet and violin play at the same frequency, if we do not see the players.

#### **7.5. Sounds for acoustic testing**

**Pure tone:** One of the most important test sound in acoustics is the pure tone. Advantage: big signal to noise ratio, disadvantage: long measurement time on the complete audible range.

**Swept sinus:** The swept sinus is a pure tone sound with a continuously varying frequency on the test range. Advantages: big signal to noise ratio and short measurement time on the complete audible range, disadvantage: sophisticated test apparatus requirement.

**White noise:** White noise is a random sound. In a long time period average white noise spectrum the amplitudes of the frequency components are identical. The spectrum of the white noise is a horizontal line. The name of white noise originated from optics, where the white colour was the mixture of different frequency components. A white noise is generated, when the air is released from a pressurised reservoir. Advantages: short measurement time on the complete audible range, disadvantage: low signal to noise ratio.

**Pink (rose):** The spectrum of a pink noise can characterise with increasing frequency a decreasing amplitude. The pink is the mixture of the broad band white and low frequency red. In constant relative bandwidth resolution the spectrum of the rose noise is a horizontal line. Comparing to the white noise the advantage of the pink noise is the higher signal to noise ratio in the usually critical low frequency range.

**Impulsive noise:** The short duration ( $\sim 10\text{ms}$ , or smaller) test sounds allow to investigate the sound propagation process in time, the reverberation effects and the phase behaviour in acoustic systems.

#### **7.6. Test questions and solved problems**

T.Q.1. Define the octave and the one-third octave, and put down the related middle frequencies! What are the difference between resolutions, and compare their advantages and disadvantages!

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