Chapter 8

Noise of Induction Machines

Marcel Janda, Ondrej Vitek and Vitezslav Hajek

Additional information is available at the end of the chapter

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1. Introduction

Diagnostics of electric machines is very interesting and extensive. There are many methods used to detect properties of electrical machines. Between diagnostic methods include too the measurement and analyze of noise, which generates electrical machines.

Itself the noise of electric machines is byproduct of the machine operation. The generation of noise is involved in many physical principles.

Noise of electrical machinery is generated by the vibration of machine parts. Gradual spread of vibration from the engine to the surroundings causes pulses of air with certain frequencies. This creates a sound wave generator, which can be within a certain frequency range, audible to humans.

The main sources of noise in electrical machines are time change of the electromagnetic fields, noise of bearings and other mechanical sources. Finally, the unwanted noise is creating too due to coolant flow or parts that come into contact with coolant in electric machines. Level of noise sources in electrical machines depends on the structural arrangement and the accuracy of engine design.

A major problem in measurement noise is interference environment. For a perfect suppression ambient noise is necessary to have a specialized laboratory. It should be also measured machine have isolated from vibration, which it may be transferred from storage.

2. Basic concepts of noise

The sound wave is generated by vibrating objects and can be defined as mechanical interference with the finite speed of advancing through the media. These waves have small amplitude, adiabatic oscillation are characterized by a wave speed, wavelength, frequency and amplitude. Sound has the character of longitudinal sound waves in the direction of propagation in the environment. In other words, it is the movement of individual particles of the medium in a direction parallel to the transmission of energy. Sound waves spread in three-dimensional environment from the source. It is same in all directions, if is the environment homogeneous. Sound waves can be polarized, they cannot have orientation. Non-polarized waves can oscillate in any direction in the plane perpendicular to the direction of propagation.

Sound amplitude can be measured as sound pressure level (SPL), sound intensity (SIL), sound power level (SWL) and the intensity of the acoustic energy (SED). The human ear can perceive sound waves of sufficient intensity and frequencies are ranging from 20 to 20,000 Hz. The Minimum sound intensity is different for different frequency and it is called the threshold of audibility. Range of sound intensity, which can capture the human ear, is 10-12 to 1 W/m^2corresponding sound pressure of 20 MPa. Maximum sound level in which humans feel pain is called threshold of pain. Amplitude of sound about pressure 100 Pa is very loud.

2.1. Acoustic pressure

Concentration of particle of vibrating environment corresponds with increase or decrease pressure inside gasses and liquids. This means that the total pressure in the environment is changing and therefore fluctuates around the initial static value or barometric pressure. The acoustic pressure is then considered deviation of the total pressure from the static pressure. For acoustic pressure is valid relationship

$$p_c = p_{\mathrm{b}} + p(t) \tag{1}$$

$$p(t) = p_0.cos(\omega.t + \varphi) = \mathrm{p}_0.cos(2.\pi.f.t + \varphi) \tag{2}$$

$$p_c = p_0 + p_0.cos(2.\pi.f.t + \varphi) \tag{3}$$

Where

- $\mathrm{p_c}$… Acoustic Pressure [Pa]
- p_{b}… Barometric pressure [Pa]
- $\mathrm{p_0}$…Amplitude of sound pressure [Pa]
- f… Frequency [Hz]
- t… Time [s]
- φ…phase shift

For effective sound pressure value is valid relationship

$$\mathrm{p_{ef}}\frac{p_0}{\sqrt{2}} \tag{4}$$

Acoustic pressure is a variable and it describing the noise source quantitatively. The measured level depends on the observer's distance from the source and the quality of the transmission environment Acoustic pressure level gives us information on the total sound pressure across a entire audible band. For sound pressure level is valid relationship

$$L\_p = 20.log(p/p\_0\ ) \tag{5}$$

Where

- p ... Static pressure [Pa]
- p_0 ...Minimum value of static pressure, which is able to capture the human ear [Pa]

2.2. Sound power level

Mechanical vibrations are transmitted in form of mechanical energy from the source through acoustic waves. Sound power level is called the energy that passes per unit time over surface. For sound output, we can write the relationship

$$P_{ac} = p_c . v . A \tag{6}$$

Where

P_{ac}… Sound power level [W]
p_c… Acoustic pressure [Pa]
v… Vibration velocity of particles[m/s]
A… Area [m^2]

The sound power level depend on the the environment parameters and distance from the measurement point. The sound power level can be expressed as

$$L_{Pac} = 20. \log\left(\frac{v}{10^{-9}}\right) + k \tag{7}$$

Where

k… constant

2.3. Acoustic intensity

Acoustic intensity is a vector quantity that describes the amount and direction of flow of acoustic energy in the environment. Vector of acoustic intensity is time-change of instantaneous sound pressure and it is corresponding instantaneous speed of vibrating particle environment in the same place

$$I = \overline{p(t).v(t)} \tag{8}$$

Where

I… Acoustic intensity[W/m^2]

3. Noise sources

From the physical point of view, mechanical sound is waves in a flexible environment. The Frequency range of sound audibly for human ear is from 20 Hz to 20 kHz. The sound spreads in all directions from resources by transmitting acoustic wave energy. Division by frequencies of sound waves:

- Infrasound - up to 20Hz
- Low frequency - 20Hz to 40Hz
- RF - 8kHz to 16kHz
- Ultrasound - 20kHz over

Dividing the sound by timing:

- Steady
- variable
- intermittent
- pulse

The interest noise frequency is over 1000 Hz for induction machines. Noise of Electrical Machines is characterized as a set of sounds that are caused by rapid changes in air pressure. These changes cause most commonly:

- Vibration of machine parts or the whole of its surface
- Aerodynamic phenomena that lead to pulsation of pressure near the machine

Basic sources of noise are induction motors (see diagram):

- Electromagnetic source
- The mechanical source
- The aerodynamic source

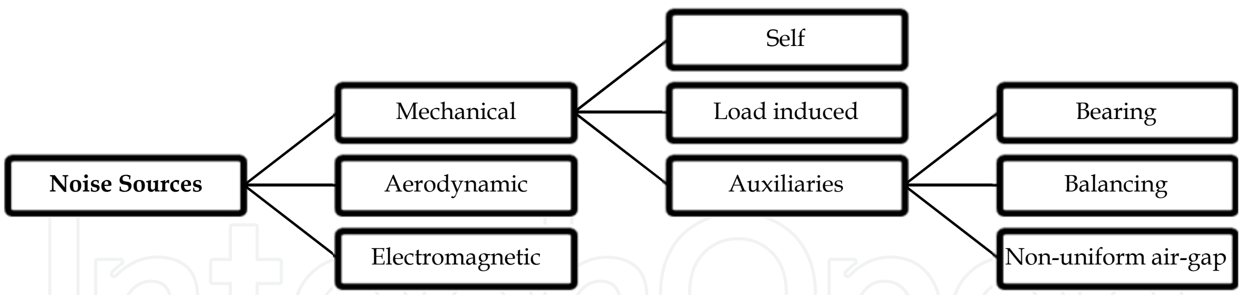


Figure 1. Division of noise sources in electrical machines

The noise from electromagnetic source is the most typical component noise of electrical machine. Its cause is the vibration of motor body, or other parts of the machine on which work the electromagnetic forces. Frequency Spectrum noise of the electromagnetic source has discrete character, while there is very distinct directional radiation characteristics of this component in many cases.

Determining the influence of this component on the overall noise of electric machine is often simply done so, that after switching off the machine from the network is observed decline in the acoustic signal in time. If is this decline immediately, then it is obviously a component of the noise of electromagnetic origin. Another method of investigation is the measurement of electromagnetic noise spectrum for different values of power - or even frequency.

Noise origin of ventilation is crucial observe especially in machines with high rotational speed. Detailed analysis of the fan noise shows that the main source in this case is very fan with its nearest surroundings. It is the decisive exceeds other sources of noise, which can be, for example rotor wings, radial or axial cooling channels in the machine, input and output caps and the like.

Frequency analysis of noise ventilation origin shows that the spectrum has a broadband character, either discrete or vice versa. In the first case, the aerodynamic noise is created from turbulent airflow near fan blade and near the entrance, but also the output edges of blades. These pulsations are uneven both in space and in time, so the frequency spectrum created of wind noise is broadband and contains all components of the audible band.

In contrast, discrete nature of the spectrum, sometimes the siren phenomenon can arise. This phenomenon arise if the fan or behind obstacles (such as a blade with these obstacles) is not profile of velocity uniform air flow around the wheel circumference, leading to periodic pulsation of pressure. Then the siren noise is produced naturally.

The noise of mechanical origin is primarily inflicted on roller bearings and unbalance of rotating machine parts. Rolling bearings can create multiple frequency components, which have their origin mainly in inequality as part of rolling paths of the bearing rings. In principle, the noise of mechanical origin has a mixed character.

3.1. Electromagnetic noise

The influence of magnetic induction in the air gap formed magnetic forces; these forces operate across various directions. They may also have various amplitude and frequency. Their work is split between the rotor and stator of electric machine. Their characteristics depend on the size and shape of the air gap and a number of other factors.

The construction of the rotor is the main radiator noise machine. If the frequency is close to the radial force or equal to one natural frequency of the stator system, resonance occurs which leads distorted stator system with vibration and noise. Magnetostriction noise electric machine can be neglected in most cases due low and high frequency 2f arrangement r = 2p of radial forces, where f is the fundamental frequency and p is the number of pole pairs. However, the radial forces due magnetostriction can reach up to 50% the radial forces produced in the air gap magnetic field.

Magnetic flux density wave

$$\text{Stator: } B_{m1}.cos(\omega_1.t + k.\alpha + \Phi_1) \tag{9}$$

$$\text{Rotor: } B_{m2}.cos(\omega_2.t + l.\alpha + \Phi_2) \tag{10}$$

Where

- B_{m1} … Amplitude of magnetic flux density in stator [T]
- B_{m2}… Amplitude of magnetic flux density in rotor [T]
- ω_{Φ_1} … Angular frequency of stator magnetic fields
- ω_{Φ_1} … Angular frequency of rotor magnetic fields
- k,l … Variable (values 1,2,3,4,….)

For total wave of magnetic flux density can be write relationship

$$P_{mr} = 0{,}5.B_{m1}.B_{m2}.cos[(\omega_1 + \omega_2).t + (k + l).\alpha + (\Phi_1 + \Phi_2)] +$$

$$+0{,}5.B_{m1}.B_{m2}.cos[(\omega_1 + \omega_2).t + (k - l).\alpha + (\Phi_1 - \Phi_2)] \quad (11)$$

The magnetic stress wave has worked in radial directions on the stator and on active surfaces of rotor. This causing the deformation and subsequently cause the vibration and noise.

The mixed product of stator and rotor winding space harmonic create forces at frequencies

$$f_r = f_1.\left[\frac{n.Z_r}{p}.(1 - s) + 2\right]$$

$$f_r = f_1.\left[\frac{n.Z_r}{p}.(1 - s)\right] \quad (12)$$

Where

- f_1… Supply frequency [Hz]
- n…. value n=0, ±1, ±2,… [-]
- p… number of pole pairs [-]
- N_{rs}…Number of rotor slots [-]
- s… slip

The mixed product of stator winding and rotor eccentricity space harmonics create forces with frequencies

$$f_r = f_1.\left[\frac{n.N_{rs}}{p}.(1 - s) + 2\right]$$

$$f_r = f_1.\left[\frac{n.N_{rs}}{p}.(1 - s)\right]$$

$$f_r = f_1.\left[\frac{n.N_{rs}}{p}.(1 - s) + \frac{1 - s}{p}\right]$$

$$f_r = f_1.\left[\frac{n.N_{rs}}{p}.(1 - s) + 2 + \frac{1-s}{p}\right] \quad (13)$$

The mixed product of stator winding and rotor saturation harmonics create forces at frequencies

$$f_r = f_1.\left[\frac{n.N_{rs}}{p}.(1-s)+4\right] \tag{14}$$

$$f_r = f_1.\left[\frac{n.N_{rs}}{p}.(1-s)+2\right] \tag{15}$$

3.2. Rotor eccentricity

The air gap width depends only on position (no on time) in the static eccentricity. We conclude that the magnetic field in the air gap is rotating synchronous speed. That is given by the mains frequency and with the number of pole pair's induction machine. Modulation of magnetic field in one period is function, which is represented by a variable air gap, i.e. a function of its conductivity. Static eccentricity is defined as the rotor axis offset from the axis of the stator. The air gap has a variable character. There is stronger interaction of stator and rotor magnetic field at the point where the gap is smaller. Influence of the static eccentricity manifests as the emergence of side frequency bands, which are shifted from the mains frequency f_1 of the synchronous frequency f. For static eccentricity is the angular frequency $\Omega_\varepsilon = 0$.

Static eccentricity is straight-line. The frequency for static eccentricity is twice power frequency

$$f_{stat} = 2.f_1 \tag{16}$$

The relative eccentricity ε is defined as

$$\varepsilon = \frac{e}{g} = \frac{e}{R-r} \tag{17}$$

Where

- R… Inner stator core radius
- r… Outer rotor radius
- e… Rotor eccentricity
- g… Ideal uniform air-gap for e=0

Dynamic eccentricity occurs when the rotor failure or its affiliates. Ratios are complicated by the fact that the width of air gap is not just a function of position, but is also a function of time. The variable air gap is changing at the rotation of the rotor. There is emergence of side bands that appears in the frequency range of vibrations of electric machine.

Angular frequency for dynamic eccentricity

$$\Omega_\varepsilon = \Omega.(1-s) = \frac{\omega}{p}.(1-s) = 2.\pi.\frac{f}{p}.(1-s) \tag{18}$$

The frequency generated by the dynamic eccentricity

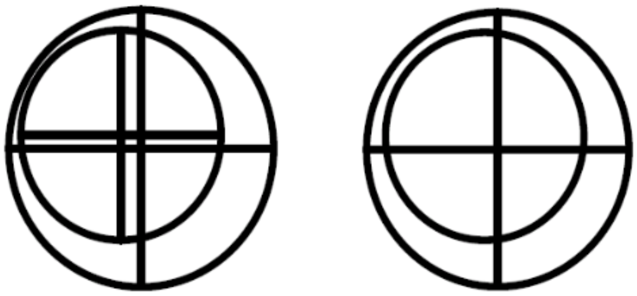
$$f_{DYN} = f_1 \pm (1-s).f_{SO} \tag{19}$$

For frequency generated by eccentricity is true also relationship

$$f_{exc}\left[(n_{rt}.R \pm n_d).\frac{1-s}{p}.n_{\omega s}\right].f \tag{20}$$

Where

- R…Number of grooves engine
- s… Chute
- p… Number of pole pairs



Static eccentricity Dynamic eccentricity

Figure 2. Rotor eccentricity

3.3. Aerodynamic noise

Aerodynamic noise arises most often around the fan, or in the vicinity of the machine that behaves like a fan. Noise can be created too on the necks stator slot windings or rotor. The aerodynamic noise sources can also include the noise produced by air flow inside and outside the design of electrical machines.

The main reason for the fan noise is formation of turbulent air flow around the blades. This noise is characterized by spectrum in a wide range, which has continuous character. Acoustic performance is increasing with the square of velocity. Siren noise can be eliminated by increasing the distance between the impeller and the stationary obstacle.

For the fan noise can write the relationship

$$L_A = 60.logU_2 + 10.logD_2.b_2 + \sum k_1 \tag{21}$$

Where

- U_2…Outer speed of fan on the circuit $[m.s^{-1}]$
- D_2…Outer diameter of the fan [m]
- B_2… Fan width [m]
- k_1… Constants for the correction

The vortex frequency is expressed by

$$f_v = 0{,}185.\frac{v}{D_2} \tag{22}$$

The frequency of the pure tone due to the fan blades is given by relationship

$$f_f = N_b.\frac{N}{60} \tag{23}$$

Where

- N…speed [rev/min.]
- N_b… Number of fan blades [-]

Sound power level of aerodynamic noise is

$$L_w = 67 + 10.log_{10}(P_{out}) + 10.log_{10}(p) \tag{24}$$

$$L_w = 40 + 10.log_{10}(Q) + 20.log_{10}(p) \tag{25}$$

$$L_w = 94 + 20.log_{10}(P_{out}) - 10.log_{10}(Q) \tag{26}$$

Where

- P_{out}… Motor rated power [kW]
- p… Fan static pressure [Pa]
- Q…Flow rate [$m^3.s^{-1}$]

Reducing aerodynamic noise in electrical machines can be use the following ways:

- Reducing the required amount of coolant used for ventilation of electrical machines
- Optimal design of fan. Especially the number and shape of the fan blades has an impact on the noise generated by the electric machine.
- To minimize the noise is needed to prevent vibration machine parts, which come into contact with a cooling medium.

3.4. Mechanical noise sources

Mechanical noise is mainly due with bearings, their defects, ovality, sliding contacts, bent shaft, rotor unbalance, shaft misalignment, couplings, U-joints, gears etc. In principle, the mechanical source of noise has a mixed character. The noise caused by unbalance of rotating parts and noise of bearing is spread after machine constructions very well. Dynamic balancing in production serves to reducing the noise of mechanical source. Especially for machines with high speed is necessary to perfect balance. Also, compliance with the manufacturing tolerances and technological processes, especially in the manufacture of small machines is the best solution to reduce the noise of mechanical source. Any change in noise from this source can mean failure of the mechanical parts inside the motor. For example, the bearings failure (damaged ball) is appear in the noise spectrum. There are specific frequencies by individual damage. The very faults of bearings and their effect on the noise spectrum of the electric machines are now well mapped.

Design of bearings can be either a sliding or rolling bearings. Rolling bearings can create multiple vibration frequencies, which have their origin mainly in the uneven parts or rolling themselves paths to the bearing rings. If bearing has mechanical damage, there is uneven movement of the whole system and thus increasing vibration and noise of the electric machine.

The main mechanical sources of the noise

- Alignment
- Inaccurate machining of parts
- Running speed
- Number of rolling elements carrying the load
- Mechanical resonance frequency of the outer ring
- Lubrication conditions
- Temperature

3.4.1. Rolling bearings

The noise of rolling bearings depends on the type of bearing and its construction and accuracy of bearing parts. The increase in vibration and noise level of bearings, when the rotational speed changes from $n_1$ton_2 can be expressed as

$$\Delta L_v = 20. log \frac{n_2}{n_1} \tag{27}$$

Ball pass frequency – outer race

$$f_{or} = \frac{N_b}{2}. n_m. \left(1 - \frac{d_b}{D}. cos\alpha\right) \tag{28}$$

Where

- D…Pitch diameter [m]
- n_m… Rotation speed [rev/s]
- N_b…Number of balls [-]
- d_b…Diameter of balls]m]
- α…Contact angle of balls

Ball pass frequency – inner race

$$f_{ir} = \frac{N_b}{2}. n_m. \left(1 + \frac{d_b}{D}. cos\alpha\right) \tag{29}$$

3.4.2. Sleeve bearings

- Uneven journal

$$f_{ov} = k. n_m \tag{30}$$

k=1, 2, 3, …

- Axial groves

$$f_{gr} = N_g. n_m \tag{31}$$

N_g…number of groove

3.4.3. Load induced noise

In certain cases, the vibrations and thus noise transmitted from the load, which is connected to the induction motor. In most cases, this occurs with wrong balance or bad connects of couplings. Uneven distribution load acting on the motor shaft or inappropriate use of gears may also affect noise machine. The only possible protection against these effects is the perfect balance of the whole set and if possible an even distribution of forces acting on the connecting elements. Noise arises too due to coupling of the machine with a load, e.g., shaft misalignment. Next noise arises from belt transmission, from cogwheels and couplings. It may also arise to noise due to mounting the machine on foundation or other structure.

4. Noise measurement

For measurement noise of induction machines can be used several techniques. The basic method for the measurement noise is the sound meter. It is a device which measures sound pressure.

4.1. Measurement process

Measurement of noise can be divided into three main parts. The first part is data capture. For this purpose, the most commonly used microphones, or specialized equipment to measure noise (sound level meter). Their output is usually an analog signal, which must be further processed. When choosing of microphone is needed careful heed on certain parameters that can affect measurement accuracy. One of the most important parameter is the sensitivity of frequency. Worse microphones not recorded of the entire spectrum of the measured noise. Thanks to this complicates achieve it of accurate analysis results. Other parameters include the microphone sensitivity, which indicates the size of the output voltage (mV / Pa), depending on the pressure acting on the membrane. In addition, the structural dimensions of the measurement microphone and also the type of sound field that which is measured. Computers are most frequently use for Signal processing. For this reason it is necessary to convert from analog signal to digital form.

Large numbers of types A/D converters is on the market. Some are stand-alone converters; others are integrated to the specialized measurement cards. In both cases, the measurement depends on the three main parameters. The first is the measuring range of the converter. It gives the minimum, respectively maximum, measurable value. Because the signal is weak from a microphone, there should be used an amplifier for its amplification. Another parameter of the A/D converter is the bit depth conversion. This parameter defines the limitations of this device.

Figure 3. Block diagram of measurement process

Factors to selecting a suitable type of microphone are as follows

Characteristics of sound field	Required accuracy	Environmental conditions
Freely field for a closed chamber	Tolerance sensitivity	Noise level background
An important range of sound pressure levels	Frequency distortion tolerance	Humidity
An important frequency range	Phase distortion tolerance	Atmospheric pressure
	Tolerance of non-linear distortion	wind
	Own noise tolerance	Strong electromagnetic fields
		Mechanical shock

Table 1. Selecting factors of microphone

4.2. Sound level meter

Sound level meter is an essential instrument for measuring sound pressure levels. This device consists of the following components: Microphone, preamp, overload detector, central Unit, weighing Network, filters, amplifier, RMS detector, Output and Display.

One of the basic parameters of sound level meter is range of frequency. The sound intensity I has broad frequency range. The dispersion of the frequencies is from lower f_1 to higher f_2 . The immediate value is indicated by I (f). For sound intensity is valid the relationship

$$I = \int_{f_1}^{f_2} I(f)df \tag{32}$$

Where $I(f) = \frac{\Delta I}{\Delta f}$ is intensity in the frequency interval f = 1 Hz.

Spectral intensity level (ISL) L_{Is} is defined

$$L_{Is} = 10log\left[\frac{I(f)}{I_{ref}}\right] \tag{33}$$

Where I_{ref} is the reference intensity levels (for air $\frac{10^{-12}W}{m^2}$).

$$L_I = L_{Is} + 10log(\Delta f) \tag{34}$$

Similarly, the sound pressure level L_p is related to the level of spectral noise L_{ps}as follows:

$$L_p = L_{ps} + 10log(\Delta f) \tag{35}$$

$$\Delta f = f_u - f_l \tag{36}$$

Where f_l and f_u are the lower and upper frequency to half power.

5. Fast Fourier Transformation (FFT)

Fast Fourier Transformation is one of the most common mathematical functions, which is used for noise analysis of electrical machines. The Fast Fourier Transformation is applied in an increasing scale in science, engineering, and technology. The use of complex exponentials has often been convenient rather than fundamental. Most signals and functions used in real applications are real rather than complex. In areas such as digital filtering, convolution, correlation, image processing, and partial differential equations, the actual signals or functions, are real, but they are considered to be the real part of a complex quantity in order to be able to use the complex formulation of Fourier series and transforms. The complex Fourier transform (CFT) of a signal$x(t) - \infty \leq t \leq -\infty$ with finite energy, is defined as

$$x_c(f) = \int_{-\infty}^{\infty} x(t).\, e^{-j2.\pi.f.t} dt \tag{37}$$

The inverse complex Fourier transform (ICFT) is given by

$$x(t) = \int_{-\infty}^{\infty} x_c(f).\, e^{j.2.\pi.f.t} dt \tag{38}$$

The real Fourier transform (RFT) of $x(t)$ can be defined as

$$x(f) = 2\int_{-\infty}^{\infty} x(t).\, cos\big(2.\pi.f.t + \Theta(f)\big)dt \tag{39}$$

$$\text{Where: } \Theta(f) = \begin{cases} 0, & f \geq 0 \\ \frac{\pi}{2}, & f < 0 \end{cases}$$

The inverse real Fourier transform (IRFT) is given by

$$x(t) = \int_{-\infty}^{\infty} x(f).\, cos\big(2.\pi.f.t + \Theta(t)\big)df \tag{40}$$

Equation (3) and (5) can be written for $f \geq 0$ as follows

$$x_1(f) = 2\int_{-\infty}^{\infty} x(t).\, cos(2.\pi.f.t)dt \tag{41}$$

$$x_0(f) = 2\int_{-\infty}^{\infty} x(t).\, sin(2.\pi.f.t)dt \tag{42}$$

And

$$x(t) = \int_{-\infty}^{\infty} [x_1(t).\, cos(2.\pi.f.t) + x_0(t).\, sin(2.\pi.f.t)]df \tag{43}$$

Thus $x(f)$ equals $x_1(f)$for$f \geq 0$, and $x_0(f)$ for$f < 0.x_1(f)$and$x_0(f)$ will be referred toas the cosine and the sine parts. The relationship between the CFT and the RFT can be expressed for $f \geq 0$ as$x_c(0) = x_1(0)$

$$\begin{bmatrix} x_c(f) \\ x_c(-f) \end{bmatrix} = \frac{1}{2}.\begin{bmatrix} 1 & -j \\ 1 & j \end{bmatrix}.\begin{bmatrix} x_1(f) \\ x_{10}(f) \end{bmatrix}, f \neq 0 \tag{44}$$

Equation (44) reflects the fact that $x_1(f)$ and $x_0(f)$are even and odd functions, respectively.

The inverse of (44) for $x_1(f)$ and $x_0(f)$ is

$$\begin{bmatrix} x_1(f) \\ x_0(-f) \end{bmatrix} = \begin{bmatrix} 1 & 1 \\ 1 & -j \end{bmatrix} \cdot \begin{bmatrix} x_c(f) \\ x_c(-f) \end{bmatrix} \quad (45)$$

Equations (44) and (45) are very useful to convert from one representation to the other. When $x(t)$is real, $x_1(f)$ and $x_0(f)$are also real. Then, (44) shows that $x_c(f)$ and $x_c(-f)$ are complex conjugates of each other. Equations (44) and (45) are also valid in the case of the discrete time Fourier transformation. In addition, they are valid for Fourier series and the discrete Fourier transforms with the replacement of fby the frequency index n. The RFT relations given by (43) can be proven by using (44), and writing (38) as

$$x(t) = \int_0^{\infty} \frac{1}{2}.[x_1(f) - jx_0(f)].e^{j.2.\pi.f.t}df + \int_0^{-\infty} \frac{1}{2}.[x_1(-f) - jx_0(-f)].e^{j.2.\pi.f.t}df \quad (46)$$

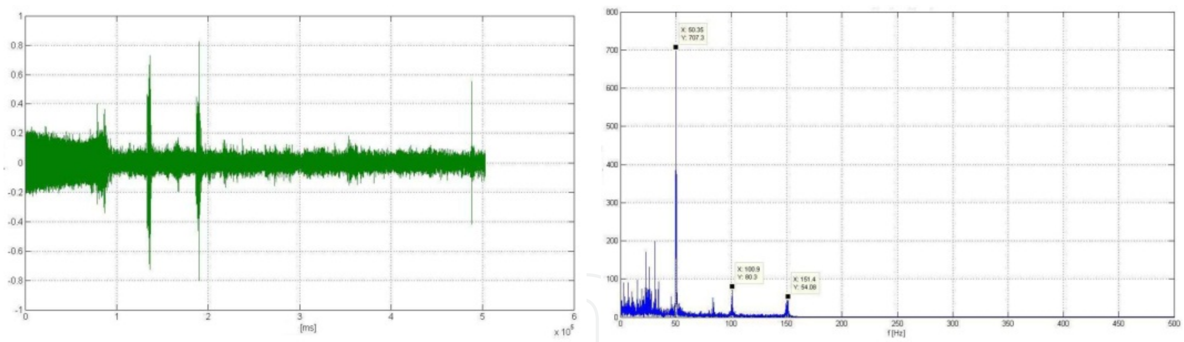
Then

$$x(t) = \int_0^{\infty} [x_1(f).cos(2.\pi.f.t) + x_0(f).sin(2.\pi.f.t)]df \quad (47)$$

6. Measurement noise of induction machines

6.1. Disturbed surroundings

Surrounding noise sources have an impact on the measurement of electrical machinery. It is not always possible to perform measurements in specialized laboratories, which are perfectly sound-insulated. To laboratory measurement can penetrate the noise from nearby sources (see Fig. 4), which is inaudible to the human ear. The interference from other sources can be created undesirable frequencies in the frequency band.



a) Noise detected in the laboratory b)Fast Fourier Transformation of laboratory noise

Figure 4. Noise measurement in the laboratory when the machine is switched off

Interference of other sources in the neighborhood of workplace cannot be directly prevented, but you can minimize their impact on analysis of the measured signal. Before the measurements it must be made measurement ambient noise before the main measurements. It is necessary to determine whether the background noise is random, or it is periodically repeated. In the case of random noise is preferable to wait to other time of measurement or it must count with errors in the measurement. In the event that can be measurement of noise repeated. Can be recorded the extent of spectral interference with which will be calculate when evaluating the measured results. From Spectral analyses of interference is possible to determine the proportion of individual harmonics. These harmonic then they can be the "subtracted" from the noise levels of electrical machines.

The next part of the measurement was performed on the induction motor which worked without a load. The electric motor was loosely placed on a foam board. This board was for suppression the transmission of vibrations from the surroundings. External vibrations are not desirable for accurate measurements.

Measurement noise of electric machine, that is run, is shown in Fig. 5. As seen from the measured values, that the noise level is constantly fluctuating.

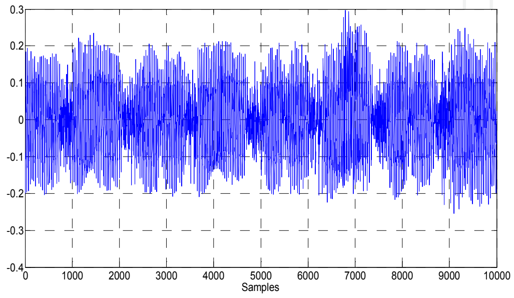


Figure 5. Noise of induction machines - no load

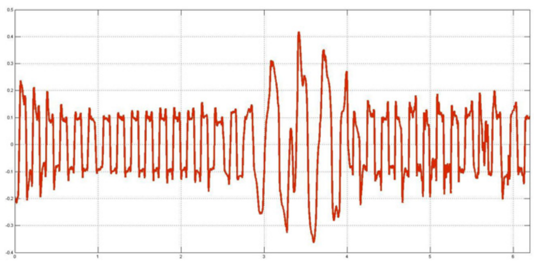


Figure 6. Noise of induction machine – 1 rotation

6.2. Noise of induction machine

On Fig. 7 is an analysis of the measured noise using MATLAB. Specifically, was carried Fast Fourier Transform (FFT). Dominant frequency is 600 Hz. This frequency is multiple of power supply frequency. It is a frequency of radial forces. In measurement signal can be involved many harmonics frequencies of radial forces. Than we can write equation

$$f_v = 6.k.f \tag{48}$$

Where

- f_v … Frequency of radial force [Hz]
- f … Power supply frequency [Hz]
- k … Number (k=1, 2, 3, …..)

For $f = 50Hz$ are frequencies of radial forces $f_v = 300, 600, 900, \ldots Hz$.

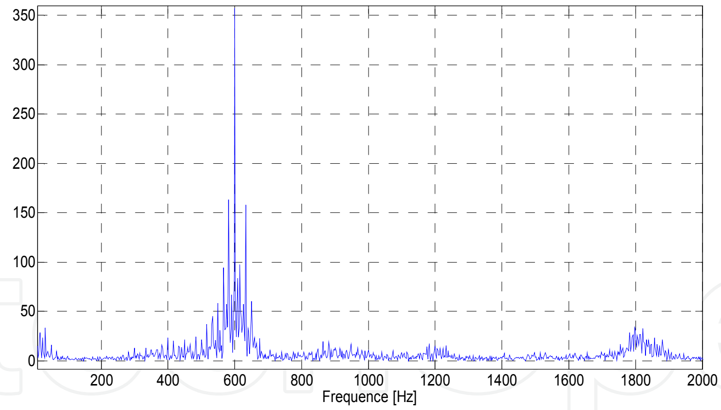


Figure 7. Fast Fourier Transformation of induction machine noise

It was done measurements eccentricity of rotor. Eccentricity of rotor is shown in Fig. 9. From the measured values it was found that the largest deviations occur in the range of approximately 120 degrees.

When comparing the noise of induction machines recorded on one rotation and values of rotor eccentricity can see a connection. In both cases (Fig. 8 and Fig. 9) appeared larger deflection in the range of 120 degrees. Extreme deviation is in a different quadrant in each graph. This is due to the different measurement principles. Noise measurements done digitally, while measuring the eccentricity was used mechanical method. It was therefore not possible to accurately determine the initial rotor position in both measurements.

it can be argued that the noise of induction machines is generated of the rotor who has eccentricity. Given that the, that machine is equipped with a ventilator, there are two sources of noise. The influence of the fan but will not cause displacement of only a specific part of one rotation.

Given that the measured induction motor was not equipped with cooling system (fan) can be assumed, that the vibration and thus the noise are produced only by electromagnetic source and mechanical source.

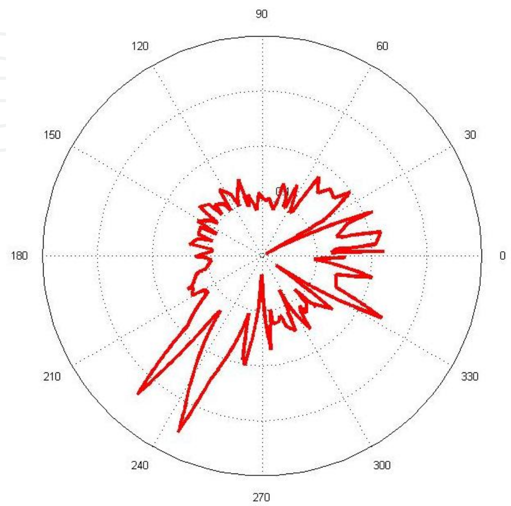


Figure 8. Noise envelope – 1 rotation

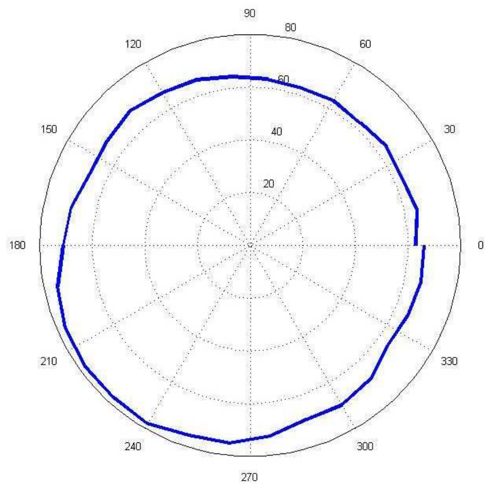


Figure 9. Rotor Eccentricity - Mechanical measurement

Analyze of noise was performed on the one rotation of rotor. The Fig 5 shows the noise levels depending on the position of the rotor. As the graph shows it is to generate greater levels of noise in the position of the rotor from 300 to 60 degrees (about 120 degrees).

7. Conclusion

Diagnosis of induction motors is a very complex issue that has many components. One of them is the analysis of motor noise. Noise measurement asynchronous machines are the commonly used diagnostic method. This method is relatively simple. You need to be near an electrical machine quality microphone and recording equipment. Analysis itself can be the performed on specialized software, either on the spot or later in laboratory.

Subsequent analysis of the signal can then indicate whether the machine operates as required, or whether there was damage to electrical equipment. Based on the fast Fourier analysis of noise can be determined which components of the signal are dominant. Based on knowledge of layout design of the engine is then possible to determine what is causing individual harmonics. According to the frequency it is possible to determine which there the main sources of noise are.

A major problem in measuring the noise may be interference from nearby sources. To avoid the external influence of external noise is possible only in specialized laboratories.

During measurements realized appeared possible link between noise and rotor eccentricity of electrical machinery. In the analysis of noise is dominant skew in the range of 120 ˚ in one rotation. In the same range (120 ˚) was measured the dominant deflection of rotor eccentricity this rotor machine. Given that the machine has not a cooling system, there is not source of aerodynamic noise; there are only two possible causes of this deviation. Source of electromagnetic noise would not cause deviation only at certain rotor position, but in the whole rotation. Displacement of noise in a certain position the rotor it cannot assign too resources source of mechanical noise. This group includes vibration bearings. During the measurement was verified that the bearings are not damaged. There are not larger deviations of movement in rotation of bearing.

As a source of noise is impact of rotor eccentricity on the running of the induction motor. Unfortunately, the verification of this theory would require accurate measurement with recording of the rotor position and size of air gap. This measurement is very difficult.

Author details

Marcel Janda, Ondrej Vitek and Vitezslav Hajek
Brno University of Technology, Czech Republic

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